EN 1992-1-2
Fire design of concrete structures

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

- 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
- *fire design consultant*		
Dr.Ing. Nils Erik Forsén	Multiconsult AS	Norway
- *structural design consultant*		
Mr. Tauno Hietanen	Concrete Industry Association	Finland
- *concrete industry and standardization*		Convenor
Mr. José Maria Izquierdo	INTEMAC	Spain
- *research institute, especially fire damages*		
Mr. Alain Le Duff	CSTB	France
- *fire research institute*		
Dr.-Ing. Ekkehard Richter	TU Braunschweig	Germany
- *fire research institute*		
Mr. Robin T. Whittle	Ove Arup & Partners	United Kingdom
- *structural design consultant,*		Technical secretary

and National Technical Contacts

Technical background

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

Scope of EN 1992-1-2

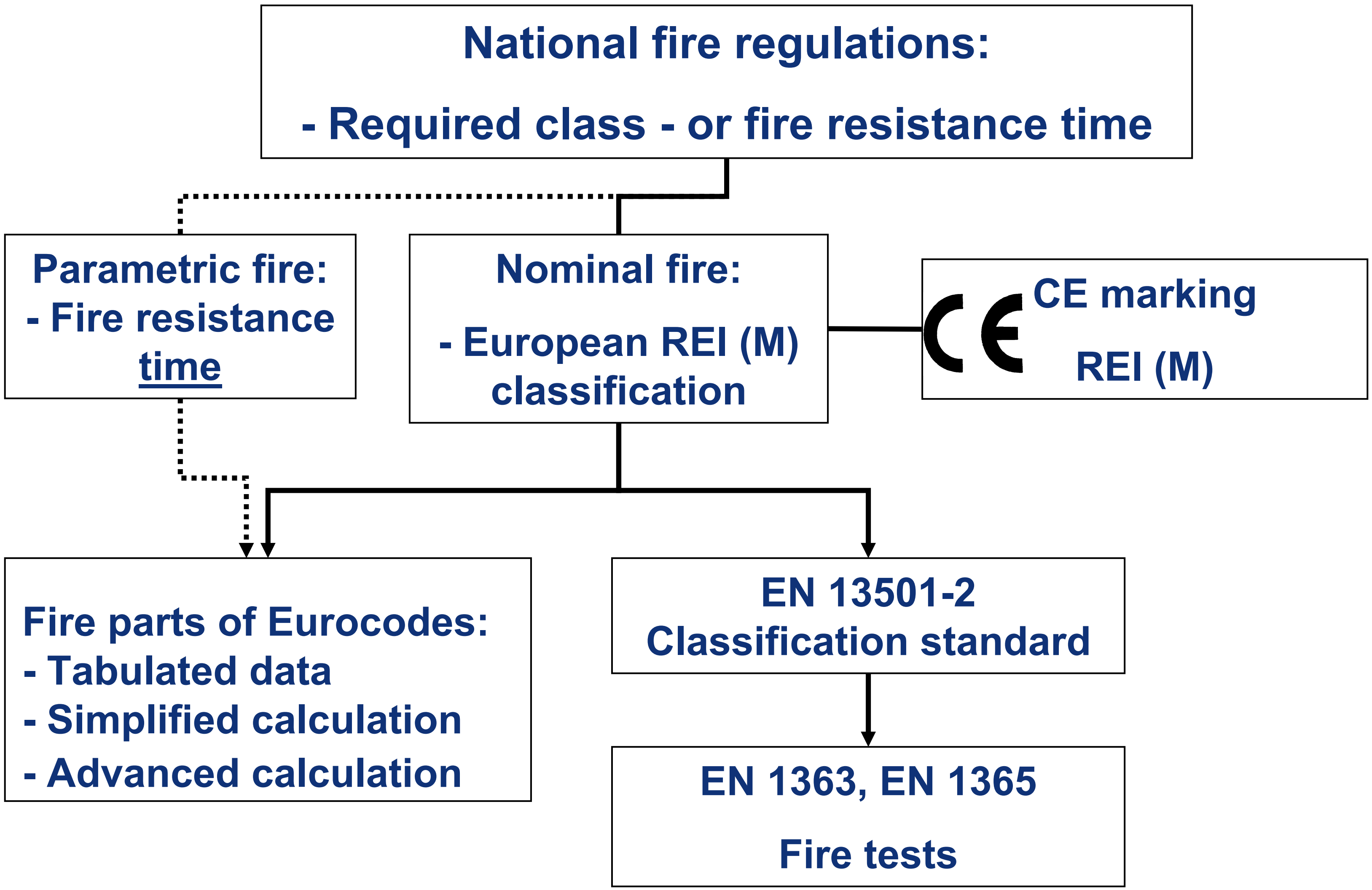
(5)P This Part 1-2 of EN 1992 applies to structures, or parts of structures, that are within the scope of EN 1992-1-1 and are designed accordingly. However, it does not cover:
- structures with prestressing by external tendons
- shell structures

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

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

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

Resistance to Fire CE-marking



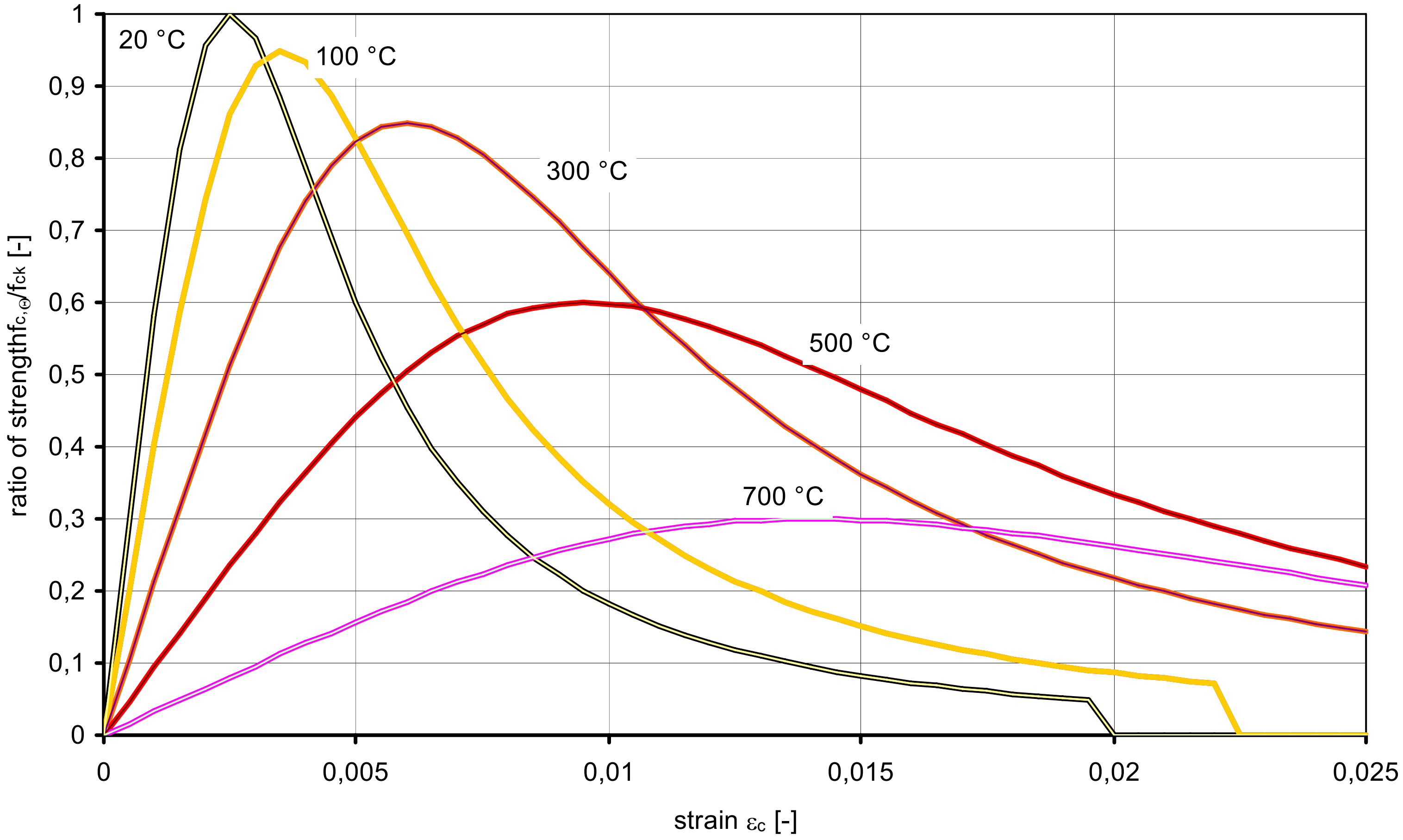
EN 1992-1-2
Fire design of concrete structures

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

Section 3 Material properties

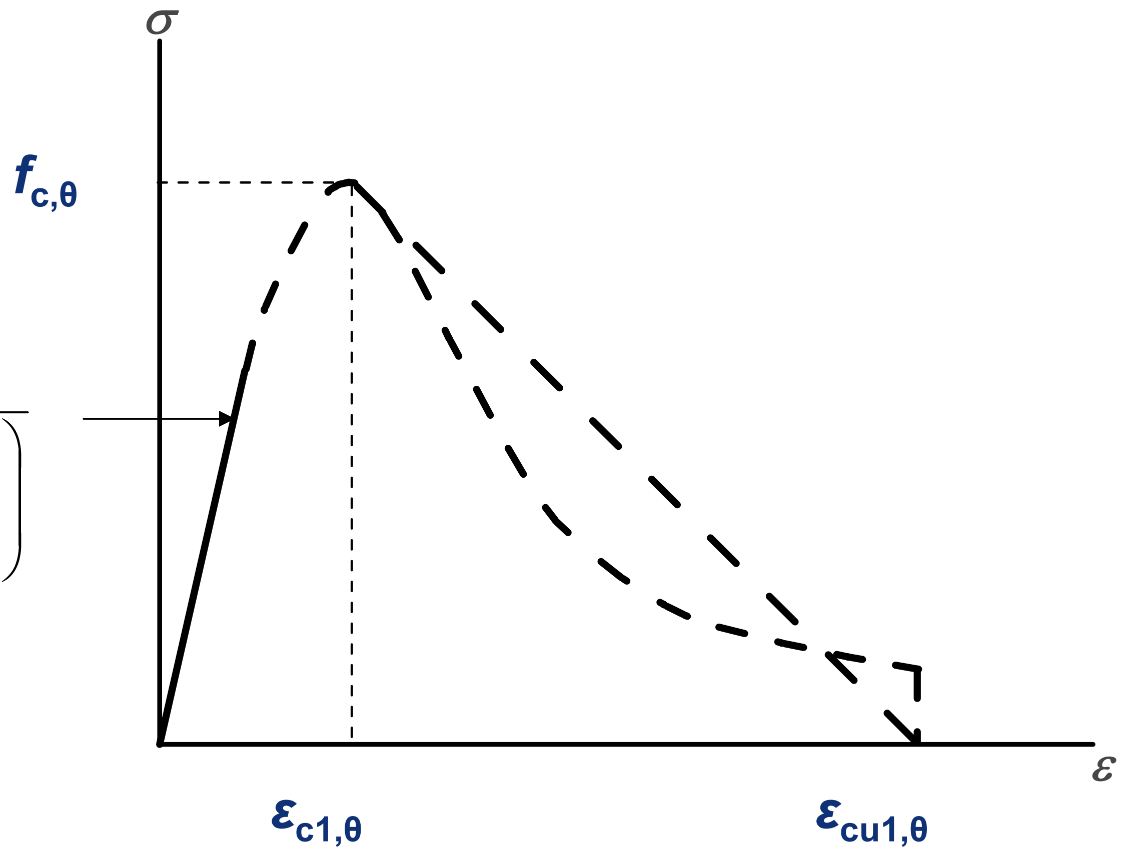
- Strength and deformation properties in Section 3 are given for simplified and advanced calculation methods
- Strength reduction curves for Tabulated data (in Section 5) and Simplified calculation methods (in Section 4) are derived from material properties in section 3
- Thermal properties are given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

