CSTB
le futur en construction

DIRECTION SECURITE, STRUCTURES et FEU

Division Mécanique et Résistance au Feu

REPORT No 26051287

Ripple R-fix

RIPPLE CONSTRUCTION PRODUCTS PVT LTD+

on

Ripple R-fix injection systems
in conjunction with concrete reinforcing bar (ϕ 8 to 32mm)
and subjected to fire exposure

REQUESTED BY:

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The laboratories of the SAFETY, STRUCTURES, and FIRE Department of the CSTB Experimentation Division are accredited by COFRAC's Test Section, French Accreditation Committee, for the following programmes, defined in Agreement 1-0301:
- no. 3 (tests on hydraulic concrete and its components)
- no. 39, part 2 (tests of mechanical fastening elements, tests of expansion anchors)

"As a signatory to the ILAC MRA, ICBO ES recognizes the technical equivalence of COFRAC accreditation of CSTB for the tests contained in this report."
Conference of Building Officials (ICBO):5360 Workman Mill Road Whittier, CA 90601 USA

It comprises 38 pages numbered from 1/38 to 38/38

CONTENT

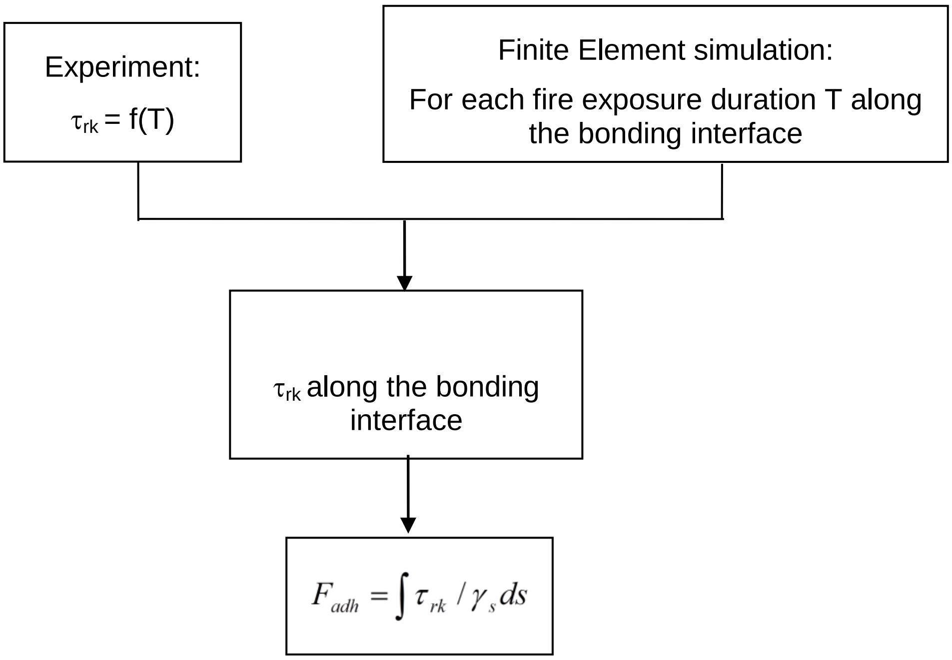
1 SCOPE

When subjected to fire exposure, construction elements performances are reduced by the effect of the temperature increase. At the RIPPLE CONSTRUCTION PRODUCTS PVT LTD+ company request, CSTB has performed a study aimed at the evaluation of the fire behaviour of injection resin system used in conjunction with concrete reinforcing rebar (grade b500; ϕ 8 to 32 mm).

The maximum loads applicable through a rebar in conjunction with Ripple R-fix as a function of both fire duration and anchorage length have been assessed for slab to slab connections, wall to slab connections, beam to beam connections and wall to beam connections.

The evaluation of these characteristics is based on a three steps procedure:

1. The first step is an experimental program aimed at the determination of the thermo-mechanical properties of the Ripple R-fix injection anchoring system, when exposed to fire.
2. The second step consists in the finite element modelling of the temperature profiles at the bonding interface of the four considered connection types.
3. The third step consists in the determination of the bonding stress along the bonding interface using steps 1 and 2. The maximum load applicable through a rebar anchored with Ripple R-fix mortar is then calculated by integrating this bonding stress over the interface area.



Where:

τ_{rk} is the characteristic bonding stress

T is the temperature

F_{adh} is the maximum load applicable to the rebar.

γ_S is the appropriate safety factor.

The present study 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 NORMATIVE REFERENCES

ISO 834-1 Fire resistance Tests - Element of building construction – Part1 general requirements

EN 1363-1 Fire resistance tests Part 1 General Requirements.

NF EN 1991-1-2 Eurocode1 Actions on structures – Part 1-2: General actions - Actions on structures exposed to fire, 2003

NF EN 1992-1-2 (+NA) Eurocode2 Design of concrete structures – Part 1-2: General rules – Structural fire design, 2005.

NF EN 1993-1-2 (+NA) Eurocode3 Design of steel structures – Part 1-2: General rules – Structural fire design, 2005.

3 THERMO-MECHANICAL PROPERTIES

3.1 Experimental program

The experimental program is aimed at the determination of the bonding stress as a function of the temperature for the Ripple R-fix injection system.

The tests are performed on small tensile-stressed specimens exposed to a monotonous rise in temperature of 10 degrees per minutes. The tables here after define the tests configurations which are performed in order to determine the behaviour of the Ripple R-fix under fire exposure. These tests were carried out from 15/11/2011 to 18/01/2012 in the fire resistance laboratory of the CSTB at the MARNE-LA-VALLEE Research Centre.

Diameter [mm]	Embedment depth [mm]	Applied load [kN]
8	80	5.0
		20.0
10	100	10.0
		25.0
12	120	3.0
		10.0
		20.0
		30.0
		50.0
		16.0
		35.0
		42.5
		55.5
		62.0
		69.0
		75.0
16	160	30.0
		50.0
20	200	50.0
		100.0

table 1 : Test program

3.2 Test description

The tests were carried out in an electric furnace. For each specimen, a hole with a nominal diameter, equal to the diameter of the rebar plus 4 mm, is drilled to a depth of 10 times the rebar diameter, in each concrete cylinder. Prior to setting the rebar, temperature sensors were fastened in such a way that the temperature of the rebar could be measured at a depth of about 10 mm below the surface of the concrete, and at the rebar lower end close to the bottom of the hole. A pure tensile load is applied to the rebar by means of hydraulic jack.

