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DEPARTEMENT SAFETY STRUCTURES FIRE
Mechanical and Fire Resistance Division

REPORT No MRF 18 26076371/C

Mechanical behavior under heat for FISCHER – FIS EM Plus injection system

Tabulated values for design purposes

21/05/2019– CSTB/DSSF - K. REGNIER– E. BRUCHET

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Tabulated values for design purposes

REQUESTED BY:

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It comprises 24 pages numbered from 1/24 to 24/24

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1. TOPIC

When subjected to fire exposure, construction elements performances are reduced by the effect of the temperature increase. At the FISCHER company request, CSTB has performed a study aimed at the evaluation of the fire behavior of the **FISCHER – FIS EM Plus injection system** used in conjunction with concrete reinforcing rebar (d 8 to 32 mm).
It has been assessed in this study that the FISHER - FIS EM Plus injection system has a mechanical behavior under heat equivalent to previous formulation FISHER - FIS EM injection system (see Evaluation Report No MRF 18 26076371/B).

WARNING

This report does not deal with the mechanical design at ambient temperature; neither does it deal with the design according to other accidental solicitations. Design at ambient temperature shall be carried out before fire design.

2. REFERENCES

[1] EAD 330087-00-0601, SYSTEMS FOR POST-INSTALLED REBAR CONNECTIONS WITH MORTAR, July 2015

[2] Evaluation Report No MRF 15 26054133/B, Fire Evaluation of Post installed rebar connections With FISCHER – FIS EM injection system, 2015, Centre Scientifique et Technique du Bâtiment

[3] Evaluation Report No MRF 18 26076371/B, Fire Evaluation of Post installed rebar connections With FISCHER – FIS EM Plus injection system, 2018, Centre Scientifique et Technique du Bâtiment

[4] CEN. EN 1991-1-2. Eurocode 1, Part 1-2: Actions on structures: general actions – actions on the structures exposed to fire. CEN, Bruxelles, Belgique; 2002.

[5] CEN. EN 1992-1-1. Eurocode 2, Part 1-1: Design of concrete structures - General rules and rules for buildings. CEN, Bruxelles, Belgique; 2005.

[6] CEN. EN 1992-1-2. Eurocode 2, Part 1-2: Design of concrete structures – General rules and structural fire design. CEN, Bruxelles, Belgique; 2005.

3. AUTHORS

Marne-la-Vallée, FRANCE,

on may the 21st 2019

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4. BACKGROUND

4.1 Evaluation method

The fire evaluation is performed with three steps.

1) First, an experimental program of pullout tests at high temperatures is carried out in order to determine a relationship between bond resistance and temperature [2] and [3]. This relationship is then expressed by a temperature reduction factor $0<k(\theta)<1$ which describes the decrease of resistance of the bond system (see PART 5).

2) Secondly, a thermal calculation using the method described in EN 1991-1-2, section 3 [4] is performed in order to determine the temperature distribution along the bonded rebar for each fire duration and for a given structural configuration.

3) Finally, at each time during the fire, the bond resistances are determined along the bonded rebar. For the anchor application the load resistance is calculated by integrating the bond resistances along the embedded depth.

Figure 1 presents the steps of the method used in this evaluation and the corresponding parts of the report.

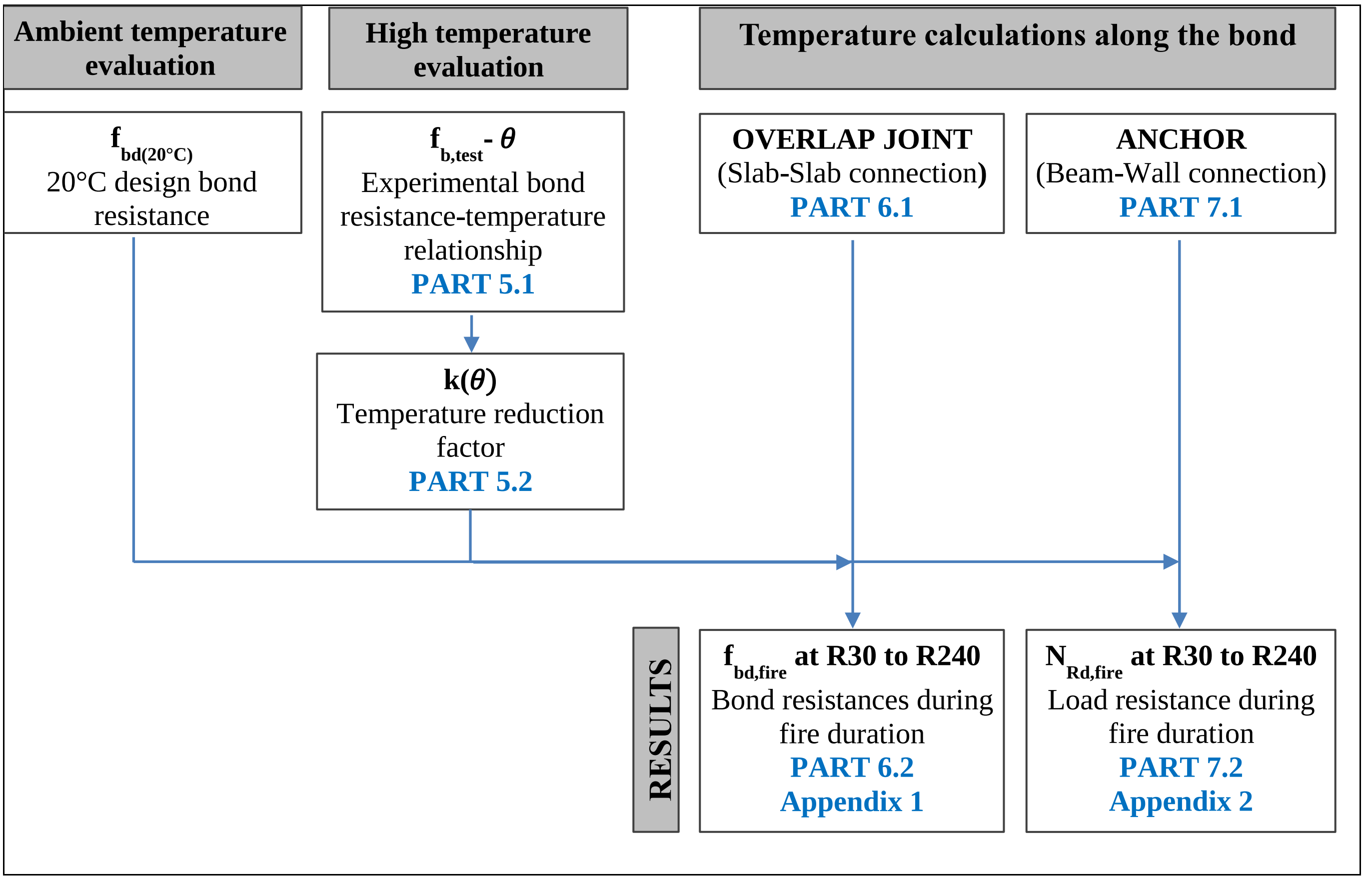


Figure 1 : Method used for fire evaluation of bonded rebars

The evaluation covers two structural uses of post-installed rebars in concrete (Figure 2): i) the overlap joint application and ii) the anchor application.

i) In the overlap joint application for a slab-slab configuration where the lower surface is exposed to fire, the temperature is uniform. The bond resistance is uniform along the bond and depends on the concrete cover and the duration of the fire (PART 6.2).

ii) In the anchor application for a beam-wall configuration where at least one side of the wall is exposed to fire, the temperature along the bond (inside the wall) is not uniform. This leads to different bond resistances and the load resistance is calculated by integration of the bond resistances along the lateral surface of the rebar (PART 7.2).