Concrete compressive strength



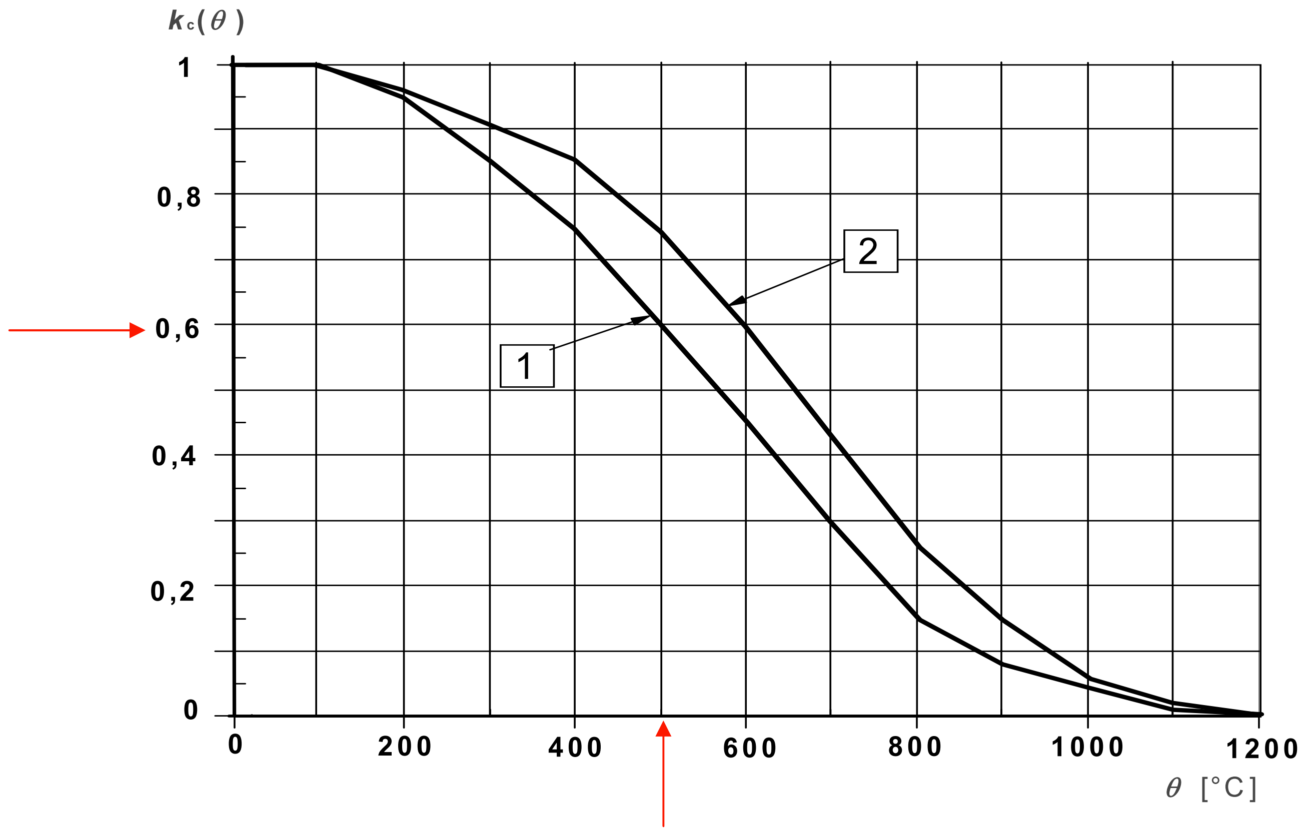
Mathematical model and parameters $f_{c,\theta}$, $\varepsilon_{c1,\theta}$ and $\varepsilon_{cu1,\theta}$ α_{CC} = 1,0 in fire design

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



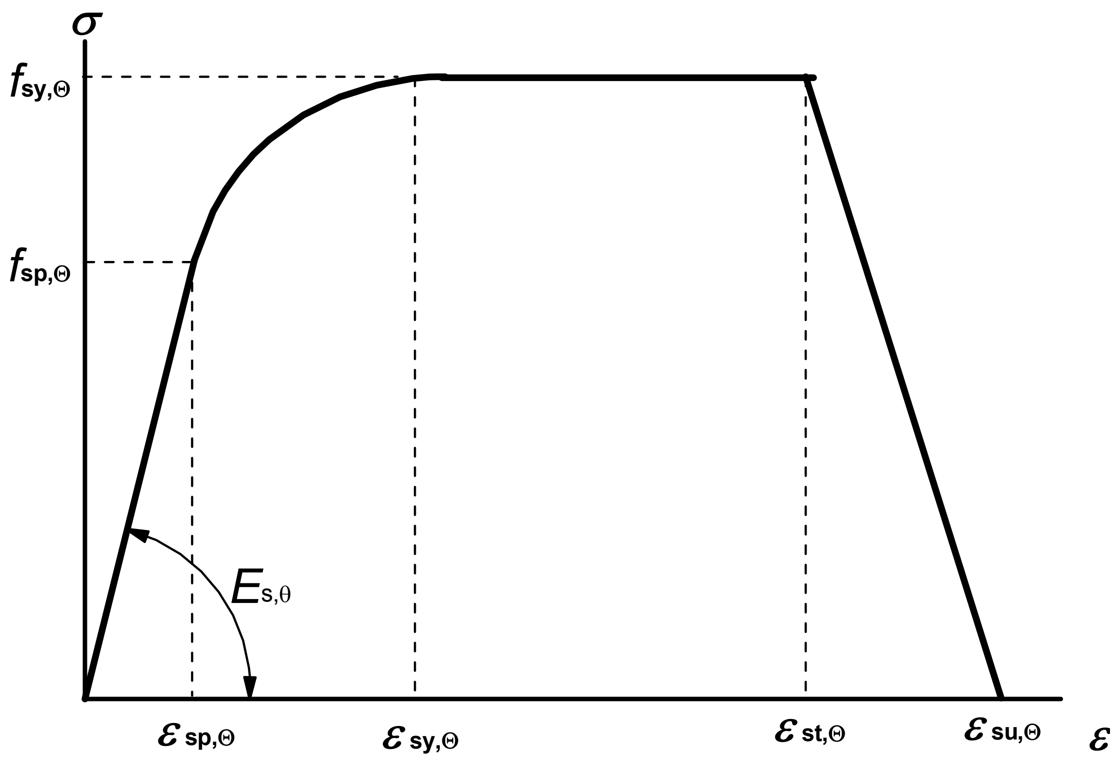
Strength reduction of concrete

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



Reinforcing and prestressing steel: Stress-strain relationship

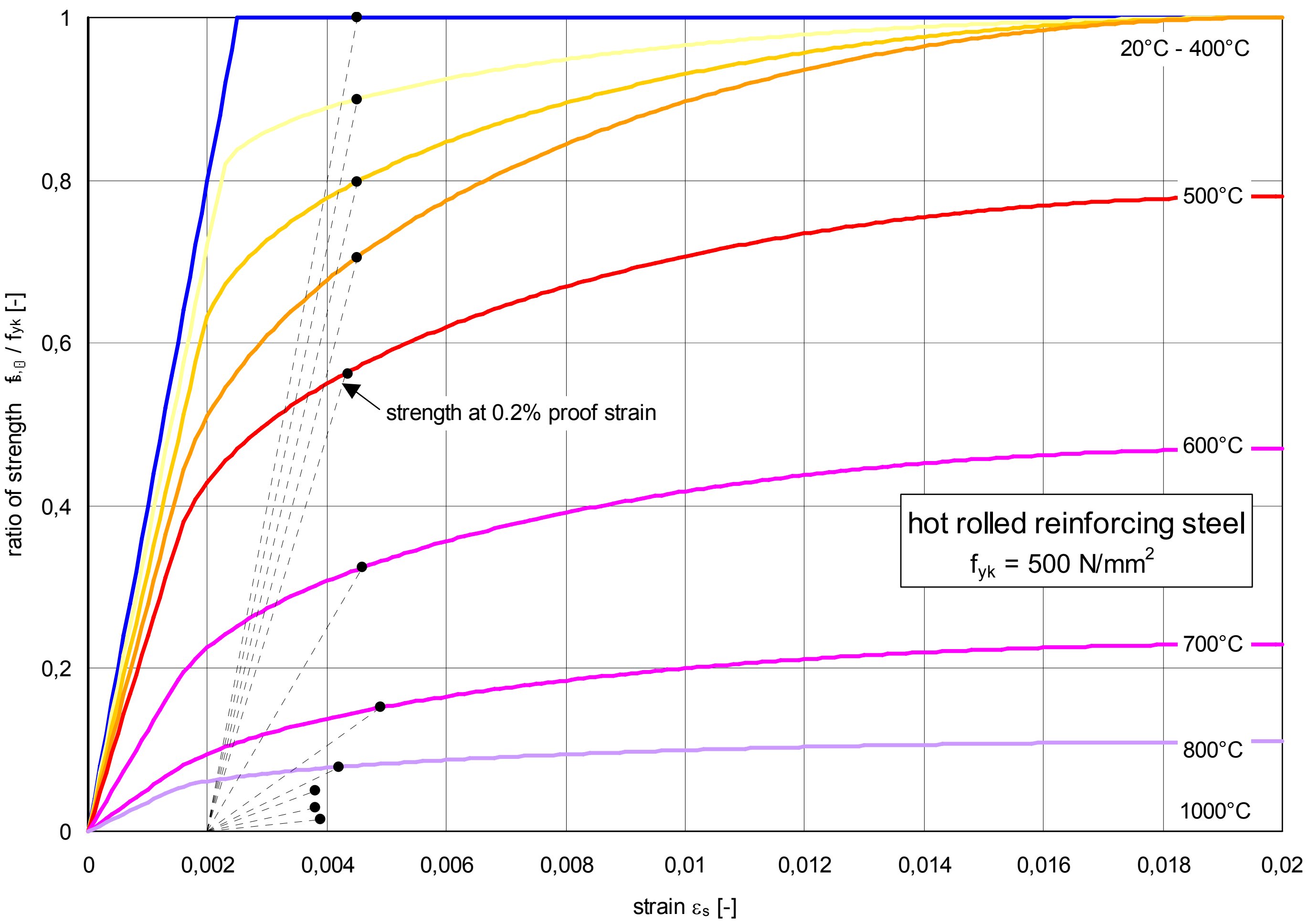
- **Mathematical model and parameters $f_{sp,\theta}$, $f_{sy,\theta}$ and $E_{s,\theta}$**



