Revision of EN 1992-1-2

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TT. Month JJJJ, Place

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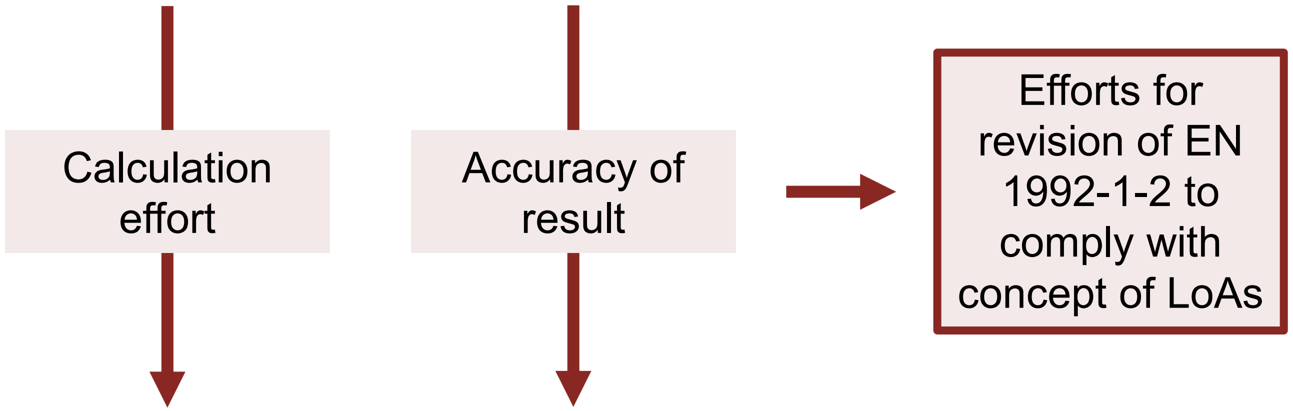
Agenda

1. Overview
2. Clause 4: Basis of design
3. Clause 5: Material properties
4. Clause 6: Tabulated design data
5. Clause 7: Simplified design methods
6. Clause 9: Detailing
7. Clause 10: Spalling

Clause 4
Basis of design

Basis of design

- Principally, EN 1992-1-2 provides **four levels of approximation**:
  - Level 1: **Tabulated design data**
  - Level 2: **Simplified design methods** (cross-sectional resistance)
  - Lever 3: **Advanced design methods** (FEM)
  - Level 4: **Tests**



- The choice for the appropriate level of approximation depends on the required amount of information and the required accuracy of the design.
- Tabulated design data, Simplified design methods **and rules for explosive spalling** from EN 1992-1-2 are **based on the ISO 834 fire curve.**

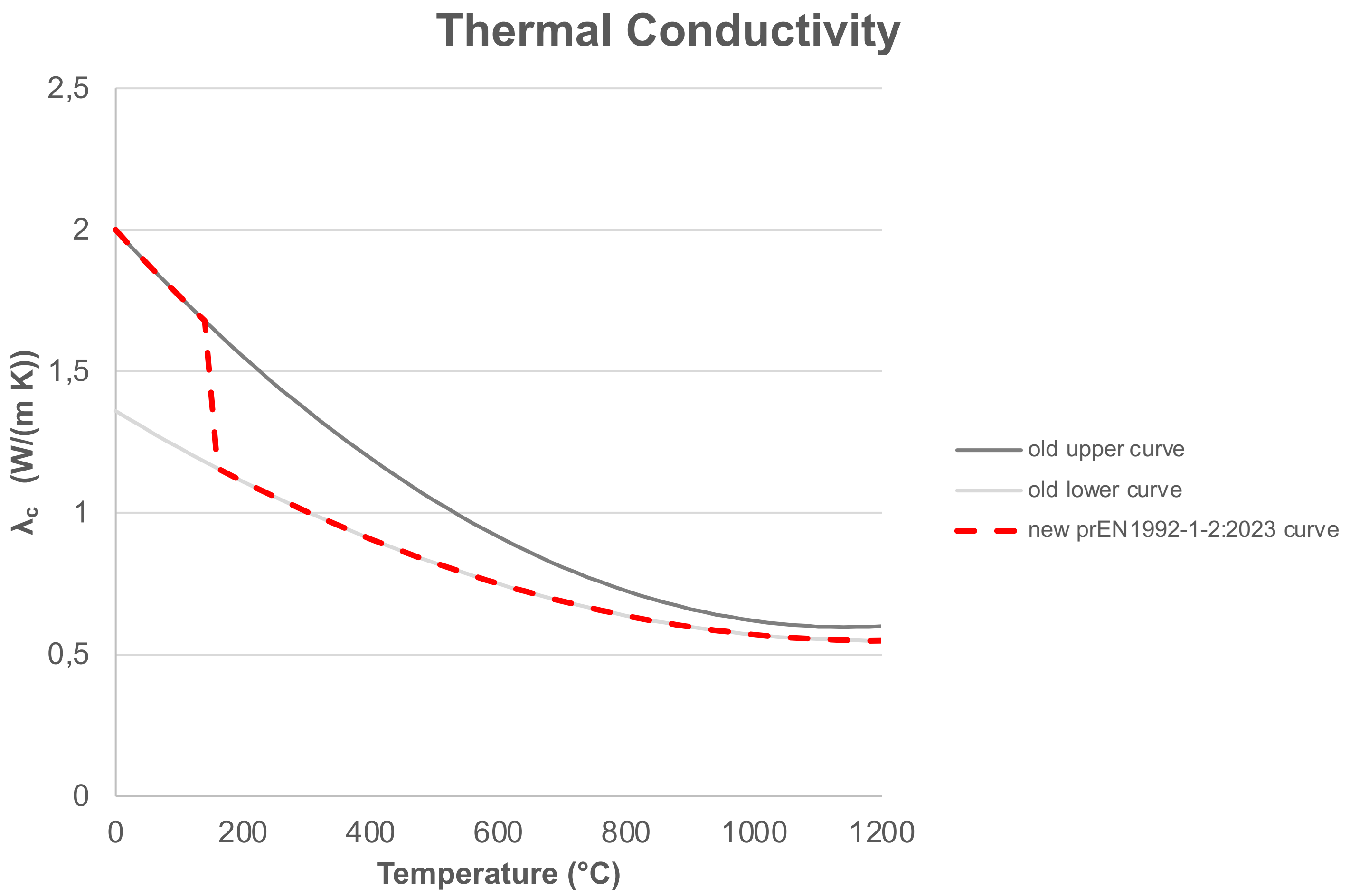
Clause 5
Material properties

Material properties

Main changes

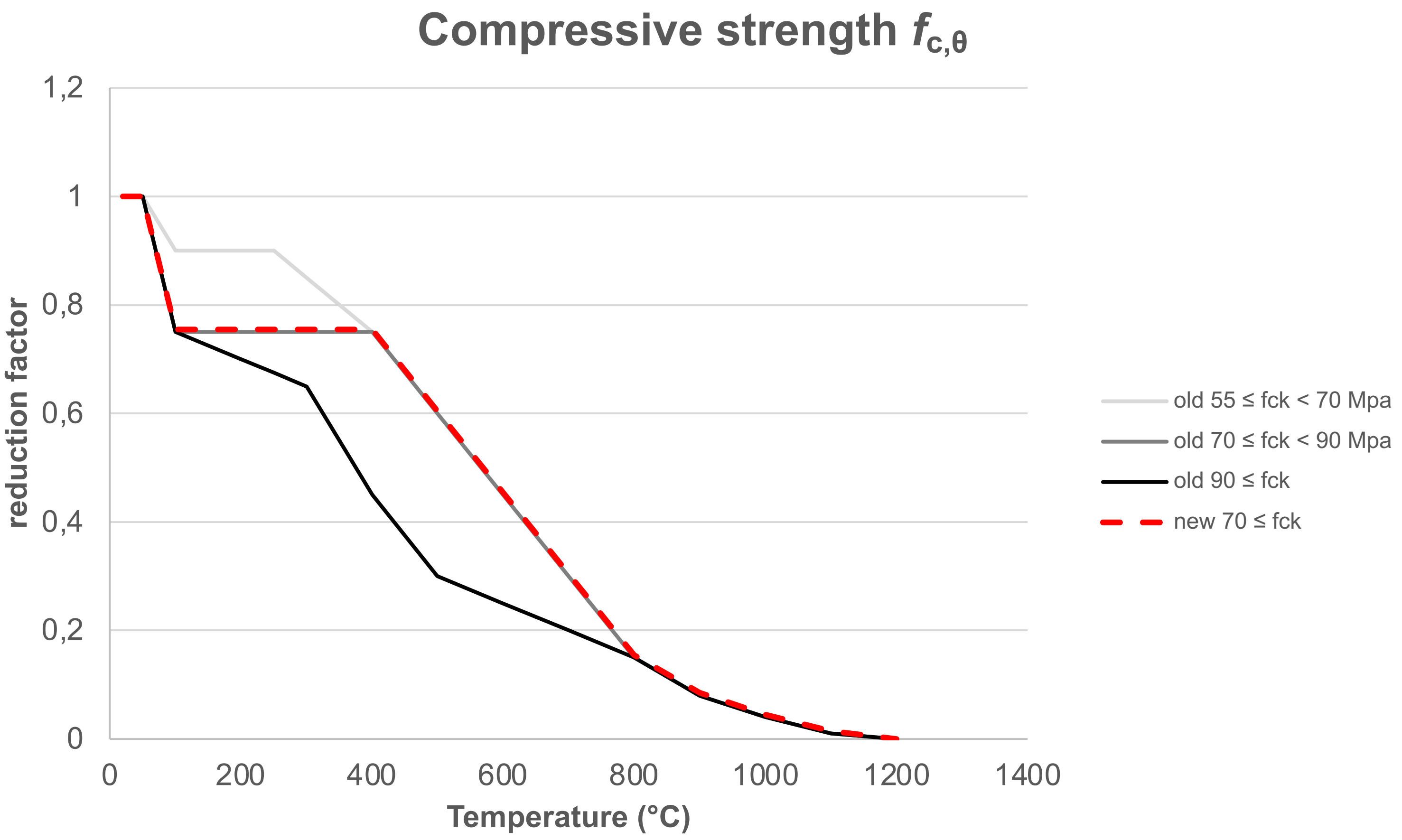
- Conductivity of normal weight concrete and high strength concrete at elevated temperatures
- High Strength Concrete reduction factor
- Concrete strength when considering the descending temperature branch for natural fire
- Steel strength decay for strains within the range between the proportional limit and the yield strain
- Strength and deformation properties for prestressing steel
- Three new annexes :
  - lightweight aggregate concrete (normative)
  - fibre reinforced concrete (informative)
  - recycled aggregates concrete (informative)

Conductivity of normal weight concrete and high strength concrete at elevated temperatures



Material properties

High Strength Concrete reduction factor



Concrete strength when considering the descending temperature branch for natural fire

(5) For thermal actions in accordance with prEN 1991-1-2:2021, 5.3 (Physically based models), when considering the cooling phase, the strength of concrete heated to a maximum temperature $\theta_{c,max}$ and having cooled down to 20 °C may be taken according to Formula (5.15):

$$f_{c,\theta,20\,°C} = \varphi\, f_{ck} \tag{5.15}$$

where for:

— $f_{ck} < 70$ MPa

$$\varphi = f_{c,\theta max}/f_{ck} \quad \text{for } 20\,°C \le \theta_{max} < 100\,°C \tag{5.16}$$

$$\varphi = (-0{,}0005 \times \theta_{max} + 1{,}05)\,(f_{c,\theta max}/f_{ck}) \quad \text{for } 100\,°C \le \theta_{max} < 300\,°C \tag{5.17}$$

$$\boxed{\varphi = 0{,}9\,(f_{c,\theta max}/f_{ck})} \quad \text{for } \theta_{max} \ge 300\,°C \tag{5.18}$$

— $f_{ck} \ge 70$ MPa

$$\varphi = f_{c,\theta max}/f_{ck} \quad \text{for } 20\,°C \le \theta_{max} < 1\,200\,°C \tag{5.19}$$

The reduction factor $(f_{c,\theta max}/f_{ck})$ which corresponds to the coefficient $(f_{c,\theta}/f_{ck})$ at the maximum temperature $\theta_{c,max}$, should be taken according to Table 5.1.