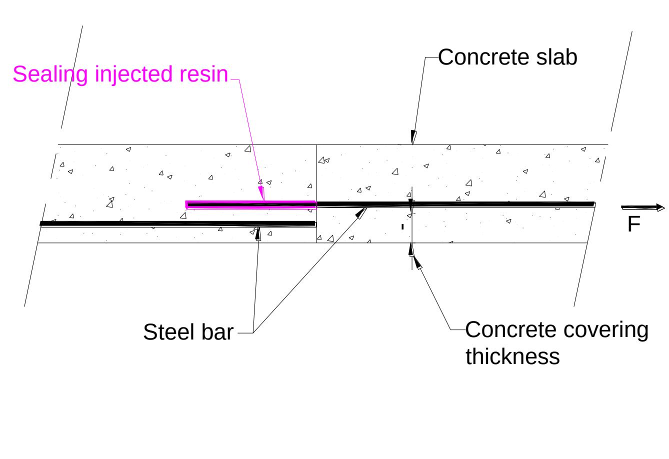
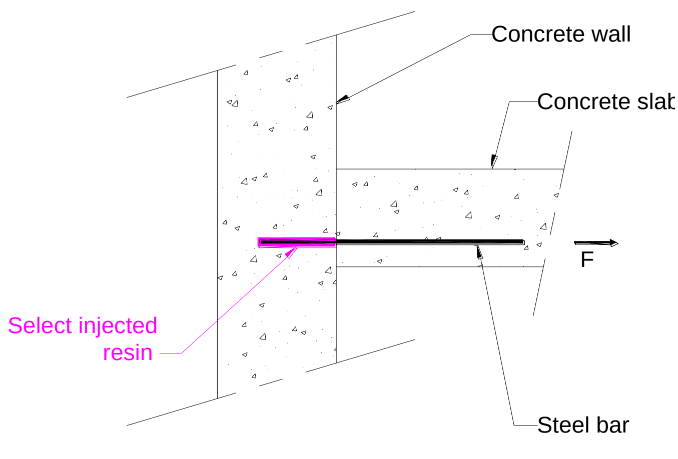
OVERLAP JOINT (Slab-Slab connection)	**ANCHOR (Beam-Wall connection)**
	

Figure 2 : Sketches of a Slab-Slab connection left and of a Beam-Wall connection

4.2 Application scope

The values of load resistances presented in this report are applicable for given parameters: Concrete class, structural configuration, fire duration, bar diameter, bond length, concrete cover and maximal temperatures. The result tables are provided in appendices 1 and 2.

i) **Concrete class**
The fire evaluation is applicable for C20/25[1] concrete. According to the EAD [1], the ultimate bond resistance in C20/25 concrete is equal to $f_{bd,C20/25}$ =2,30 N/mm² for bar diameters between 8 and 32 mm.

ii) **Structural configurations**
The fire evaluation covers slab-slab and beam-wall configurations for beams with a width higher than 40 cm. Load resistances of the beam-wall configuration may be conservatively applied to a slab-slab configuration. The bond resistances of the slab-slab configuration SHALL NOT be applied to a beam-beam configuration.

iii) **Fire durations**
The bond resistances and load resistances are provided at 30, 60, 90, 120, 180 and 240 min under a standardized ISO 834-1 fire. Thermal loading is calculated using the method described in EN 1991-1-2, section 3 [4].

[1] The values of load resistances presented in this report can be used for concrete strength up to C50/60 without increased risk.

iv) **Bar diameters**
The fire evaluation covers steel rebars with diameters of 8, 10, 12, 14, 16, 20, 25, 28 and 32 mm with a yield strength of 500 N/mm².

v) **Bond lengths**
For the slab-slab configuration, the bond resistances are provided. The calculation of the bond length shall be carried out in accordance with EN 1992-1-1, section 8 [5].

For the beam-wall connection, the load capacities are calculated for lengths between the minimal length $l_{b,min}$ and the maximal anchorage length conditioned by the yielding of steel. The minimal embedment length $l_{b,min}$ is calculated in accordance with EN 1992-1-1, section 8 [5] (see equation below).

$l_{fire,min} = l_{b,min} = \max\{0,3 \cdot l_{b,rqd}\ ;\ 10 \cdot d\ ;\ 100\ \text{mm}\}$

Where $l_{b,rqd}$ is the required basic anchorage length

$$l_{b,rqd} = \frac{d}{4} \cdot \frac{\sigma_{sd}}{f_{bd}} = \frac{d}{4} \cdot \frac{\sigma_{s,yeild}}{\gamma_M \cdot f_{bd}}$$

Where:

$\sigma_{s,\ yield}$ = 500 N/mm² is the yield stress of steel
γ_M = 1,5 is the material coefficient
f_{bd} = 2.3 N/mm² is the design bond strength in C20/25 concrete.
d is the diameter of the bar

$$N_{rebar\ yield} = \frac{\sigma_{s,yeild}}{\gamma_{M,20°C}} \cdot \pi \cdot (\frac{d}{2})^2$$

Where:

$\sigma_{s,\ yield}$ = 500 N/mm² is the yield stress of steel
$N_{rebar\ yield}$ is the design yielding load of the rebar
γ_M = 1,5 is the material coefficient
d is the diameter of the bar

Table 1 presents the minimal embedment lengths and yielding loads.

Table 1 : Minimal embedment lengths and yielding loads

Rebar diameter (mm)	**8**	**10**	**12**	**14**	**16**	**20**	**25**	**28**	**32**
Required anchorage length $l_{b,rqd}$ (mm)	290	362	435	507	580	725	906	1014	1159
Minimum anchorage length $l_{b,min}$ (mm)	100	109	130	152	174	217	272	304	348
Design Yielding load of the rebar (kN)	16.8	26.2	37.7	51.3	67.0	104.7	163.6	205.3	268.1

vi) **Concrete cover**
Choice of the concrete cover shall be carried out in accordance with EN 1992-1-1, section 4 [5]. In this evaluation, concrete cover is only considered for the thermal protection it brings to the rebar.

For the slab-slab configuration, bond resistances are provided for different concrete covers starting at 40 mm.
For the beam-wall connection, the concrete cover in the beam influences the temperature distribution along the rebar in the thickness of the wall. The load resistances are provided for concrete covers inside the beam of 10, 20, 30 and 40 mm. Results are only provided for concrete covers superior to the diameter of the bar in accordance with EN 1992-1-1, section 4 [5].

vii) **Maximal temperatures**
In accordance to EN 1992-1-2, section 5 [6] steel resistance remains constant between 20°C and 350°C for bar laminated at high temperature. Therefore resistances are only considered along the parts of the bond below 350°C. Furthermore, the resistance is considered equal to zero above the temperature θ_{max} (described in PART 5.1) linked to the mortar behavior.

5. TEMPERATURE REDUCTION FACTOR

5.1 Mean bond resistance

An exponential trend curve is used to describe the mean bond resistance-temperature relationship analytically using the following equation.

$$f_{bm}(\theta) = a \cdot e^{-b.\theta}$$

Where:
$f_{bm}(\theta)$ *is the* mean bond resistance at the temperature θ (in N/mm²)
θ is the temperature of the bond material
a and b are the exponential fitting curve constants

The cut-off temperature (determined according to EAD 330087-00-0601 [1]) is identified as θ_{max}.

For the FISCHER – FIS EM Plus injection system, the a, b and θ_{max} parameters are presented in Table 2.

Table 2 : Injection system parameters

Mortar parameters		
a=	26.41	N/mm²
b=	0.02	/°C
θ max=	135	°C
θ1=	49	°C

5.2 Temperature reduction factor

The temperature reduction factor k(θ) is determined from the fitted curve $f_{bm}(\theta)$ to describe the variation of resistance of the injection system with temperature. It is calculated using the fallowing equations.

$$k(\theta) = \frac{f_{bm}(\theta)}{f_{bm,req,d}} \leq 1 \quad for \quad 20°C \leq \theta \leq \theta_{max}$$

$$k(\theta) = 0 \quad for \quad \theta > \theta_{max}$$

Where:
k(θ) temperature reduction factor
$f_{bm}(\theta)$ *is* the mean bond resistance at the temperature θ
$f_{bm,req,d}$ *=min{10 N/mm² ; $f_{bm}(\theta)$} is the* required bond resistance at cold state
θ is the temperature of the bond
θ_{max} cut-off temperature

Figure 3 presents the variation of the temperature reduction factor vs. temperature for the FISCHER – FIS EM Plus injection system.
No extrapolation beyond cut-off temperature (θ_{max}) is allowed. For temperatures higher than the cut-off temperature (θ_{max}), the reduction factor k(θ) is equal to zero.