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

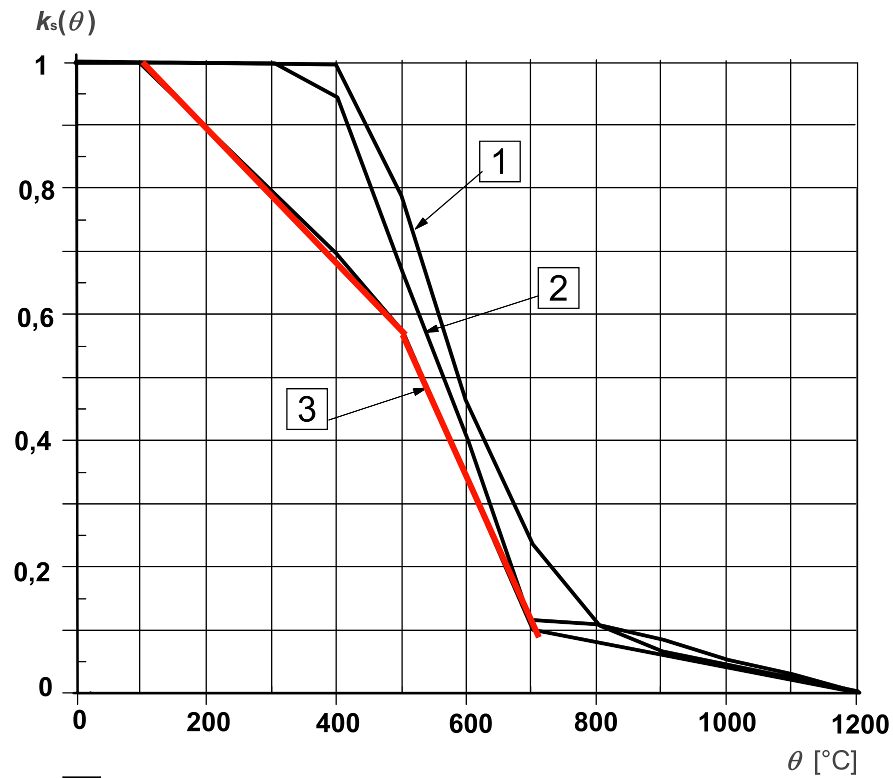
Class A reinforcement: $\varepsilon_{st,\theta} = 0{,}05$ $\varepsilon_{su,\theta} = 0{,}10$

Reinforcing steel strength



Strength reduction for simplified calculation methods in Section 4

- Class N (normal)



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

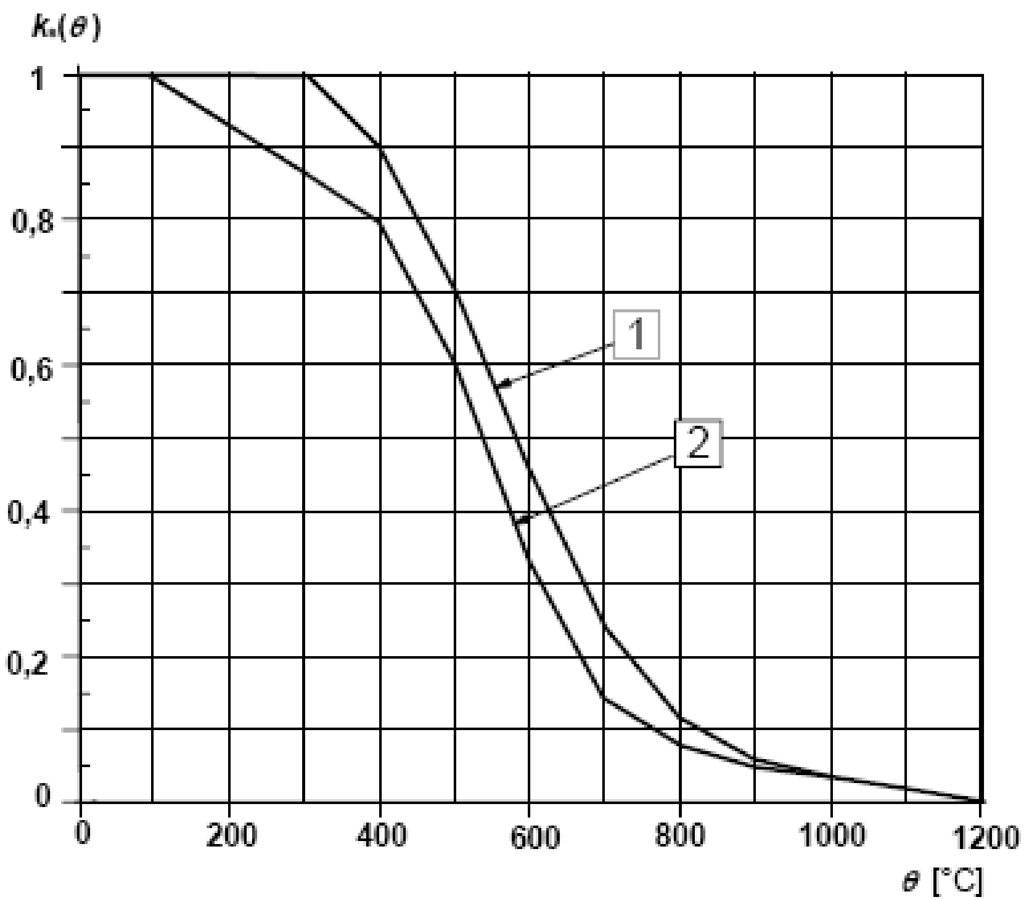
Curve $\boxed{2}$: Tension reinforcement (cold worked) for strains $\varepsilon_{s,fi} \geq$ 2%

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

Strength reduction of steel

Strength reduction for simplified calculation methods in Section 4

- Class X: recommended only when there is experimental evidence



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

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

Reinforcing steel Class X

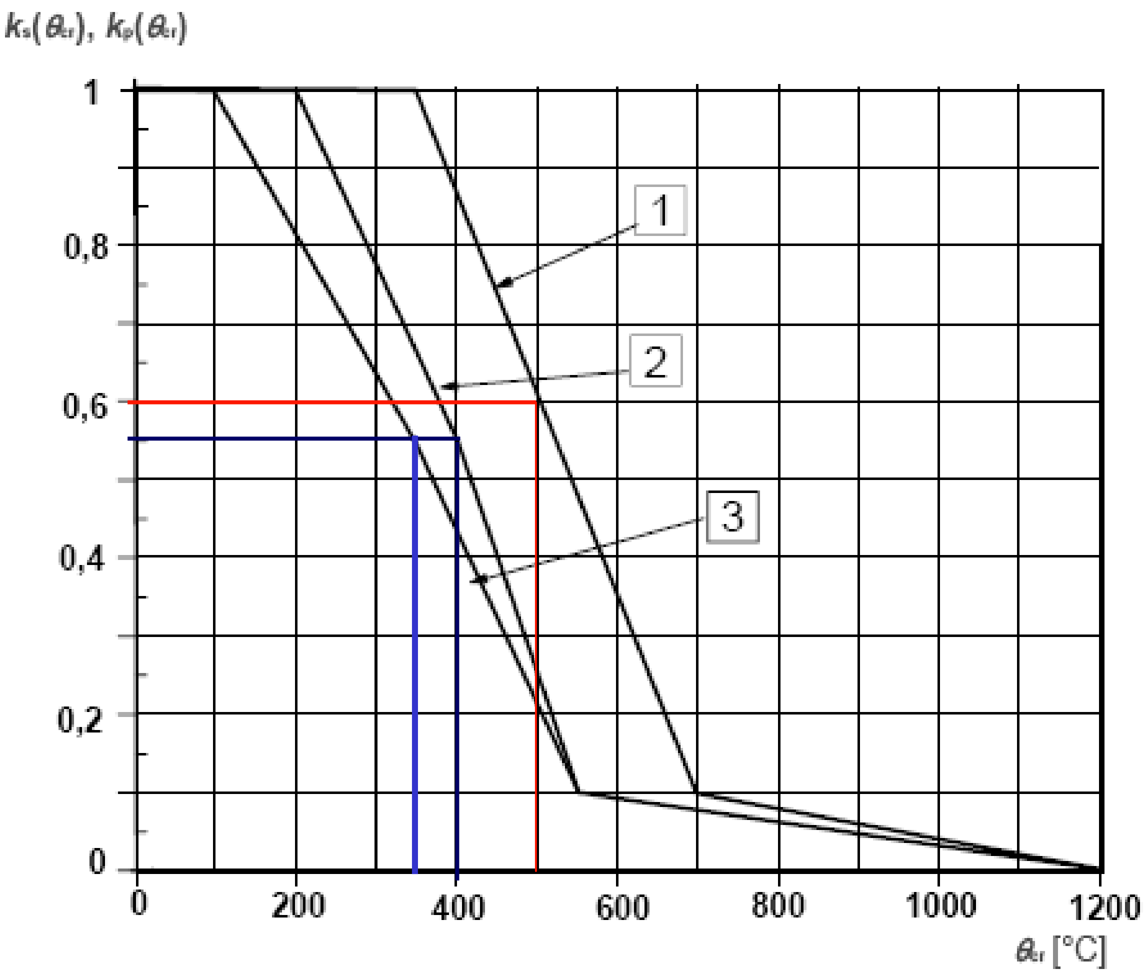
Class X was proposed by Finland because initial testing of steel strength at elevated temperatures is required in Finnish standard

FINNISH NA:

- Class X may be used with following additional conditions:
- Strength properties at elevated temperatures are determined by applying standard SFS-EN 10002-5.
- Strength properties of reinforcing steel at elevated temperatures are subject to initial type testing at temperatures 300 °C, 400 °C, 450 °C, 500 °C and 550 °C.
- Requirements for 0,2 % proof strength *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: 1 Strength requirements of reinforcing steel at elevated temperatures