Steel strength decay for strains within the range between the proportional limit and the yield strain

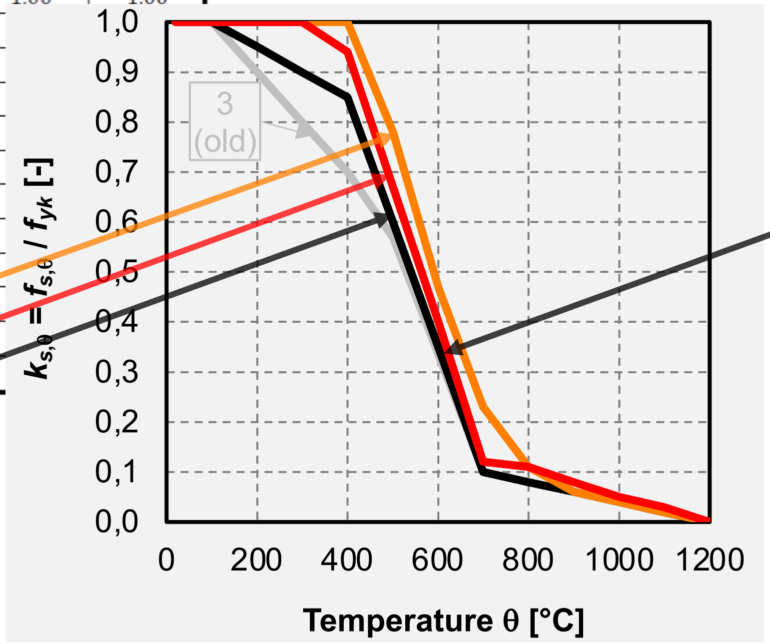
Table 5.3 — Values for the parameters of the stress-strain relationship of hot rolled and cold worked reinforcing steel at elevated temperatures

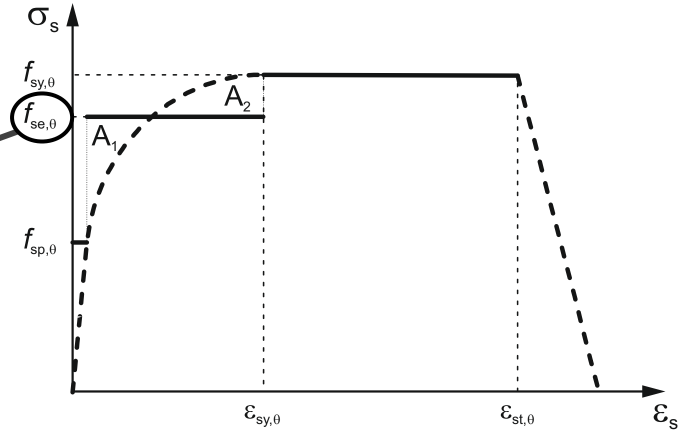
Steel temperature θ [°C]	$k_{sy,\theta} = f_{sy,\theta}/f_{yk}$		$k_{sp,\theta} = f_{sp,\theta}/f_{yk}$		$k_{se,\theta} = f_{se,\theta}/f_{yk}$	$k_{Es,\theta} = E_{s,\theta}/E_s$	
	hot rolled	cold worked	hot rolled	cold worked	hot rolled or cold worked	hot rolled	cold worked
1	2	3	4	5	6	7	8
20	1,00	1,00	1,00	1,00	1,00	1,00	1,00
100	1,00	1,00	1,00	0,96	1,00	1,00	1,00
200	1,00	1,00	0,81	0,92	0,95	[illegible]	[illegible]
300	1,00	1,00	0,61	0,81	0,90	[illegible]	[illegible]
400	1,00	0,94	0,42	0,63	0,85	[illegible]	[illegible]
500	0,78	0,67	0,36	0,44	0,60	[illegible]	[illegible]
600	0,47	0,40	0,18	0,26	0,35	[illegible]	[illegible]
700	0,23	0,12	0,07	0,08	0,10	[illegible]	[illegible]
800	0,11	0,11	0,05	0,06	0,08	[illegible]	[illegible]
900	0,06	0,08	0,04	0,05	0,06	[illegible]	[illegible]
1 000	0,04	0,05	0,02	0,03	0,04	[illegible]	[illegible]
1 100	0,02	0,03	0,01	0,02	0,02	[illegible]	[illegible]
1 200	0,00	0,00	0,00	0,00	0,00	[illegible]	[illegible]

1: Tension reinforcement for members mainly loaded in bending (hot rolled) with strains $\varepsilon_{s,\theta} \geq 2\%$

2: Tension reinforcement for members mainly loaded in bending (cold worked) with strains $\varepsilon_{s,\theta} \geq 2\%$

3: Compression reinforcement and tension reinforcement for members loaded in bending and axial load with strains $\varepsilon_{s,\theta} < 2\%$

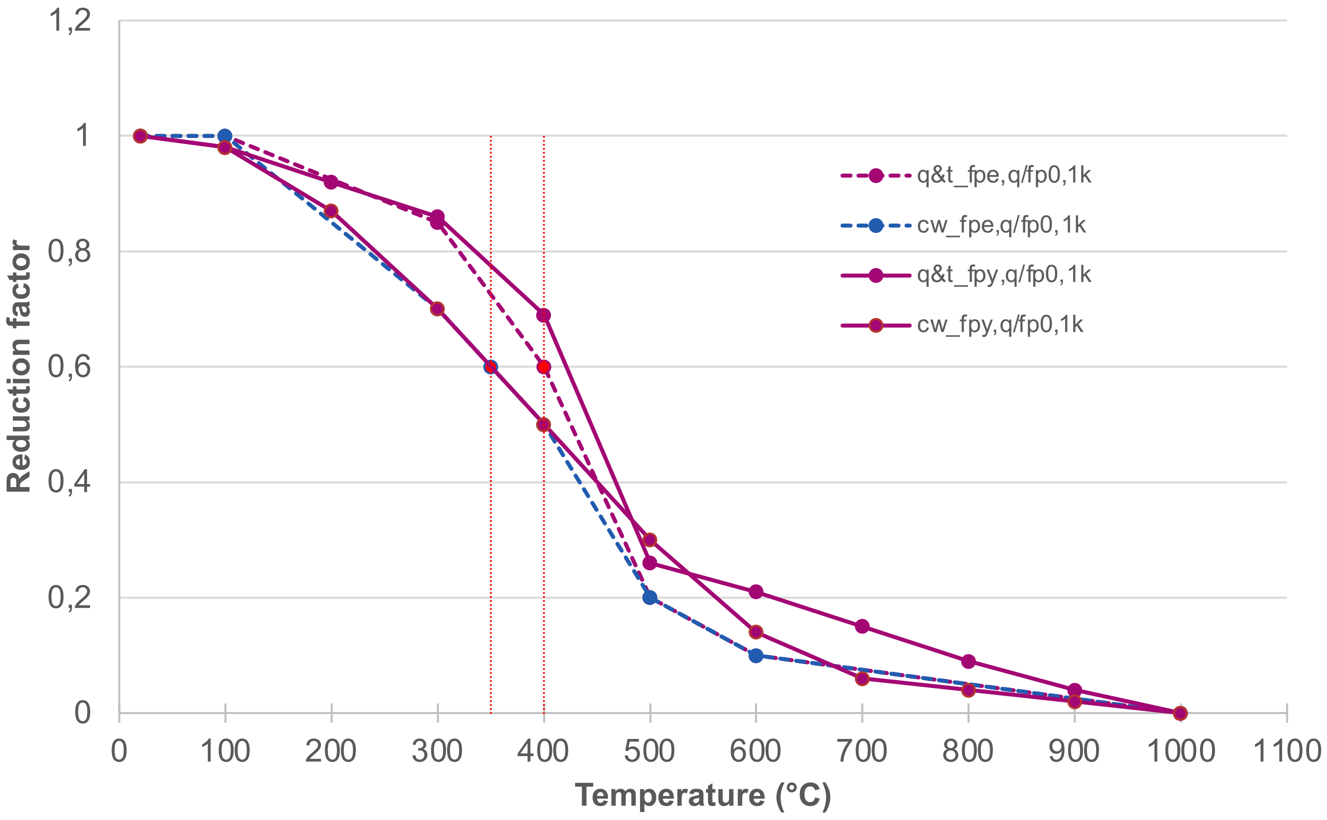




$f_{se,\theta}$: to evaluate the **critical temperature** of reinforcing steel in clause 6 and may be used in 7.3.4.2 to describe the **reinforcing steel strength**

Material properties

Strength and deformation properties for prestressing steel



quenched and tempered = bars

cold worked = wires and strands

Lightweight aggregate concrete structures (Annex A – normative)

- Material properties : thermal conductivity, specific heat, thermal strain are given. Parameters related to mechanical properties in compression for lightweight aggregate concrete should be based on testing.
- Tabulated data : For lightweight aggregate concrete used in beams or slabs the minimum dimension of the cross-section may be reduced by 10 %.
- Rules for spalling : a specific assessment of spalling should be undertaken regardless of concrete strength, or polypropylene fibres should be specified for the concrete mix (see Clause 10) due to the expected high moisture content or specific behaviour.

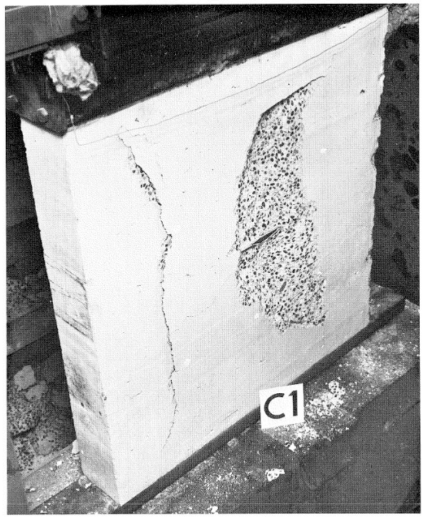


Fig. 1. Slab-type lightweight concrete specimen after a fire test.

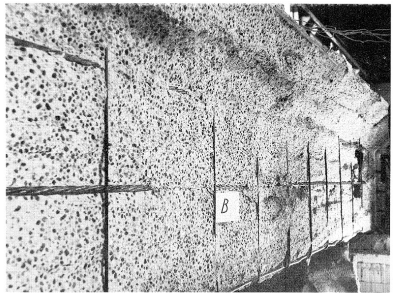


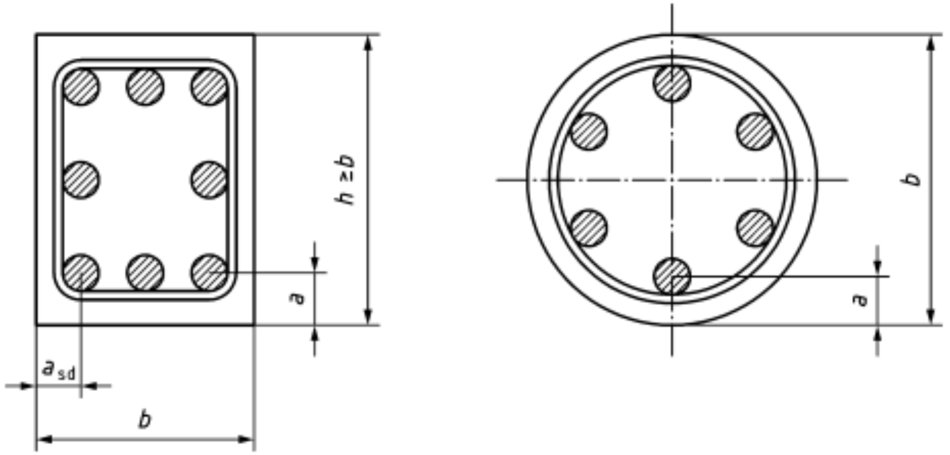
Fig. 34. Beam b_2 after the fire test.

Clause 6
Tabulated design data

Tabulated design data
General rules

Changes

- Concretes of usual density between 2000 and 2600 kg/m³
- For concretes with $f_{ck} \geqslant 70$ MPa, tabulated data should not be used for > R 120
- There is a risk of severe spalling if the limitation rules to avoid spalling (Chapter 10) are not complied with.
- When minimum dimensions given in Clause 6 are followed, further checks for shear, torsion and anchorage may be omitted.
- Axis distances to a reinforcing steel bar, prestressing steel wire or tendon should be considered as nominal values.
- Linear interpolation between the values given in the tabl
  may be carried out.
- All tables are based on a reference load level η_{fi} = 0,7.