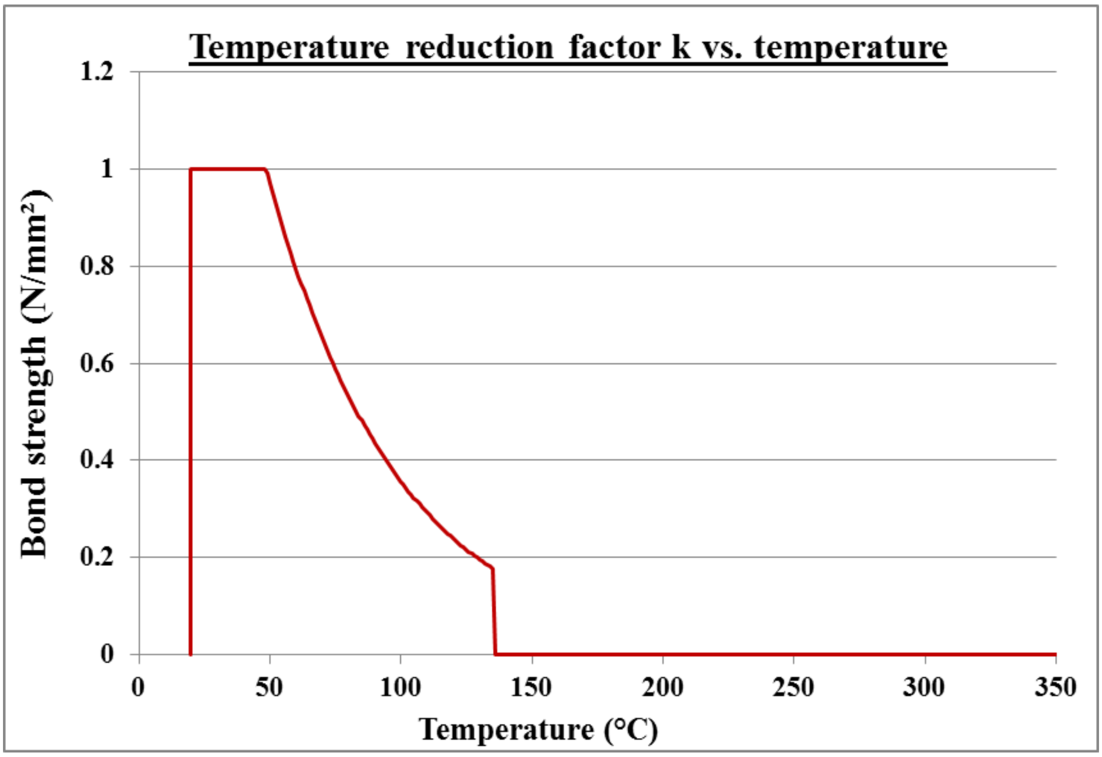


Figure 3 : Temperature reduction factor k(θ) vs. temperature

6. OVERLAP JOINT APPLICATION (SLAB-SLAB CONNECTION)

6.1 Temperature fields

The knowledge of the fire behavior of traditional concrete structures to assess the temperature distribution for every fire duration by modeling the thermal exchanges inside concrete elements. The temperature profile depends on the connection configuration: slab-slab or beam-wall. These temperatures are calculated using the finite elements method in accordance with EN 1991-1-2, section 3 [3] with the CAST3M software.

At the initial time (t=0) every element temperature is supposed equal to 20°C.

The fire is modeled by a heat flux on the exposed faces of the structure. This heat flux is a function of the gas temperature θ_g for which the evolution is given by the conventional ISO 834-1 time-temperature relationship (EN 1991-1-2, section 3 [3]).

$$\boldsymbol{\theta_g(t) = \theta_0 + 345 \cdot log_{10}(8 \cdot t + 1)}$$

Where:

θ_g is the gas temperature
θ_0=20°C is the initial temperature
t is the time in minutes

The entering flux in a heated element is the sum of the convective and the radiation parts:

- convective flux density: $\boldsymbol{\varphi_c = h \cdot (\theta_g - \theta_s)}$ (W/m²),
- radiation flux density: $\boldsymbol{\varphi_c = \varepsilon \cdot \sigma \cdot \left(\theta_g^4 - \theta_s^4\right)}$ (W/m²).

Where:

σ is the Stefan-Boltzmann parameter
θ_s is the surface temperature of the heated element
ε is the resulting emissive coefficient
h is the exchange coefficient for convection

The exchange coefficients, presented in Table 4, are given by EN 1992-1-2, appendix A [5].

Table 4 : Values for the exchange coefficients

	h(W/m²K)	ε
Fire exposed side	**25**	***0.7***

In this study, only concrete is considered in the thermal calculation (EN 1992-1-2, section 4 [5]). The concrete thermal properties are provided by EN 1992-1-2, section 3 [5]. The variations of thermal conductivity, mass density and specific heat are represented in Figure 8. The peak of the specific heat corresponds to a concrete having a water percentage of 1,5% in accordance with EN 1992-1-2, appendix A [5].

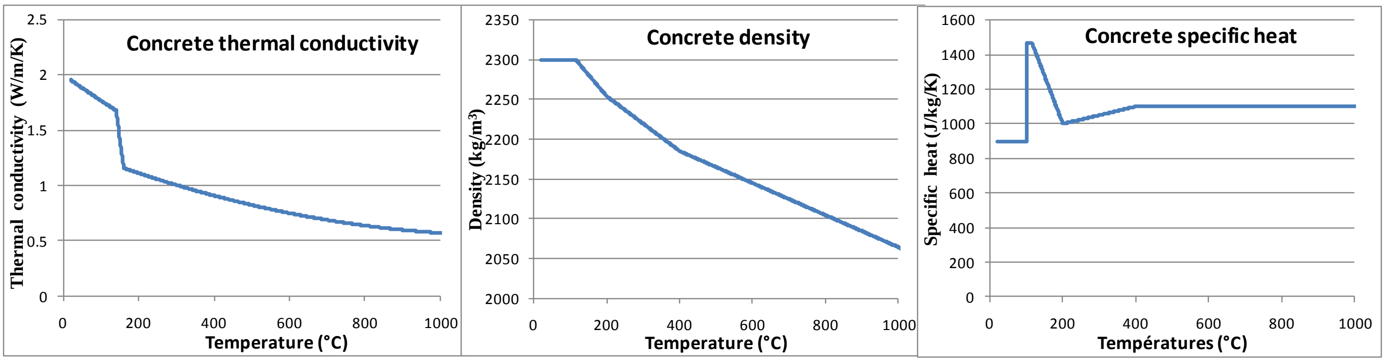


Figure 4 : Variations of thermal conductivity, density and specific heat of concrete according to EN 1992-1-2

For a slab-slab connection (Figure 2), the thermal calculation is carried out on a two dimensional mesh by applying the fire heat flux as boundary condition on the lower surface. No boundary condition at 20°C is applied on the upper surface to be conservative.

The isotherms are horizontal implying that the temperature is uniform along the bonding interface and equal to the temperature in a slab at a depth equivalent to the concrete cover. Figure 5 presents the temperature versus concrete cover at 0, 30, 60, 90, 120, 180 and 240 min during an ISO 834-1 fire. The same temperature curves are provided in EN 1992-1-2, appendix A [5].

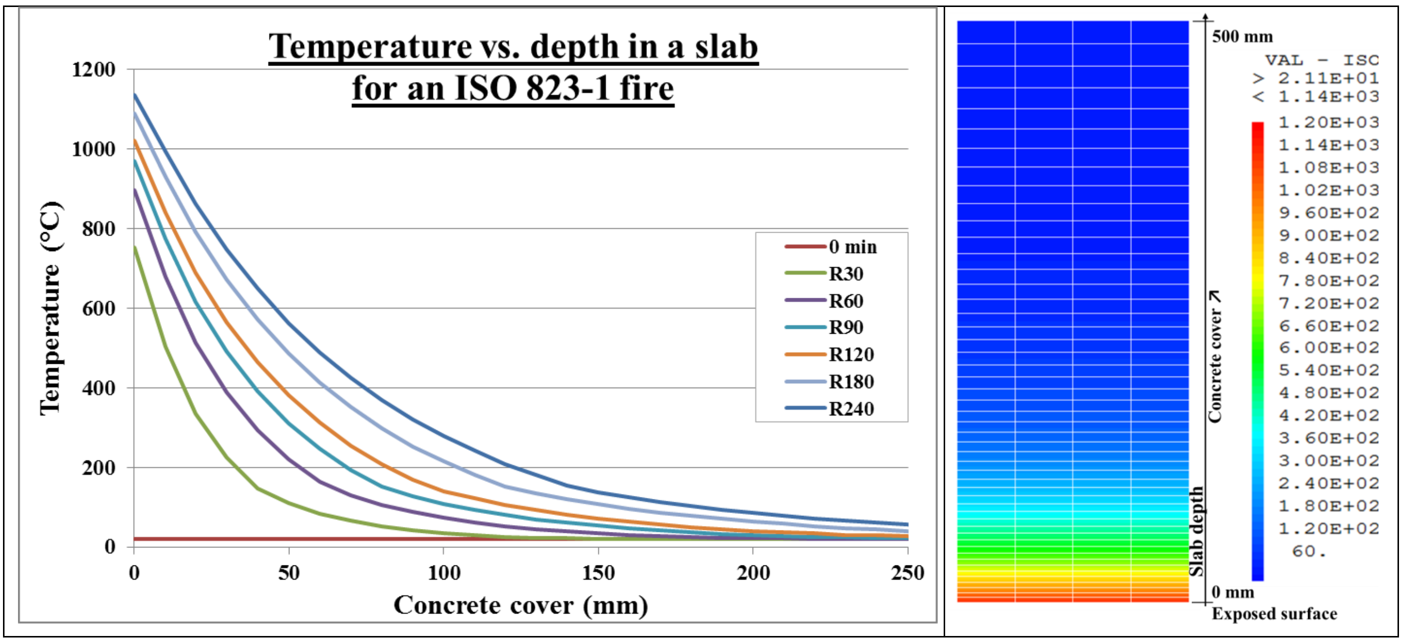


Figure 5 : Temperature vs. concrete cover temperature at 0, 30, 60, 90, 120, 180 and 240 min during an ISO 834-1 fire