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

Reference curve for Tabulated data in Section 5



1. Reinforcing steel

θ_{cr} = 500˚C

0,6 stress level

2. Prestressing bars

θcr = 400˚C

0,55 stress level

3. Prestressing wires and strands

θcr = 350˚C

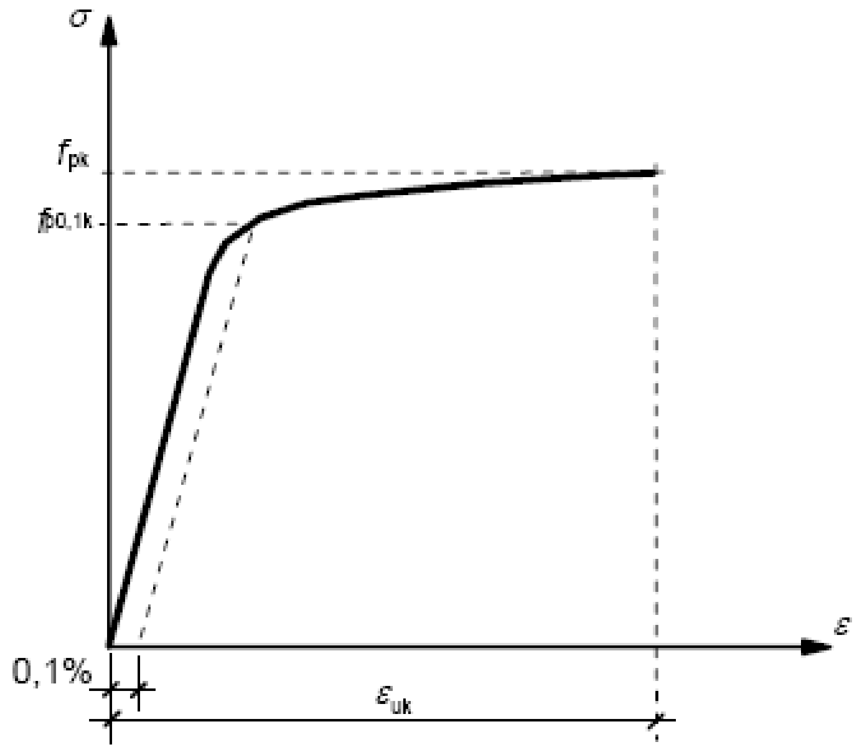
0,55 stress level

Strength reduction of prestressing steel

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

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

- **Class B: $\beta = 0{,}9$**

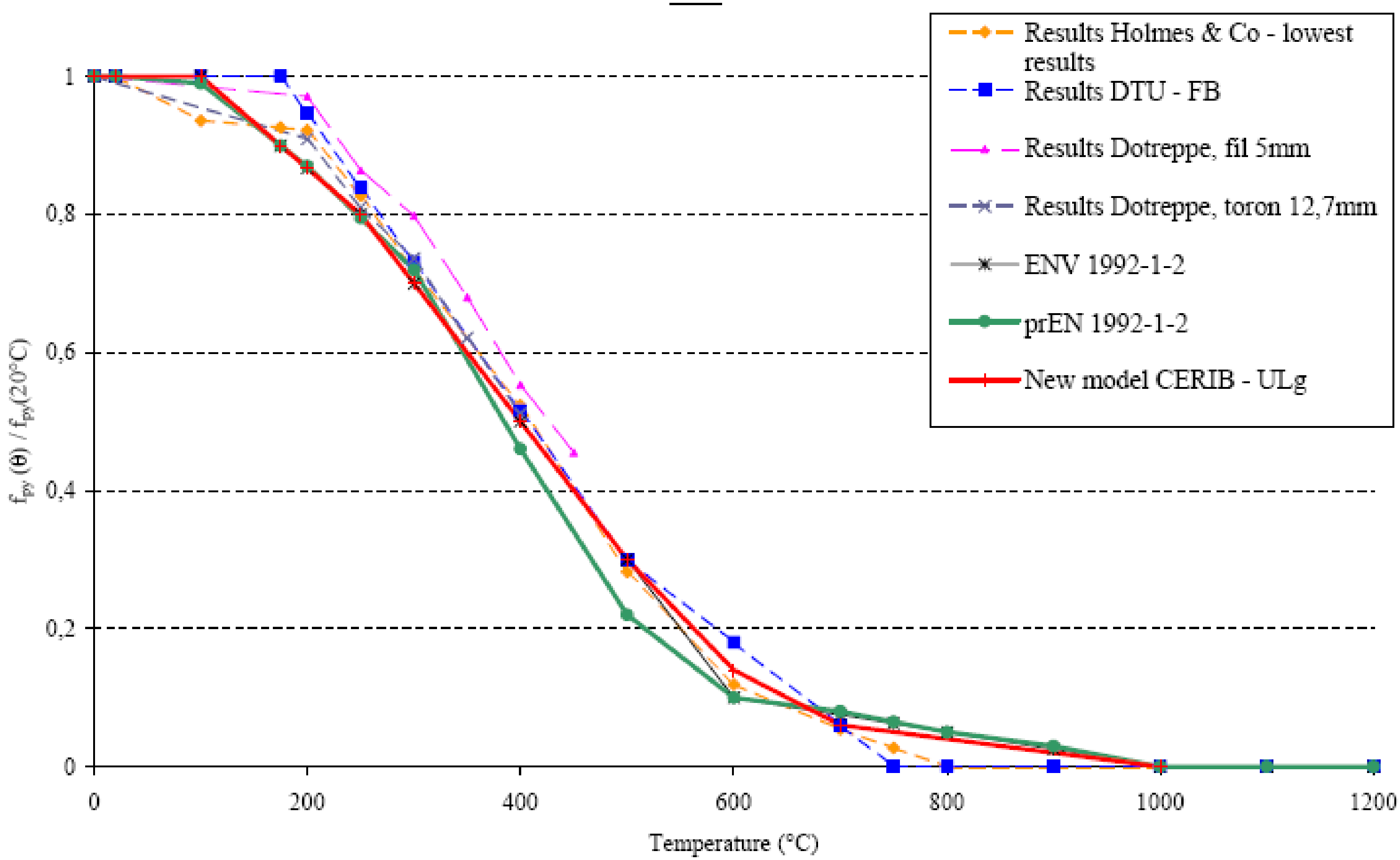


Background for Class A

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

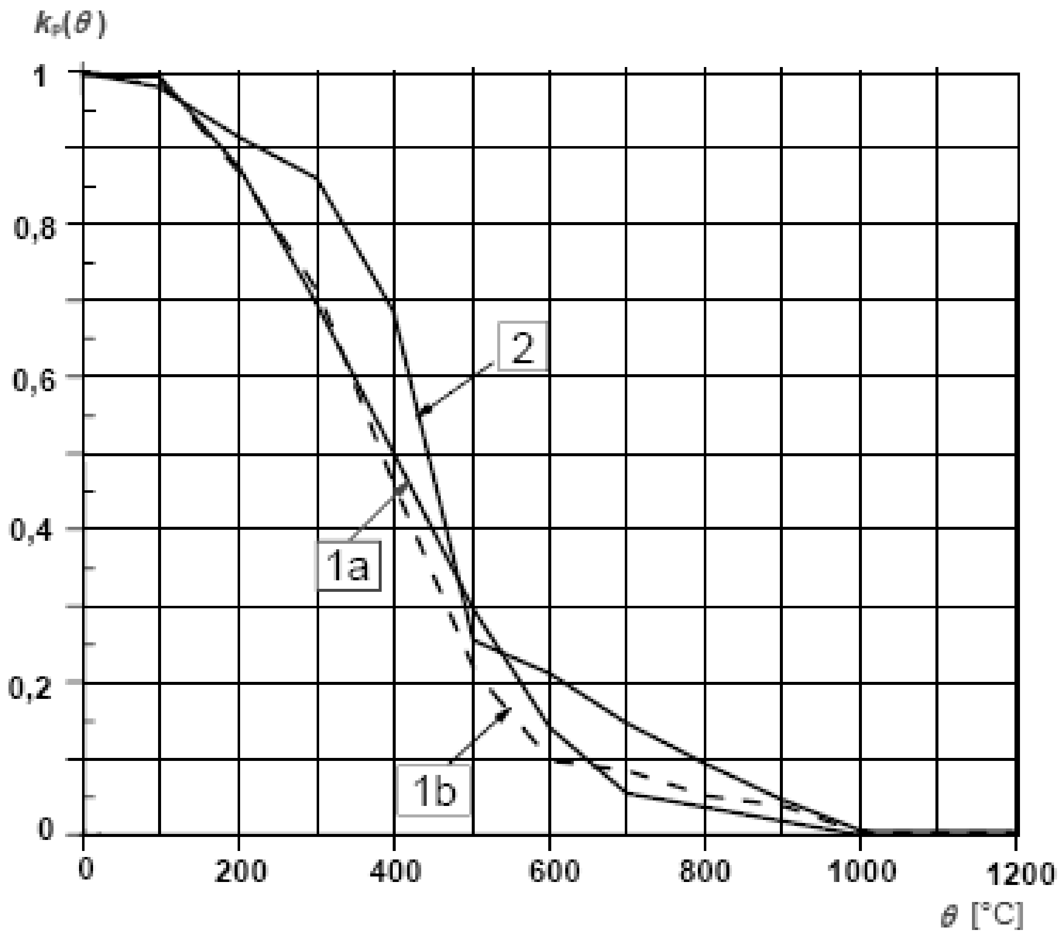
September 12th 2003

Figure A.1 : Coefficient $k_p(\theta)$ allowing for decrease of characteristic strength (βf_{pk}) of prestressing steel