Tabulated design data
Columns

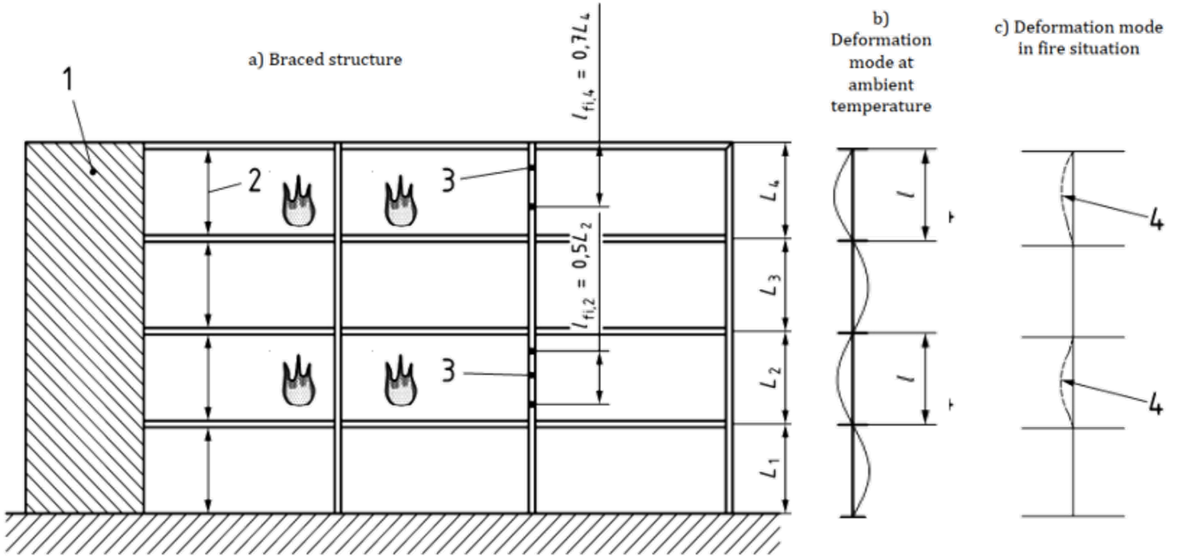
- For assessing the fire resistance of columns two Methods, Method A and B, may be used
- Method A shall be used for braced structures only, Method B may also be used for unbraced structures
- Degree of utilisation: $\mu_{fi} = |N_{Ed,fi}| / N_{Rd}$
- Method A apply where $l_{0,fi} = 0{,}5\ l_0$

- **Application of Method A for columns with $l_{0,fi} \neq 0{,}5\ l_0$**

  $K = l_0 / l_{0,fi} = 2$

  Calculation of degree of utilisation μ_{fi}' for N_{Rd} with a modified effective length $l_0' = 2\ l_{0,fi}$

  $\mu_{fi}' = E_{d,fi} / N_{Rd} (l_o') > \mu_{fi} = E_{d,fi} / N_{Rd} (l_o)$



Key

1 shear wall or other bracing system

2 height of separate fire compartments in each storey

3 effective length of column exposed to fire

4 deformation mode in fire

Tabulated design data
Columns

- New Method B (Annex D)
- New Method B with extended field of application, also for unbraced structures
- specified: maximum permissible effective column length l_0 reliant on dimensions of cross-section and degree of utilisation

Table D.3 — Maximum permissible effective column length l_0 for braced and unbraced columns: R 60

		$l_{0,fi} = 1,0\ l_0$			$0,1 < \omega_{mod} < 1,0$														
	b (mm):	≥ 600			500			400			300			250			200		
	μ_{fi}:	0,3	0,5	0,7	0,3	0,5	0,7	0,3	0,5	0,7	0,3	0,5	0,7	0,3	0,5	0,7	0,3	0,4	0,5
e_0	a (mm)	$l_{0,max}$ (m)			$l_{0,max}$ (m)			$l_{0,max}$ (m)			$l_{0,max}$ (m)			$l_{0,max}$ (m)			$l_{0,max}$ (m)		
20 mm	25	10,6	8,0	5,4	8,4	6,4	3,3	6,0	4,2		3,5	1,4		2,4					
20 mm	35	10,9	9,5	7,6	8,7	7,5	5,9	6,2	5,3	3,8	3,7	3,1		2,7	2,2				
20 mm	45	11,6	9,7	8,3	9,2	7,8	6,5	6,9	5,7	4,6	4,2	3,5	2,5	3,1	2,5		2,0		
20 mm	60	13,3	11,1	9,7	10,5	8,7	7,5	8,0	6,4	5,3	4,7	3,7	2,9	3,3	2,6		2,0		
0,5 b	25	5,0			3,8			2,2											
0,5 b	35	14,5	5,7		11,5	4,2		8,4	2,1		3,6			2,4					
0,5 b	45	24,0	10,6	3,3	20,0	8,2		16,0	5,8		6,9	2,0		4,6			2,4		
0,5 b	60	24,0	20,6	8,8	20,0	15,3	6,5	16,0	9,9	3,9	12,0	3,9		8,7	1,8		2,5		
1,0 b	25	8,2			6,6			4,8											
1,0 b	35	24,0	10,2		20,0	7,9		15,0	5,8		6,8			4,9					
1,0 b	45	24,0	18,7	8,3	20,0	14,6		16,0	10,6		12,0	4,9		9,0			5,3		
1,0 b	60	24,0	24,0	13,0	20,0	20,0	10,1	16,0	16,0	7,6	12,0	7,7		10,0	4,5		5,3		

width

degree of utilisation

axis distance of reinforcement

eccentricity

Tabulated design data
Columns

- New design table for columns exposed to one side
  - EN 1992-1-2: 2004
  - FprEN 1992-1-2: 2023

Exposed on one side
$\mu_{fi} = 0.7$
5
155/25
155/25
155/25
175/35
230/55
295/70

Table 6.2 — Minimum column dimensions and axis distances for rectangular columns exposed on one side with $l_0 \leq 6$ m for ambient temperature conditions and $l_{0,fi} \leq 3$ m for fire situations

Standard fire resistance	Minimum dimensions (mm) Column width b_{min}/axis distance a of the main reinforcement		
	$\mu_{fi} = 0,2$	$\mu_{fi} = 0,5$	$\mu_{fi} = 0,7$
1	**2**	**3**	**4**
R 30	100/10	120/15	130/25
R 60	110/10	130/15	140/25
R 90	120/20	140/25	155/25
R 120	150/25	160/30	175/35
R 180	185/45	200/50	230/55
R 240	230/60	240/65	290/70

Tabulated design data
Walls

- New design tables for load bearing walls
  - EN 1992-1-2: 2004

Standard fire resistance	Minimum dimensions (mm) Wall thickness/axis distance for			
	μ_{fi} = 0,35		μ_{fi} = 0,7	
	wall exposed on one side	wall exposed on two sides	wall exposed on one side	wall exposed on two sides
1	2	3	4	5
REI 30	100/10*	120/10*	120/10*	120/10*
REI 60	110/10*	120/10*	130/10*	140/10*
REI 90	120/20*	140/10*	140/25	170/25
REI 120	150/25	160/25	160/35	220/35
REI 180	180/40	200/45	210/50	270/55
REI 240	230/55	250/55	270/60	350/60

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

Note: For the definition of μ_{fi} see 5.3.2 (3).

- FprEN 1992-1-2: 2023

Table 6.4 — Minimum dimensions and axis distances for load-bearing reinforced concrete walls exposed on one long side (left) or on both long sides (right) with $l_0 \leq 4{,}5$ m for ambient temperature conditions and $l_{0,fi} \leq 2{,}25$ m for fire situations

Standard fire resistance	Minimum dimensions (mm) Wall thickness h_w/axis distance a			Standard fire resistance	Minimum dimensions (mm) Wall thickness h_w/axis distance a		
	$\mu_{fi}=0,2$	$\mu_{fi}=0,5$	$\mu_{fi}=0,7$		$\mu_{fi}=0,2$	$\mu_{fi}=0,5$	$\mu_{fi}=0,7$
Exposed on one side				Exposed on both sides			
1	2	3	4	5	6	7	8
REI 30	100/10	110/10	120/10	R 30	100/10	120/10	130/10
REI 60	110/10	120/15	130/20	R 60	120/15	155/20	170/25
REI 90	120/20	135/25	140/30	R 90	140/20	185/30	210/35
REI 120	135/25	150/30	160/35	R 120	165/30	210/40	240/45
REI 180	155/35	170/40	180/45	R 180	200/45	250/50	280/55
REI 240	180/40	200/45	210/50	R 240	250/50	305/55	340/60

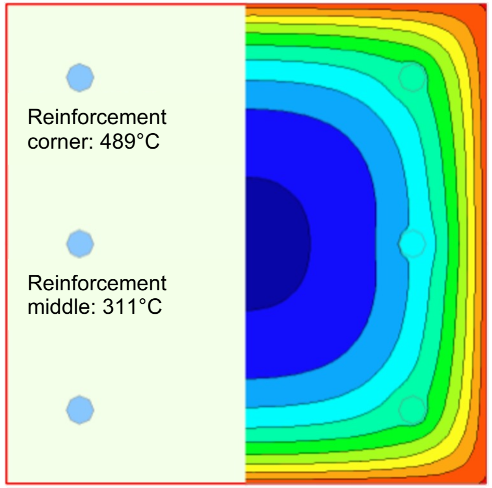
Table 6.5 — Minimum dimensions and axis distances for load-bearing reinforced concrete walls exposed on one long side (left) or on both long sides (right) with $l_0 \leq 2{,}5$ m for ambient temperature conditions and $l_{0,fi} \leq 1{,}25$ m for fire situations

Standard fire resistance	Minimum dimensions (mm) Wall thickness h_w/axis distance a			Standard fire resistance	Minimum dimensions (mm) Wall thickness h_w/axis distance a		
	$\mu_{fi}=0,2$	$\mu_{fi}=0,5$	$\mu_{fi}=0,7$		$\mu_{fi}=0,2$	$\mu_{fi}=0,5$	$\mu_{fi}=0,7$
Exposed on one side				Exposed on both sides			
1	2	3	4	5	6	7	8
REI 30	80/10	90/10	100/10	R 30	90/10	100/10	110/10
REI 60	90/10	100/10	110/15	R 60	110/10	125/15	140/20
REI 90	100/10	110/15	120/20	R 90	125/15	155/25	170/30
REI 120	120/15	120/20	130/25	R 120	140/25	175/35	200/40
REI 180	150/20	150/25	150/30	R 180	175/30	215/40	240/45
REI 240	170/25	175/30	175/35	R 240	200/35	250/45	280/50

Clause 7
Simplified design methods

Simplified design methods

1. Thermal analysis
   a. Simplified design method (FprEN 1992-1-2)
   b. Advanced design method (FEM)



Temperature profile after 90 minutes of fire exposure (ISO 834) *[Infograph]*

2. Mechanical analysis
   Principle:

$$F_{cd,fi}(t) = x_{e,fi} \cdot b_{fi} \cdot k_c(\theta_M) \cdot f_{ck} \cdot \gamma_{c,fi}$$

$$F_{sd,fi}(t) = A_s \cdot k_s(\theta_s) \cdot f_{yk} \cdot \gamma_{s,fi}$$

$$\gamma_{c,fi} = \gamma_{s,fi} = 1$$

$$\boxed{\text{Verification}: M_{R,fi,d} = F_{sd,fi} \cdot z_{fi} \geq M_{E,fi,d}}$$

Thermal analysis

Simplified design method (available in FprEN 1992-1-2)

Formulae for temperature profile to check the load-bearing capacity in the event of fire (function R)

$$\theta_1 = 345°\text{C} \cdot \log\left(\frac{7\left(R_{fi} - 720\ \text{s}\right)}{60\ \text{s}} + 1\right) \cdot e^{-y\sqrt{\frac{0.9 \cdot k}{R_{fi}}}} \text{ or } 345°\text{C} \cdot \log\left(\frac{7\left(R_{fi} - 720\ \text{s}\right)}{60\ \text{s}} + 1\right) \cdot e^{-z\sqrt{\frac{0.9 \cdot k}{R_{fi}}}}$$

R_{fi} = duration of the standard fire

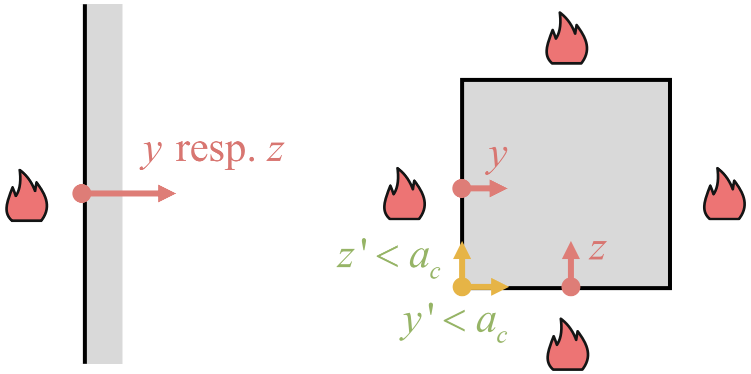
y resp. z = distance from the exposed surface

$k = \rho \cdot c_p / \lambda = 3.3 \cdot 10^6\ \text{s/m}^2$

member exposed on one side: $\theta = \theta_1\left(y \text{ resp. } z, R_{fi}\right) + 20°\text{C}$

member exposed on two sides: $\theta_2 = \theta_1\left(y \text{ resp. } z, R_{fi}\right) + \theta_1\left(b - y \text{ resp. } h - z, R_{fi}\right) + 20°\text{C}$

b and h = member dimensions in direction y resp. z



member exposed on four sides: $\theta_4 = \theta_2\left(y, R_{fi}\right) + \theta_2\left(z, R_{fi}\right) + \frac{\theta_2\left(y, R_{fi}\right) \cdot \theta_2\left(z, R_{fi}\right)}{\theta_0\left(0, R_{fi}\right)} + \left(345°\text{C} \cdot \log\left(\frac{8R_{fi}}{60\ \text{s}} + 1\right) - \theta_0\left(0, R_{fi}\right)\right) \cdot \frac{\left(a_c - y'\right) \cdot \left(a_c - z'\right)}{a_c^2} + 20°\text{C}$

$$a_c = \begin{matrix} 0.04\ \text{m for } R_{fi} \leq 60\ \text{min} \\ 0.10\ \text{m for } R_{fi} > 60\ \text{min} \end{matrix}$$

Simplified design methods
Mechanical analysis

Available methods in EN 1992-1-2:2004

Bending	Bending and axial load	Shear
• **Annex B.1** (informative) 500°C Isotherm Method (ISO 834, physically based fire) • **Annex B.2** (informative) Zone Method (ISO 834) • **Annex E** (informative): Simplified calculation method for beams and slabs	• **Method A** (normative) (ISO 834) • **Annex B.1** (informative): 500°C Isotherm Method (ISO 834, physically based fire) • **Annex B.2** (informative): Zone Method (ISO 834) • **Annex B.3** (informative, laborious): Assessment of a reinforced concrete cross-section exposed to bending moment and axial load by the method based on estimation of curvature (ISO 834, physically based fire) • **Amended Annex C** (informative): based on Refined Zone Method (based on B.2)	• **Annex D** (informative): Calculation methods for shear, torsion and anchorage