6.2 Design bond resistances

From the temperature curves (Part 6.1, Figure 5) and the temperature reduction factor k(θ) (Part 5.2, Figure 3), the values of the design bond resistances $f_{bd,fire}$ are determined using the fallowing equation.

$$f_{bd,fire}(\theta) = f_{bd,20°C} \cdot \frac{\gamma_{M,20°C}}{\gamma_{M,fire}} \cdot k(\theta)$$

Where:
$f_{bd,fire}(\theta)$ is the design bond resistance that depends on temperature
$f_{bd,20°C}$=2,3 for C20/25 concrete is the design bond strength at 20°C
$\gamma_{M,20°C}$=1,5 is the material coefficient at ambient temperature
$\gamma_{M,fire}$=1 is the material coefficient in a fire situation
k(θ) is the temperature reduction factor

Appendix 1 presents values of the design bond resistance for different concrete covers at 30, 60, 90, 120, 180 and 240 min during an ISO 834-1 fire.

The material safety factor applicable for the accidental situation of fire is equal to 1 according to EN 1992-1-2, section 2 [5], while it is equal to 1,5 at ambient temperature. This leads to obtaining higher values of load resistances at the beginning of a fire in fire design in comparison to ambient temperature design for the same rebar geometry. Design at ambient temperature shall be carried out before fire design.

7. ANCHOR APPLICATION (BEAM-WALL CONNECTION)

7.1 Temperature fields

For a beam-wall connection (Figure 2) where the rebar is bonded inside the wall, there is a temperature gradient in the thickness of the wall. The temperature along the bonding interface is not uniform and depends on the fire duration, the anchoring length and the concrete cover of the rebar inside the beam (which acts as a protection against thermal exposure). Therefore, the temperature profiles along the bond are determined for each fire duration, for each bonded length and for the concrete covers inside the beam of 10, 20, 30 and 40 mm.

A three-dimensional mesh was used. Due to symmetry considerations only half of the structure is meshed (Figure 6). The same calculation parameters (material thermal properties, time-temperature curve, convective and radiation exchange coefficients) as the ones described in PART 6.1 are applied.

The boundary conditions are:

- On the lower and lateral sides of the beam fire heat fluxes are applied to the elements.
- On the side of the wall where the beam is connected, the fire heat fluxes are applied to the elements.
- No heat exchange condition is applied on the other sides.

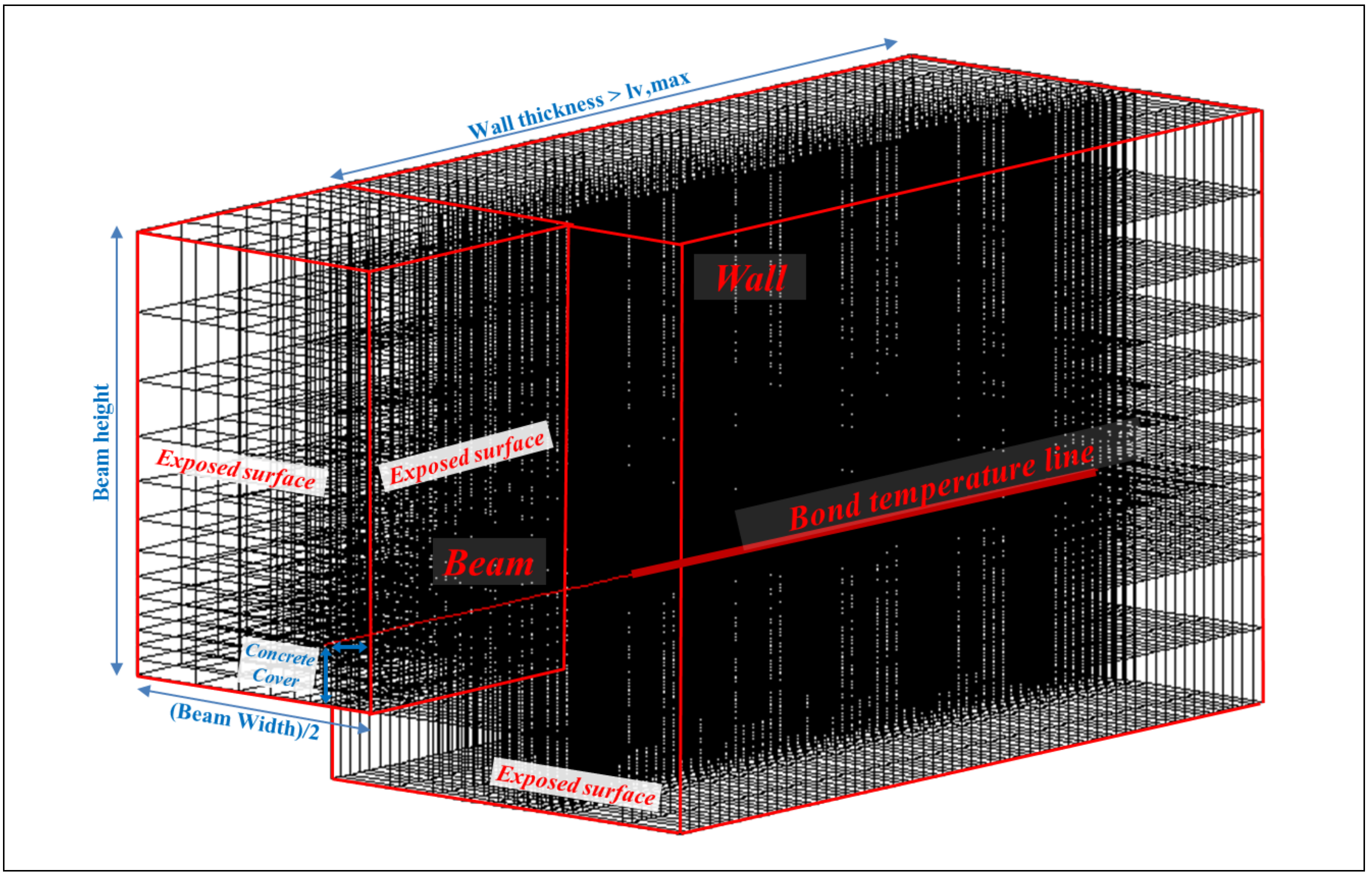


Figure 6 : Mesh used for thermal calculations for the beam-wall connection

Figure 7 presents the calculated thermal fields at 30, 90 and 240 min. The geometry of the mesh of the beam used for calculations is taken large enough so that the isotherms at 240 min of heating are parallel to the concrete surfaces (Figure 7). This implies that the same temperature profiles along the rebar would be obtained for larger and higher beams. The beam height was equal to 300 mm and the beam width was equal to 400 mm.