Strength reduction of prestressing steel

Strength reduction for simplified calculation methods in Section 4



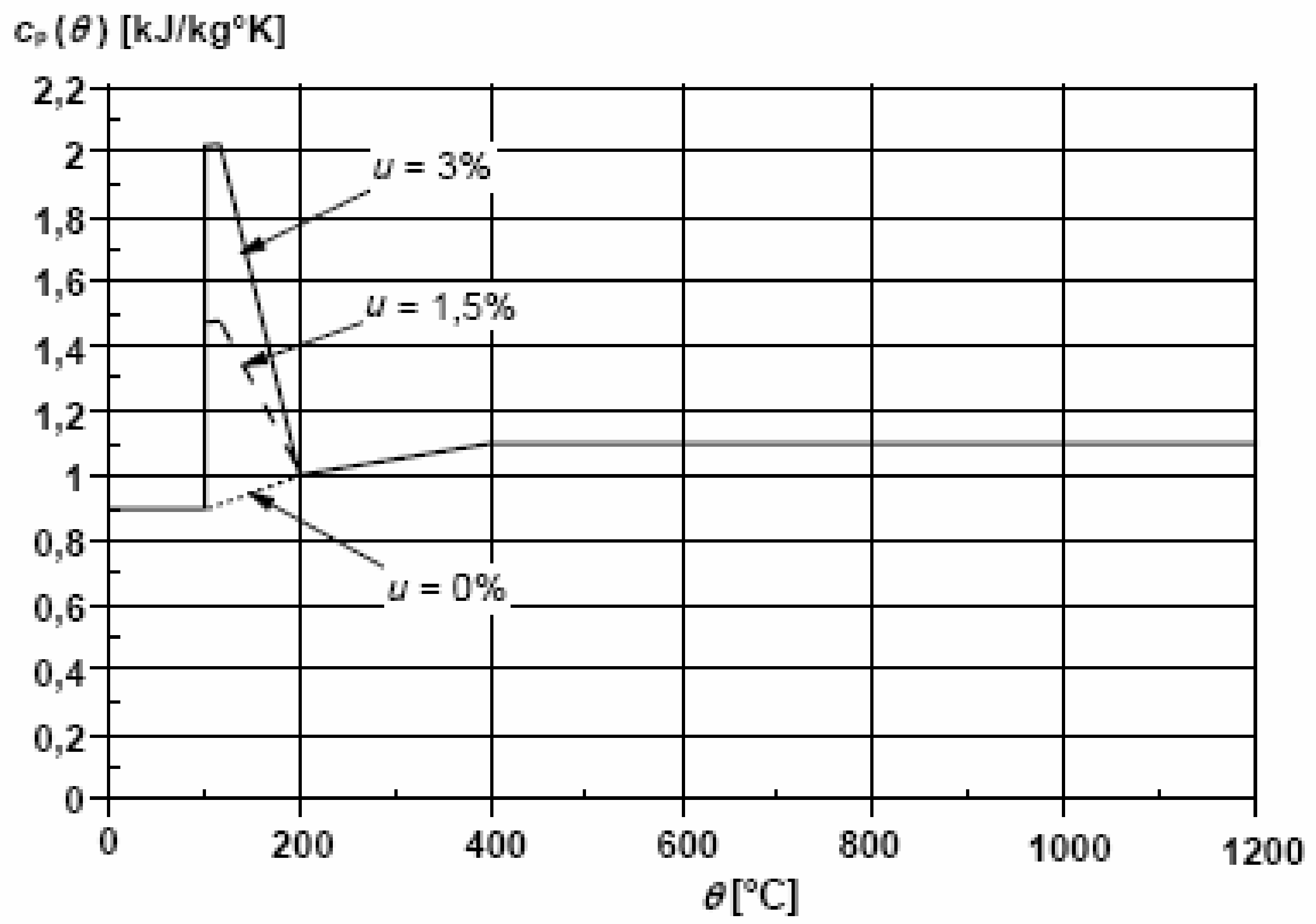
Curve 1a : Cold worked prestressing steel (wires and strands) Class A

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

Curve 2 : Quenched and tempered prestressing steel (bars)

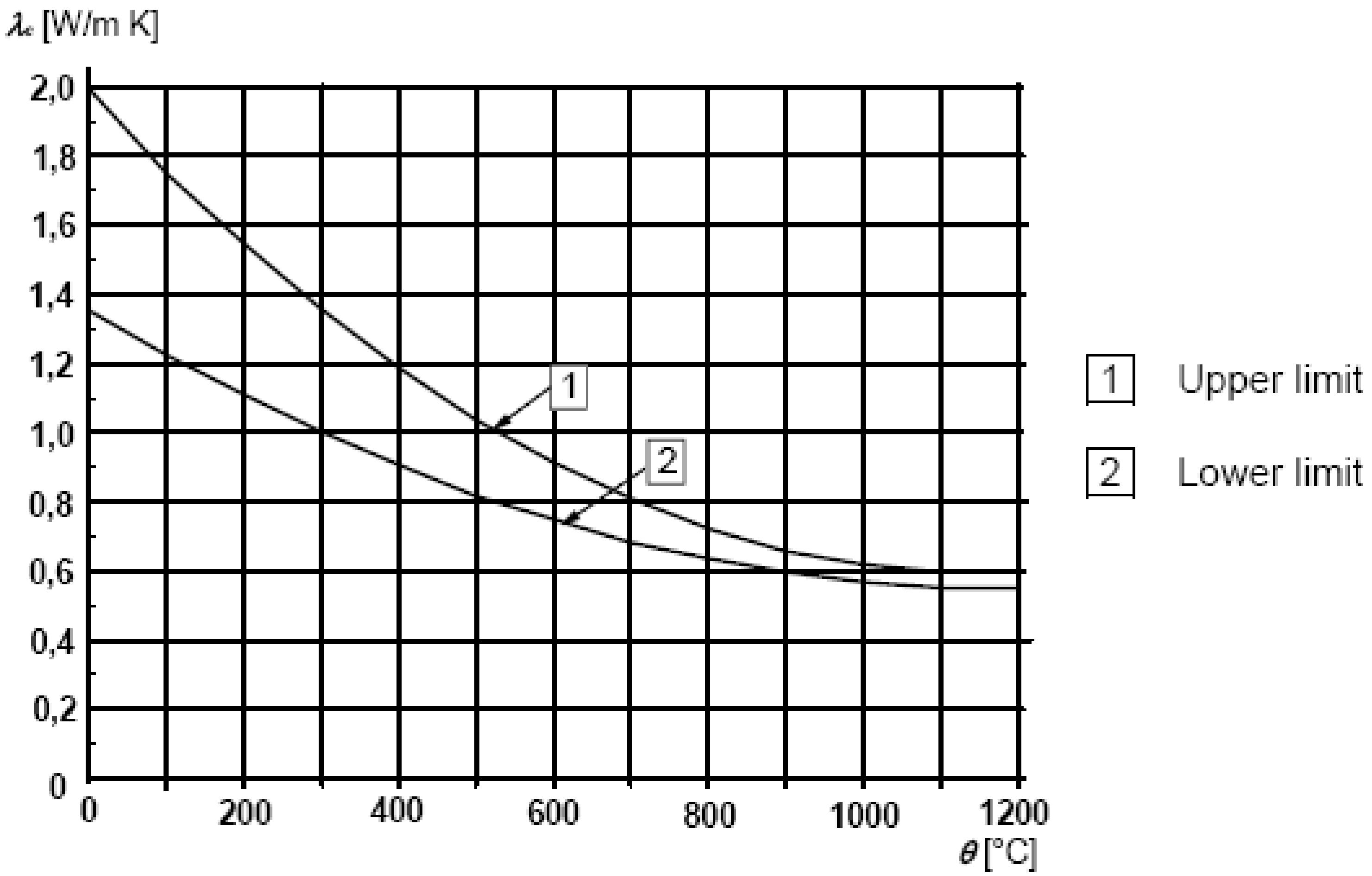
Thermal properties

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



Thermal properties

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



Background for thermal conductivity

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

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

EN 1992-1-2
Fire design of concrete structures

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

Design methods

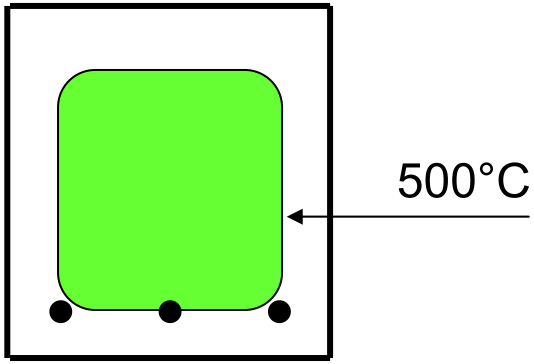
- **advanced calculation methods for simulating the behaviour of structural members, parts of the structure or the entire structure, see 4.3**
  - only principles are given, no detailed design rules
- **simplified calculation methods for specific types of members, see 4.2**
  - **Annex B.1 "500°C isotherm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

- ***Shear, torsion and anchorage; spalling; joints***

Simplified calculation method

- **500°C isotherm method**

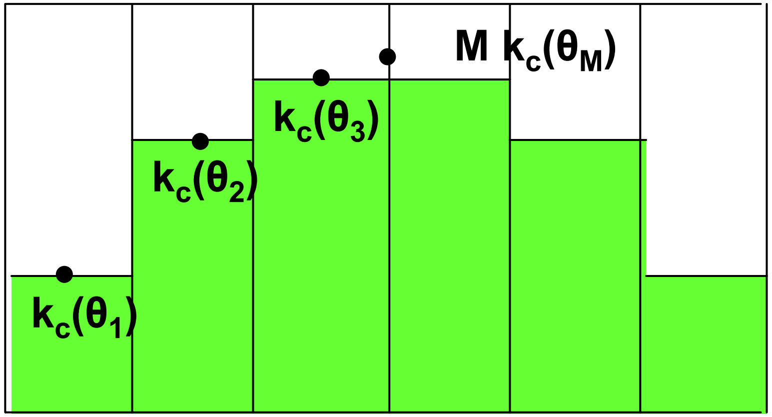
  Concrete with temperature below 500°C retains full strength and the rest is disregarded



- **Zone method**

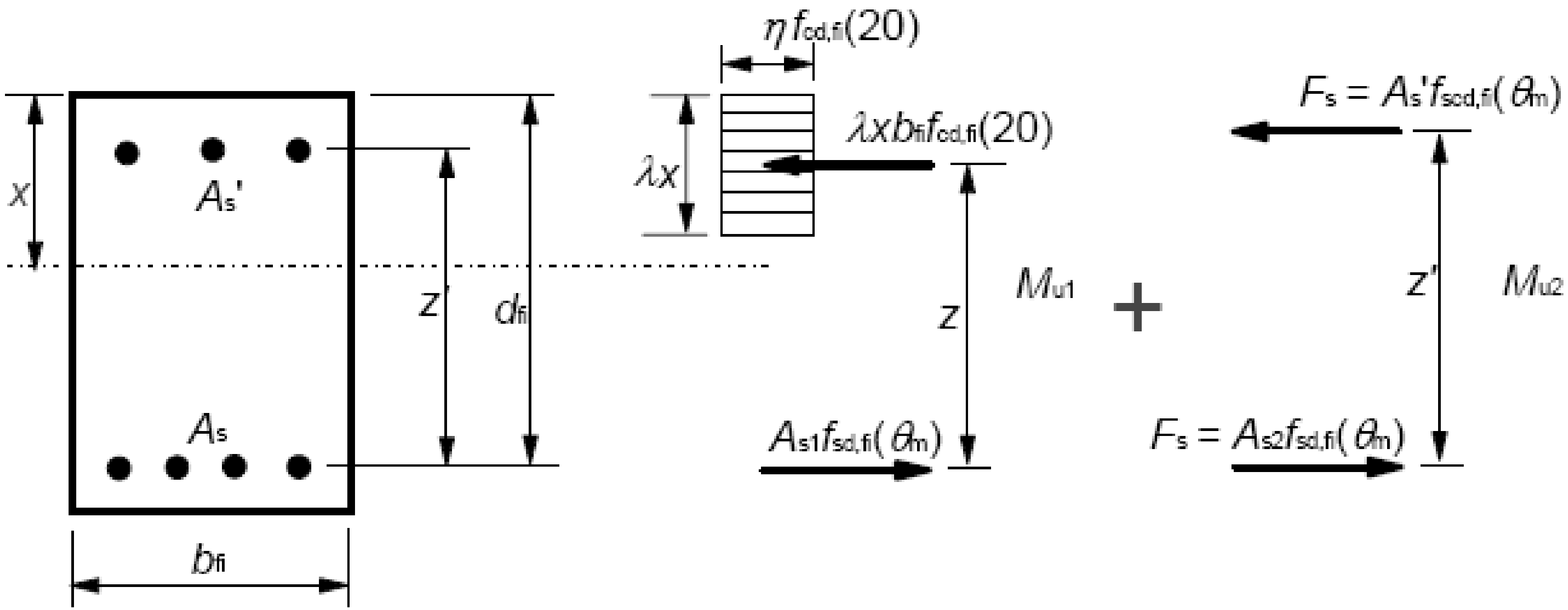
  Cross section is divided in zones. Mean temperature and corresponding strength of each zone is used