→ Aims: (1) reduce number of available methods, (2) comply with concept of LoA

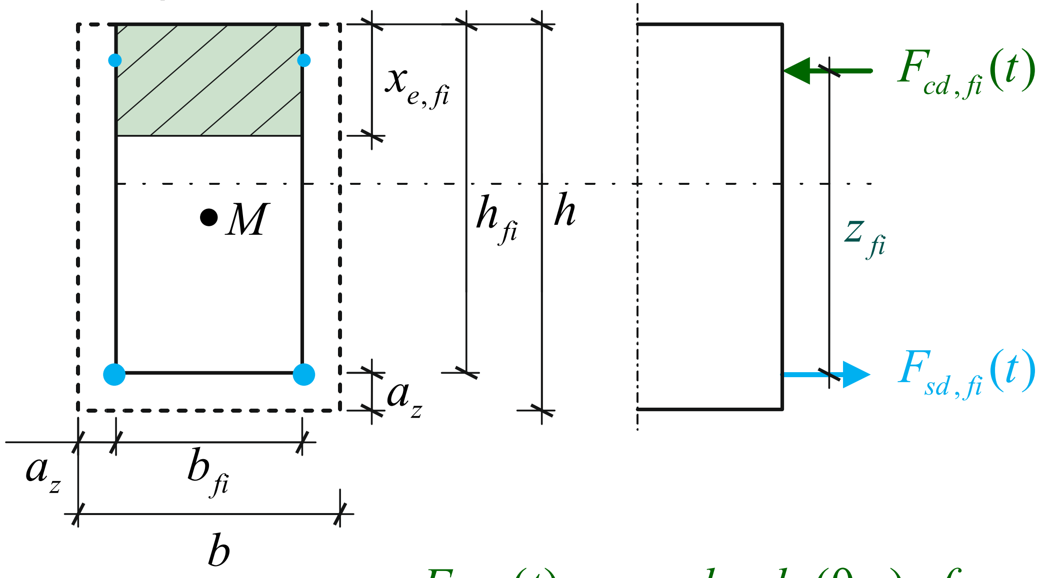
Mechanical analysis

Design method

Work steps	**M-A**	**B.1**	**B.2**	**B.3**	**E**	**RZM**
1 Reduction of cross-section		x	x			x
2 Reduction of reinforcing steel strength		x	x	x	x	x
3 Reduction of concrete strength			x	x		x
4 Determination of ultimate load-bearing capacity	x	x	x	x	x	x

2. Mechanical analysis

Principle:



$$F_{cd,fi}(t) = x_{e,fi} \cdot b_{fi} \cdot k_c(\theta_M) \cdot f_{ck} \cdot \gamma_{c,fi}$$

$$F_{sd,fi}(t) = A_s \cdot k_s(\theta_s) \cdot f_{yk} \cdot \gamma_{s,fi}$$

$$\boldsymbol{\gamma_{c,fi} = \gamma_{s,fi} = 1}$$

$$\boxed{\text{Verification}: M_{R,fi,d} = F_{sd,fi} \cdot z_{fi} \geq M_{E,fi,d}}$$

Bending / Bending and axial load

Refined Zone Method (RZM) in FprEN 1992-1-2, 7.3

Work steps

1 Reduction of cross-section

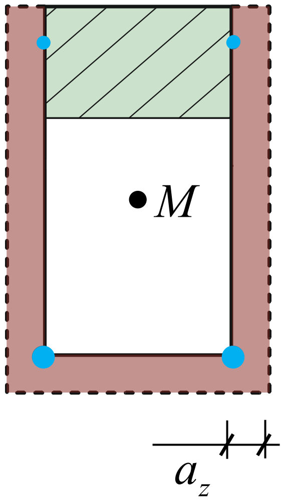
2 Reduction of reinforcing steel strength

3 Reduction of concrete strength

4 Determination of ultimate load-bearing capacity

Equation:

$$a_z = \begin{cases} 0.011 \cdot \sqrt{1 + \frac{R_{fi} - 27}{27} \cdot \sqrt{\frac{w}{0.0125}}} & \text{for } 0.075 \le w < 0.20 \\ 0.011 \cdot \sqrt{1 + 4\frac{R_{fi} - 27}{27}} & \text{for } w \ge 0.20 \end{cases},$$



Simplified design methods
Bending / Bending and axial load

Refined Zone Method (RZM) in FprEN 1992-1-2, 7.3

Work steps

1 Reduction of cross-section

2 Reduction of reinforcing steel strength

3 Reduction of concrete strength

4 Determination of ultimate load-bearing capacity

Strength depending on temperature at positions of reinforcing bars:

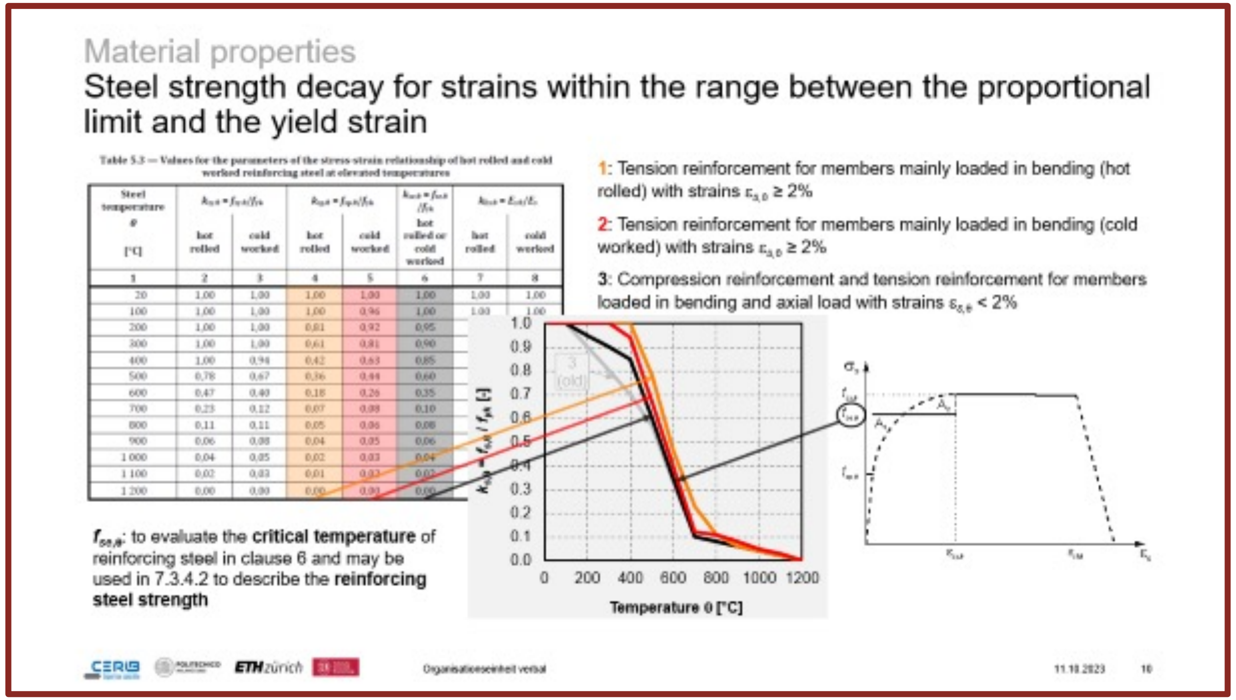


Table 5.3 — Values for the parameters of the stress-strain relationship of hot rolled and cold worked reinforcing steel at elevated temperatures

Steel temperature θ [°C]	$k_{sy,\theta} = f_{sy,\theta}/f_{yk}$ hot rolled	$k_{sy,\theta} = f_{sy,\theta}/f_{yk}$ cold worked	$k_{sp,\theta} = f_{sp,\theta}/f_{yk}$ hot rolled	$k_{sp,\theta} = f_{sp,\theta}/f_{yk}$ cold worked	$k_{s0,\theta} = f_{s0,\theta}/f_{yk}$ hot rolled or cold worked	$k_{Es,\theta} = E_{s,\theta}/E_s$ hot rolled	$k_{Es,\theta} = E_{s,\theta}/E_s$ cold worked
1	2	3	4	5	6	7	8
20	1,00	1,00	1,00	1,00	1,00	1,00	1,00
100	1,00	1,00	1,00	0,96	1,00	1,00	1,00
200	1,00	1,00	0,81	0,92	0,95	[illegible]	[illegible]
300	1,00	1,00	0,61	0,81	0,90	[illegible]	[illegible]
400	1,00	0,94	0,42	0,63	0,85	[illegible]	[illegible]
500	0,78	0,67	0,36	0,44	0,60	[illegible]	[illegible]
600	0,47	0,40	0,18	0,26	0,35	[illegible]	[illegible]
700	0,23	0,12	0,07	0,08	0,10	[illegible]	[illegible]
800	0,11	0,11	0,05	0,06	0,08	[illegible]	[illegible]
900	0,06	0,08	0,04	0,05	0,06	[illegible]	[illegible]
1 000	0,04	0,05	0,02	0,03	0,04	[illegible]	[illegible]
1 100	0,02	0,03	0,01	0,02	0,02	[illegible]	[illegible]
1 200	0,00	0,00	0,00	0,00	0,00	[illegible]	[illegible]

Bending / Bending and axial load

Refined Zone Method (RZM) in FprEN 1992-1-2, 7.3

Work steps

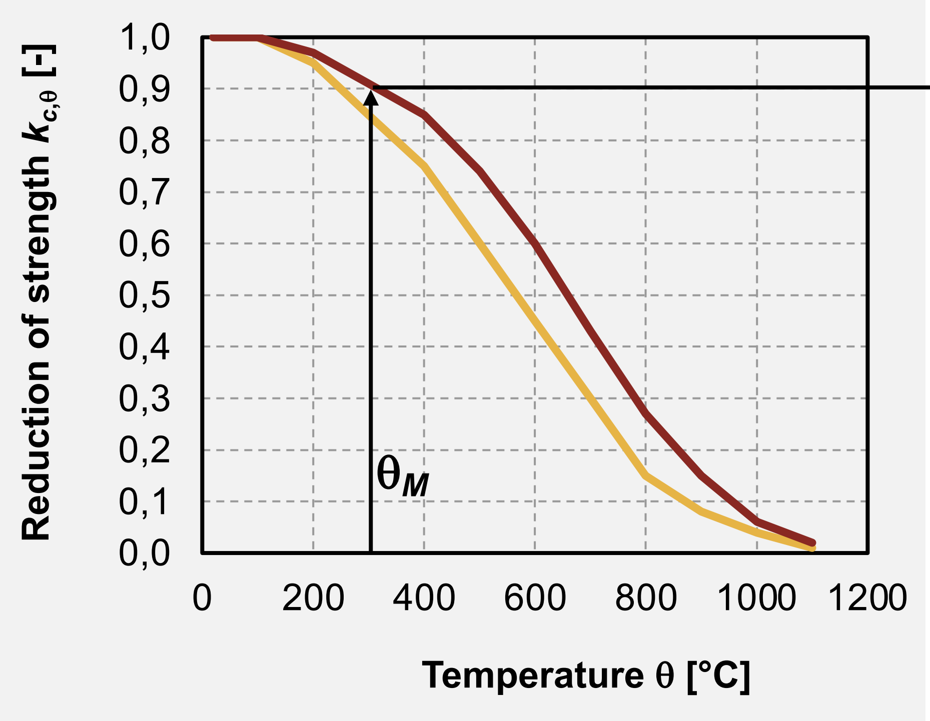
1 Reduction of cross-section

2 Reduction of reinforcing steel strength

3 Reduction of concrete strength

4 Determination of ultimate load-bearing capacity

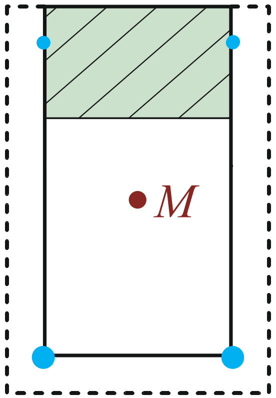
Strength depending on temperature in the centre of the cross-section:



