REPORT No MRF 26074021/B

On

Fire Evaluation of

Post installed rebar connections

With RAMSET Chemset™ 801 Xtrem™ /

RAMSET Chemset™ 800 Xtrem™ injection system

REQUESTED BY:

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It comprises 23 pages numbered from 1/23 to 23/23

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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 ITW company request, CSTB has performed a study aimed at the evaluation of the fire behaviour of the RAMSET CHEMSET™ 801 XTREM™ / RAMSET CHEMSET™ 800 XTREM™ injection resin system used in conjunction with concrete reinforcing rebar (d 8 to 32 mm).

The present study is aimed at supplying data for the design of the injection anchoring system when exposed to fire. This report presents values of bond capacities and load capacities respectively an for overlap joint application and for an anchorage application using the mortar product RAMSET CHEMSET™ 801 XTREM™ / RAMSET CHEMSET™ 800 XTREM™.

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.

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2. REFERENCES

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

[2] ETA-17/0513 of 27 October 2017, SPIT VIPER XTREM, Deutsches Institut für Bautechnik according to EAD 330087-00-0601

[3] 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.

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

[5] 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

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on 2nd May 2018

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4. BACKROUND

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]. 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 [3] 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.
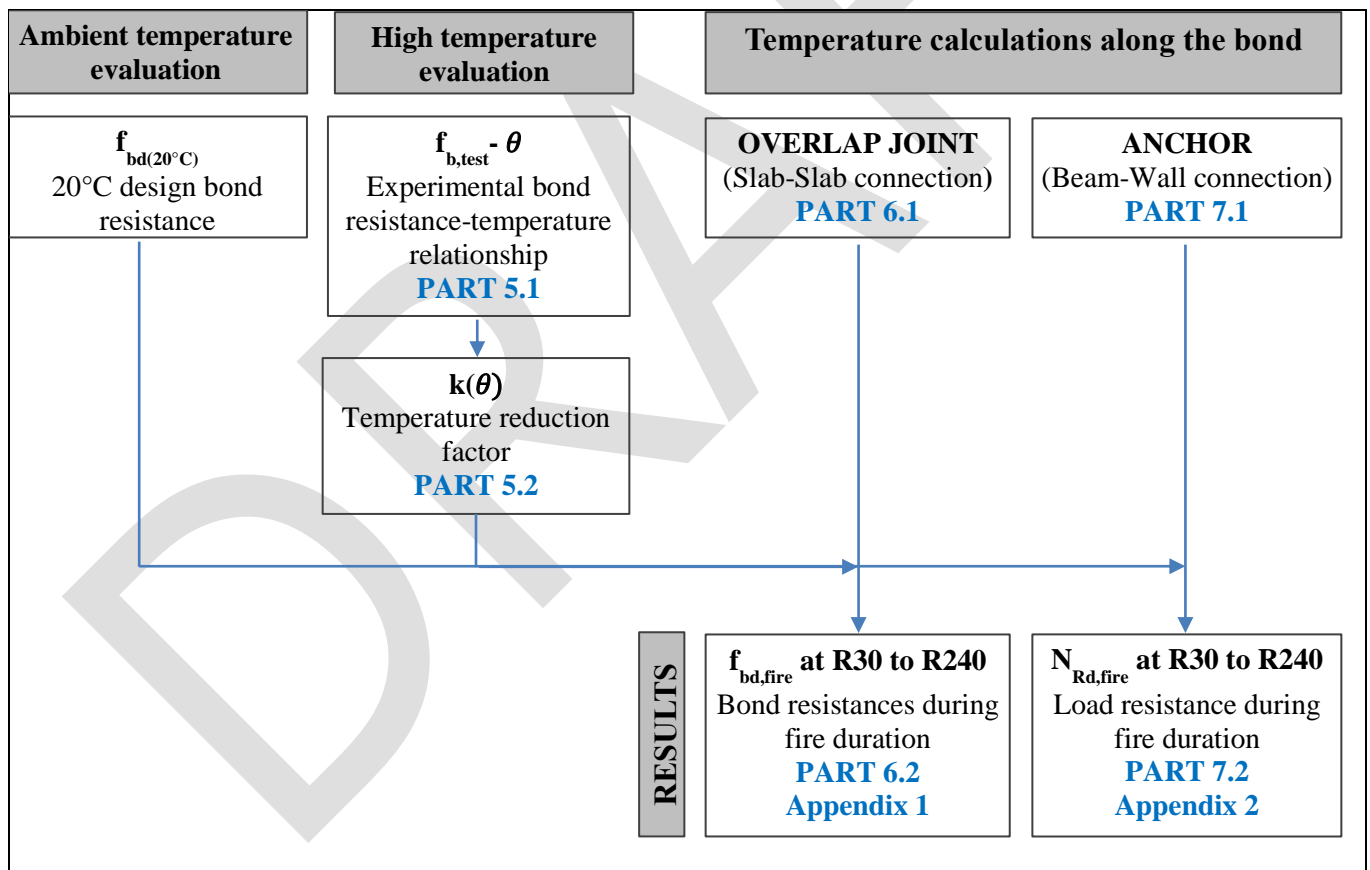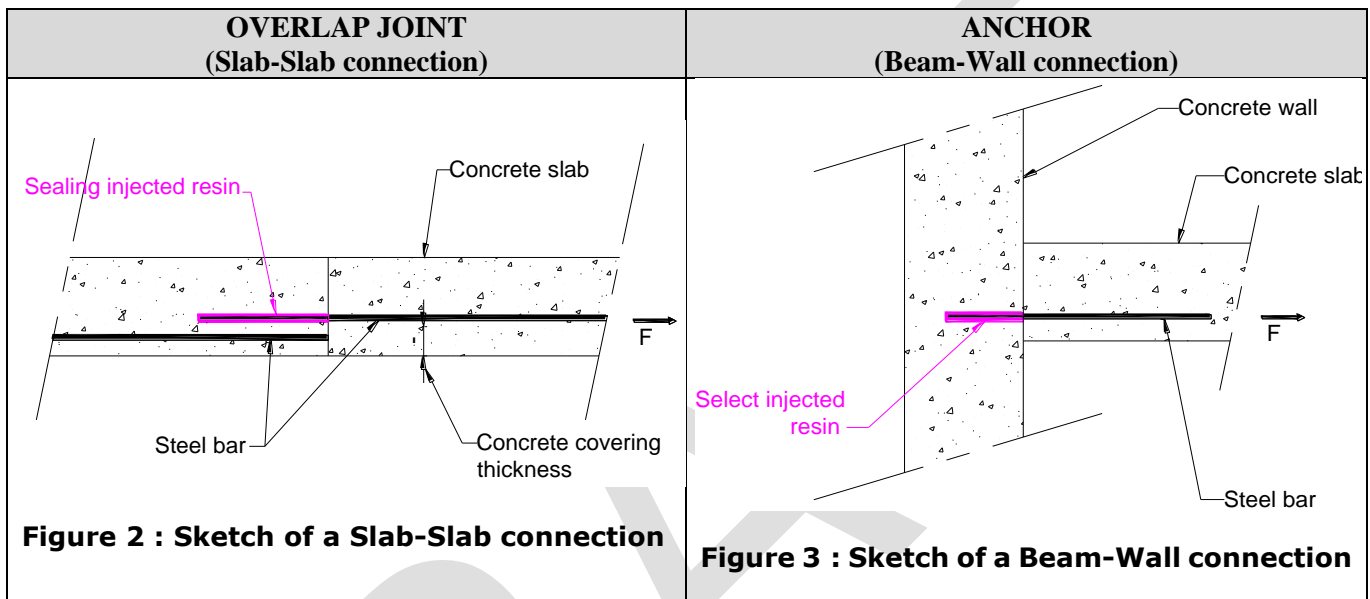