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



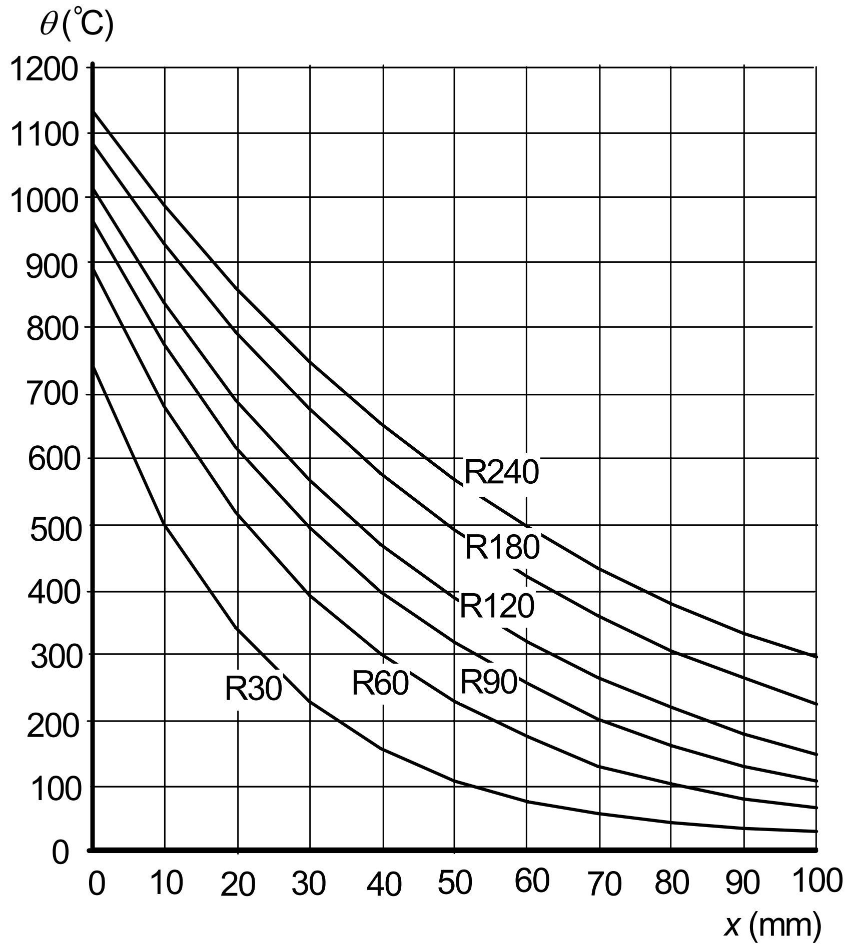
500°C isotherm method

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



Temperature profiles

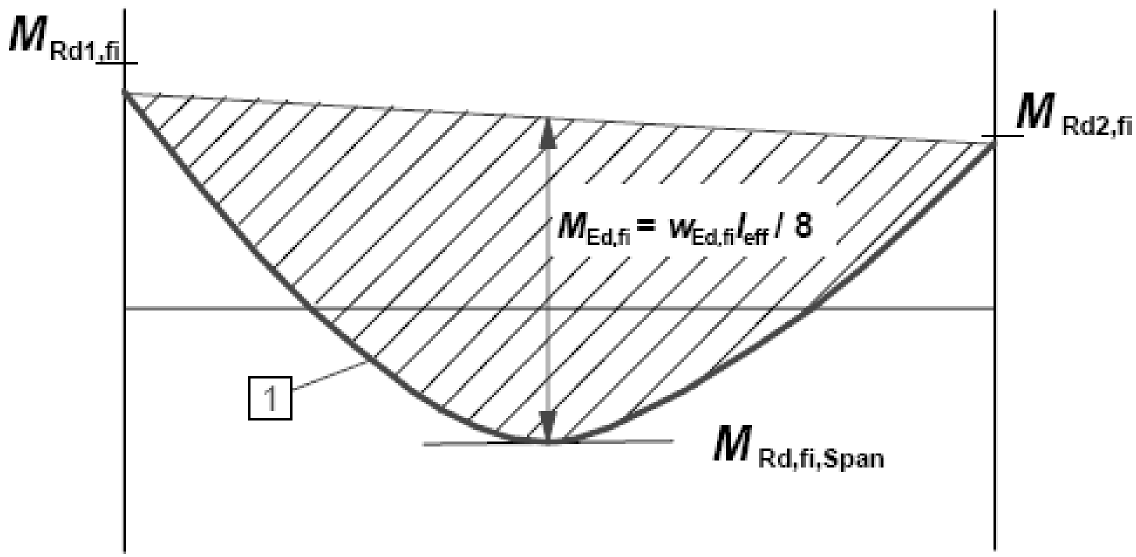
- **Temperature distribution in the cross section can be calculated from the thermal properties**
- **Annex A of EN 1992-1-2 gives temperature profiles for slabs, beams and columns**



Simplified calculation method for beams and slabs

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

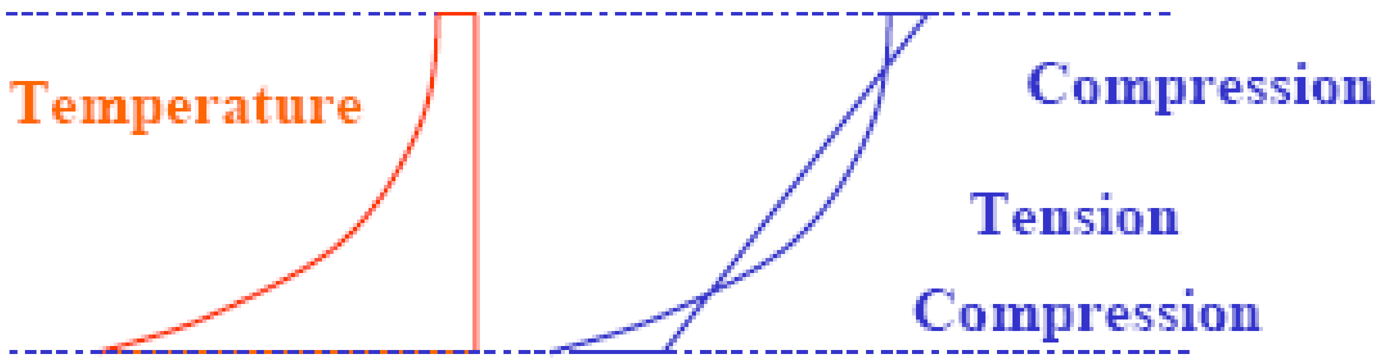
$$M_{Rd,fi} = (\gamma_s / \gamma_{s,fi}) \times k_s(\theta) \times M_{Ed} \, (A_{s,prov} / A_{s,req})$$



1 Free moment diagram for uniformly distributed load under fire conditions

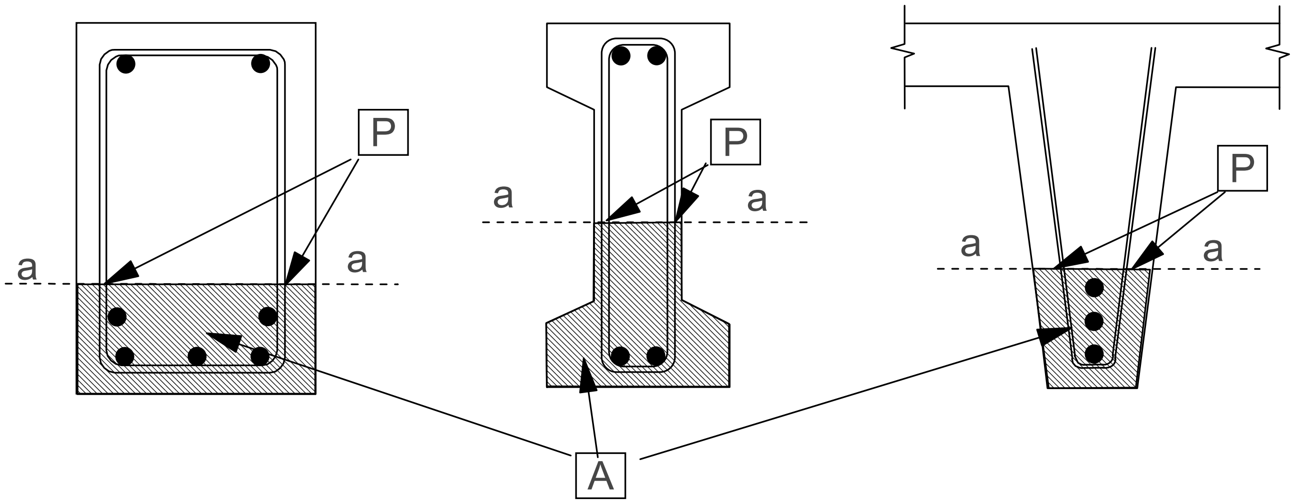
Annex D (informative)

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



Calculation for shear

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



Spalling of normal strength concrete

CALCULATION METHODS

Define exposure class

↓ **X0 or XC1 (dry)** ↓ **Moisture content ≤ 3 %** ↓ **OK**

↓ **other** ↓ **Is moisture content known**

Yes ≤ 3 % ← **Moisture content ≤ 3 %**

No, or yes but > 3 % ↓ **Avoid spalling by more accurate assessment**

Moisture content, type of aggregates, permeability of concrete, heating rate

Yes ← **OK**

No ↓ **Has the correct behaviour been checked by tests**

Yes ← **OK**

No → **Assume loss of cover and calculate R**

Solid slabs OK, some beams OK

TABULATED DATA

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

Falling off of normal strength concrete

Shall be minimised or taken into account

$c \geq 70$ mm	No →	OK
↓Yes		
Tests to show that falling of does not occur	Yes →	OK
No ↓		
Provide sur-face rein-forcement		