Figure 1: Monitoring device

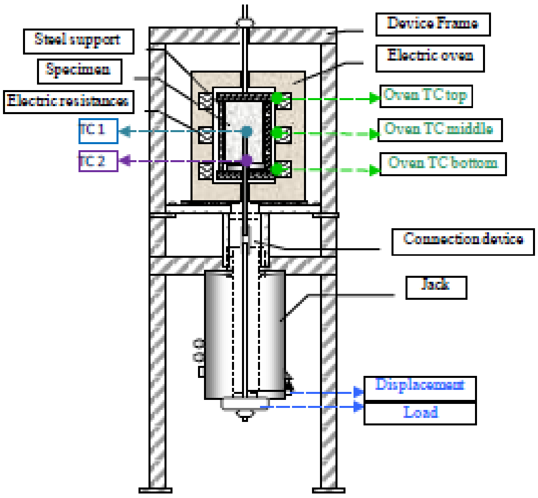


Figure 2: Loading device

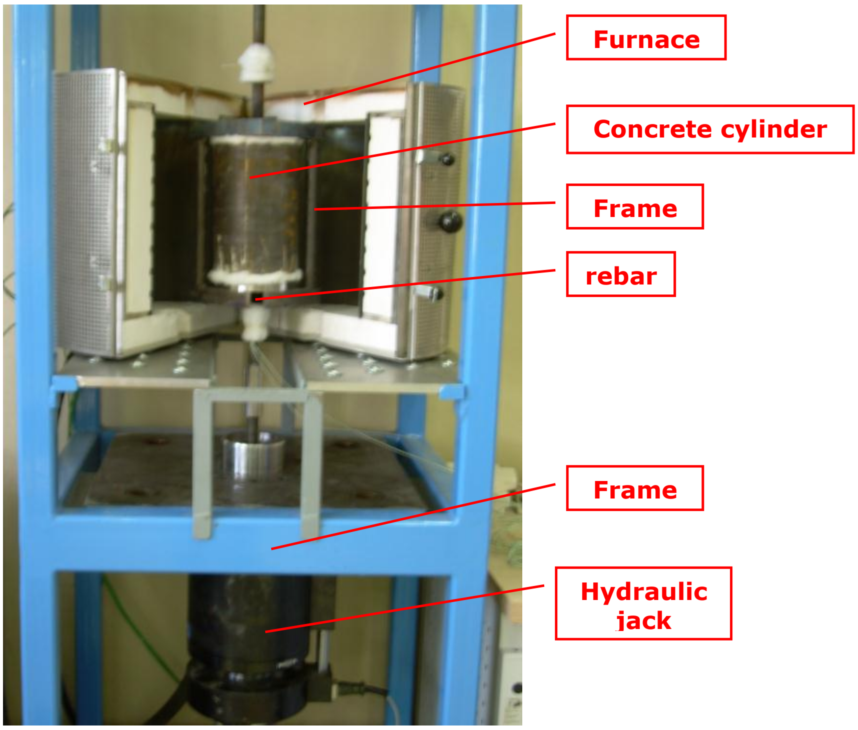
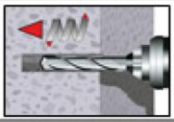
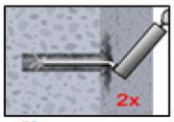
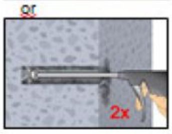
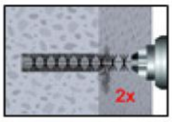
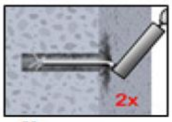
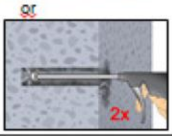
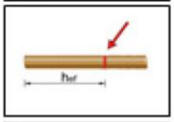
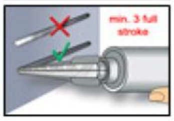


Figure 3: high temperature, regulated, furnace

3.3 Product presentation and test specimen

The Ripple R-fix is a 3:1 ratio injection type chemical anchor. Installation is by a dispenser from a side by side foil pack using a special mixing nozzle into a pre-drilled hole to the required installation dept. A steel bar with a diameter between 8mm and 32mm, grade b500 is then inserted into the resin.

The holes are drilled according to the specifications of the manufacturer. They are cleaned according to the written installation instructions of the manufacturer with the cleaning equipment specified by the manufacturer. The mortar and the rebar are installed according to the manufacturer's installation instruction with the equipment supplied by the manufacturer. Further details concerning the application can be found in the following figures.

	1. Drill with hammer drill a hole into the base material to the size and embedment depth required by the selected anchor (Table 2 or Table 3).
 or 	**Attention! Standing water in the bore hole must be removed before cleaning.** 2a. Starting from the bottom or back of the bore hole, blow the hole clean with compressed air or a hand pump (Annex 8) a minimum of two times. If the bore hole ground is not reached an extension shall be used. The hand-pump can be used for anchor sizes up to bore hole diameter 20 mm. For bore holes larger then 20 mm or deeper 240 mm, compressed air (min. 6 bar) **must** be used.
	2b. Check brush diameter acc. Table 5 and attach the brush to a drilling machine or a battery screwdriver. Brush the hole with an appropriate sized wire brush > $d_{0,nom}$ (Table 5) a minimum of two times. If the bore hole ground is not reached with the brush, a brush extension shall be used (Table 5).
 or 	2c. Finally blow the hole clean again with compressed air or a hand pump acc. Annex 8 a minimum of two times. If the bore hole ground is not reached an extension shall be used. The hand-pump can be used for anchor sizes up to bore hole diameter 20 mm. For bore holes larger then 20 mm or deeper 240 mm, compressed air (min. 6 bar) **must** be used. **After cleaning, the bore hole has to be protected against re-contamination in an appropriate way, until dispensing the mortar in the bore hole. If necessary, the cleaning has to be repeated directly before dispensing the mortar. In-flowing water must not contaminate the bore hole again.**
	3. Attach a supplied static-mixing nozzle to the cartridge and load the cartridge into the correct dispensing tool. For every working interruption longer than the recommended working time (Table 4) as well as for new cartridges, a new static-mixer shall be used.
	4. Prior to inserting the anchor rod into the filled bore hole, the position of the embedment depth shall be marked on the anchor rods.
	5. Prior to dispensing into the anchor hole, squeeze out separately a minimum of three full strokes and discard non-uniformly mixed adhesive components until the mortar shows a consistent grey or red colour.

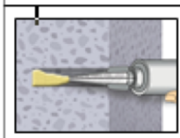
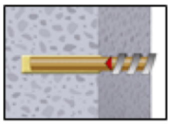
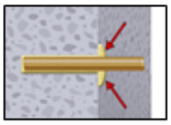
	6. Starting from the bottom or back of the cleaned anchor hole fill the hole up to approximately two-thirds with adhesive. Slowly withdraw the static mixing nozzle as the hole fills to avoid creating air pockets. For embedment larger than 190 mm an extension nozzle shall be used. For overhead and horizontal installation in bore holes larger than ⌀ 20 mm a piston plug and extension nozzle (Annex 8) shall be used. Observe the gel-/ working times given in Table 4.
	7. Push the threaded rod or reinforcing bar into the anchor hole while turning slightly to ensure positive distribution of the adhesive until the embedment depth is reached. The anchor should be free of dirt, grease, oil or other foreign material.
	8. Be sure that the anchor is fully seated at the bottom of the hole and that excess mortar is visible at the top of the hole. If these requirements are not maintained, the application has to be renewed. For overhead installation fix embedded part (e.g. wedges).
	9. Allow the adhesive to cure to the specified time prior to applying any load or torque. Do not move or load the anchor until it is fully cured (attend Table 4).
	10. After full curing, the add-on part can be installed with the max. torque (Table 2) by using a calibrated torque wrench.

table 2 : Installation instruction and cleaning method

Figure 4**:** Cleaning method

Threaded rod	Rebar	d_0 Drill bit - Ø	d_b Brush - Ø	$d_{b,min}$ min. Brush - Ø
(mm)	(mm)	(mm)	(mm)	(mm)
M8		10	12	10,5
M10	8	12	14	12,5
M12	10	14	16	14,5
	12	16	18	16,5
M16	14	18	20	18,5
	16	20	22	20,5
M20	20	24	26	24,5
M24		28	30	28,5
M27	25	32	34	32,5
M30	28	35	37	35,5
	32	40	41,5	40,5

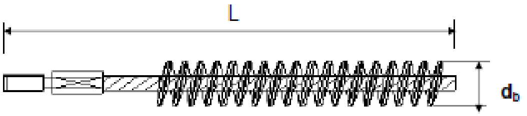


Figure 5: Brushes for cleaning the drilled holes.

Figure 6: Applicator guns

The bars are embedded in steel-encased concrete cylinders of diameter 150mm.

A total of 20 rebar of diameters ranging from 8 to 20 were set in the steel-encased concrete cylinders using Ripple R-fix injection adhesive mortar. Afterwards, they were tested under pure tensile loading and exposed under fire in order to determine the thermo-mechanical properties as well as the pull-out behaviour and to develop a passive fire prevention design concept for the use of rebar connection.