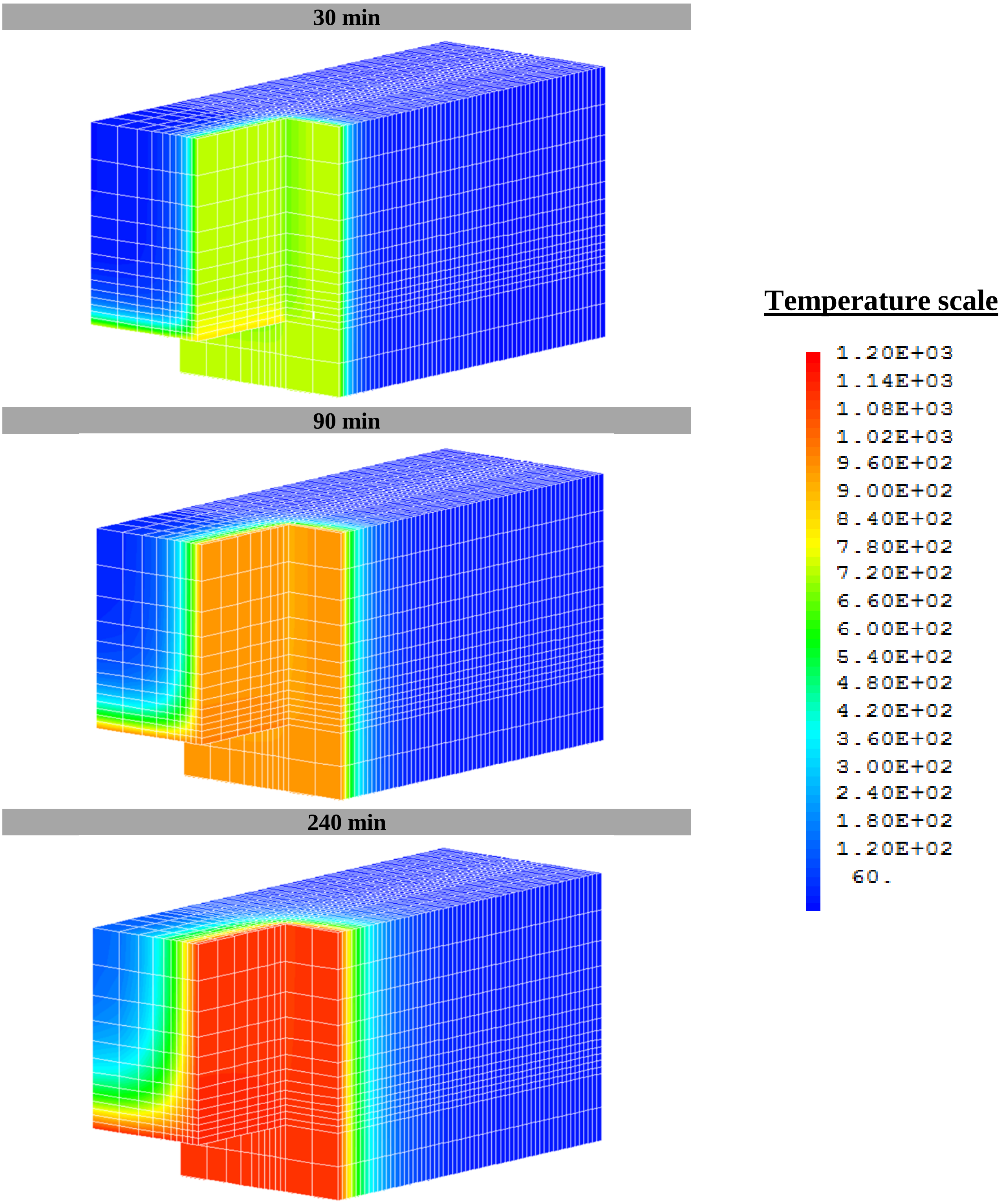


Figure 7 : Temperature fields at 30, 90 and 240 min during an ISO 834-1 fire for the beam-wall connection

7.2 Design load resistances

From the calculated temperature profiles and from the temperature reduction factor k(θ) (Part 5.2, Figure 3), the values of design load capacities $N_{Rd,fire}$ are determined by integration of the design bond resistances.

$$N_{Rd,fire} = \pi \cdot d \cdot \int_0^{l_v} f_{bd,fire}(\theta(x)) \cdot dx = \pi \cdot d \cdot f_{bd,20°C} \cdot \frac{\gamma_{M,20°C}}{\gamma_{M,fire}} \cdot \int_0^{l_v} k(\theta(x)) \cdot dx$$

Where:
$N_{Rd,fire}$ is the design load resistance at a given time during the fire
$f_{bd,20°C}$=2,3 for C20/25 concrete is the design bond strength at 20°C
$\gamma_{M,20°C}$=1,5 is the material coefficient at ambient temperature
$\gamma_{M,fire}$=1 is the material coefficient in a fire situation
k(θ) is the temperature reduction factor
l_v is the embedment depth of the bonded rebar

The integration is performed by finite differences using the following equation.

$$N_{Rd,fire} \approx \pi \cdot d \cdot f_{bd,20°C} \cdot \frac{\gamma_{M,20°C}}{\gamma_{M,fire}} \cdot \sum_0^{l_v} k(\theta_i) \cdot \Delta x$$

For the calculation, the value of Δx was taken equal to 10 mm and the maximal temperature reduction factor k(θ_i) on the length of Δx was taken into account.

Figure 8 presents a general example (not from the FISCHER – FIS EM Plus mortar) of the calculation of the design load resistance by integration of f_{bd} on a bond length of 250 mm by using the temperature profile along the bond at 120 min during an ISO 834-1 fire with a concrete cover of 20 mm in the beam.

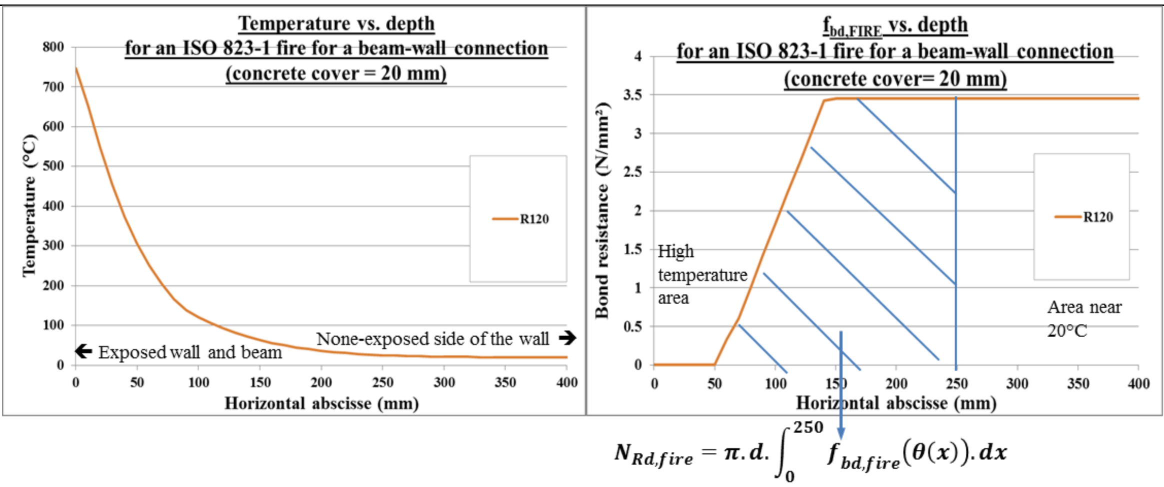


Figure 8 : General example of the calculation of the design load resistance by integration of f_{bd}

Appendices 2.1, 2.2, 2.3 and 2.4 present the values of $N_{Rd,fire}$ at different fire durations for different bond lengths respectively for concrete covers of 10 mm, 20 mm, 30 mm and 40 mm. The minimal and maximal values of bond lengths are in accordance with PART 4.2.

8. LIST OF APPENDICES

Appendix 1: Design bond resistances for an overlap joint application (slab-slab connection)

Appendix 2.1: Design load resistances for an anchoring application (beam-wall connection) with a concrete cover of 10 mm for diameters 8 and 10 mm

Appendix 2.2: Design load resistances for an anchoring application (beam-wall connection) with a concrete cover of 20 mm for diameters 8, 10, 12, 14, 16 and 20 mm

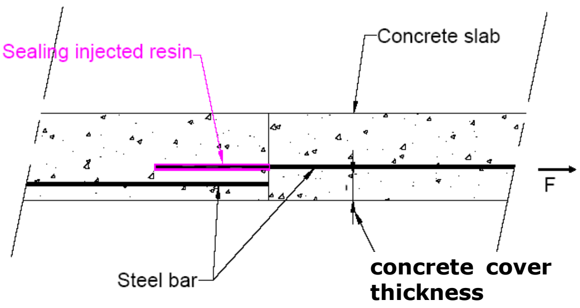
Appendix 2.3: Design load resistances for an anchoring application (beam-wall connection) with a concrete cover of 30 mm for diameters 8, 10, 12, 14, 16, 20, 25 and 28 mm

Appendix 2.4: Design load resistances for an anchoring application (beam-wall connection) with a concrete cover of 40 mm for diameters 8, 10, 12, 14, 16, 20, 25, 28 and 32 mm

Appendix 1:
Maximum applicable bond stress for an overlap joint application

The table presents design bond resistances (f_{bd}) for a **Slab-Slab connection** using **C20/25 concrete**[2] and rebars with a yield strength **f_y=500 N/mm²** in an **ISO 834-1 fire** (at 30, 60, 90, 120, 180 and 240 min) for concrete covers between 50 and 270 mm.