EN 1992-1-2
Fire design of concrete structures

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

Scope of Tabulated data

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

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

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

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

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

Tabulated data - General

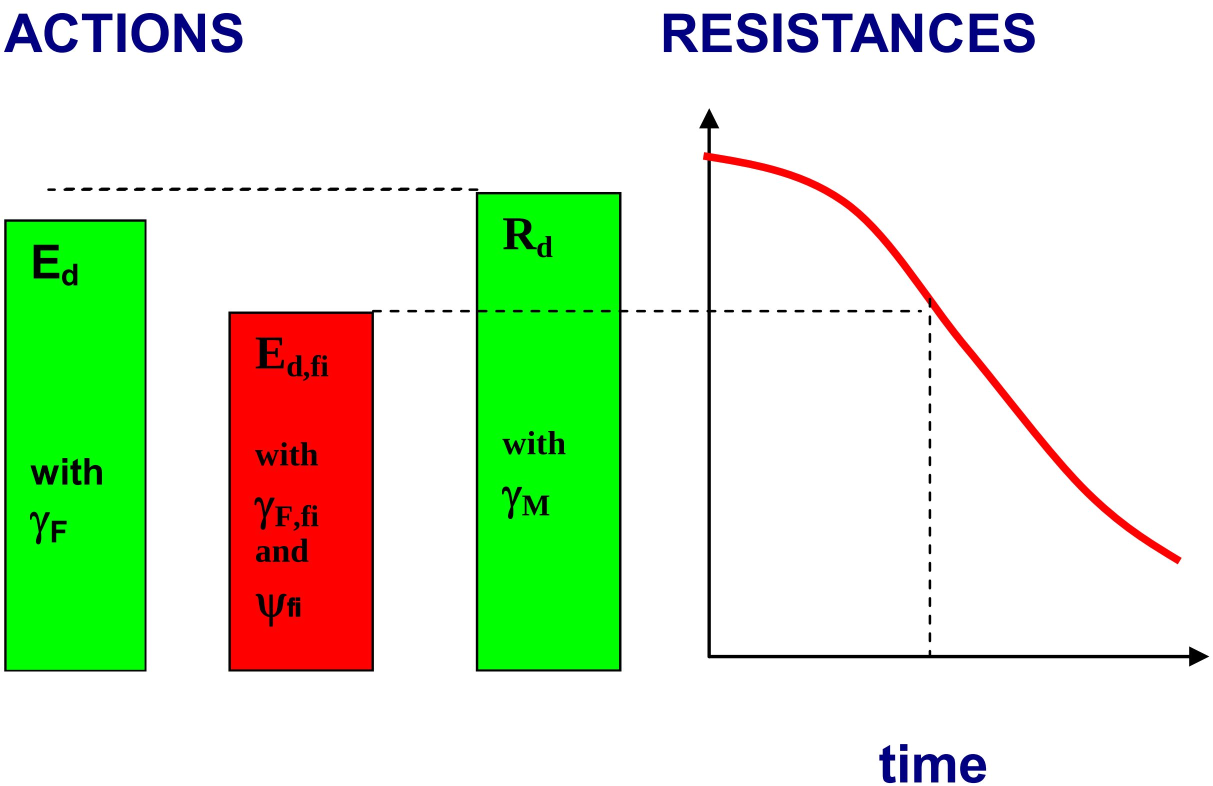
Tabulated data are based on a reference load level η_{fi} = 0,7, unless otherwise stated in the relevant clauses.

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

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

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

Load level and degree of utilisation

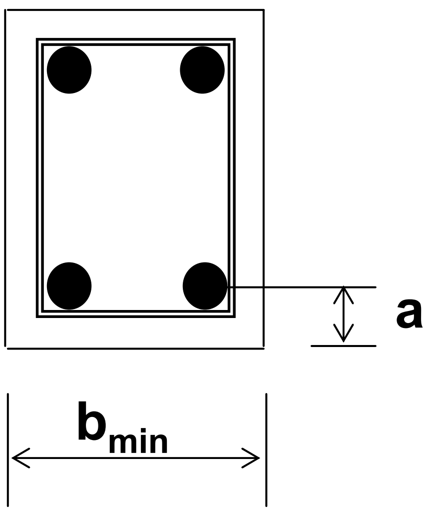


$E_d \times \eta_{fi} = E_{d,fi}$ R_d $R_{d,fi}$

η_{fi} = load level

$\mu_{fi} = E_{d,fi} / R_d$ = degree of utilisation takes into account if the structure is not fully loaded

Tabulated data – main principle



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

Axis distance is nominal value, no need to add tolerance

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

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

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

Tabulated data in EN 1992-1-2

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

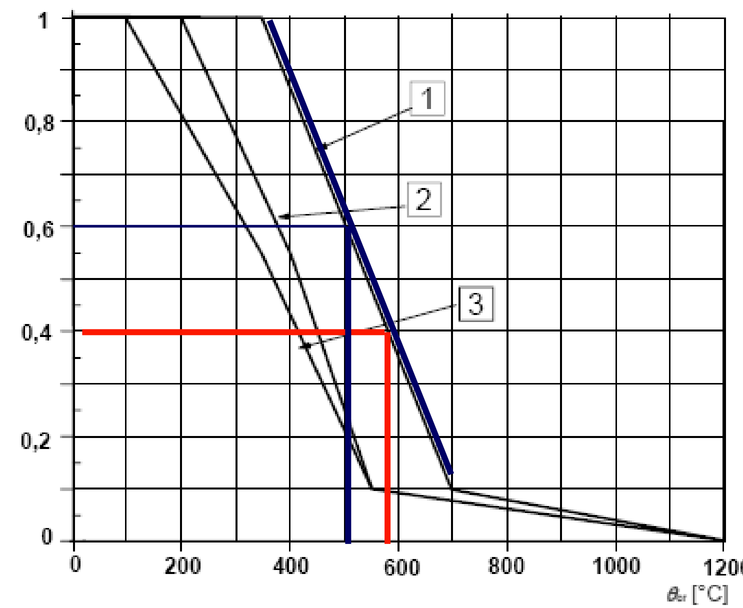
a) Calculate the actual steel stress

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

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

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

$\sigma_{s,fi} / f_{yk} = 0,4$



T_{cr} = 580˚C, Δa = - 8 mm

Tabulated data for columns

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

Parameters for columns

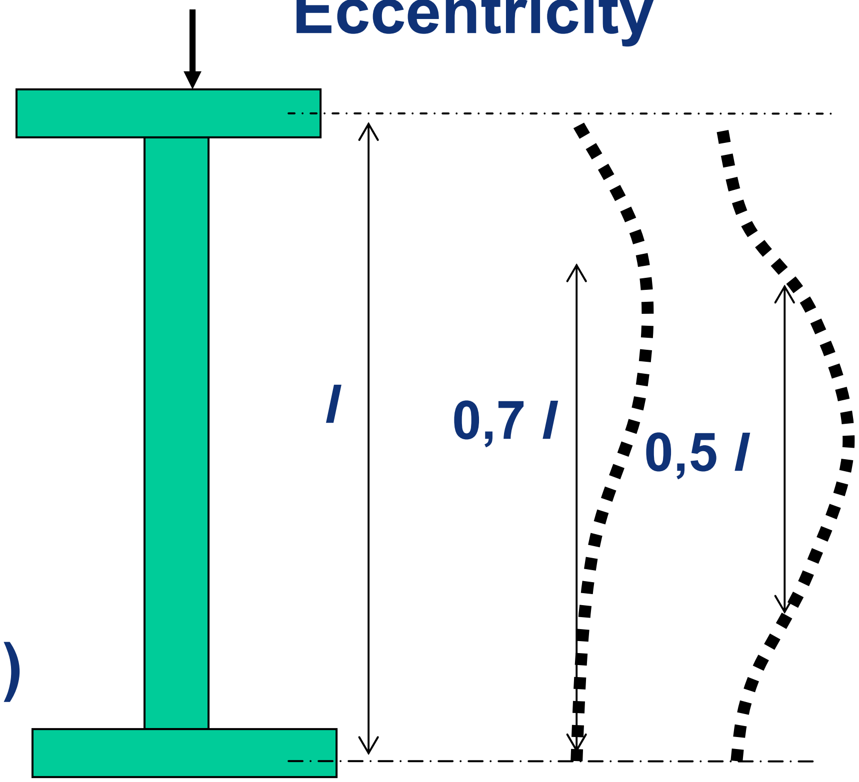
In Method A degree of utilisation:

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

In Method B load level is defined as:

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

Eccentricity



Slenderness, $l_{o,fi}$

- upper floor 0,7 *l*
- intermediate floor 0,5 *l*

Method A for columns

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

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

Method B for columns

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

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

Simple calculation for method A

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

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

R_a = 1,60 (a – 30)

R_l = 9,60 (5 – $l_{o,fi}$)

R_b = 0.09 b'

R_n = 0 for n = 4 (corner bars only)

= 12 for n > 4

a = axis distance to the longitudinal steel bars (mm); 25 mm ≤ a ≤ 80 mm

$l_{0,fi}$ = effective length of the column under fire conditions; 2 m ≤ $l_{0,fi}$ ≤ 6 m;

b' = $2A_c/(b+h)$ for rectangular cross-sections

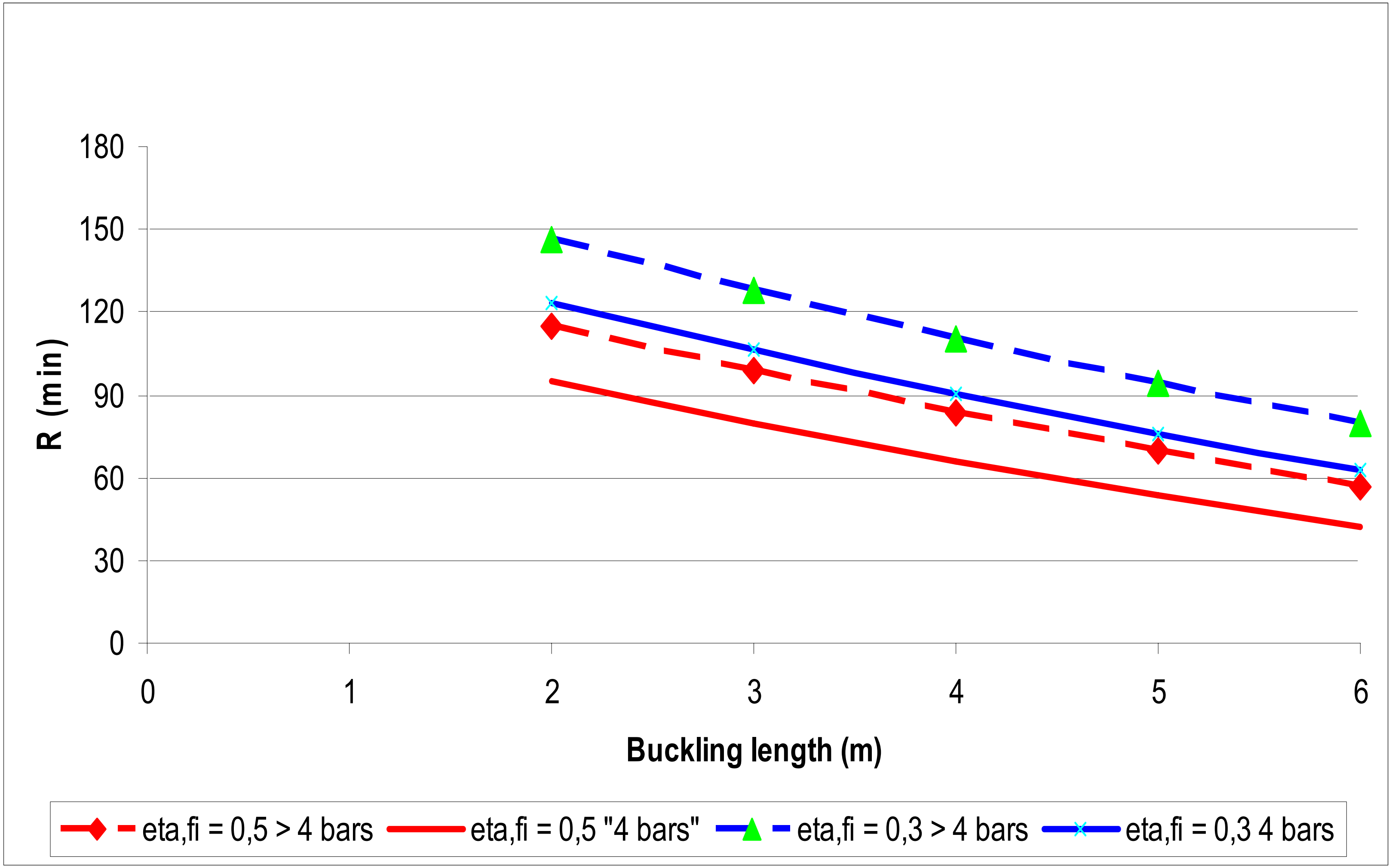
= ϕ_{col} for circular cross-sections (mm) ;

200 mm ≤ b' ≤ 450 mm; h ≤ 1,5 b.