Figure 1 : Method used for fire evaluation of bonded rebars

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 : Sketch of a Slab–Slab connection	**Figure 3 : Sketch 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 concrete or concretes presenting lower resistances. According to the EAD [1], the ultimate bond resistance in C20/25 concrete is equal to f_{bd}=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 [3].

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 [4].

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 [4] (see equation below).

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

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

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

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 [4]. 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 [4].

vii) Maximal temperatures

In accordance to EN 1992-1-2, section 5 [5] 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. BOND RESISTANCE – TEMPERATURE RELATIONSHIP

5.1 Bond resistances

The ETA-17/0513 of 27 October 2017 [2] presents the decay of bond resistance versus temperature. An exponential trend curve is used to describe the bond resistance-temperature relationship analytically using the following equation.

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

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 maximal temperature reached during the tests is identified as θ_{max}.

For the RAMSET CHEMSET™ 801 XTREM™ / RAMSET CHEMSET™ 800 XTREM™ injection system, the a, b and θ_{max} parameters are presented in Table 3.

Table 3 : Injection system parameters

Mortar parameters		
a=	23.755	N/mm²
b=	0.011	/°C
θ max=	281	°C
θ1=	79	°C

5.2 Temperature reduction factor

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

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

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

Where:
k(θ) temperature reduction factor
f$_{bm}$(θ) is the mean bond resistance at the temperature θ
f$_{bm,req,d}$ =min{10 N/mm² ; f$_{bm}$(θ)} is the required bond resistance at cold state
θ is the temperature of the bond
θ$_{max}$ maximal temperature measured during the tests

Figure 4 presents the variation of the temperature reduction factor vs. temperature for the RAMSET CHEMSET™ 801 XTREM™ / RAMSET CHEMSET™ 800 XTREM™ injection system.
No extrapolation beyond test temperatures is allowed. For temperatures higher than the maximal measured temperature during the tests (θ$_{max}$), the reduction factor k(θ) is equal to zero.
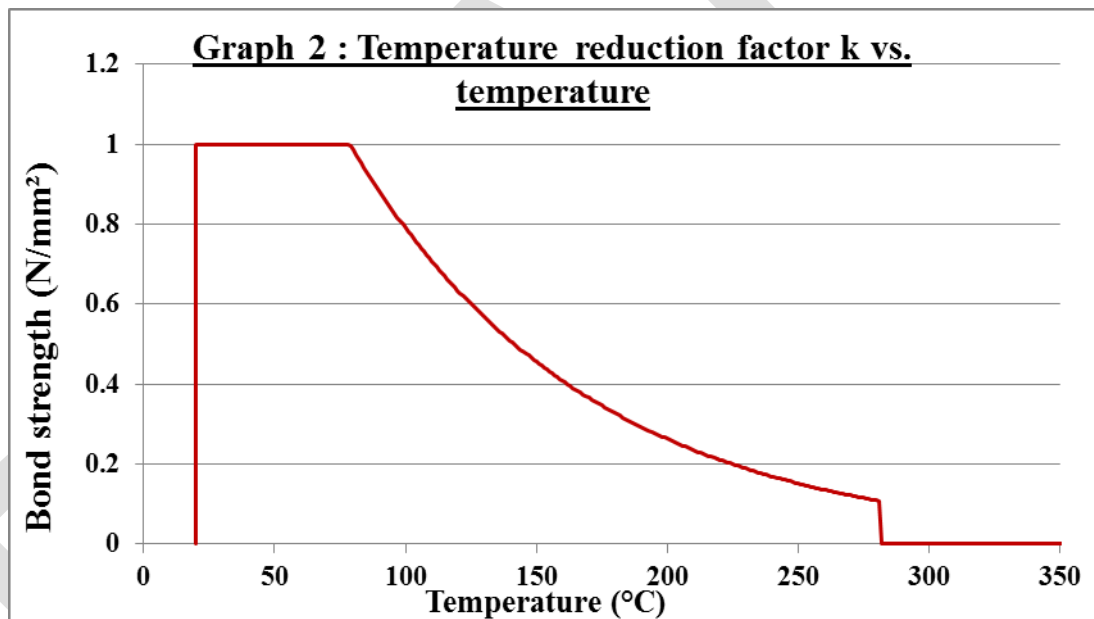

Figure 4 : Temperature reduction factor k(θ) vs. temperature

6. OVERLAP JOINT APPLICATION (SLAB-SLAB CONNECTION)

6.1 Temperature fields

The knowledge of the fire behaviour 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]).