Concrete strength for calcareous concrete

$f_{c,\theta}(\theta_M) = k_{c,\theta}(\theta_M)\ f_{ck}$

in the centre M of the cross-secion



Bending / Bending and axial load

Refined Zone Method (RZM) in FprEN 1992-1-2, 7.3

Work steps

1 Reduction of cross-section

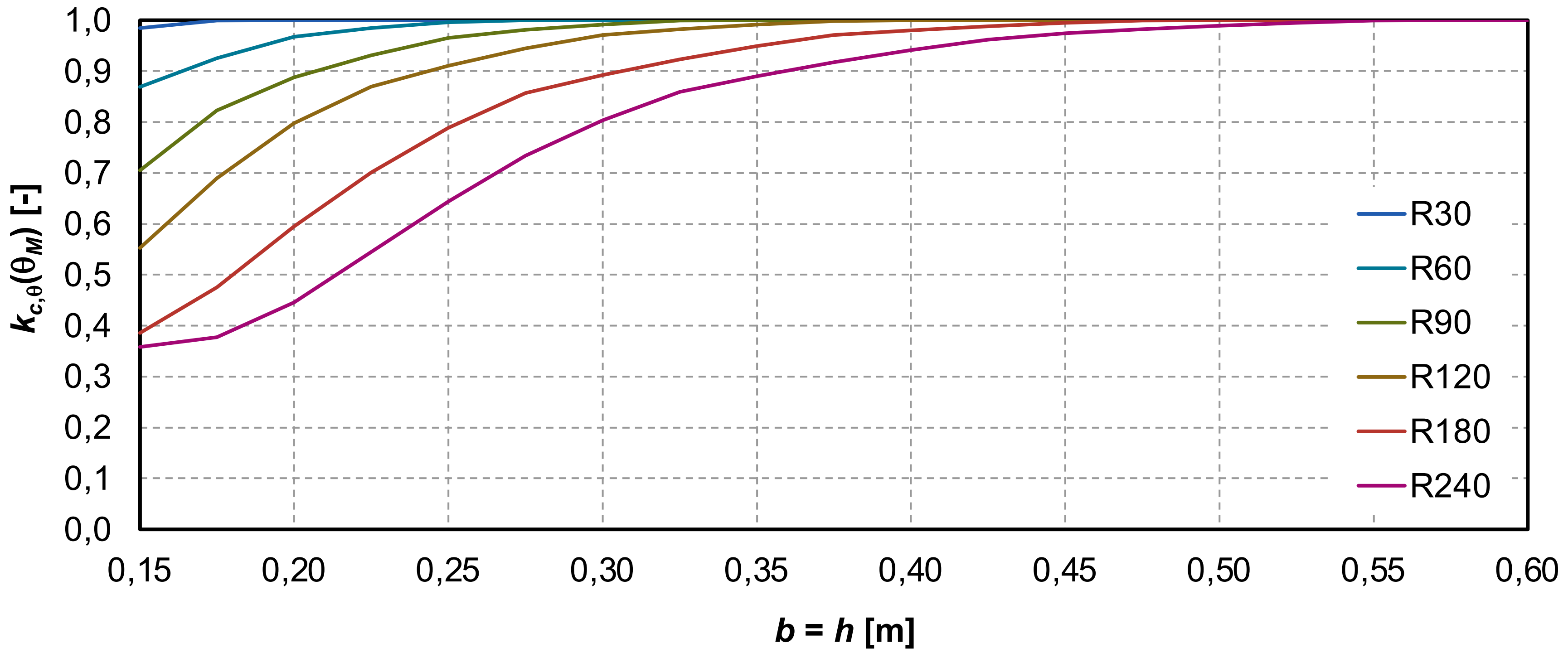
2 Reduction of reinforcing steel strength

3 Reduction of concrete strength

4 Determination of ultimate load-bearing capacity

Simplifying graphs for NA possible

(here for concrete with calcareous aggregates and squared cross-section exposed to fire on four sides)



Bending

Refined Zone Method (RZM) in FprEN 1992-1-2, 7.3

Work steps

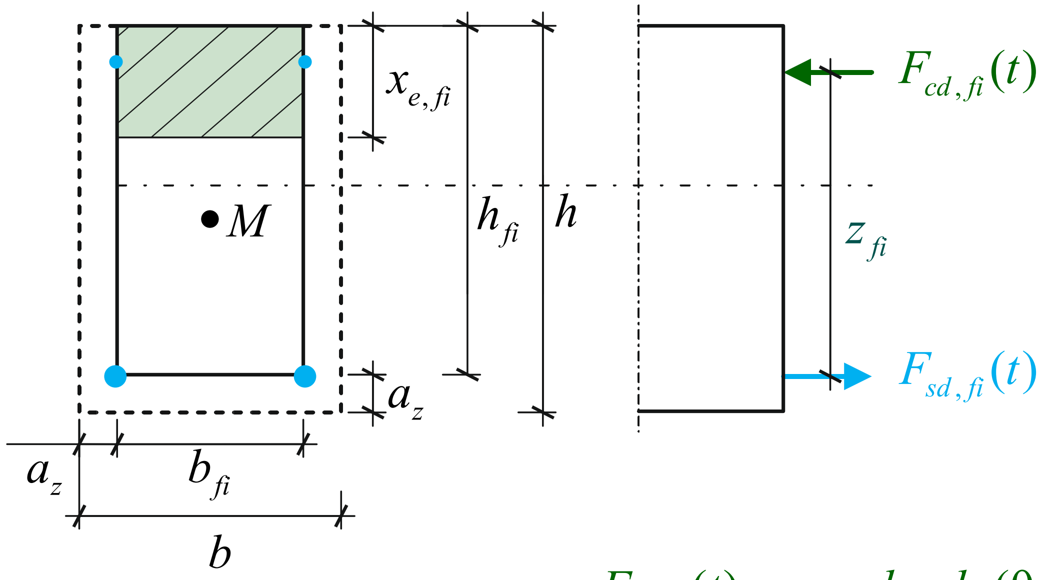
1 Reduction of cross-section

2 Reduction of reinforcing steel strength

3 Reduction of concrete strength

4 Determination of ultimate load-bearing capacity

Bending:



$$F_{cd,fi}(t) = x_{e,fi} \cdot b_{fi} \cdot k_c(\theta_M) \cdot f_{ck} \cdot \gamma_{c,fi}$$

$$F_{sd,fi}(t) = A_s \cdot k_s(\theta_s) \cdot f_{yk} \cdot \gamma_{s,fi}$$

$$\boldsymbol{\gamma_{c,fi} = \gamma_{s,fi} = 1}$$

Verification: $M_{R,fi,d} = F_{sd,fi} \cdot z_{fi} \geq M_{E,fi,d}$

Bending and axial load

Refined Zone Method (RZM) in FprEN 1992-1-2, 7.3

Work steps

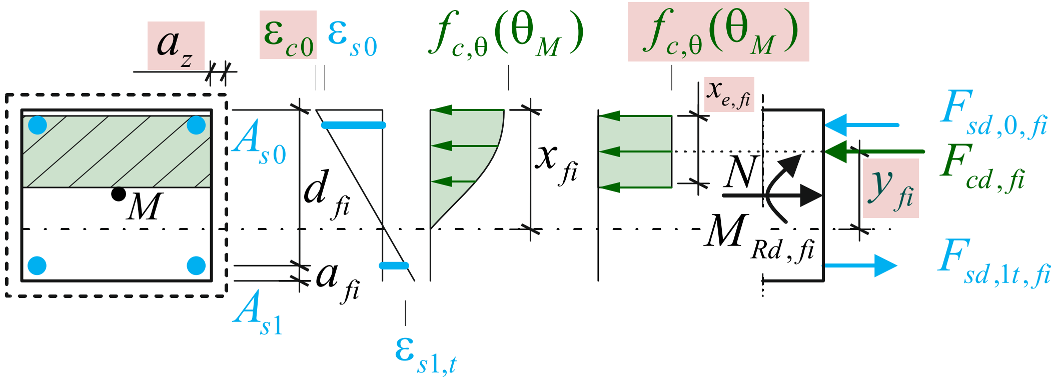
1 Reduction of cross-section

2 Reduction of reinforcing steel strength

3 Reduction of concrete strength

4 Determination of ultimate load-bearing capacity

Bending and axial load:



i. Compression zone for $0 \leq x_{fi} < 3\left(d_{fi} + a_{fi}\right)$

$\varepsilon_{c0} \leq \varepsilon_{c1,\theta}$ für $x_{fi} < \left(d_{fi} + a_{fi}\right)$,

$\varepsilon_{c0} = \varepsilon_{c1,\theta}$ für $\left(d_{fi} + a_{fi}\right) \leq x_{fi} < 3\left(d_{fi} + a_{fi}\right)$,

$$x_{e,fi} = \min\left(0.6\frac{\varepsilon_{c0}}{\varepsilon_{c1,\theta}},\ 0.75 - 0.15\frac{x_{fi}}{d_{fi} + a_{fi}}\right)x_{fi},$$

$$y_{fi} = \max\left(0.65,\ 0.55 + 0.10\frac{x_{fi}}{d_{fi} + a_{fi}}\right)x_{fi},$$

Bending and axial load

Refined Zone Method (RZM) in FprEN 1992-1-2, 7.3

Work steps

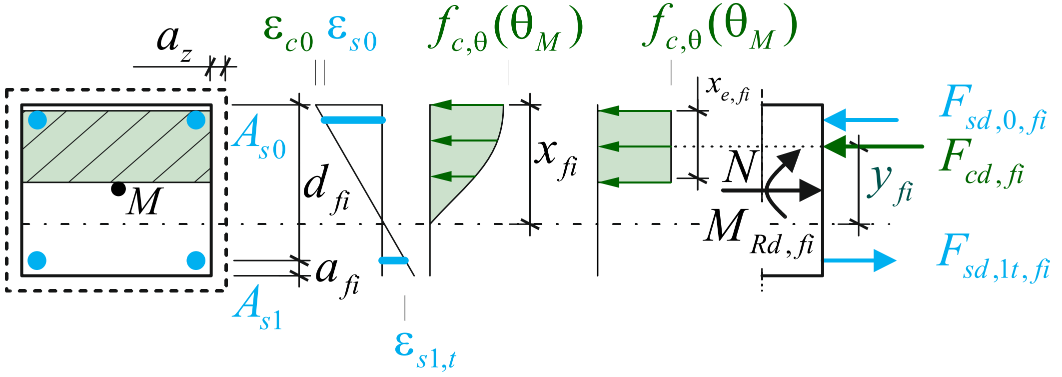
1 Reduction of cross-section

2 Reduction of reinforcing steel strength

3 Reduction of concrete strength

4 Determination of ultimate load-bearing capacity

Bending and axial load:



ii. Forces in reinforcement

$$F_{sd,0,fi} = \max \begin{Bmatrix} E_{s,fi} A_{s0} \left(\varepsilon_{s0} - 1.35 \cdot 10^{-5} (\theta_{sc} - 20°C)(1 - a_{fi}/d_{fi}) \right) \\ -A_{s0} k_{se,\theta} f_{yk} \end{Bmatrix}$$

!

$$F_{sd,1t,fi} = \min\left\{ E_{s,fi} A_{s1} \varepsilon_{s1,t} ; A_{s1} k_{se,\theta} f_{yk} \right\} \text{ if } x_{fi} < d_{fi}$$

$$F_{sd,1c,fi} = \max\left\{ E_{s,fi} A_{s1} \varepsilon_{s1,c} ; -A_{s1} k_{se,\theta} f_{yk} \right\} \text{ if } x_{fi} > d_{fi}$$

$$\theta_{sc} = \frac{\sum_{i=1}^{i=n_{sc}} \theta_{sc,i}}{n_{sc}}$$

[°C] represents the average temperature of all effective reinforcing bars in the compression zone with n_{sc} being the number of effective reinforcing bars in the compression zone.

Simplified design methods
Bending and axial load

Refined Zone Method (RZM) in FprEN 1992-1-2, 7.3

Work steps

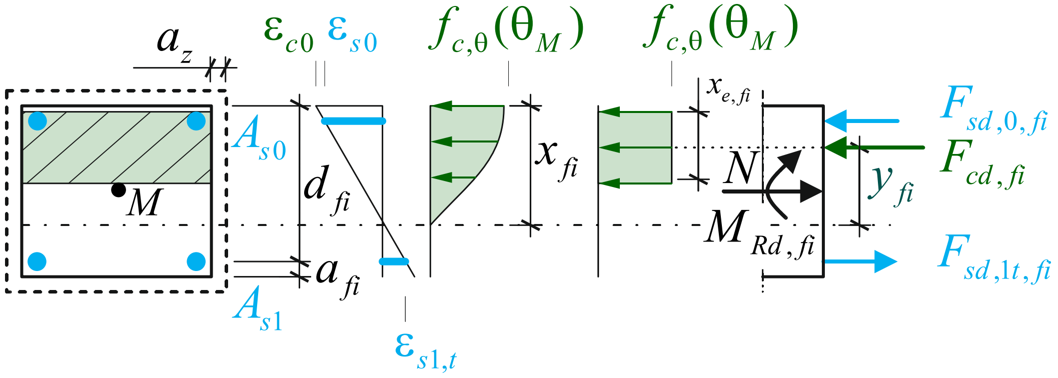
1 Reduction of cross-section

2 Reduction of reinforcing steel strength

3 Reduction of concrete strength

4 Determination of ultimate load-bearing capacity

Bending and axial load:



iii. Design moment

$$M_{d,fi} = -N_{d,fi} \cdot e_d \text{ mit } e_d = e_0 + e_i + e_2 + e_{thermal}$$

!

e_{0d}, e_{1d}, and e_{2d} are defined as given in EN 1992-1-1.