ω = mechanical reinforcement ratio at normal temperature conditions $= \dfrac{A_s f_{yd}}{A_c f_{cd}}$

α_{cc} = coefficient for compressive strength (see EN 1992-1-1)

300 x 300 a = 35


180
150
120
90
60
30
0
R (min)
0
1
2
3
4
5
6
Buckling length (m)
eta,fi = 0,5 > 4 bars
eta,fi = 0,5 "4 bars"
eta,fi = 0,3 > 4 bars
eta,fi = 0,3 4 bars

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

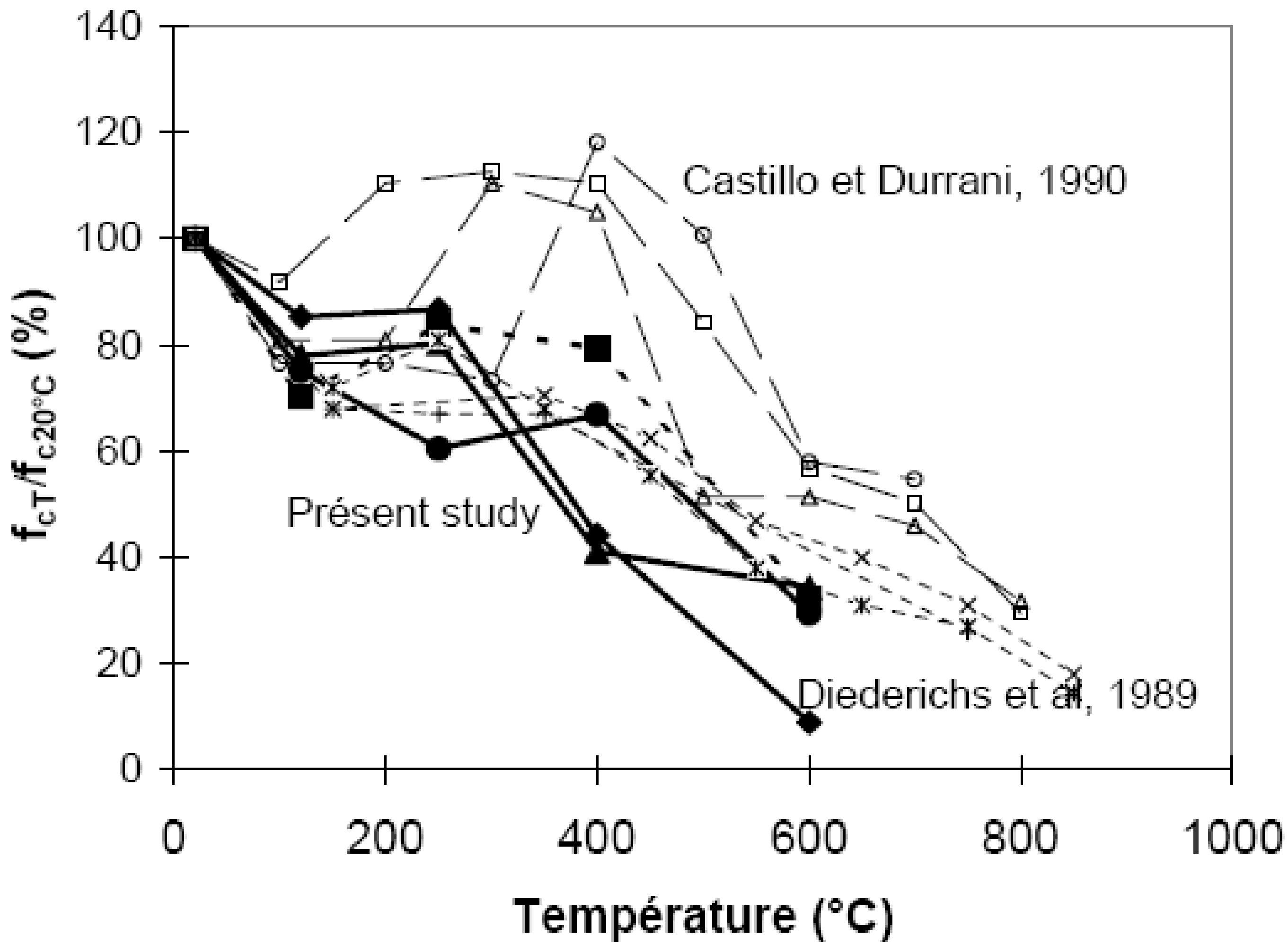
Beams, slabs, tensile members

- **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 (to more conservative direction)

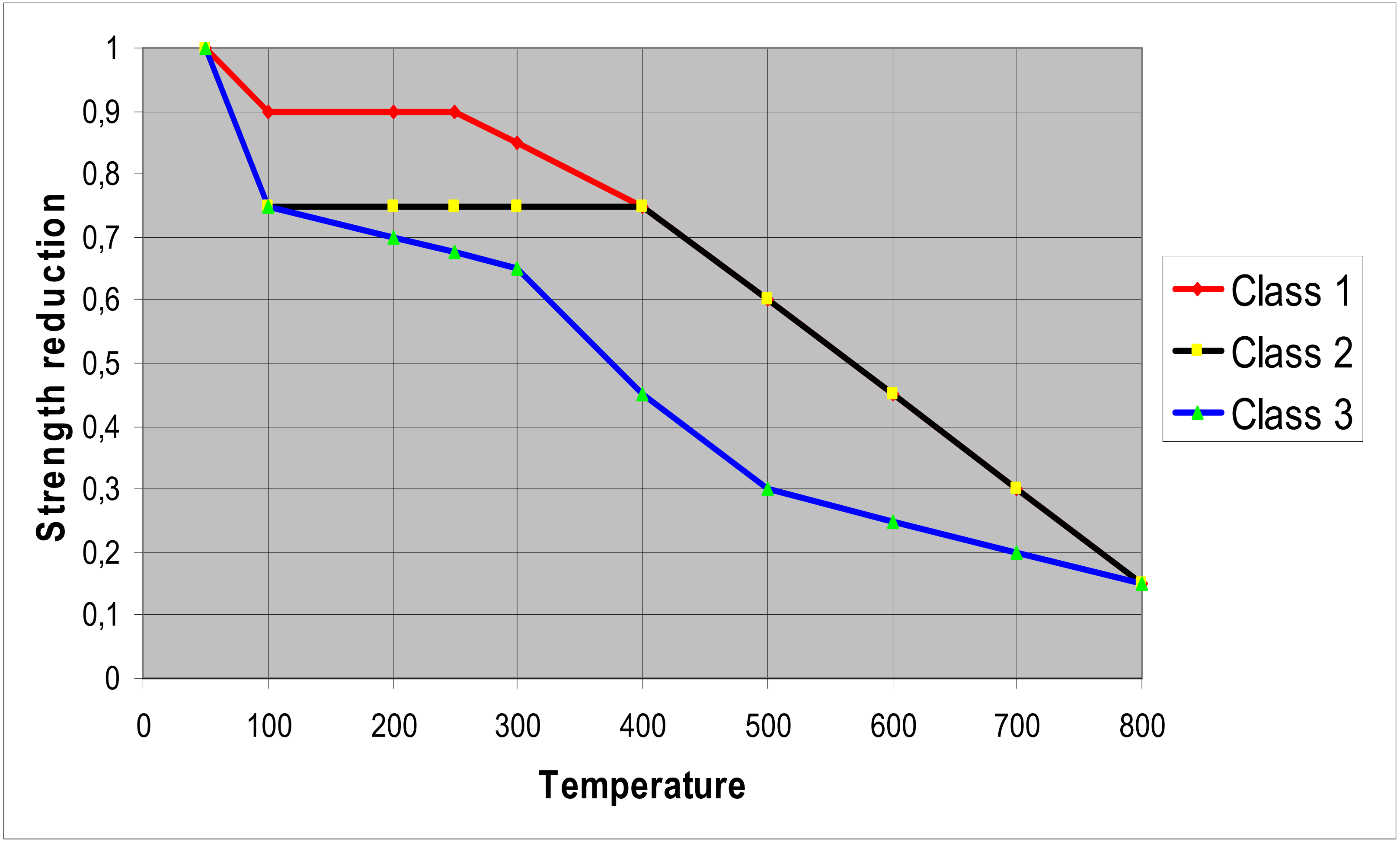
- Sections 1 and 2 General, Basis of design
- Section 3 Material properties
- Section 4 Design procedures
  - **Simplified calculation method 4.2, Annex A, B and E**
  - **Shear, torsion and anchorage 4.4 and Annex D**
  - **Spalling 4.5**
- Section 5 Tabulated data
  - **Annex C**
- Section 6 High strength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

Strength reduction of high strength concrete

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



HSC strength reduction is NDP



HSC Tabulated data

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		

HSC simplified calculation

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 compression zone	0,98	0,95
Slabs exposed to fire in the tension side, $h_s \geq 120$ mm	0,98	0,95
Slabs exposed to fire in the tension side, $h_s = 50$ mm	0,95	0,85

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 ≥ 2 mm with a pitch ≤ 50 x 50 mm. The nominal cover to the main reinforcement should be ≥ 40 mm.
  - **B:** A type of concrete for which it has been demonstrated (by local experience or by testing) that no spalling of concrete occurs under fire exposure.
  - **C:** Protective layers for which it is demonstrated that no spalling of concrete occurs under fire exposure
  - **D:** Include in the concrete mix more than 2 kg/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