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

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: $\boldsymbol{\varphi_c = h. (\theta_g - \theta_s)}$ (W/m²),

 ➢ radiation flux density: $\boldsymbol{\varphi_c = \varepsilon. \sigma. (\theta_g^4 - \theta_s^4)}$ (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 5. 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].
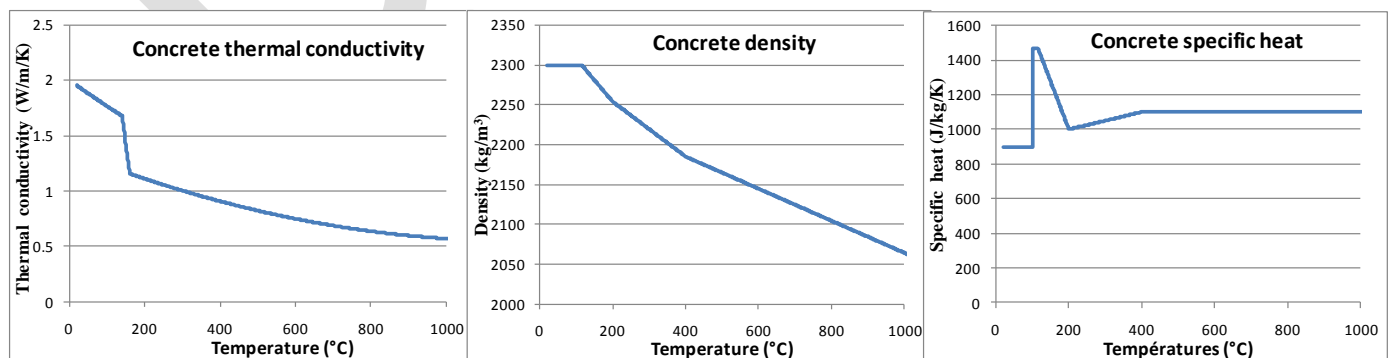

Figure 5 : Variations of thermal conductivity, density and specific heat of concrete according to EN 1992-1-2

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 6 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].
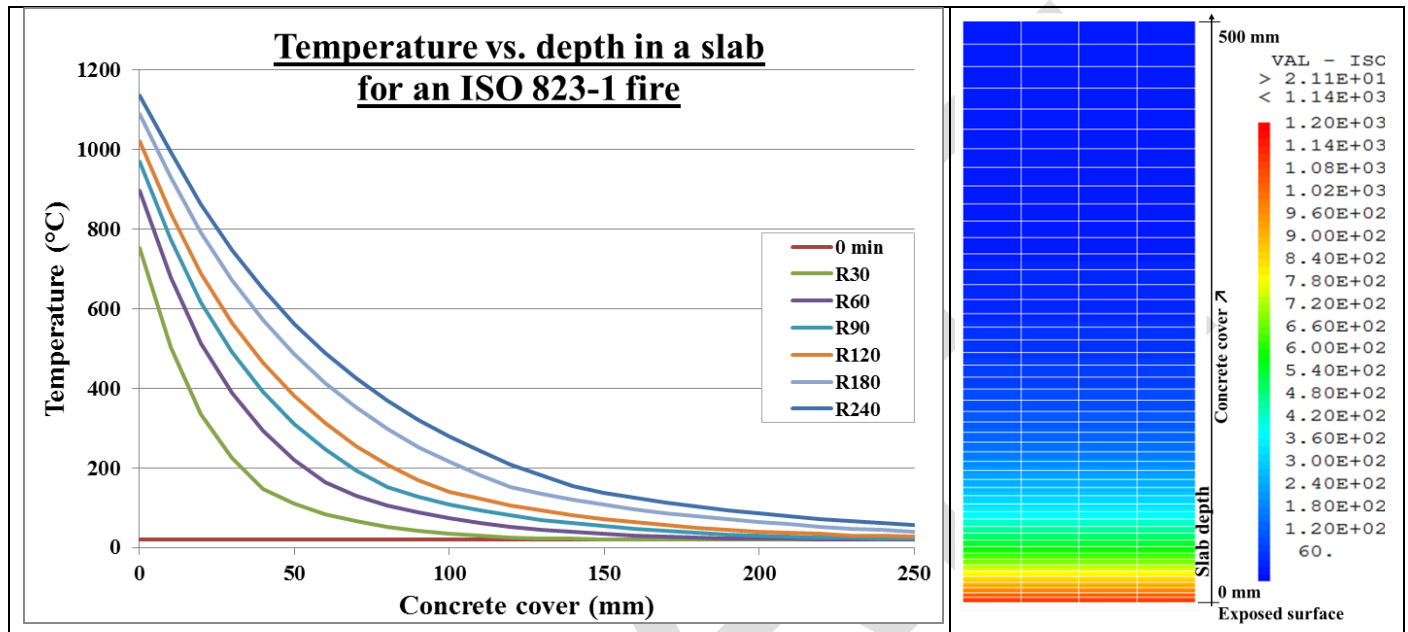
Figure 6 : Temperature vs. concrete cover temperature at 0, 30, 60, 90, 120, 180 and 240 min during an ISO 834-1 fire

6.2 Design bond resistances

From the temperature curves (Part 6.1, Figure 6) and the temperature reduction factor k(θ) (Part 5.2, Figure 4), the values of the design bond resistances $f_{bd,fire}$ are determined using the fallowing equation.