The drawing below gives details of the setting of the rebar in the concrete cylinders.

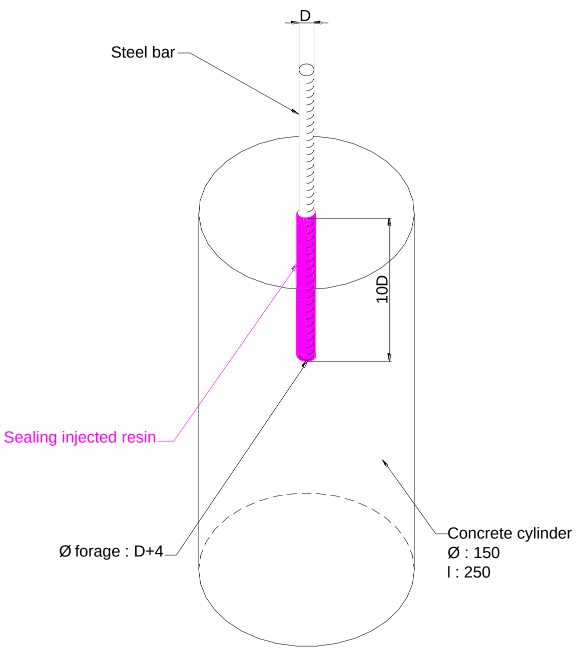


Figure 7: Steel-encased concrete cylinders

The characteristics of the concrete constituents as well as the way of making it, comply with the requirements of the ETAG 001.

Test results

The failure temperature values, for each rebar diameter and applied load considered are given in the table below.

Diameter [mm]	Embedment depth [mm]	Applied load [kN]	Failure temperature [°C]
8	80	5.0	100
		20.0	64
10	100	10.0	97
		25.0	93
12	120	3.0	278
		10.0	125
		16.0	96
		20.0	85
		30.0	79
		35.1	71
		42.5	71
		50.0	58
		55.4	62
		62.0	60
		69.0	51
		75.1	52
16	160	30.0	91
		50.0	39
20	200	49.8	77
		99.5	63

table 3: Test results

Figure 8: Bond failure after fire exposure

From these data we obtain by reference to the 5% percentile at 90% degree of confidence the relation between the temperature and the critical bond stress:

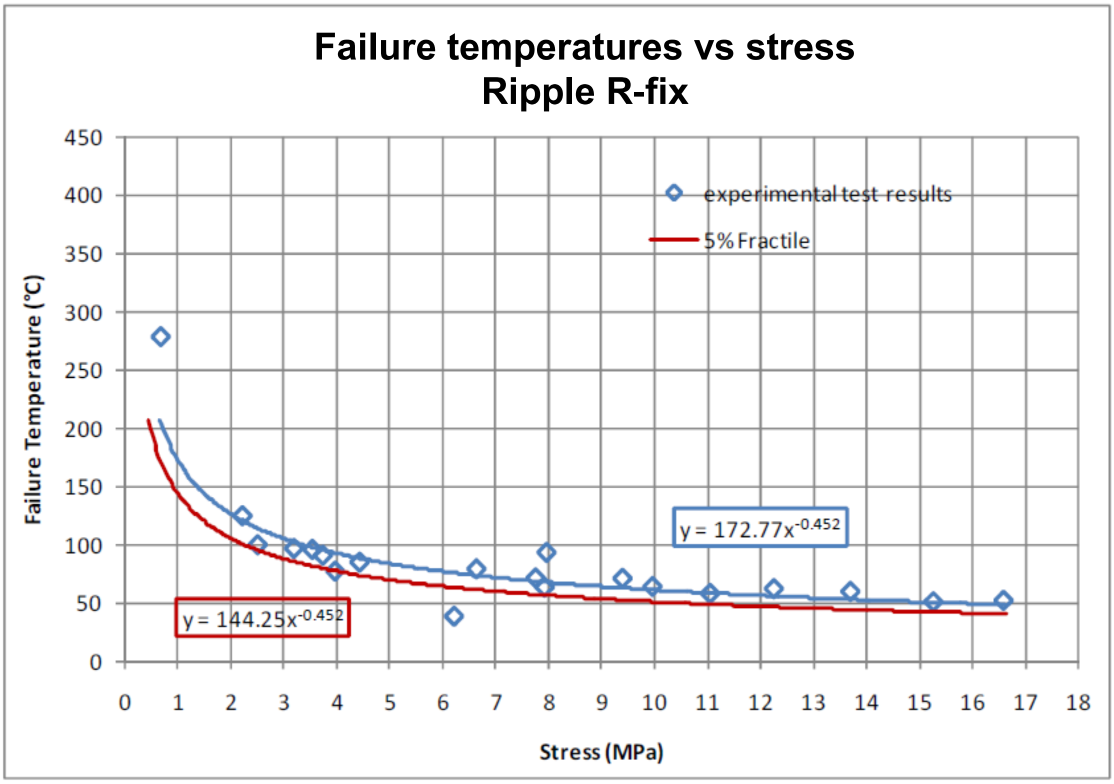


Figure 9: Ripple R-fix Characteristic bonding stress – temperature relationship (red points are experimental results, black curve is the corresponding characteristic law).

4 BONDING INTERFACE TEMPERATURE PROFILES

The knowledge of the fire behaviour of traditional concrete structures allows to assess the temperature distribution, for every duration of the fire exposure by modelling the thermal exchanges inside concrete elements. The temperature profile depends on the connection configuration: slab to slab connections or wall to slab connections or beam to beam connections or wall to beam connections. These temperatures are calculated using the finite elements method.

4.1 Modelling assumptions

Thermal actions modelling:

At the origin (t=0) every element temperature is supposed to be 20°C.

The fire is modelled by a heat flux on the exposed faces of the structure. This heat flux is a function of the gas temperature T_g which evolution is given by the conventional temperature / time relationship (ISO 834-1) :

- $T_g = T_0 + 345 Log_{10}(8t + 1)$

Where:

T_0 is the initial temperature (°C)

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: $\varphi_c = h(T_g - T_s)$ (W/m²),
- radiation flux density: $\varphi_r = \varepsilon\sigma(T_g^4 - T_s^4)$ (W/m²).

Where:

σ is the Stefan-Boltzmann parameter

T_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 are given by Eurocode1 part 1.2 and Eurocode2 part 1.2 (NA) (see table 4.)

	h(W/m²K)	ε
Fire exposed side	25	*0.7*
side opposite to fire	*4*	*0.7*

table 4 : values for the exchange coefficients.

Materials thermal properties:

In this study, only concrete is considered in thermal calculation (EC2 part 1.2 art.4.3.2). The concrete thermal properties are provided by Eurocode2 part 1.2 + NA. This document considers three different kinds of concrete depending on the type of aggregates (silicate, calcareous, light). Considering that light aggregate concrete was less common than the two others the corresponding set of coefficients was rejected. Preliminary investigations lead to the choice of the silicate aggregate concrete set of coefficients as it gives conservative results.

4.2 Slab to slab connection (lapped splice / joint)

For a slab to slab connection (see Figure 10) the temperature along the bonding interface is safely supposed uniform and equal to the temperature in a slab at a depth equivalent to the concrete cover. Therefore, the temperature profiles are calculated by finite element simulation of a slab heated on one side.