The bond resistance values shall not be applied for beam-beam connections. Post-installed rebars shall be designed in ambient temperature conditions before being designed in fire conditions.



Concrete Cover (mm)	R30	R60	R90	R120	R180	R240
	Fire Design Bond Resistance $f_{bd,FIRE}$ (N/mm²)					
50	1.0	0	0	0	0	0
60	1.7	0	0	0	0	0
70	2.4	0	0	0	0	0
80	3.2	1.1	0	0	0	0
90	3.5	1.6	0	0	0	0
100	3.5	2.1	1.0	0	0	0
110	3.5	2.6	1.4	0	0	0
120	3.5	3.2	1.8	1.1	0	0
130	3.5	3.5	2.2	1.4	0	0
140	3.5	3.5	2.7	1.8	0	0
150	3.5	3.5	3.1	2.1	1.1	0
160	3.5	3.5	3.5	2.5	1.3	0
170	3.5	3.5	3.5	2.9	1.6	0
180	3.5	3.5	3.5	3.3	1.9	1.2
190	3.5	3.5	3.5	3.5	2.2	1.4
200	3.5	3.5	3.5	3.5	2.5	1.6
210	3.5	3.5	3.5	3.5	2.8	1.9
220	3.5	3.5	3.5	3.5	3.2	2.2
230	3.5	3.5	3.5	3.5	3.5	2.4
240	3.5	3.5	3.5	3.5	3.5	2.7
250	3.5	3.5	3.5	3.5	3.5	3.0
260	3.5	3.5	3.5	3.5	3.5	3.3
270	3.5	3.5	3.5	3.5	3.5	3.5

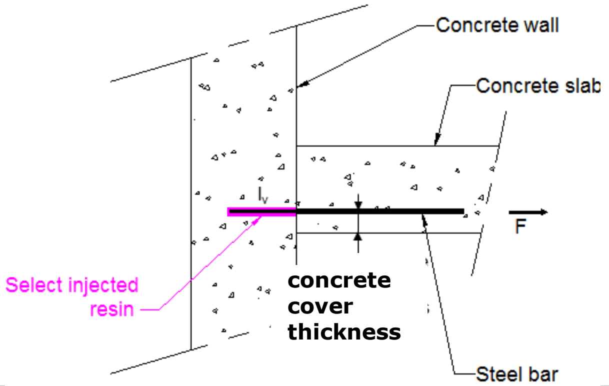
The present table is aimed at supplying data for the design of the injection anchoring system when exposed to fire. This study does not deal with the mechanical design at ambient temperature, neither does it deal with the design according to other accidental solicitations, these shall be done in addition.

[2] The values of fire design load resistance can be used in case of higher concrete strength up to C50/60.

Appendix 2.1:
Maximum applicable loads for an anchoring application (beam-wall connection) with a concrete cover of 10 mm for diameters 8 and 10 mm

The table presents design load resistances for a **Beam-Wall connection** using **C20/25 concrete**[3] and rebars with a yield strength **f_y=500 N/mm²** in an **ISO 834-1 fire** (at 30, 60, 90, 120, 180 and 240 min) for a **concrete cover of 10 mm** and for diameters 8 and 10 mm.

The design load values may be used safely for a slab-wall connection. Post-installed rebars shall be designed in ambient temperature conditions before being designed in fire conditions.



Concrete Cover = 10 mm		Fire Design Load Resistance $N_{Rd,fire}$ (kN)					
Diameter (mm)	**Length lv (mm)**	**R30**	**R60**	**R90**	**R120**	**R180**	**R240**
8	**100**	4.4	1.7	0.7	0.2	0.0	0.0
	140	7.9	5.0	3.1	1.7	0.0	0.0
	180	11.3	8.5	6.6	4.7	2.2	1.1
	220	14.8	12.0	10.0	8.2	5.3	3.2
	250	16.8	14.6	12.6	10.8	7.9	5.5
	280		16.8	15.2	13.4	10.5	8.1
	300			16.8	15.1	12.2	9.8
	320				16.8	13.9	11.5
	360					16.8	15.0
	390						16.8
10	**110**	6.6	3.0	1.4	0.0	0.0	0.0
	140	9.8	6.3	3.9	2.2	0.0	0.0
	180	14.1	10.6	8.2	5.9	2.8	1.4
	220	18.5	15.0	12.5	10.3	6.6	4.0
	250	21.7	18.2	15.8	13.5	9.8	6.8
	300	26.2	23.6	21.2	18.9	15.2	12.2
	330		26.2	24.5	22.2	18.5	15.5
	350			26.2	24.4	20.7	17.7
	370				26.2	22.8	19.8
	410					26.2	24.2
	430						26.2

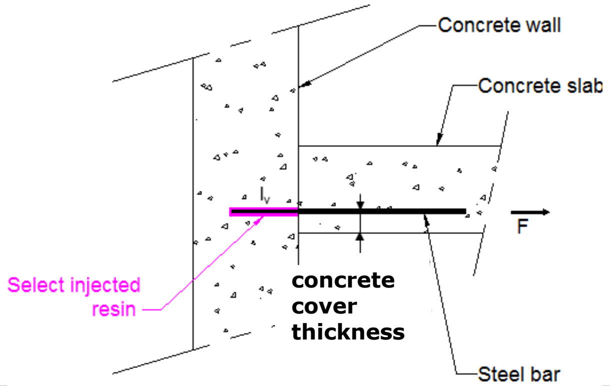
Intermediate values may be interpolated linearly. Extrapolation is not possible. The present table is aimed at supplying data for the design of the injection anchoring system when exposed to fire. This study does not deal with the mechanical design at ambient temperature, neither does it deal with the design according to other accidental solicitations, these shall be done in addition.

3 The values of fire design load resistance can be used in case of higher concrete strength up to C50/60.

Appendix 2.2:
Maximum applicable loads for an anchoring application (beam-wall connection) with a concrete cover of 20 mm for diameters 8, 10, 12, 14, 16 and 20 mm

The table presents design load resistances for a **Beam-Wall connection** using **C20/25 concrete**[4] and rebars with a yield strength **f_y=500 N/mm²** in an **ISO 834-1 fire** (at 30, 60, 90, 120, 180 and 240 min) for a **concrete cover of 20 mm** and for diameters 8, 10, 12, 14, 16 and 20 mm

The design load values may be used safely for a slab-wall connection. Post-installed rebars shall be designed in ambient temperature conditions before being designed in fire conditions.



Concrete Cover = 20 mm		Fire Design Load Resistance $N_{Rd,fire}$ (kN)					
Diameter (mm)	**Length lv (mm)**	**R30**	**R60**	**R90**	**R120**	**R180**	**R240**
8	**100**	4.6	2.0	0.0	0.0	0.0	0.0
	150	8.9	6.2	4.1	2.5	1.0	0.0
	200	13.3	10.6	8.5	6.6	3.9	2.2
	240	16.8	14.0	11.9	10.1	7.3	4.9
	280		16.8	15.4	13.6	10.8	8.3
	300			16.8	15.3	12.5	10.1
	320				16.8	14.2	11.8
	350					16.8	14.4
	380						16.8
10	**110**	6.8	3.5	1.5	0.0	0.0	0.0
	150	11.2	7.8	5.2	3.1	1.3	0.0
	190	15.5	12.1	9.5	7.2	3.9	2.2
	240	20.9	17.5	14.9	12.6	9.1	6.1
	290	26.2	23.0	20.3	18.1	14.5	11.5
	320		26.2	23.6	21.3	17.8	14.8
	350			26.2	24.6	21.0	18.0
	370				26.2	23.2	20.2
	400					26.2	23.4
	430						26.2

The table continues on the next page.

[4] The values of fire design load resistance can be used in case of higher concrete strength up to C50/60.