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

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
$k(\theta)$ 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 7). 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.
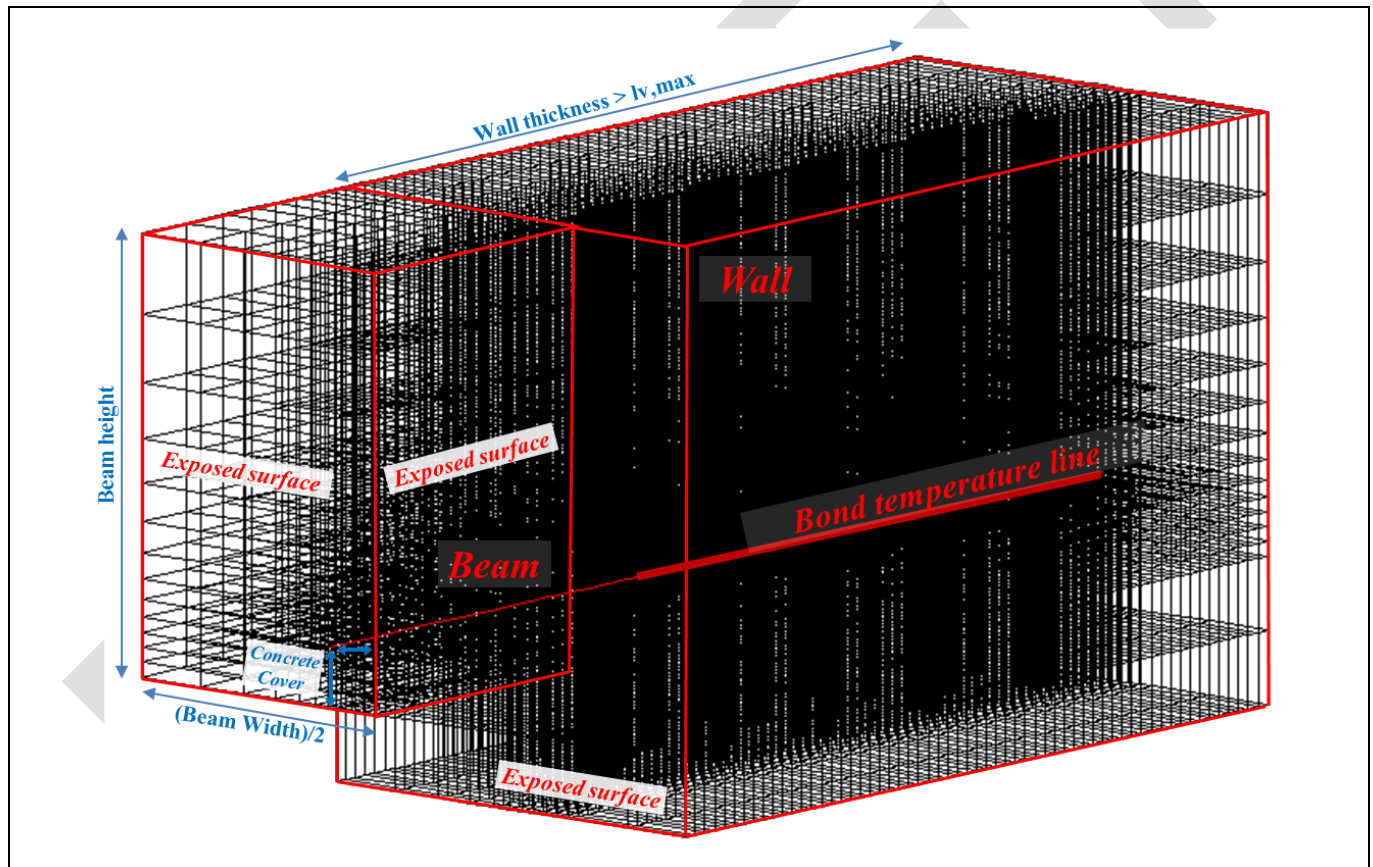
Figure 7 : Mesh used for thermal calculations for the beam-wall connection

Figure 8 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 8). 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.
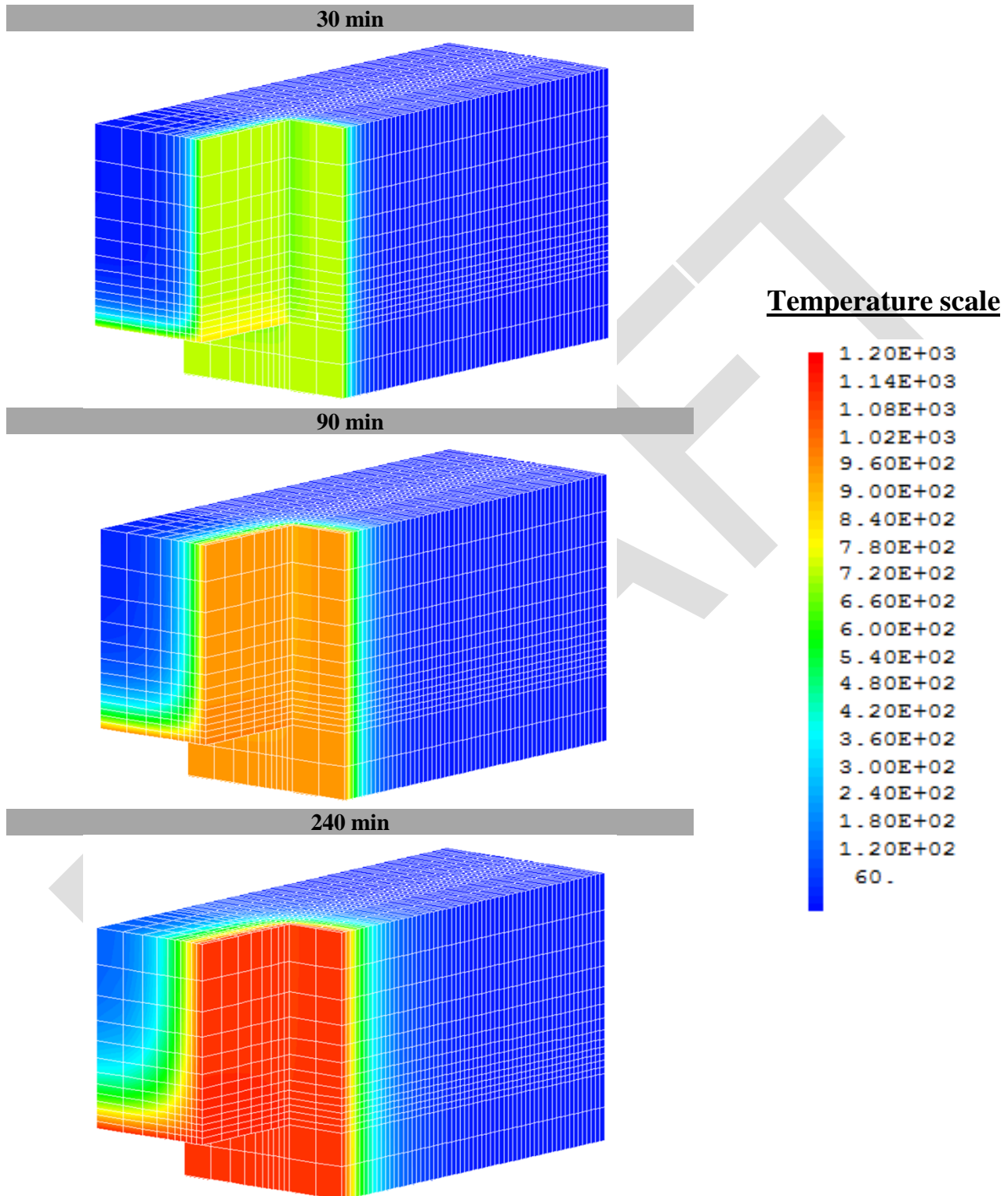
Figure 8 : Temperature fields at 30, 90 and 240 min during an ISO 834-1 fire for the beam-wall connection