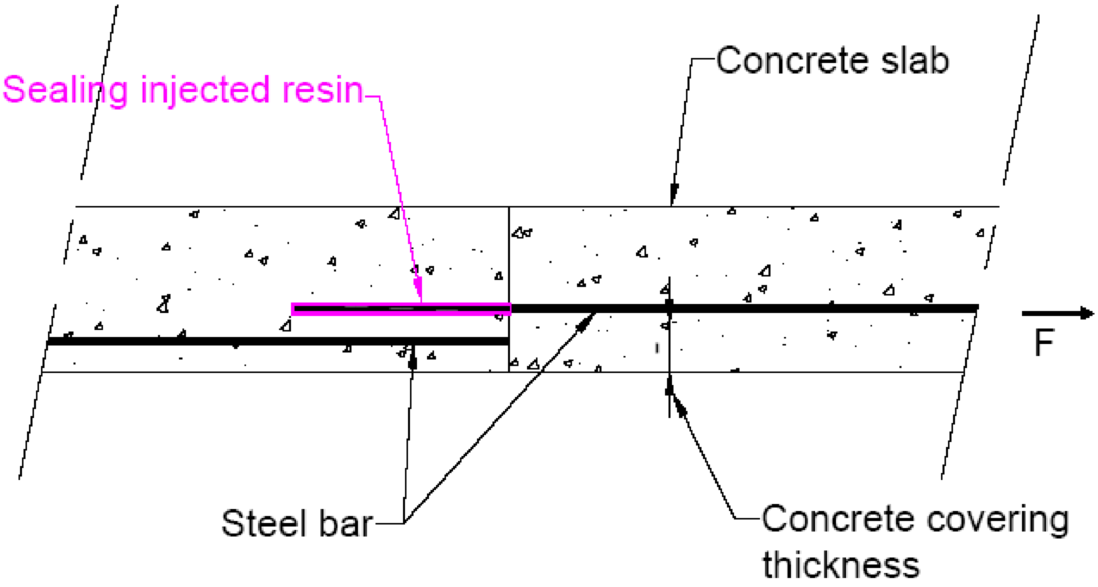


Figure 10: Slab to slab connection

The temperatures versus the concrete cover are plotted on Figure 11 for fire durations ranging from 30 minutes to four hours.

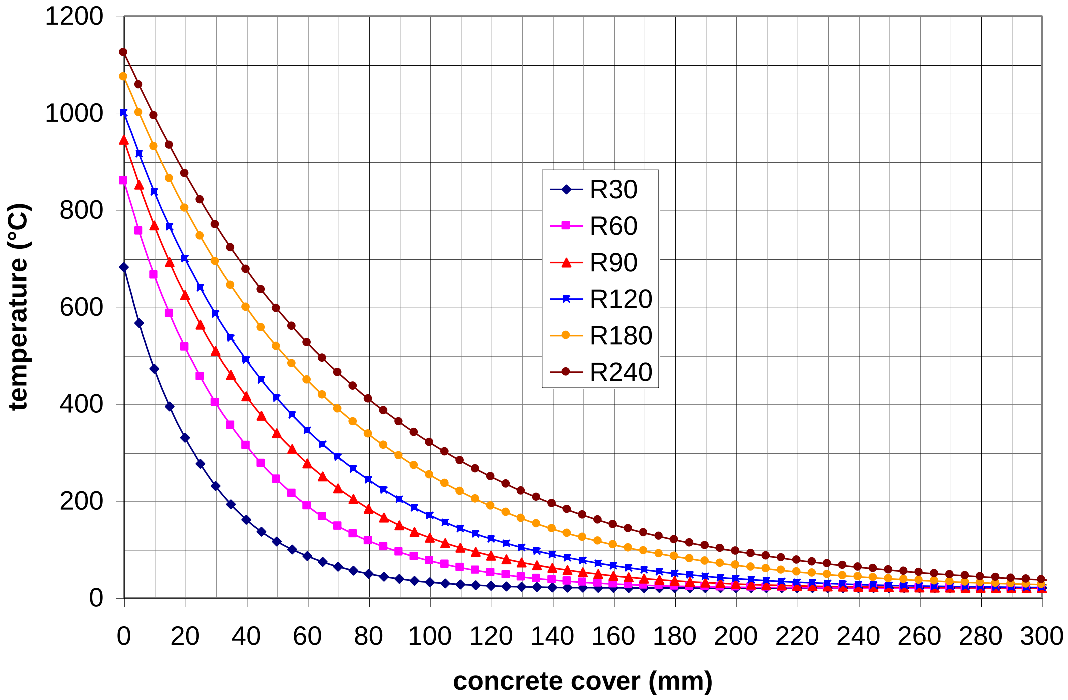


Figure 11: Temperature at the bonding interface as a function of concrete cover.

4.3 Wall to slab connection (anchoring)

For a wall to slab connection (see Figure 12) the temperature along the bonding interface is not uniform and depends on the fire duration and the anchoring length. Therefore, the temperature profiles are obtained by finite element modelling for each fire duration and each anchor length considered.

Model description

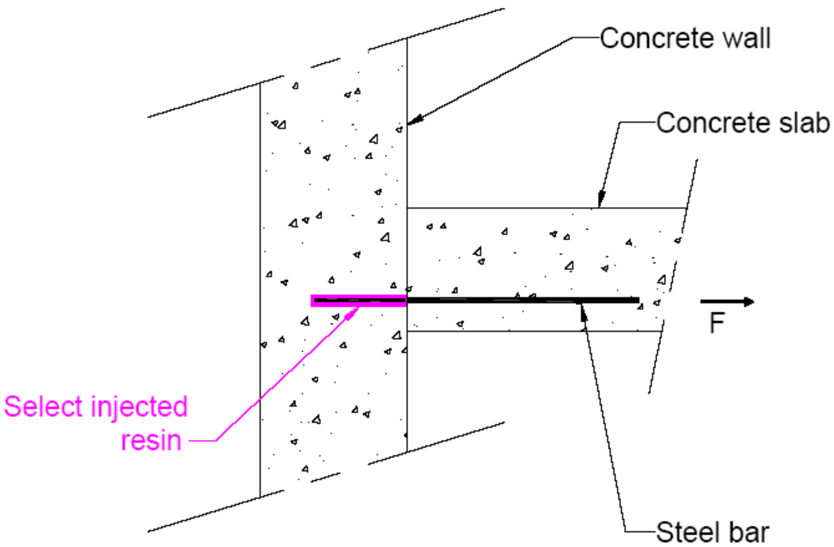


Figure 12: Wall to slab connection

The modelled fire is the standard temperature / time curve with duration of 30, 60, 90, 120, 180 and 240 minutes. The considered anchor lengths range from 10 times the rebar diameter to the length that enables a load equal to the rebar yielding load.

The simulations are made taking into account the minimal concrete cover for each rebar diameter and fire exposure duration as given in the Eurocode 3 part 1.2 + NA (table 5). The anchoring length varied from 10 times the rebar diameter to the length allowing a force equal to the maximum load in a rebar not submitted to a fire.

		Fire duration (min)											
ϕ (mm)	D (mm)	30		60		90		120		180		240	
		C-C (mm)	S-T (mm)	C-C (mm)	S-T (mm)	C-C (mm)	S-T (mm)	C-C (mm)	S-T (mm)	C-C (mm)	S-T (mm)	C-C (mm)	S-T (mm)
8	12	10	60	20	70	25	90	35	110	50	150	70	175
10	14	10	60	20	70	25	90	35	110	50	150	70	175
12	16	12	60	20	70	25	90	35	110	50	150	70	175
14	18	14	60	20	70	25	90	35	110	50	150	70	175
16	20	16	60	20	70	25	90	35	110	50	150	70	175
20	25	20	60	20	70	25	90	35	110	50	150	70	175
25	30	25	75	25	75	25	90	35	110	50	150	70	175
28	35	28	84	28	84	28	90	35	110	50	150	70	175
32	40	32	96	32	96	32	96	35	110	50	150	70	175

Where :

- D is the drill hole diameter
- C-C is the concrete cover
- S-T slab thickness

table 5 : Summary of the modelled configurations each rebar diameter (ϕ) and fire duration.

Three dimensional meshes were used. Due to symmetry considerations only half of the structure is meshed (see figure 14).