Concrete Cover = 20 mm		Fire Design Load Resistance $N_{Rd,fire}$ (kN)					
Diameter (mm)	Length lv (mm)	R30	R60	R90	R120	R180	R240
12	140	12.1	8.1	4.9	2.7	1.0	0.0
	170	16.0	12.0	8.8	6.1	2.9	1.4
	210	21.2	17.2	14.0	11.3	7.0	4.2
	250	26.4	22.4	19.2	16.5	12.2	8.6
	300	32.9	28.9	25.7	23.0	18.7	15.1
	340	37.7	34.1	30.9	28.2	23.9	20.3
	370		37.7	34.8	32.1	27.8	24.2
	400			37.7	36.0	31.7	28.1
	420				37.7	34.3	30.7
	450					37.7	34.6
	480						37.7
14	160	17.2	12.4	8.7	5.6	2.5	1.1
	200	23.2	18.5	14.8	11.6	6.8	3.9
	240	29.3	24.6	20.9	17.7	12.8	8.6
	290	36.9	32.2	28.5	25.3	20.3	16.1
	340	44.5	39.7	36.0	32.9	27.9	23.7
	390	51.3	47.3	43.6	40.4	35.5	31.3
	420		51.3	48.2	45.0	40.1	35.9
	450			51.3	49.6	44.6	40.4
	470				51.3	47.7	43.4
	500					51.3	48.0
	530						51.3
16	180	23.1	17.7	13.5	9.8	5.0	2.6
	220	30.0	24.6	20.4	16.7	11.1	6.8
	270	38.7	33.3	29.1	25.4	19.8	15.0
	320	47.4	42.0	37.7	34.1	28.5	23.6
	380	57.8	52.4	48.1	44.5	38.9	34.0
	440	67.0	62.8	58.5	54.9	49.3	44.4
	470		67.0	63.7	60.1	54.5	49.6
	490			67.0	63.6	57.9	53.1
	510				67.0	61.4	56.6
	550					67.0	63.5
	580						67.0
20	220	37.5	30.8	25.5	20.9	13.9	8.6
	280	50.6	43.8	38.5	33.9	26.9	20.9
	340	63.6	56.8	51.5	46.9	39.9	33.9
	400	76.6	69.8	64.5	60.0	52.9	46.9
	470	91.7	85.0	79.7	75.1	68.1	62.1
	530	104.7	98.0	92.7	88.1	81.1	75.1
	570		104.7	101.4	96.8	89.8	83.7
	590			104.7	101.1	94.1	88.1
	610				104.7	98.4	92.4
	640					104.7	98.9
	670						104.7

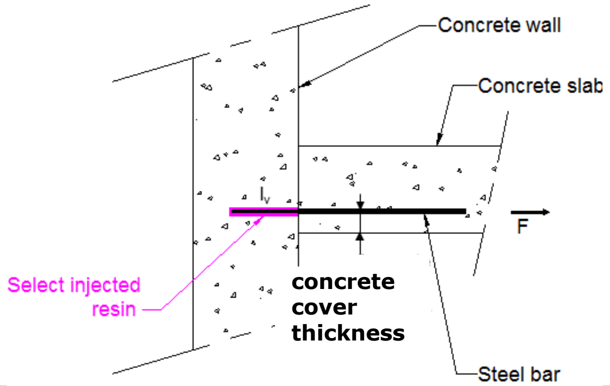
Intermediate values may be interpolated linearly. Extrapolation is not possible. The present table is aimed at supplying data for the design of the injection anchoring system when exposed to fire. This study does not deal with the mechanical design at ambient temperature, neither does it deal with the design according to other accidental solicitations, these shall be done in addition.

Appendix 2.3:

Maximum applicable loads for an anchoring application (beam-wall connection) with a concrete cover of 30 mm for diameters 8, 10, 12, 14, 16, 20, 25 and 28 mm

The table presents design load resistances for a **Beam-Wall connection** using **C20/25 concrete**[5] and rebars with a yield strength **f_y=500 N/mm²** in an **ISO 834-1 fire** (at 30, 60, 90, 120, 180 and 240 min) for a **concrete cover of 30 mm** and for diameters 8, 10, 12, 14, 16, 20, 25 and 28 mm

The design load values may be used safely for a slab-wall connection. Post-installed rebars shall be designed in ambient temperature conditions before being designed in fire conditions.



Concrete Cover = 30 mm		Fire Design Load Resistance $N_{Rd,fire}$ (kN)					
Diameter (mm)	**Length lv (mm)**	**R30**	**R60**	**R90**	**R120**	**R180**	**R240**
8	**100**	5.1	2.2	0.0	0.0	0.0	0.0
	140	8.6	5.6	3.5	2.1	0.0	0.0
	190	12.9	10.0	7.8	6.1	3.3	1.8
	240	16.8	14.3	12.1	10.5	7.5	5.1
	270		16.8	14.7	13.1	10.1	7.6
	300			16.8	15.7	12.7	10.2
	320				16.8	14.4	12.0
	350					16.8	14.6
	380						16.8
10	**110**	7.5	3.8	1.7	0.9	0.0	0.0
	150	11.8	8.1	5.4	3.5	1.3	0.5
	190	16.2	12.4	9.8	7.7	4.1	2.3
	230	20.5	16.8	14.1	12.0	8.2	5.3
	290	26.2	23.3	20.6	18.5	14.8	11.7
	320		26.2	23.8	21.7	18.0	15.0
	350			26.2	25.0	21.3	18.2
	370				26.2	23.4	20.4
	400					26.2	23.6
	430						26.2

The table continues on the next page.

5 The values of fire design load resistance can be used in case of higher concrete strength up to C50/60.

Concrete Cover = 30 mm		Fire Design Load Resistance $N_{Rd,fire}$ (kN)					
Diameter (mm)	Length lv (mm)	R30	R60	R90	R120	R180	R240
12	140	12.9	8.4	5.2	3.2	1.1	0.0
	180	18.1	13.6	10.4	7.9	3.9	2.0
	230	24.6	20.1	16.9	14.4	9.9	6.4
	280	31.1	26.6	23.4	20.9	16.4	12.8
	340	37.7	34.4	31.2	28.7	24.2	20.6
	370		37.7	35.1	32.6	28.1	24.5
	390			37.7	35.2	30.7	27.1
	410				37.7	33.3	29.7
	450					37.7	34.9
	480						37.7
14	160	18.1	12.9	9.1	6.2	2.6	1.1
	200	24.1	18.9	15.2	12.2	7.1	4.0
	240	30.2	25.0	21.2	18.3	13.1	8.8
	280	36.3	31.1	27.3	24.4	19.1	14.9
	330	43.9	38.7	34.9	32.0	26.7	22.5
	380	51.3	46.3	42.5	39.6	34.3	30.1
	420		51.3	48.6	45.6	40.4	36.1
	440			51.3	48.7	43.4	39.2
	460				51.3	46.4	42.2
	500					51.3	48.3
	520						51.3
16	180	24.1	18.2	13.9	10.5	5.2	2.7
	230	32.8	26.8	22.5	19.2	13.2	8.5
	270	39.7	33.8	29.5	26.1	20.1	15.3
	310	46.7	40.7	36.4	33.1	27.1	22.2
	370	57.1	51.1	46.8	43.5	37.5	32.6
	430	67.0	61.5	57.2	53.9	47.9	43.0
	470		67.0	64.2	60.8	54.8	50.0
	490			67.0	64.3	58.3	53.4
	510				67.0	61.8	56.9
	550					67.0	63.8
	570						67.0
20	220	38.8	31.4	26.0	21.8	14.3	8.9
	280	51.8	44.4	39.0	34.8	27.3	21.3
	340	64.8	57.4	52.0	47.8	40.3	34.3
	400	77.8	70.4	65.0	60.8	53.3	47.3
	460	90.9	83.4	78.0	73.8	66.4	60.3
	530	104.7	98.6	93.2	89.0	81.5	75.5
	560		104.7	99.7	95.5	88.0	82.0
	590			104.7	102.0	94.5	88.5
	610				104.7	98.9	92.8
	640					104.7	99.3
	670						104.7

The table continues on the next page.