7.2 Design load resistances

From the calculated temperature profiles and from the temperature reduction factor k(θ) (Part 5.2, Figure 4), the values of design load capacities $N_{Rd,fire}$ are determined by integration of the design bond resistances.

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

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.

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

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 9 presents a general example (not from the RAMSET CHEMSET™ 801 XTREM™ / RAMSET CHEMSET™ 800 XTREM™ 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.
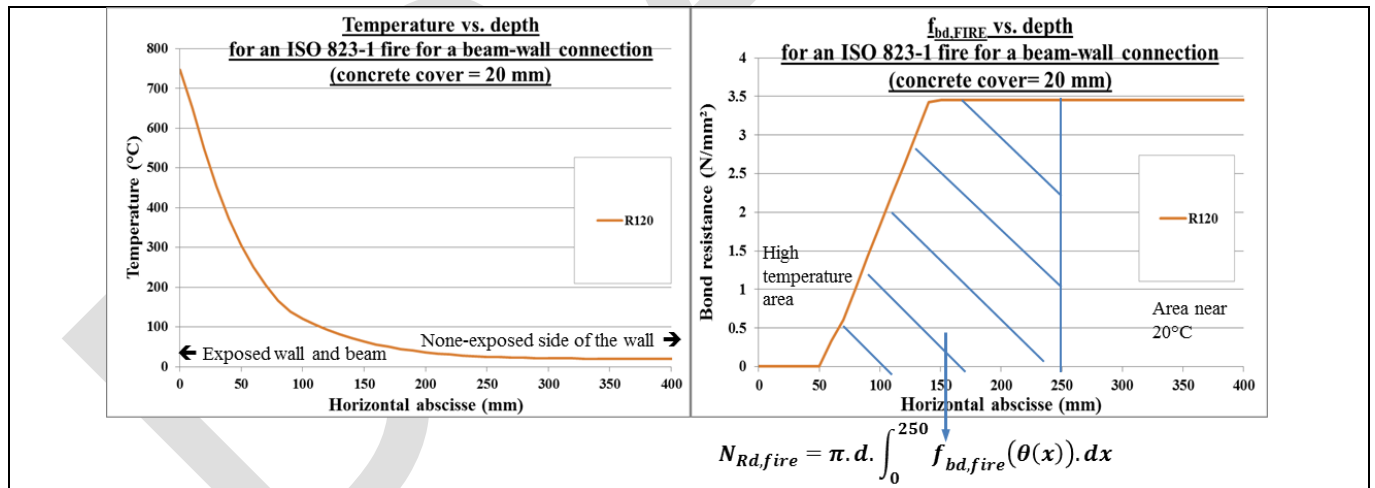
Figure 9 : General example of the calculation of the design load resistance by integration of f_{bd}

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 <u>concrete cover of 10 mm</u> for diameters 8 and 10 mm

Appendix 2.2: Design load resistances for an anchoring application (beam-wall connection) with a <u>concrete cover of 20 mm</u> 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 <u>concrete cover of 30 mm</u> 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 <u>concrete cover of 40 mm</u> 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 underlined design bond resistances (f_{bd}) for a **Slab-Slab connection** using **C20/25 concrete** and rebars with a yield strength $f_y=500 \text{ N/mm}^2$ in an **ISO 834-1 fire** (at 30, 60, 90, 120, 180 and 240 min) for concrete covers between 30 and 230 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.
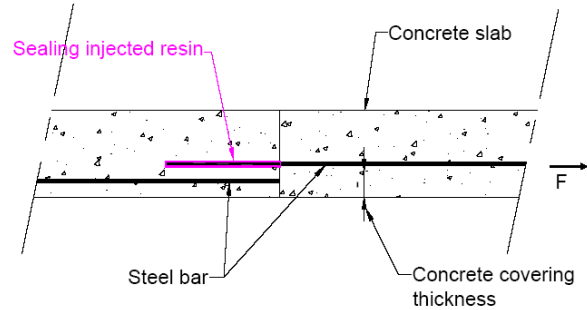
Fire Design Bond Resistance $f_{bd,FIRE}$ (N/mm²)						
Concrete Cover (mm)	**R30**	**R60**	**R90**	**R120**	**R180**	**R240**
40	1.6					
50	2.4	0.7				
60	3.2	1.4	0.5			
70	3.5	2.0	1.0	0.5		
80		2.6	1.5	0.8		
90		3.1	2.0	1.3	0.5	
100		3.5	2.5	1.7	0.8	0.4
110			2.9	2.1	1.1	0.6
120			3.4	2.5	1.5	0.8
130			3.5	2.9	1.9	1.1
140				3.3	2.2	1.5
150				3.5	2.5	1.8
160					2.8	2.1
170					3.1	2.4
180					3.5	2.6
190						2.9
200						3.2
210						3.4
220						3.5
230						