Considering that the wall located above the slab will stay at a temperature of 20°C, it has not been meshed. Therefore the modelled structure presents an L shape instead of a T shape as presented on Figure 12.

The boundary conditions are:

- On the heated sides, heat flux density, as a function of the gas temperature equal to the conventional temperature / time relationship.
- On the unexposed sides, heat flux density with a constant gas temperature of 20°C.

- No heat exchange condition on the other sides.

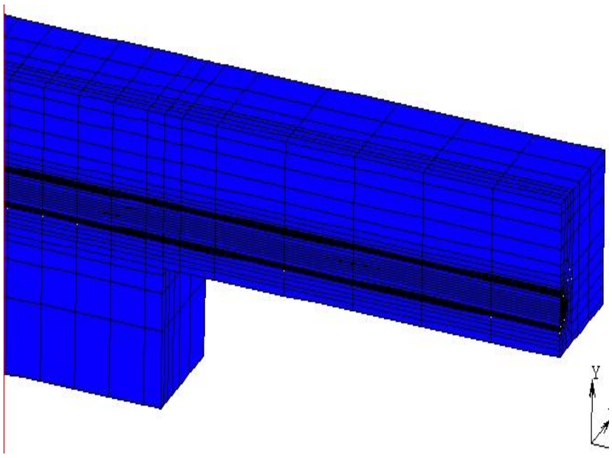


Figure 13: Mesh used for the wall to slab connection temperature model.

4.4 Beam to beam connection (lapped splice / joint)

For a beam to beam connection (see figure 15) the temperature along the bonding interface is safely supposed uniform and equal to the temperature in a beam at a depth equivalent to the concrete cover. Therefore, the temperature profiles are calculated by finite element simulation of a beam heated on three sides.

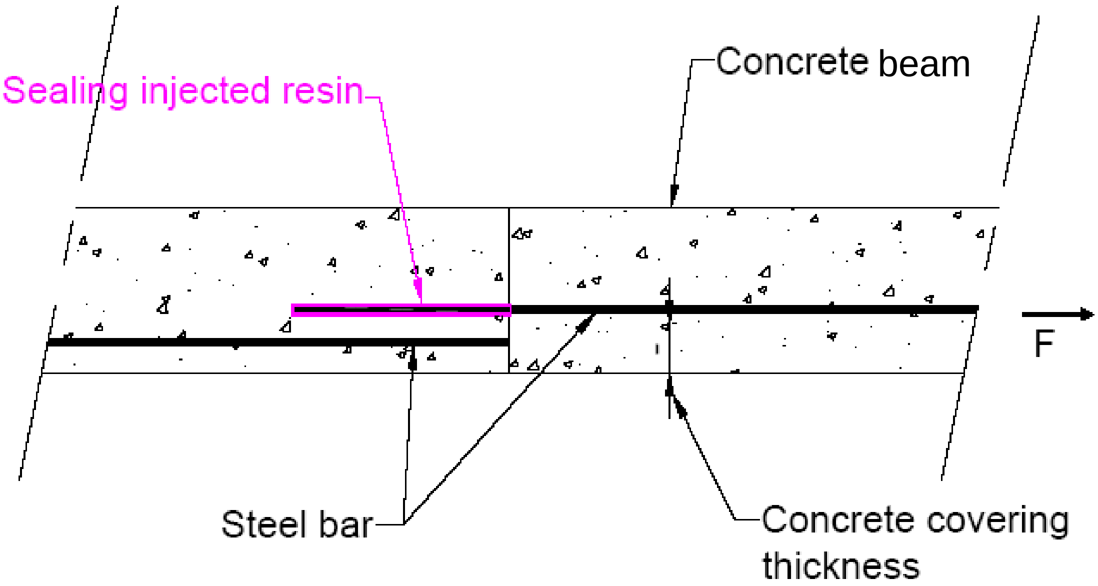


Figure 14: beam to beam connection

Four beams' widths were studied: 20 cm, 30 cm, 40 cm and 100 cm. Because same results were observed on the 40 cm and 100 cm beams' widths, the results are only presented for the 20 cm, 30 cm, "40 cm and more" beams' widths.

With regard to Eurocode 2 part 1.2, fire resistances are limited in accordance with beams' widths. For the 40 cm and more beams' widths, a 240 minutes fire resistance can be obtained. On the other hand, fire resistance is limited to 120 minutes for 30 cm beams' widths and to 90 minutes for 20 cm beams' widths.

Two dimensional meshes were used. Due to symmetry considerations, only half of the section is meshed (see figure 16).

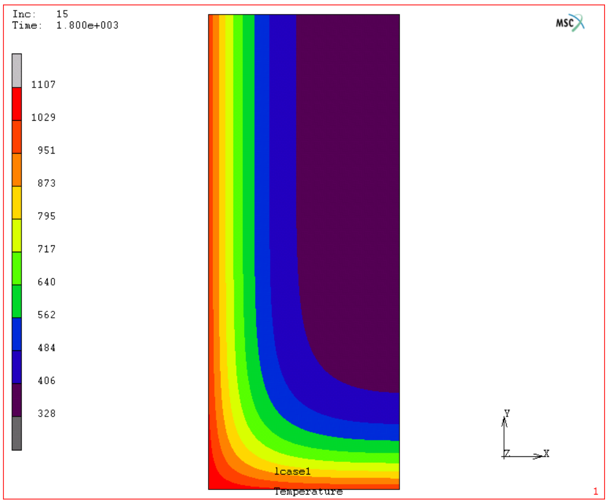


Figure 15: An example of temperature profile (T °Kelvin) – fire duration = 30 minutes – beam's width = 20 cm

Contour lines of temperature obtained by simulation are presented here after. The range of temperatures was defined in accordance with a reasonable maximum anchorage depth (see 5.4). On the following figures, a grid of a 10 mm x-spacing and 20 mm y-spacing is superimposed in order to locate easily the contour lines on the beams' sections. The contour lines correspond to 40, 60, 80, 100 and 120°C.

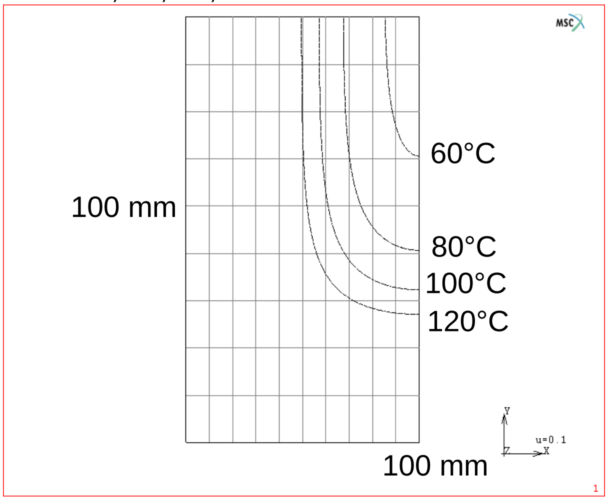


Figure 16: Temperature contour lines for beam's width = 20 cm and fire duration = 30 min

There is no significant area in which the temperature keeps below 120°C after 30 minutes in a 20 cm beam's width.