$e_{thermal}$ is defined as:

$$e_{thermal} = \frac{l_{0,fi}^2}{8} \cdot \max\left\{\frac{1.2 \cdot 10^{-5} \cdot \max(\theta_T - 20°C;\ 180°C)}{d_{fi} + a_{fi} + a_z - y_T}; \frac{1.35 \cdot 10^{-5}(\theta_{st} - 20°C)}{d_{fi}}\right\}$$

θ_T (°C.) = concrete temperature in the reference point T.
θ_{st} (°C.) = average temperature of all effective reinforcing bars in the tension zone with n_{st} being the number of effective reinforcing bars in the tension zone.

Bending and axial load

Refined Zone Method (RZM) in FprEN 1992-1-2, 7.3

Work steps

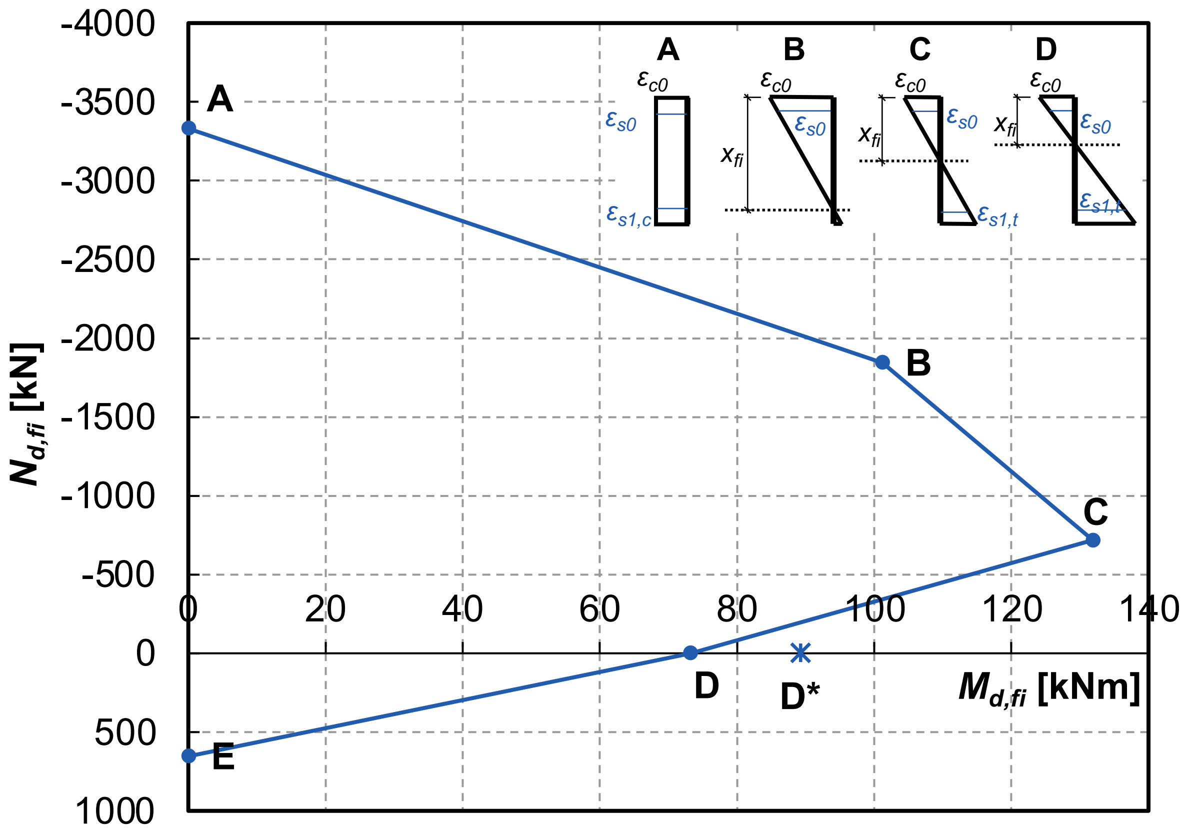
1 Reduction of cross-section

2 Reduction of steel strength

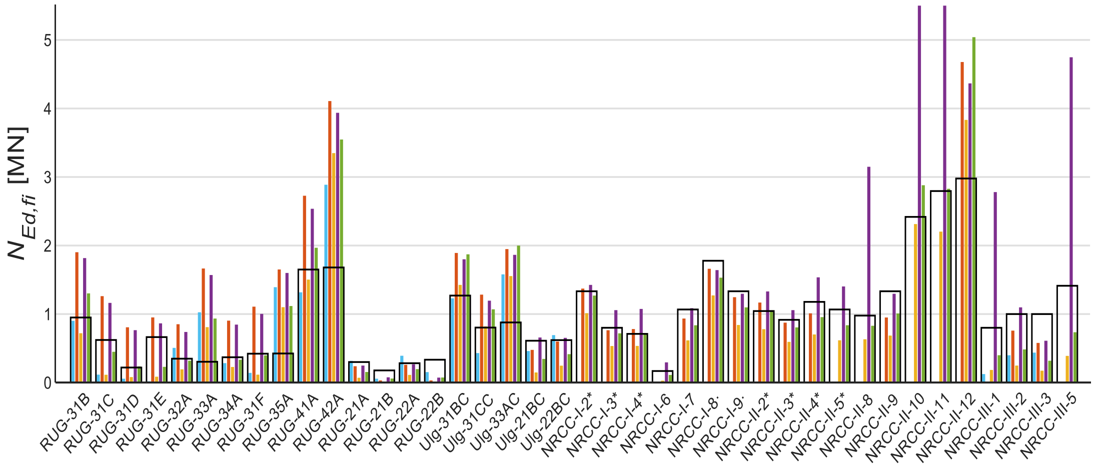
3 Reduction of concrete strength

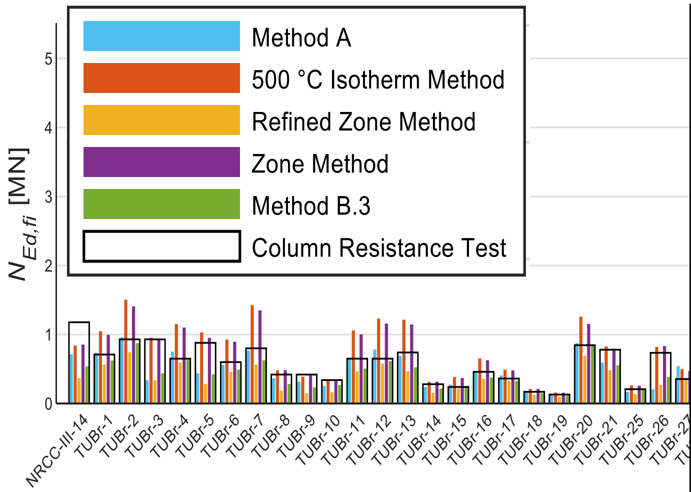
4 Determination of ultimate load-bearing capacity

Bending and axial load:



Validation of Refined Zone Method





$\mu_{Method\ A/test} = 0.95$

$\sigma_{Method\ A/test} = 0.58$

$\mu_{500/test} = 1.47$

$\sigma_{500/test} = 0.80$

$\mu_{RZM/test} = 0.70$

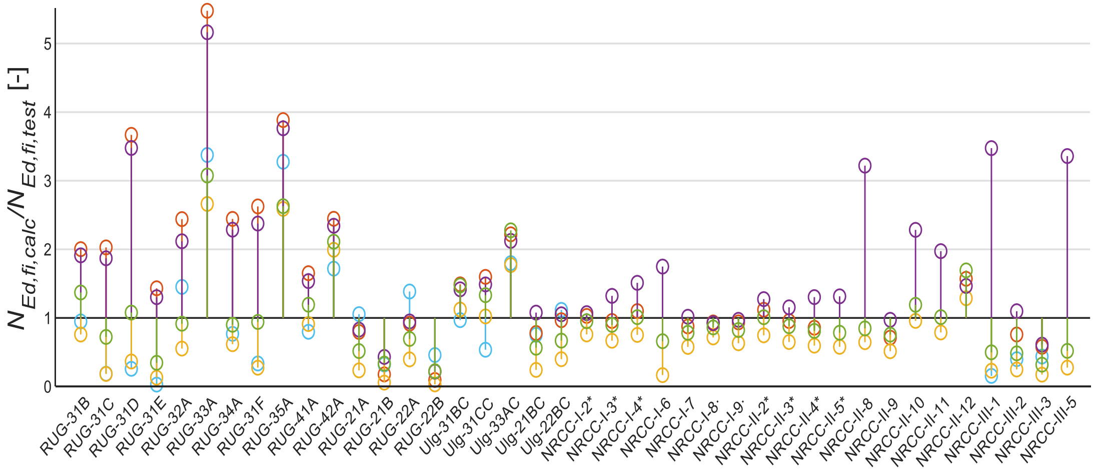
$\sigma_{RZM/test} = 0.47$

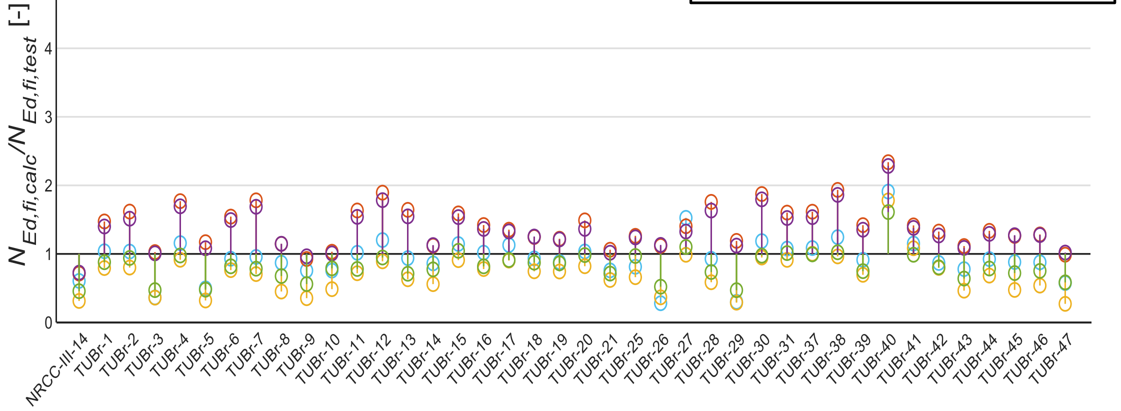
$\mu_{ZM/test} = 1.55$

$\sigma_{ZM/test} = 0.77$

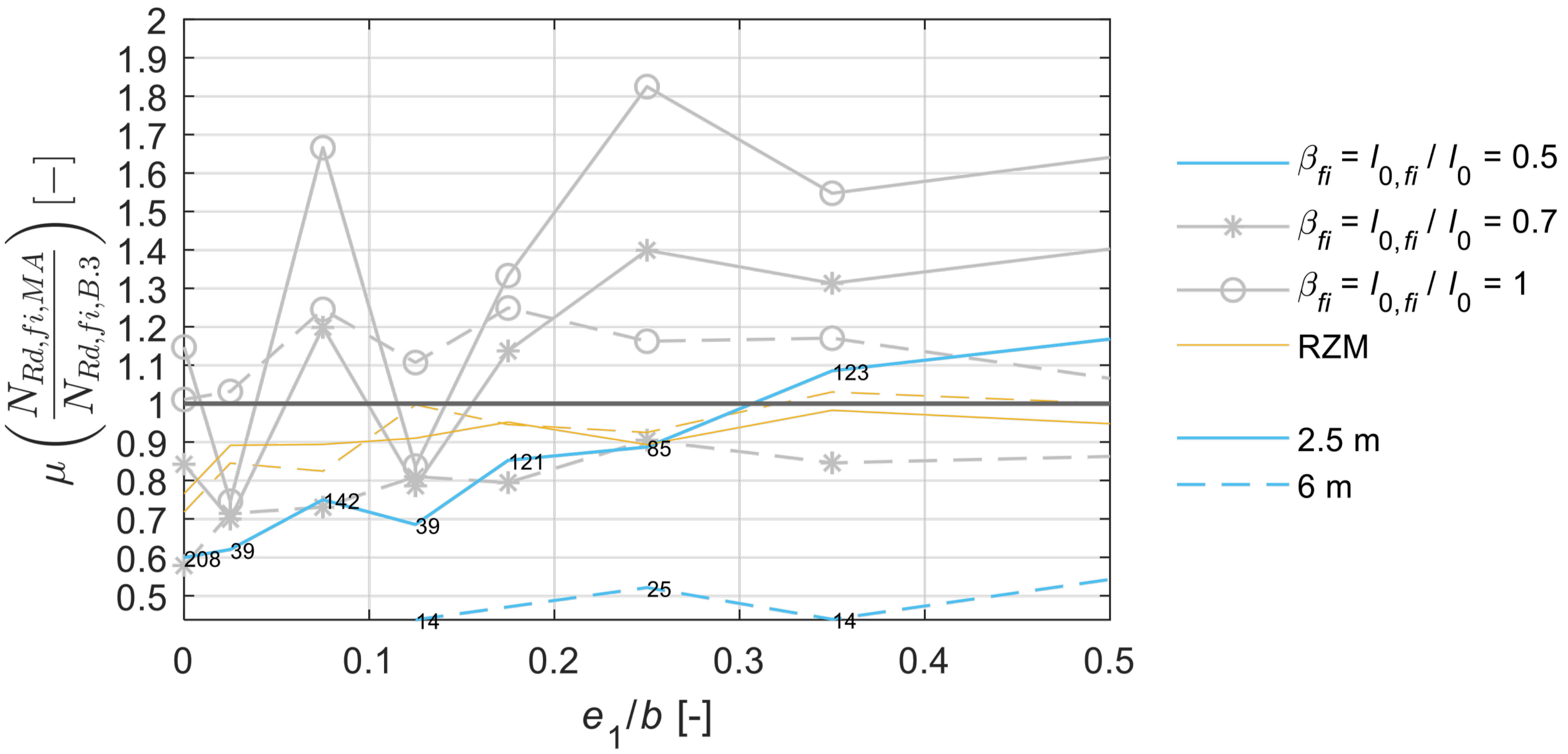
$\mu_{B.3/test} = 0.91$

$\sigma_{B.3/test} = 0.47$





Comparison Method A (MA) vs Refined Zone Method (RZM)