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 2.1:
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 <u>design load resistances</u> for a **Beam-Wall connection** using **C20/25 concrete** 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.
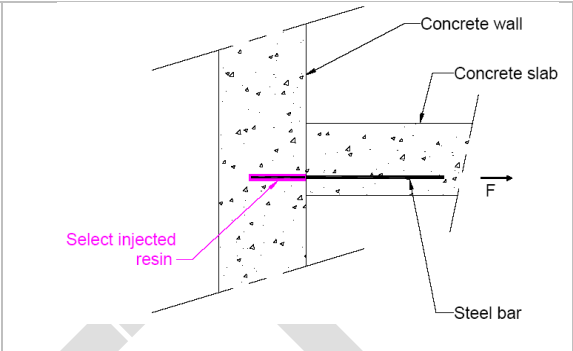
Concrete Cover = 10 mm		Fire Design Load Resistance N Rd,Fire (kN)					
Diameter (mm)	Length lv (mm)	R30	R60	R90	R120	R180	R240
8	100	5.1	3.1	1.7	1.0	0.3	0.1
	140	8.6	6.5	5.0	3.7	2.0	1.1
	180	12.0	10.0	8.4	7.1	5.0	3.4
	220	15.5	13.5	11.9	10.6	8.4	6.7
	240	16.8	15.2	13.6	12.4	10.2	8.4
	260		16.8	15.4	14.1	11.9	10.1
	280			16.8	15.8	13.6	11.9
	300				16.8	15.4	13.6
	320					16.8	15.3
	340						16.8
10	110	7.5	4.9	3.0	1.9	0.7	0.3
	150	11.8	9.2	7.3	5.7	3.2	2.0
	190	16.1	13.6	11.6	10.0	7.3	5.1
	230	20.5	17.9	16.0	14.4	11.6	9.4
	270	24.8	22.2	20.3	18.7	16.0	13.7
	290	26.2	24.4	22.5	20.9	18.1	15.9
	310		26.2	24.6	23.0	20.3	18.1
	330			26.2	25.2	22.5	20.2
	340				26.2	23.5	21.3
	370					26.2	24.6
	390						26.2

Calculations are carried out taking the minimal concrete cover. 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 2.2:

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 <u>design load resistances</u> for a **Beam-Wall connection** using **C20/25 concrete** 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.
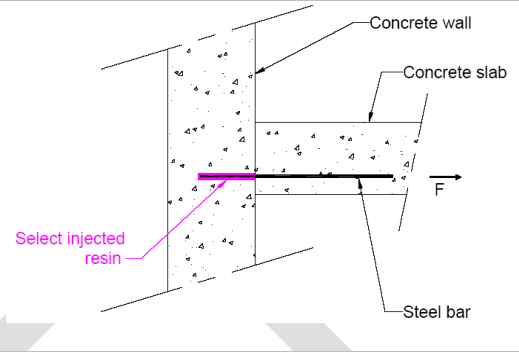
Concrete Cover = 20 mm		Fire Design Load Resistance $N_{Rd,fire}$ (kN)					
Diameter (mm)	Length lv (mm)	R30	R60	R90	R120	R180	R240
8	**100**	5.5	3.3	1.9	1.1	0.3	0.1
	140	8.9	6.8	5.2	3.9	2.1	1.2
	180	12.4	10.2	8.7	7.4	5.1	3.5
	220	15.9	13.7	12.1	10.8	8.6	6.8
	240	16.8	15.4	13.9	12.6	10.4	8.6
	260		16.8	15.6	14.3	12.1	10.3
	280			16.8	16.0	13.8	12.0
	290				16.8	14.7	12.9
	320					16.8	15.5
	340						16.8
10	**110**	7.9	5.2	3.3	2.1	0.8	0.3
	150	12.2	9.5	7.6	6.0	3.4	2.1
	190	16.6	13.9	11.9	10.3	7.5	5.3
	230	20.9	18.2	16.3	14.6	11.9	9.6
	280	26.2	23.6	21.7	20.0	17.3	15.0
	310		26.2	24.9	23.3	20.5	18.3
	330			26.2	25.5	22.7	20.5
	340				26.2	23.8	21.5
	370					26.2	24.8
	390						26.2

The table continues on the next page.

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	13.4	10.1	7.8	5.8	3.1	1.8
	200	21.2	17.9	15.6	13.6	10.3	7.6
	260	29.0	25.7	23.4	21.4	18.1	15.4
	320	36.8	33.5	31.2	29.3	25.9	23.2
	330	37.7	34.8	32.5	30.6	27.2	24.5
	360		37.7	36.4	34.5	31.1	28.5
	370			37.7	35.8	32.4	29.8
	390				37.7	35.0	32.4
	420					37.7	36.3
	440						37.7
14	160	18.6	14.9	12.1	9.8	6.1	3.9
	220	27.8	24.0	21.2	19.0	15.1	11.9
	280	36.9	33.1	30.4	28.1	24.2	21.1
	340	46.0	42.2	39.5	37.2	33.3	30.2
	380	51.3	48.2	45.5	43.2	39.4	36.2
	410		51.3	50.1	47.8	43.9	40.8
	420			51.3	49.3	45.4	42.3
	440				51.3	48.5	45.3
	460					51.3	48.4
	480						51.3
16	180	24.8	20.4	17.3	14.7	10.3	7.0
	240	35.2	30.9	27.8	25.1	20.7	17.1
	300	45.6	41.3	38.2	35.5	31.1	27.5
	360	56.0	51.7	48.6	45.9	41.5	37.9
	430	67.0	63.8	60.7	58.1	53.7	50.1
	450		67.0	64.2	61.5	57.1	53.5
	470			67.0	65.0	60.6	57.0
	490				67.0	64.1	60.5
	510					67.0	63.9
	530						67.0
20	220	39.6	34.2	30.4	27.1	21.5	17.1
	280	52.7	47.2	43.4	40.1	34.5	30.1
	340	65.7	60.2	56.4	53.1	47.6	43.1
	400	78.7	73.2	69.4	66.1	60.6	56.1
	460	91.7	86.3	82.4	79.1	73.6	69.1
	530	104.7	101.4	97.6	94.3	88.7	84.3
	550		104.7	101.9	98.6	93.1	88.6
	570			104.7	102.9	97.4	92.9
	580				104.7	99.6	95.1
	610					104.7	101.6
	630						104.7