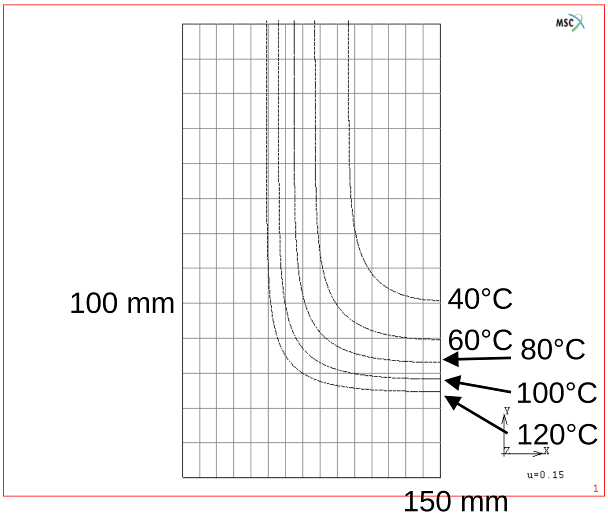


Figure 17: Temperature contour lines for beam's width = 30 cm and fire duration = 30 min

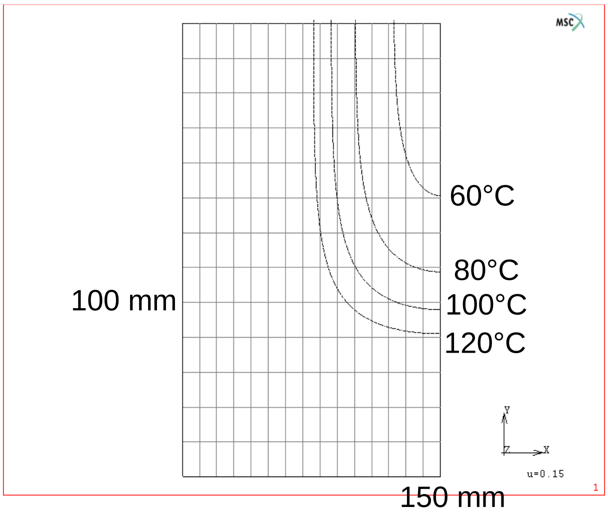


Figure 18: Temperature contour lines for beam's width = 30 cm and fire duration = 60 min

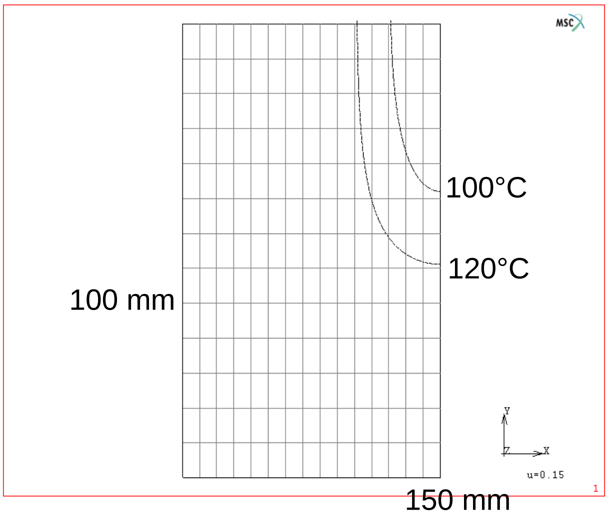


Figure 19: Temperature contour lines for beam's width = 30 cm and fire duration = 90 min

There is no significant area in which the temperature keeps below 120°C after 90 minutes in a 30 cm beam's width.

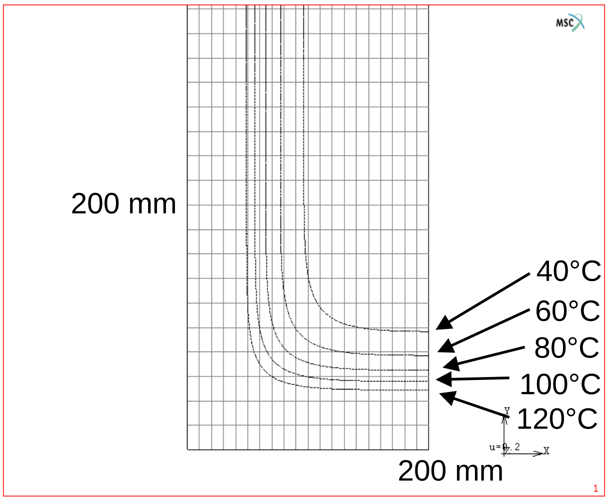


Figure 20: Temperature contour lines for beam's width = 40 cm and fire duration = 30 min

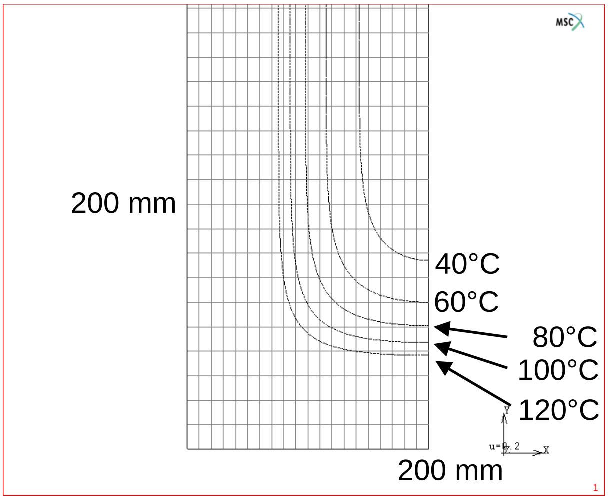


Figure 21: Temperature contour lines for beam's width = 40 cm and fire duration = 60 min

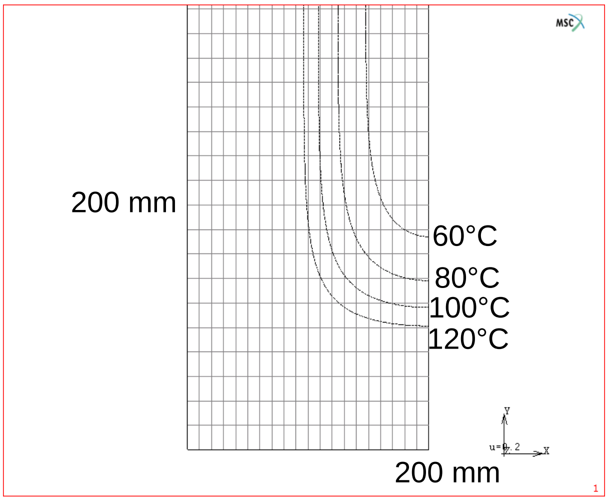


Figure 22: Temperature contour lines for beam’s width = 40 cm and fire duration = 90 min

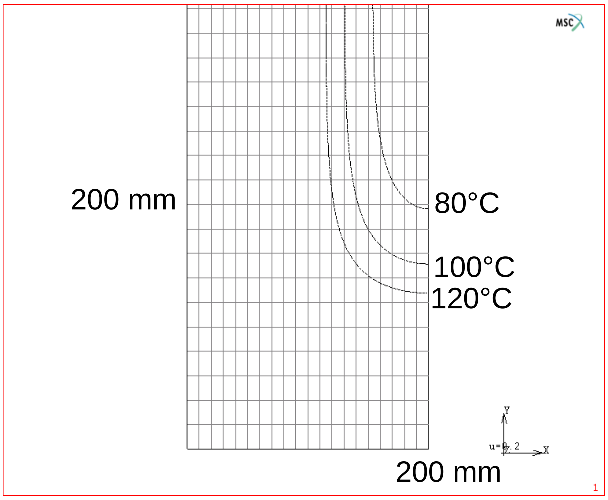


Figure 23: Temperature contour lines for beam’s width = 40 cm and fire duration = 120 minutes

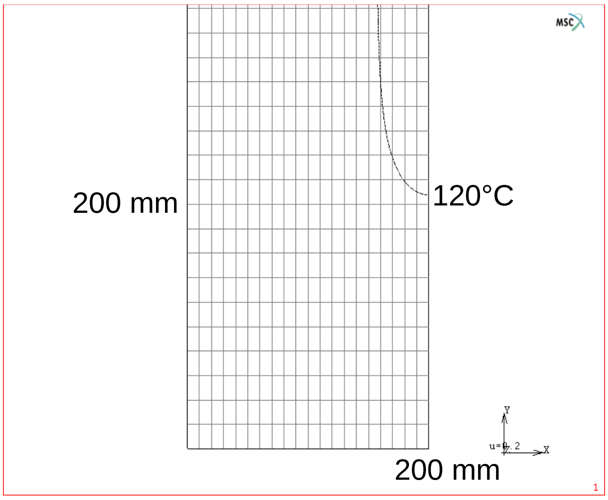


Figure 24: Temperature contour lines for beam’s width = 40 cm and fire duration = 180 minutes

There is no significant area in which the temperature keeps below 120°C after 180 minutes in a 40 cm or more beam’s width.