Simplified design methods
Mechanical analysis

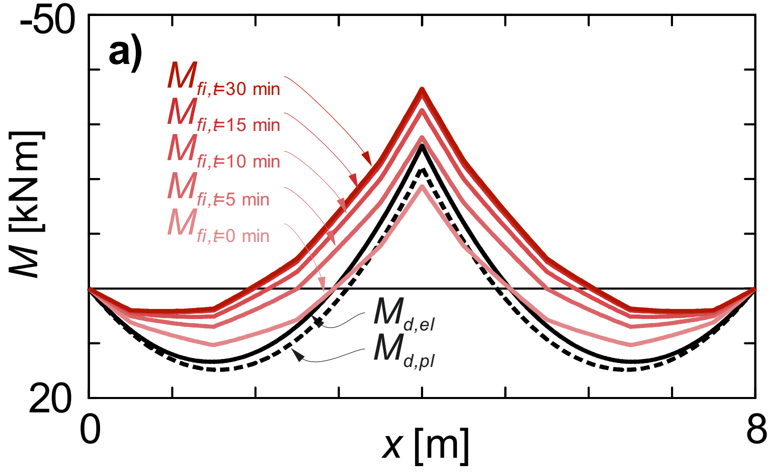
Available methods in EN 1992-1-2:2004

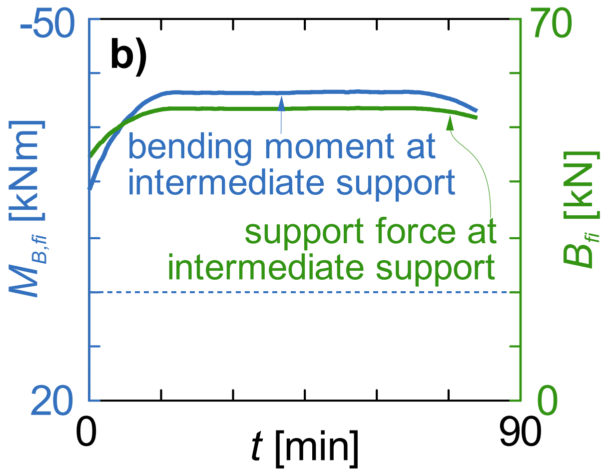
Bending	Bending and axial load	Shear
• ~~**Annex B.1** (informative)~~ 500°C Isotherm Method (ISO 834, physically based fire) • ~~**Annex B.2** (informative)~~ Zone Method (ISO 834) • **Annex E** (informative): Simplified calculation method for beams and slabs **Mostly applicable for positive bending; Alternative: RZM**	• **Method A** (normative) (ISO 834) **Use restricted** • ~~**Annex B.1** (informative):~~ 500°C Isotherm Method (ISO 834, physically based fire) • ~~**Annex B.2** (informative): Zone~~ Method (ISO 834) • **Annex B.3** (informative, laborious): Assessment of a reinforced concrete cross-section exposed to bending moment and axial load by the method based on estimation of curvature (ISO 834, physically based fire) **Alternative for Advanced design methods; laborious; good performance** • **Amended Annex C** (informative): based on Refined Zone Method (based on B.2) **Main Simplified design method**	• **Annex D** (informative): Calculation methods for shear, torsion and anchorage

→ Aims: (1) reduce number of available methods, (2) comply with concept of LoA

Clause 9
Detailing

Detailing
Continuous slabs





- Clause 9 contains detailing provisions from Clause 5 (Tabulated Data) in EN 1992-1-2:2004:
  - Minimum reinforcement of $A_s \geq 0{,}005\ A_c$ for (i) continuous slabs using B500A reinforcing steel or (ii) one-way continuous slabs
  - Minimum top reinforcement for flat slabs with ≥ R90
- New notes (information) added concerning **shear** loading:
  - Clause 7: shear resistance for beams with stirrups of more than two legs
  - Clause 9: redistribution of shear forces in statically indeterminate slabs
- Note: In **two-way constructions**
  → thermal restraint actions usually ensure structural safety under fire condtions

Clause 10
Rules for spalling

Rules for spalling
Main changes

- New clause 10
- Moisture content threshold deleted
- R15 : no spalling verification
- New rules

Table 10.1 — Overview of the rules for spalling

Verification for spalling	
R15	Verification of spalling may be omitted except Clause 10(2)
— structures in a water saturated environment — insulating permanent formwork which prevents concrete from drying	Specific assessment of spalling should be undertaken or polypropylene fibres should be specified See Clause 10(7), (8), (9) or (10)
$f_{ck} < 70$ MPa and silica fume content < 6 % by weight of cement	Verification of spalling may be omitted except Clause 10(3) and (5)
$f_{ck} < 70$ MPa and silica fume content ≥ 6 % by weight of cement or $f_{ck} \geq 70$ MPa	Specific assessment of spalling should be undertaken or polypropylene fibres should be specified See Clause 10(7), (8), (9) or (10)

Table 10.1 — Overview of the rules for spalling

	Verification for spalling
R15	Verification of spalling may be omitted except Clause 10(2)
— structures in a water saturated environment — insulating permanent formwork which prevents concrete from drying	Specific assessment of spalling should be undertaken or polypropylene fibres should be specified See Clause 10(7), (8), (9) or (10)
f_{ck} < 70 MPa and silica fume content < 6 % by weight of cement	Verification of spalling may be omitted except Clause 10(3) and (5)
f_{ck} < 70 MPa and silica fume content ≥ 6 % by weight of cement or f_{ck} ≥ 70 MPa	Specific assessment of spalling should be undertaken or polypropylene fibres should be specified See Clause 10(7), (8), (9) or (10)

(2) For performance requirements R15, verification for spalling may be omitted except for isolated members with webs thinner than 80 mm and f_{ck} ≥ 70 MPa.

(5) When using simplified design methods or advanced design methods, verification of spalling may be omitted for f_{ck} < 70 MPa, provided that the maximum content of silica fume is less than 6 % by weight of cement except in the case of (3) and in the case of isolated members with three sides exposed, whose dimensions do not comply with Table 10.2. In these cases, a specific assessment of spalling should be undertaken (see (7), (8) or (9)), or polypropylene fibres should be specified for the concrete mix according to (10).

NOTE 3 When columns are highly loaded, it can result in higher susceptibility to spalling.

Table 10.2 — Minimum web thickness of isolated members below which specific assessment of spalling should be undertaken or polypropylene fibres should be specified

Standard fire resistance	Minimum web thickness $b_{w,min}$ (mm)	Minimum web thickness $b_{w,min}$ for a distance of $2h$ from an intermediate support in continuous isolated members
R 30	80	80
R ≥ 60	100	120

Table 10.1 — Overview of the rules for spalling

Verification for spalling	
R15	Verification of spalling may be omitted except Clause 10(2)
— structures in a water saturated environment — insulating permanent formwork which prevents concrete from drying	Specific assessment of spalling should be undertaken or polypropylene fibres should be specified See Clause 10(7), (8), (9) or (10)
f_{ck} < 70 MPa and silica fume content < 6 % by weight of cement	Verification of spalling may be omitted except Clause 10(3) and (5)
f_{ck} < 70 MPa and silica fume content ≥ 6 % by weight of cement or f_{ck} ≥ 70 MPa	Specific assessment of spalling should be undertaken or polypropylene fibres should be specified See Clause 10(7), (8), (9) or (10)

(7) The application of protective layers may be used to mitigate severe spalling (see 4.12).

(8) The effect on performance (R and/or EI) due to severe spalling may be taken into account by considering the loss of strength either at member or at structure level. This loss of strength may be assessed using a reduced effective cross-section, where the spalled layer of concrete is omitted when calculating the strength. The extent of the spalled layer of concrete may be based on experimental assessment according to (9).

(9) When assessment based on experimental evidence is required, it should be obtained from tests representative of the conditions of the structural member in terms of geometry, stress and moisture content.

(10) When polypropylene fibres are used to mitigate severe spalling, a minimum content k_{pp} of monofilament fibres with diameter less than or equal to 50 µm should be specified for the concrete mix. Alternative contents or diameters may be specified if experimental evidence according to (9) is provided.

NOTE 4 The value of k_{pp} is 2,0 kg/m³, unless the National Annex gives a different value.

Rules for spalling

Validity of the new spalling Section 10

Reference of the test	[1] C1	[1] C2	[1] C3	[1] C4	[2] C45	[2] C65	[2] C85	[2] C105	[3] NSC1	[3] HSC1	[3] HSC2	[3] HSC3	[3]HSCP1	[3]HSCP2
L_0 (m)	2,1	2,1	2,1	2,1	1,5	1,5	1,5	1,5	3,35	3,35	3,35	3,35	3,35	3,35
∅ or h (cm)	30	30	30	30	20	20	20	20	20,3	20,3	20,3	20,3	20,3	20,3
B (cm)	-	-	-	-	20	20	20	20	20,3	20,3	20,3	20,3	20,3	20,3
Concrete cover [mm] (stirrups)	30	30	30	30	15-20 mm	15-20 mm	15-20 mm	15-20 mm						
Concrete cover [mm] (long. bars)	38	38	38	3										
Axis distance [mm] (long. Bars)	44	44	48	4										
Reinforcement (longitudinal)	6 ∅ 12	6 ∅ 12	6 ∅ 20	6 ∅										
Steel strength f_{yk} (MPa)	500	500	500	50										
Concrete Strength f_{ck}(MPa)	C 60	C 60	C 60	C										
Aggregates type	siliceous	siliceous	siliceous	silice										
Any specificity in the mix (fillers, fibres, …) or else	none	none	none	no										
Moisture content	Not known	Not known	Not known	Not k										
Boundary conditions	Simply supported	Simply supported	Simply supported	Sim suppo										
Load level N (MN)	1,26	1,77	1,45	1,										
Load level % of ultimate load														
Eccentricity (mm)														
Calculated fire resistance	126	91	141	113										
Experimental fire resistance	156	131	187	163										
Spalling observed?	Sloughing off, 25 min	Sloughing off, 20 min	Sloughing off, 34 min	Slough off, 30										
NRd	2,82	2,82	2,82	2,82										
μfi	0,45	0,63	0,51	0,67										
R (Method A)	137	106	139	111										

Reference of the test	[4] HS2-1	[4] HS2-2	[4] HS2-3	[4] HS2-4	[4] HS2-5	[4] HS2-6	[4] HS2-7	[4] HS2-8	[4] HS2-9	[4] HS2-10
L_0 (m)	3,81	3,81	3,81	3,81	3,81	3,81	3,81	3,81	3,81	3,81
∅ or h (cm)	40,6	40,6	40,6	40,6	40,6	40,6	40,6	40,6	40,6	40,6
B (cm)	40,6	40,6	40,6	40,6	40,6	40,6	40,6	40,6	40,6	40,6
Concrete cover [mm] (stirrups)	40	40	40	40	40	40	40	40	40	40
Concrete cover [mm] (long. bars)	50	50	50	50	50	50	50	50	50	50
Axis distance [mm] (long. Bars)	62,5	62,5	62,5	62,5	62,5	62,5	62,5	62,5	62,5	62,5
Reinforcement (longitudinal)	8∅25	8∅25	8∅25	8∅25	8∅25	8∅25	8∅25	8∅25	8∅25	8∅25
Steel strength f_{yk} (MPa)	400	400	400	400	400	400	400	400	400	400
Concrete Strength f_{ck}(MPa)	69	69	69	101	101	101	127	127	127	127
Aggregates type										
Any specificity in the mix (fillers, fibres, …) or else	no fibres	no fibres	no fibres	no fibres	no fibres	no fibres	no fibres	no fibres	no fibres	no fibres
Moisture content	69,50%	58,00%	61,00%	57,00%	77,00%	98,10%	96,70%	93,20%	92,50%	96,10%
Boundary conditions	fixed-fixed	fixed-fixed	fixed-fixed	fixed-fixed	fixed-fixed	fixed-fixed	Simply supported e=27 mm	Simply supported e=27 mm	Simply supported e=27 mm	Simply supported e=27 mm
Load level N (MN)	3,895	4,328	4,328	4,567	5,373	3,546	4,233	4,981	4,981	4,981
Load level % of ultimate load	90%	100%	100%	85%	100%	66%	85%	100%	100%	100%
Eccentricity (mm)	0	0	0	0	0	0	27	27	27	27
Calculated fire resistance										
Experimental fire resistance	299	343	379	146	108	142	248	118	117	166
Spalling observed?	minimal	minimal	minimal	very significant	very significant	very significant	moderate	moderate	moderate	moderate
NRd										
μfi										
R (Method A)										