Calculations are carried out taking the minimal concrete cover. 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 <u>design load resistances</u> for a **Beam-Wall connection** using **C20/25 concrete** 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.
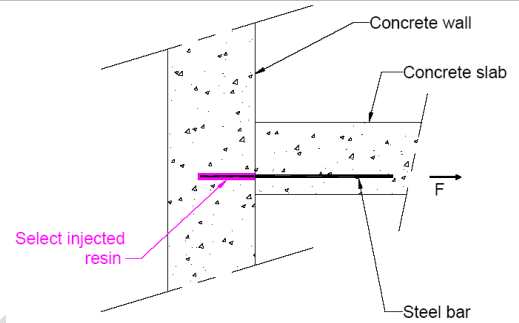
Concrete Cover = 30 mm		Fire Design Load Resistance $N_{Rd,fire}$ (kN)					
Diameter (mm)	**Length lv (mm)**	**R30**	**R60**	**R90**	**R120**	**R180**	**R240**
8	**100**	6.3	3.7	2.2	1.4	0.5	0.1
	140	9.7	7.2	5.6	4.3	2.4	1.3
	180	13.2	10.7	9.1	7.7	5.5	3.7
	220	16.7	14.1	12.5	11.2	8.9	7.0
	230	16.8	15.0	13.4	12.1	9.8	7.9
	260		16.8	16.0	14.7	12.4	10.5
	270			16.8	15.5	13.3	11.4
	290				16.8	15.0	13.1
	320					16.8	15.7
	340						16.8
10	**110**	8.9	5.8	3.7	2.4	1.0	0.4
	150	13.2	10.1	8.1	6.4	3.8	2.3
	190	17.6	14.4	12.4	10.7	7.9	5.6
	230	21.9	18.8	16.7	15.1	12.3	9.9
	270	26.2	23.1	21.1	19.4	16.6	14.2
	300		26.2	24.3	22.7	19.8	17.5
	320			26.2	24.8	22.0	19.6
	340				26.2	24.2	21.8
	360					26.2	24.0
	390						26.2

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
12	140	14.6	10.8	8.4	6.4	3.5	2.0
	200	22.4	18.6	16.2	14.2	10.8	8.0
	260	30.2	26.4	24.0	22.0	18.6	15.8
	320	37.7	34.2	31.8	29.8	26.4	23.6
	350		37.7	35.7	33.7	30.3	27.5
	370			37.7	36.3	32.9	30.1
	390				37.7	35.5	32.7
	410					37.7	35.3
	430						37.7
14	160	20.1	15.6	12.8	10.5	6.6	4.1
	220	29.2	24.7	21.9	19.6	15.6	12.3
	280	38.3	33.9	31.0	28.7	24.7	21.4
	340	47.4	43.0	40.1	37.8	33.9	30.5
	370	51.3	47.5	44.7	42.3	38.4	35.1
	400		51.3	49.2	46.9	43.0	39.6
	420			51.3	49.9	46.0	42.7
	430				51.3	47.5	44.2
	460					51.3	48.7
	480						51.3
16	180	26.4	21.3	18.1	15.4	10.9	7.4
	240	36.8	31.8	28.5	25.8	21.3	17.5
	300	47.2	42.2	38.9	36.3	31.8	27.9
	360	57.6	52.6	49.3	46.7	42.2	38.4
	420	67.0	63.0	59.7	57.1	52.6	48.8
	450		67.0	65.0	62.3	57.8	54.0
	470			67.0	65.7	61.2	57.4
	480				67.0	63.0	59.2
	510					67.0	64.4
	530						67.0
20	220	41.6	35.4	31.3	28.0	22.3	17.6
	280	54.7	48.4	44.3	41.0	35.4	30.6
	340	67.7	61.4	57.3	54.0	48.4	43.6
	400	80.7	74.4	70.4	67.0	61.4	56.6
	460	93.7	87.4	83.4	80.0	74.4	69.6
	520	104.7	100.4	96.4	93.0	87.4	82.6
	540		104.7	100.7	97.3	91.7	87.0
	560			104.7	101.7	96.1	91.3
	580				104.7	100.4	95.6
	600					104.7	100.0
	630						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	68.3	60.5	55.4	51.2	44.2	38.3
	340	84.6	76.7	71.7	67.5	60.5	54.5
	400	100.8	93.0	87.9	83.7	76.7	70.8
	460	117.1	109.2	104.2	100.0	93.0	87.0
	520	133.4	125.5	120.5	116.3	109.2	103.3
	580	149.6	141.7	136.7	132.5	125.5	119.5
	640	163.6	158.0	153.0	148.8	141.7	135.8
	670		163.6	161.1	156.9	149.9	143.9
	680			163.6	159.6	152.6	146.6
	700				163.6	158.0	152.1
	730					163.6	160.2
	750						163.6
28	310	85.6	76.8	71.2	66.5	58.6	51.9
	370	103.8	95.0	89.4	84.7	76.8	70.2
	430	122.0	113.2	107.6	102.9	95.0	88.4
	490	140.2	131.4	125.8	121.1	113.2	106.6
	550	158.5	149.6	144.0	139.3	131.4	124.8
	610	176.7	167.9	162.2	157.5	149.6	143.0
	670	194.9	186.1	180.4	175.7	167.9	161.2
	710	205.3	198.2	192.6	187.9	180.0	173.3
	740		205.3	201.7	197.0	189.1	182.4
	760			205.3	203.0	195.2	188.5
	770				205.3	198.2	191.5
	800					205.3	200.6
	820						205.3