4.5 Wall to beam connection (anchoring)

For a wall to beam connection (see figure 26) the temperature along the bonding interface is not uniform and depends on the fire duration and the anchoring length. Therefore, the temperature profiles are obtained by finite element modelling for each fire duration and each anchor length considered.

Rebar diameters and fire durations are the same as before.

Model description

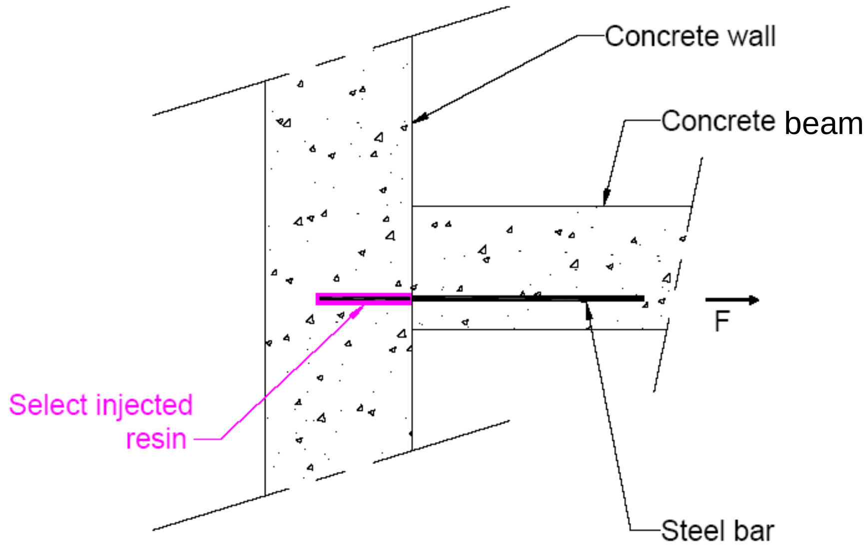


Figure 25: Wall to beam connection

The modelled fire is the standard temperature / time curve with duration of 30, 60, 90, 120, 180 and 240 minutes. The considered anchor lengths range from 10 times the rebar diameter to the length that enables a load equal to the rebar yielding load.

The simulations are made taking into account the same limitation of fire resistances as before (90 minutes for 20 cm beams' widths and 120 minutes for 30 cm beams' widths).

Moreover, with regard to Eurocode 2, three layers of reinforcement are taken into account in each beam. Concrete covers and minimal distance between layers are presented on the following figure.

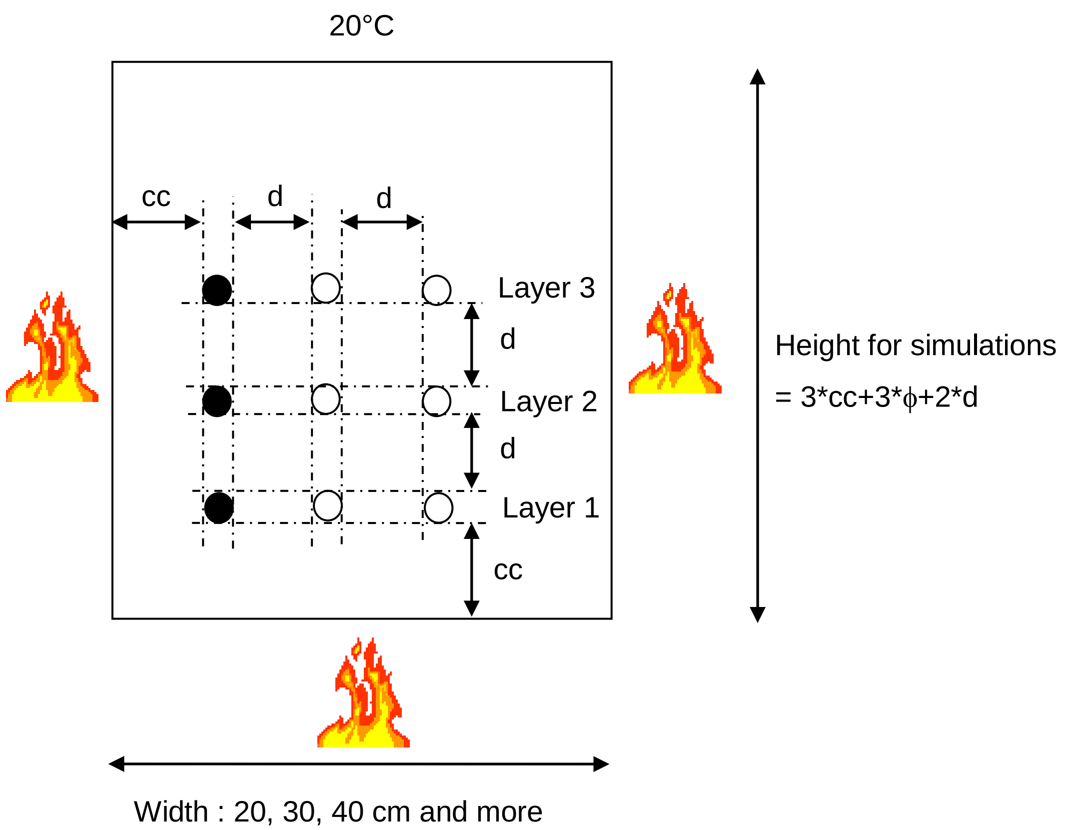


Figure 26: reinforcement frame

Concrete covers cc are defined to assure that the temperature in the more exposed rebar keeps lesser than 400°C for the fire duration required and for the beam's width. Under this temperature, steel mechanical properties keep constant. The following values are then obtained:

	Beam's width		
Fire resistance	20 cm	30 cm	40 cm and more
R30	30 mm	30 mm	28 mm
R60	55 mm	55 mm	52 mm
R90	80 mm	80 mm	70 mm
R120	Impossible	85 mm	85 mm
R180	Impossible	Impossible	110 mm
R240	Impossible	Impossible	136 mm

table 6 : concrete cover versus fire resistance duration and beam's width.

Moreover, the distance between layers is defined as:

$$d = \max(3 \times drill\ hole\ diameter\ ; 60\ mm)$$

The following values are then obtained:

Rebar diameter (mm)	8	10	12	14	16	20	22	24	25	32
Distance between layers (mm)	60	60	60	60	60	75	81	87	90	120

table 7 : distance between layers versus rebar diameter.

Three dimensional meshes were used. Due to symmetry considerations, only half of the structure is meshed (see figures 28 and 29). To impose natural boundary conditions, the real shape of elements is modelled. By this way, there is no discontinuity of gas temperatures that could perturb the temperature calculation in concrete.

The boundary conditions are:

- On the heated sides, heat flux density, as a function of the gas temperature equal to the conventional temperature time relationship.
- On the unexposed sides, heat flux density with a constant gas temperature of 20°C.
- No heat exchange condition on the other sides.