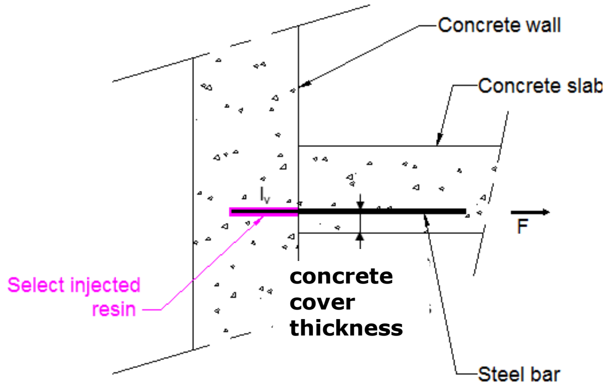
Concrete Cover = 30 mm		Fire Design Load Resistance $N_{Rd,fire}$ (kN)					
Diameter (mm)	Length lv (mm)	R30	R60	R90	R120	R180	R240
25	280	64.8	55.5	48.8	43.5	34.2	26.6
	340	81.0	71.8	65.0	59.8	50.4	42.9
	400	97.3	88.0	81.3	76.1	66.7	59.1
	470	116.3	107.0	100.3	95.0	85.7	78.1
	530	132.5	123.2	116.5	111.3	101.9	94.3
	580	146.1	136.8	130.1	124.8	115.5	107.9
	650	163.6	155.8	149.0	143.8	134.4	126.9
	680		163.6	157.2	151.9	142.6	135.0
	710			163.6	160.0	150.7	143.1
	730				163.6	156.1	148.5
	760					163.6	156.7
	790						163.6
28	310	81.7	71.3	63.7	57.9	47.4	38.9
	380	102.9	92.5	85.0	79.1	68.6	60.1
	460	127.2	116.8	109.3	103.4	92.9	84.4
	520	145.4	135.0	127.5	121.6	111.1	102.6
	580	163.6	153.2	145.7	139.8	129.3	120.8
	650	184.9	174.4	166.9	161.0	150.6	142.1
	720	205.3	195.7	188.2	182.3	171.8	163.3
	760		205.3	200.3	194.4	183.9	175.5
	780			205.3	200.5	190.0	181.5
	800				205.3	196.1	187.6
	840					205.3	199.7
	860						205.3

Intermediate values may be interpolated linearly. Extrapolation is not possible. The present table is aimed at supplying data for the design of the injection anchoring system when exposed to fire. This study does not deal with the mechanical design at ambient temperature, neither does it deal with the design according to other accidental solicitations, these shall be done in addition.

Appendix 2.4:
Maximum applicable loads for an anchoring application (beam-wall connection) with a concrete cover of 40 mm for diameters 8, 10, 12, 14, 16, 20, 25, 28 and 32 mm

The table presents design load resistances for a **Beam-Wall connection** using **C20/25 concrete**[6] and rebars with a yield strength $\mathbf{f_y=500\ N/mm^2}$ in an **ISO 834-1 fire** (at 30, 60, 90, 120, 180 and 240 min) for a **concrete cover of 40 mm** and for diameters 8, 10, 12, 14, 16, 20, 25, 28 and 32 mm

The design load values may be used safely for a slab-wall connection. Post-installed rebars shall be designed in ambient temperature conditions before being designed in fire conditions.



Concrete Cover = 40 mm		Fire Design Load Resistance $N_{Rd,fire}$ (kN)					
Diameter (mm)	**Length lv (mm)**	**R30**	**R60**	**R90**	**R120**	**R180**	**R240**
8	**100**	5.8	2.6	1.1	0.0	0.0	0.0
	140	9.2	6.1	3.9	2.3	0.0	0.0
	190	13.6	10.4	8.2	6.4	3.4	1.9
	230	16.8	13.9	11.7	9.8	6.8	4.4
	270		16.8	15.2	13.3	10.3	7.8
	290			16.8	15.0	12.0	9.6
	310				16.8	13.7	11.3
	350					16.8	14.8
	380						16.8
10	**110**	8.3	4.4	2.1	1.0	0.0	0.0
	160	13.7	9.8	7.0	4.7	2.0	0.0
	210	19.1	15.2	12.5	10.1	6.3	3.8
	250	23.5	19.5	16.8	14.5	10.7	7.6
	280	26.2	22.8	20.0	17.7	13.9	10.9
	320		26.2	24.4	22.0	18.3	15.2
	340			26.2	24.2	20.4	17.4
	360				26.2	22.6	19.5
	400					26.2	23.9
	430						26.2

The table continues on the next page.

6 The values of fire design load resistance can be used in case of higher concrete strength up to C50/60.

Concrete Cover = 40 mm		Fire Design Load Resistance $N_{Rd,fire}$ (kN)					
Diameter (mm)	**Length lv (mm)**	**R30**	**R60**	**R90**	**R120**	**R180**	**R240**
12	**140**	13.9	9.2	5.8	3.4	1.2	0.0
	180	19.1	14.4	11.0	8.2	4.1	2.1
	230	25.6	20.9	17.5	14.8	10.2	6.6
	280	32.1	27.4	24.0	21.3	16.7	13.0
	330	37.7	33.9	30.6	27.8	23.2	19.5
	360		37.7	34.5	31.7	27.1	23.4
	390			37.7	35.6	31.0	27.4
	410				37.7	33.6	30.0
	450					37.7	35.2
	470						37.7
14	**160**	19.2	13.7	9.8	6.6	2.8	1.2
	210	26.8	21.3	17.4	14.2	8.9	5.3
	260	34.4	28.9	25.0	21.8	16.5	12.2
	320	43.5	38.0	34.1	30.9	25.6	21.3
	380	51.3	47.1	43.2	40.0	34.7	30.4
	410		51.3	47.8	44.5	39.2	34.9
	440			51.3	49.1	43.8	39.5
	460				51.3	46.8	42.5
	490					51.3	47.1
	520						51.3
16	**180**	25.4	19.1	14.7	11.0	5.5	2.9
	230	34.1	27.8	23.4	19.7	13.6	8.8
	270	41.0	34.7	30.3	26.6	20.5	15.7
	310	48.0	41.7	37.3	33.5	27.5	22.6
	360	56.6	50.4	45.9	42.2	36.1	31.3
	420	67.0	60.8	56.3	52.6	46.6	41.7
	460		67.0	63.3	59.6	53.5	48.6
	490			67.0	64.8	58.7	53.8
	510				67.0	62.2	57.3
	540					67.0	62.5
	570						67.0
20	**220**	40.4	32.6	27.1	22.4	14.8	9.2
	290	55.6	47.8	42.2	37.6	30.0	23.9
	340	66.4	58.6	53.1	48.4	40.8	34.7
	390	77.3	69.4	63.9	59.3	51.7	45.6
	460	92.5	84.6	79.1	74.4	66.9	60.8
	520	104.7	97.6	92.1	87.5	79.9	73.8
	560		104.7	100.8	96.1	88.5	82.4
	580			104.7	100.5	92.9	86.8
	600				104.7	97.2	91.1
	640					104.7	99.8
	670						104.7

The table continues on the next page.

Concrete Cover = 40 mm		Fire Design Load Resistance $N_{Rd,fire}$ (kN)					
Diameter (mm)	**Length lv (mm)**	**R30**	**R60**	**R90**	**R120**	**R180**	**R240**
25	**280**	66.8	57.0	50.1	44.3	34.8	27.2
	350	85.8	76.0	69.1	63.3	53.8	46.1
	410	102.0	92.2	85.3	79.5	70.0	62.4
	470	118.3	108.5	101.6	95.8	86.3	78.7
	530	134.5	124.7	117.8	112.0	102.5	94.9
	580	148.1	138.3	131.4	125.6	116.1	108.5
	640	163.6	154.5	147.6	141.8	132.3	124.7
	680		163.6	158.5	152.7	143.2	135.6
	700			163.6	158.1	148.6	141.0
	730				163.6	156.7	149.1
	760					163.6	157.2
	790						163.6
28	**310**	83.9	72.9	65.2	58.7	48.1	39.5
	380	105.2	94.2	86.5	79.9	69.3	60.8
	460	129.4	118.5	110.7	104.2	93.6	85.1
	520	147.6	136.7	128.9	122.4	111.8	103.3
	580	165.9	154.9	147.2	140.6	130.0	121.5
	640	184.1	173.1	165.4	158.8	148.2	139.7
	710	205.3	194.3	186.6	180.1	169.5	160.9
	750		205.3	198.7	192.2	181.6	173.1
	780			205.3	201.3	190.7	182.2
	800				205.3	196.8	188.2
	830					205.3	197.3
	860						205.3
32	**350**	109.8	97.2	88.4	81.0	68.8	59.1
	440	141.0	128.5	119.6	112.2	100.0	90.3
	530	172.2	159.7	150.8	143.4	131.3	121.5
	610	200.0	187.4	178.6	171.1	159.0	149.2
	680	224.2	211.7	202.9	195.4	183.3	173.5
	750	248.5	236.0	227.1	219.7	207.6	197.8
	810	268.1	256.8	248.0	240.5	228.4	218.6
	850		268.1	261.8	254.4	242.2	232.5
	870			268.1	261.3	249.2	239.4
	890				268.1	256.1	246.4
	930					268.1	260.2
	960						268.1

Intermediate values may be interpolated linearly. Extrapolation is not possible. The present table is aimed at supplying data for the design of the injection anchoring system when exposed to fire. This study does not deal with the mechanical design at ambient temperature, neither does it deal with the design according to other accidental solicitations, these shall be done in addition.