Calculations are carried out taking the minimal concrete cover. 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 <u>design load resistances</u> for a **Beam-Wall connection** using **C20/25 concrete** 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 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.
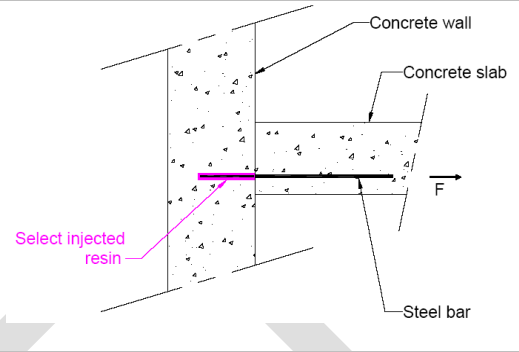
Concrete Cover = 40 mm		Fire Design Load Resistance $N_{Rd,fire}$ (kN)					
Diameter (mm)	Length lv (mm)	R30	R60	R90	R120	R180	R240
8	**100**	7.1	4.3	2.6	1.6	0.6	0.2
	140	10.6	7.8	6.0	4.6	2.6	1.5
	180	14.0	11.3	9.4	8.1	5.8	4.0
	220	16.8	14.7	12.9	11.5	9.2	7.4
	250		16.8	15.5	14.1	11.8	10.0
	270			16.8	15.9	13.6	11.7
	290				16.8	15.3	13.5
	310					16.8	15.2
	330						16.8
10	**110**	10.0	6.5	4.2	2.8	1.2	0.6
	150	14.3	10.8	8.5	6.8	4.1	2.6
	190	18.6	15.2	12.9	11.2	8.3	6.0
	230	23.0	19.5	17.2	15.5	12.6	10.3
	260	26.2	22.8	20.5	18.7	15.9	13.6
	300		26.2	24.8	23.1	20.2	17.9
	320			26.2	25.2	22.4	20.1
	330				26.2	23.5	21.1
	360					26.2	24.4
	380						26.2

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
12	140	15.9	11.7	9.0	6.9	3.9	2.3
	200	23.7	19.5	16.8	14.7	11.2	8.5
	260	31.5	27.3	24.6	22.5	19.0	16.3
	310	37.7	33.8	31.1	29.0	25.5	22.8
	320		35.1	32.4	30.3	26.8	24.1
	340		37.7	35.0	32.9	29.4	26.7
	370			37.7	36.8	33.3	30.6
	380				37.7	34.6	31.9
	410					37.7	35.8
	430						37.7
14	160	21.5	16.7	13.5	11.1	7.1	4.6
	220	30.6	25.8	22.6	20.2	16.1	12.9
	280	39.7	34.9	31.7	29.3	25.2	22.0
	340	48.9	44.0	40.8	38.4	34.4	31.1
	360	51.3	47.0	43.8	41.4	37.4	34.2
	390		51.3	48.4	46.0	41.9	38.7
	410			51.3	49.0	45.0	41.7
	430				51.3	48.0	44.8
	460					51.3	49.3
	480						51.3
16	180	28.1	22.6	18.9	16.1	11.5	8.0
	240	38.5	33.0	29.3	26.5	21.9	18.2
	300	48.9	43.4	39.7	36.9	32.3	28.6
	360	59.3	53.8	50.1	47.3	42.7	39.0
	410	67.0	62.4	58.8	56.0	51.4	47.7
	440		67.0	64.0	61.2	56.6	52.9
	460			67.0	64.7	60.1	56.4
	480				67.0	63.5	59.9
	510					67.0	65.1
	530						67.0
20	220	43.8	36.9	32.3	28.8	23.1	18.5
	300	61.1	54.2	49.6	46.1	40.4	35.8
	380	78.5	71.5	67.0	63.5	57.7	53.1
	460	95.8	88.9	84.3	80.8	75.1	70.5
	510	104.7	99.7	95.1	91.7	85.9	81.3
	540		104.7	101.6	98.2	92.4	87.8
	560			104.7	102.5	96.8	92.2
	580				104.7	101.1	96.5
	600					104.7	100.8
	620						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	71.0	62.3	56.6	52.3	45.1	39.3
	370	95.4	86.7	81.0	76.7	69.5	63.7
	460	119.8	111.1	105.4	101.0	93.9	88.1
	550	144.1	135.5	129.8	125.4	118.2	112.5
	630	163.6	157.2	151.4	147.1	139.9	134.2
	660		163.6	159.6	155.2	148.0	142.3
	680			163.6	160.6	153.5	147.7
	700				163.6	158.9	153.1
	720					163.6	158.5
	740						163.6
28	310	88.6	78.9	72.5	67.6	59.6	53.1
	370	106.8	97.1	90.7	85.8	77.8	71.4
	430	125.0	115.3	108.9	104.1	96.0	89.6
	490	143.2	133.5	127.1	122.3	114.2	107.8
	550	161.4	151.8	145.3	140.5	132.4	126.0
	610	179.6	170.0	163.5	158.7	150.6	144.2
	670	197.9	188.2	181.7	176.9	168.8	162.4
	700	205.3	197.3	190.9	186.0	178.0	171.5
	730		205.3	200.0	195.1	187.1	180.6
	750		205.3	201.2	193.1	186.7
	770				205.3	199.2	192.7
	790					205.3	198.8
	820						205.3
32	350	115.1	104.1	96.7	91.2	82.0	74.6
	410	135.9	124.9	117.5	112.0	102.8	95.4
	470	156.8	145.7	138.3	132.8	123.6	116.2
	530	177.6	166.5	159.2	153.6	144.4	137.0
	590	198.4	187.3	180.0	174.4	165.2	157.9
	650	219.2	208.1	200.8	195.2	186.0	178.7
	710	240.0	228.9	221.6	216.0	206.8	199.5
	800	268.1	260.1	252.8	247.2	238.1	230.7
	830		268.1	263.2	257.7	248.5	241.1
	850			268.1	264.6	255.4	248.0
	870				268.1	262.3	255.0
	890					268.1	261.9
	910						268.1

Calculations are carried out taking the minimal concrete cover. 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.