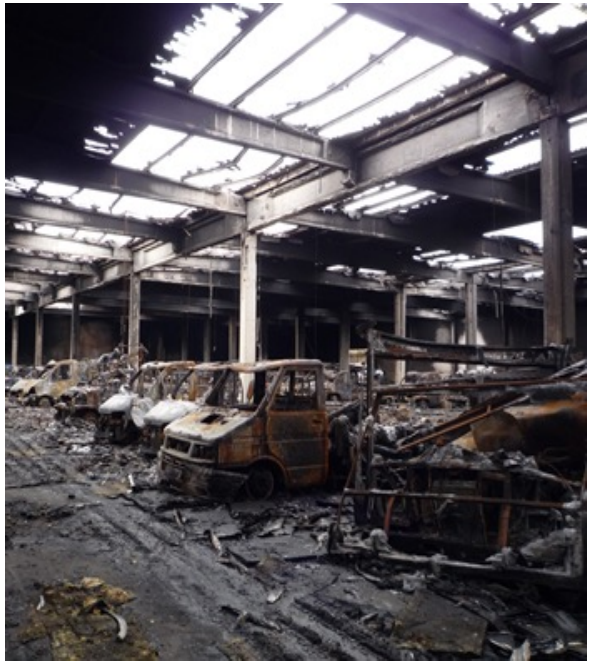
Reference of the test	[6] C60-2	[6] C60-7	[6] C60SF-8	[6] C60SF-10	[6] C70-18	[6] C70-24	[6] C70-33	[6] C70-20	[6] C70-26
L_0 (m)	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9
∅ or h (cm)	20	28	20	28	20	20	20	28	28
B (cm)	20	28	20	28	20	20	20	28	28
Concrete cover [mm] (stirrups)	-	-	-	-	-	-	-	-	-
Concrete cover [mm] (long. bars)	30	40	30	40	30	30	30	40	40
Axis distance [mm] (long. Bars)	38	50	38	50	38	38	38	50	50
Reinforcement (longitudinal)	4∅16	4∅20	4∅16	4∅20	4∅16	4∅16	4∅16	4∅20	4∅20
Steel strength f_{yk} (MPa)	B500 B	B500 B	B500 B	B500 B	B500 B	B500 B	B500 B	B500 B	B500 B
Concrete Strength f_{ck}(MPa)	C60	C60	C60	C60	C70	C70	C70	C70	C70
Aggregates type	calcareous	calcareous	calcareous	calcareous					
Any specificity in the mix (fillers, fibres, …) or else	no fibres	no fibres	no fibres	no fibres	no fibres	no fibres	no fibres	no fibres	no fibres
Moisture content	66%	83%	71%	90%	93%	76%	95%	93%	76%
Boundary conditions	simply supported e=7 mm	simply supported e=28 mm	simply supported e=7 mm	simply supported e=28 mm	simply supported e=7 mm	simply supported e=7 mm	simply supported e=7 mm	simply supported e=28 mm	simply supported e=28 mm
Load level N (MN)	1,285	1,35	1,285	1,35	1,415	1,5	1,5	1,78	1,96
Load level % of ultimate load									
Eccentricity (mm)	7	28	7	28	7	7	7	28	28
Calculated fire resistance	60	120	60	120	60	60	60	120	120
Experimental fire resistance	63	132	43	130	65	55	59	84	110
Spalling observed?	no	minor	minor	minor	no	no	no	moderate	minor
NRd	1,65	2,69	1,65	2,69	1,62	1,62	1,62	2,65	2,65
μfi	0,78	0,50	0,78	0,50	0,88	0,93	0,93	0,67	0,74
R (Method A)	57	142	57	142	45	39	39	112	101

MOISTURE CONTENT CRITERIA IS DELETED

- It is controversial below which moisture content spalling is “unlikely to occur”. Since a European agreement for the value of k could not be reached, the decision was left to national annexes (in the present version of EN 1992-1-2, varies from 2% to 4%)
- Scientific results indicate that spalling may appear from different moisture content values depending on the concrete composition, strength, section geometry, load… At first glance, a general fixed moisture limit for spalling seems like a good idea but this is not supported by the literature as so many inter-dependent factors are involved in the phenomenon.
- Even if the temperature, relative humidity (climate history) and age of concrete are known, it is a very difficult task to specify the moisture content of the concrete.
- While moisture gradients do appear instead of uniform moisture contents, nothing is said about where (at the surface, in depth...) and when (3 months after casting, at equilibrium?) the moisture content should be measured or estimated.
- The designer has difficulties to predict what will be the moisture content in the built element, and cannot influence it.

REQUIREMENTS FOR ISOLATED MEMBERS EXPOSED ON THREE SIDES

For thin webs with only one reinforcement layer in horizontal and one in vertical direction, the risk of collapse in case of spalling of the cover concrete is high as the compression resistance of concrete vanishes at the very moment of severe spalling. For webs with two layers in horizontal and vertical direction, the risk of collapse in case of spalling of the cover concrete is smaller. Therefore, the definition of minimum web dimensions (to allow for more than one vertical layer of reinforcement) is a means of providing a more robust design.



GUIDANCE ON TEST METHODOLOGY TO DETERMINE THE PERFORMANCE OF CONCRETE WITH RESPECT TO SPALLING → SEE THE BACKGROUND DOCUMENT

Clause / Subject	10 (9) – Tests representative of the conditions of the structural member in terms of geometry, stress and moisture content

Reason for change

In EN 1992-1-2 (2004), no guidance was provided on the test methodology to determine the performance of concrete with respect to spalling.

Original content

6.2 Spalling

Method 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.

Change

(9) When assessment based on experimental evidence is required, it should be obtained from tests representative of the conditions of the structural member in terms of geometry, stress and moisture content.

Background information

At the time of the revision of EN 1992-1-2, no standard has yet been published to characterize the spalling propensity of concrete structures. However, RILEM Technical Committee 256-SPF "Spalling of concrete due to fire: testing and modelling" has been working on the subject since 2013 and intends to publish some recommendations in the near future.

The state of the art performed in the framework of this TC 256-SPF clearly highlights the importance of the geometry (in terms of impact on the self-stress), the loading and the moisture content of the tested specimen.

Full scale tests are not always necessary if intermediate scale tests can be proven to be sufficiently representative in terms of stress state and spalling results. Some references to scientific articles are given in the background information section, hereafter, as well as preliminary recommendations.

Note : It should be highlighted that intermediate scale tests differ from the material screening tests which are also defined in some recommendations established by the RILEM TC 256-SPF. The material screening tests are only intended to rank concretes by sensitivity to spalling. They do not aim to provide an absolute value of the spalling behaviour.

Fire resistance tests

In order to evaluate spalling propensity and its influence on performance (R and/or EI), some standard fire resistance tests can be performed according to EN 1363-1 [9], EN 1364-X and EN 1365-X standards, provided that the boundary conditions and loading are representative of the structural element in the building.

When doing a fire resistance test, due to the size and weight of some structural elements, it might not be possible to test the real geometry due to the limitations of the fire resistance laboratory equipment. In this case, an assessment of the stress state under fire conditions through numerical calculations should be performed in order to provide a dedicated test whose boundary conditions, geometry and loading will lead to a similar stress state in the tested specimen as would be expected in the structure.

Intermediate scale tests

Intermediate scale tests may be used if it can be validated that the approach is sufficiently representative in terms of stress state and that experimental evidence of the relevance of the testing methodology can be provided (ie, the intermediate scale test will lead to a safe approximation of the spalled layer compared to a full scale test under the same thermal exposure). Research studies have been carried out to compare the relevance of intermediate scale tests compared to full scale tests (see [1], [2], [3]).

The spalled layer which is experimentally determined in the validated intermediate scale test is then used in the fire design which will be based on an effective reduced cross-section.

- ***Size/shape of specimen***

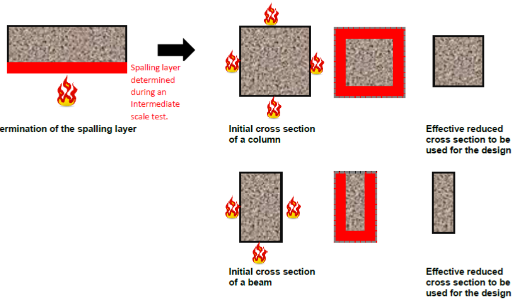
Different shapes of specimens may be designed to represent the studied structural elements. A minimum exposed size of 1m² for small scale slabs or 1 m for linear specimens is recommended as a starting point for the development of such a validated test approach.

The geometry should reproduce the self-stress state due to the thermal gradients, the depth of the small scale slab should be representative of the structural element used in practice.

A minimal depth of 30 cm for small scale slabs is recommended. This value can be increased to 40 cm in the case of specific slabs, walls or columns of very large thickness.

For specific geometries, such as I-beams, due to the fact that the web can be restrained by the upper and lower flanges, a specific assessment of the stress state should be performed to demonstrate that the intermediate scale geometry is appropriate. After this an experimental comparison is needed to validate the approach.

A structural element such as a column or a beam may, if the approach is validated, be evaluated at intermediate scale test with a loaded small slab exposed on one side provided that in the fire design, the spalled layer is deduced from the initial cross section from each exposed surface to determine the effective reduced cross section.



- ***Loading***

Simply supported structural elements with the fire exposed surfaces in tension, can be evaluated with unloaded small scale slabs of similar thickness and reinforcement.

Continuous slabs or beams exhibiting compressive stress state on the exposed side in the area of the supports should be evaluated with loaded small scale specimens with a representative loading. Even a small external loading such as 0,75 MPa may induce severe spalling compared to unloaded conditions.

Concrete for compressive structural elements should be evaluated with a small scale specimen with a representative loading.

- ***Thermal exposure***

The setup for intermediate scale tests shall have the capacity to follow the thermal exposure defined in the standard EN 1363-1 [9] with the appropriate type of furnace thermocouples.

During the test, the specimen should be heated with the controlled heating system being able to follow the required fire curve.

Moisture content

EN 1363-1 [9] states:

" At the time of the test […] the moisture content of the test specimen shall approximate to those expected in normal service. The test specimen shall preferably not be tested until it has reached an equilibrium moisture content resulting from storage in an ambient atmosphere of 50 % relative humidity at 23 °C. If the test specimen is conditioned in a different way it shall be clearly stated in the test report. Concrete elements or specimens containing concrete parts shall not be tested until they have been conditioned for at least 3 months. Masonry elements shall not be tested until they have been conditioned for at least 28 days.
Concrete elements, which can contain large amounts of moisture may take a very long time to dry out. Such specimens may be tested when the relative humidity at relevant positions of the specimen has reached 75 %. If the level of 75 % relative humidity cannot be reached within a reasonable time, measurements of the moisture content at the time of testing shall be measured and reported."

"Accelerated conditioning is permitted provided that the method does not alter the properties of component materials."

"High temperature conditioning is permitted provided that the temperature is below critical temperatures for any of the materials in the test specimen."

"The test methods for specific elements may contain additional or alternative guidance for obtaining moisture equilibrium."

Moisture equilibrium is in general reached after a few years and a moisture gradient will be generally observed. It is thus recommended to determine moisture content at the surface of the exposed side (in the first 5 cm, and even if possible from 0 to 2.5 cm depth and from 2.5 to 5 cm depth) and in the inner region of the cross section (more than 5 cm depth).

Accelerated conditioning will be permitted provided that:

- as mentioned above, the method does not alter the properties of material;
- the targeted moisture content through the accelerated conditioning will be representative of the one reached when equilibrium is observed;
- evidences that the accelerated conditioning method has been calibrated so that spalling propensity determined on a specimen which has been submitted to this accelerated conditioning is similar to the one which could be obtained on a specimen stored during a period which allows to reach naturally the target moisture equilibrium.

Note : When the unique aim of the test is to determine spalling propensity (no temperature measurement is intended to be performed for any assessment related to the fire design) and when the microstructural properties are considered to have reached a stabilised state, the tests can be performed before 3 months. When no accelerated conditioning is used, the high moisture content could lead to severe spalling.

References

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[3] F. Lo Monte, R. Felicetti, M. Alberto and A. Bortolussi, "Assessment of concrete sensitivity to fire spalling: A multi-scale experimental approach," Construction and Building Materials, vol. 212, pp. 476-485, 2019

[4] H. Carré, P. Pimienta, C. La Borderie, F. Pereira and J.-C. Mindeguia, "Effect of compressive loading on the risk of spalling," MATEC Web of Conferences, vol. 6, 2013.

[5] F. Lo Monte and R. Felicetti, "Heated slabs under biaxial compressive loading: a test setup for the assessment of concrete sensitivity to spalling," Materials and Structures, vol. 50, no. 192, 2017.

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[8] L. Boström, U. Wickström and B. Adl-Zarrabi, "Effect of specimen size and spalling conditions on spalling of concrete," Fire and Materials, vol. 31, pp. 173-186, 2007.

[9] EN 1363-1 Fire resistance tests - Part 1: General Requirements (2020)

Ease of use justification

The recommendations are clearer than in the previous Eurocode and will lead to harmonise the practice.

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