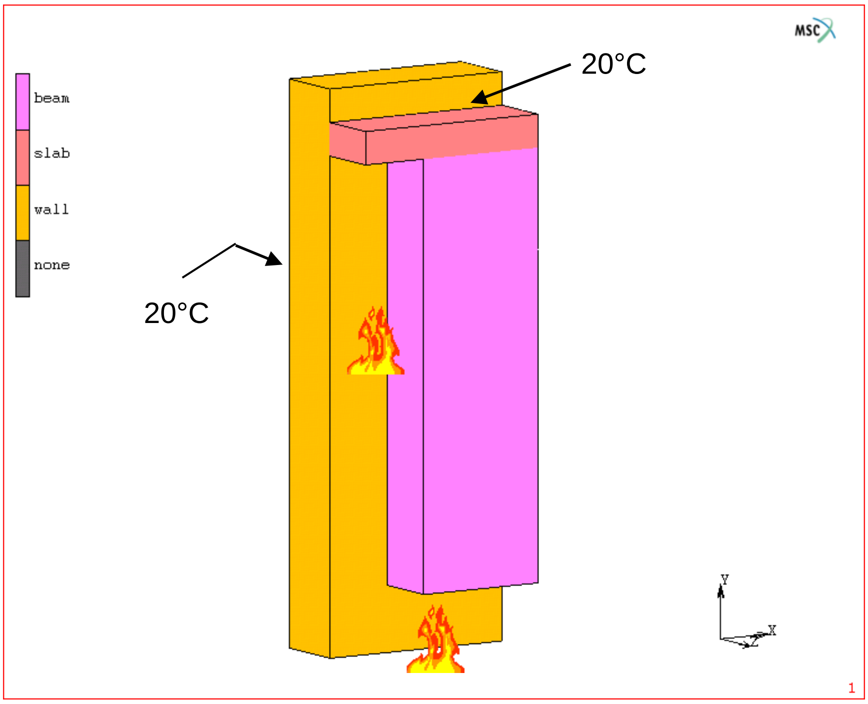


Figure 27: Mesh used for the wall to beam connection temperature model.

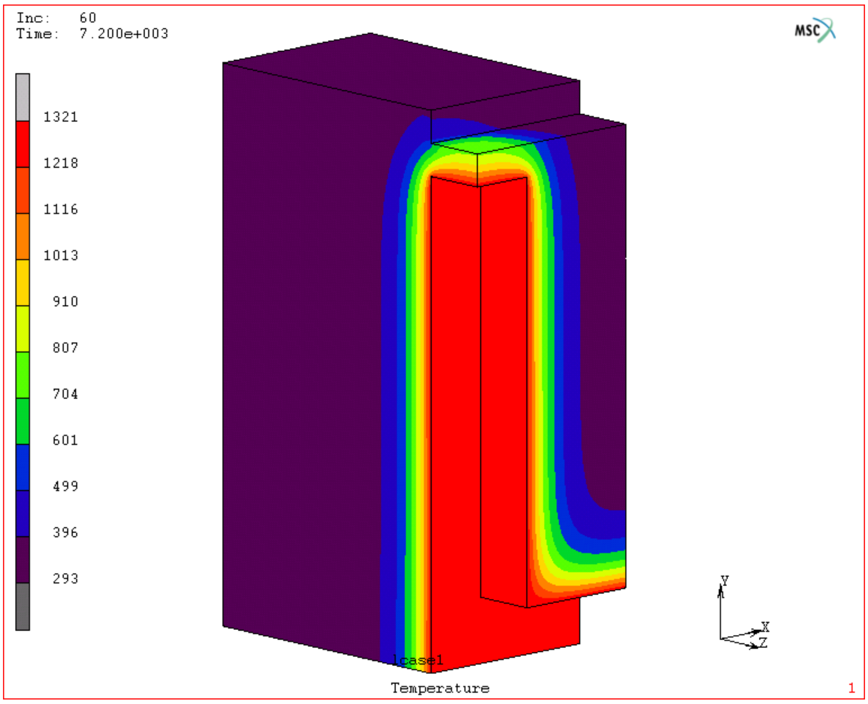


Figure 28: An example of temperature profile (T °Kelvin) – fire duration = 2 hours – beam's width = 40 cm.

5 MAXIMUM LOADS

Once the temperature along the bonding interface is known, the maximum force in the rebar (resin adhesion strength) is obtained by calculating the bonding stress using its experimental temperature dependence and integrating it over the interface area and applying the appropriate safety factor.

The results given in the following paragraphs are intended for a concrete of class C20/25 and a Fe 500 steel.

5.1 Safety factors

The global safety factor (γ_s) is the product of partial safety factors:

- γ_c partial safety factor on concrete compressive strength (1,3)
- γ_t partial safety factor on concrete tensile strength variability (1,0)
- γ_f partial safety factor on field realisation variability (1,2)

The global safety factor is γ_s = 1,6.

5.2 Slab to slab connection

The experimental temperature - bonding stress relationship is given by:

$$\tau = \left(\frac{\theta}{144{,}25} \right)^{-2{,}21} \qquad (1)$$

Where:

- θ is the temperature in °C
- τ is the bonding stress in MPa

The maximum bonding stresses for a given fire exposure duration and concrete cover are calculated by introducing the temperatures shown in Figure 11 in equation (1). The results are summarized in table 8.

Ripple R-fix	Bonding stress (MPa)					
Concrete cover (mm)	**R 30**	**R 60**	**R 90**	**R 120**	**R 180**	**R 240**
10						
20						
30	0.4					
40	0.8					
50	1.6	0.3				
60	3.2	0.5				
70	6.0	0.9	0.4			
80	10.8	1.6	0.6	0.3		
90	14.0	2.6	0.9	0.5		
100	16.5	4.1	1.3	0.7	0.3	
110	17.9	6.5	2.0	1.0	0.4	
120	19.0	9.5	3.0	1.4	0.6	0.3
130	19.7	12.5	4.4	2.1	0.8	0.4
140	20.0	14.7	6.2	2.9	1.0	0.5
150	20.4	16.1	8.4	4.1	1.4	0.7
160	20.7	17.5	11.1	5.6	1.9	0.9
170	20.7	18.2	13.3	7.5	2.5	1.2
180	20.7	19.0	14.7	10.0	3.3	1.5
190		19.7	16.1	12.2	4.2	1.9
200		20.0	17.2	13.6	5.4	2.5
210		20.0	17.9	15.0	6.9	3.1
220		20.4	18.6	16.1	8.8	4.0
230		20.7	19.0	17.2	10.8	4.9
240		20.7	19.7	17.9	12.5	6.2
250		20.7	19.7	18.6	13.6	7.8
260		20.7	20.0	19.0	15.0	9.5
270			20.4	19.7	15.7	11.1
280			20.4	19.7	16.8	12.5
290			20.7	20.0	17.5	13.6
300			20.7	20.4	17.9	14.7
310			20.7	20.4	18.6	15.7
320			20.7	20.7	19.0	16.5
330	21.1		20.7	20.7	19.3	17.2
340				21.1	19.7	17.5
350				21.1	20.0	18.2
360					20.0	18.6
370		21.1			20.4	19.0
380					20.4	19.3
390					20.7	19.7
400			21.1		20.7	20.0
410				21.1	20.7	20.4
420						20.4
430						20.7
440					21.1	20.7
450						20.7
460						21.1
470						

table 8 : Maximum bonding stresses for a slab to slab connection.

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.

5.3 Wall to slab connection

The maximum force in the rebar (resin adhesion strength) is given by:

$$F_{adh} = \int_{0}^{Ls} \frac{1}{\gamma_s} \pi * \phi * \tau_{rk}(x) dx$$

Where:

- F_{adh} is the maximum force in the rebar
- ϕ is the rebar diameter
- $\tau_{rk}(x)$ the characteristic bonding stress at a depth of x.

$\tau_{rk}(x)$ is calculated using the temperature profiles obtained by finite element simulation and the experimental bonding stress temperature dependence.

An example of the maximum evolution with respect of the anchor length is given on figure 30. The complete results are given in table 9 to table 13.

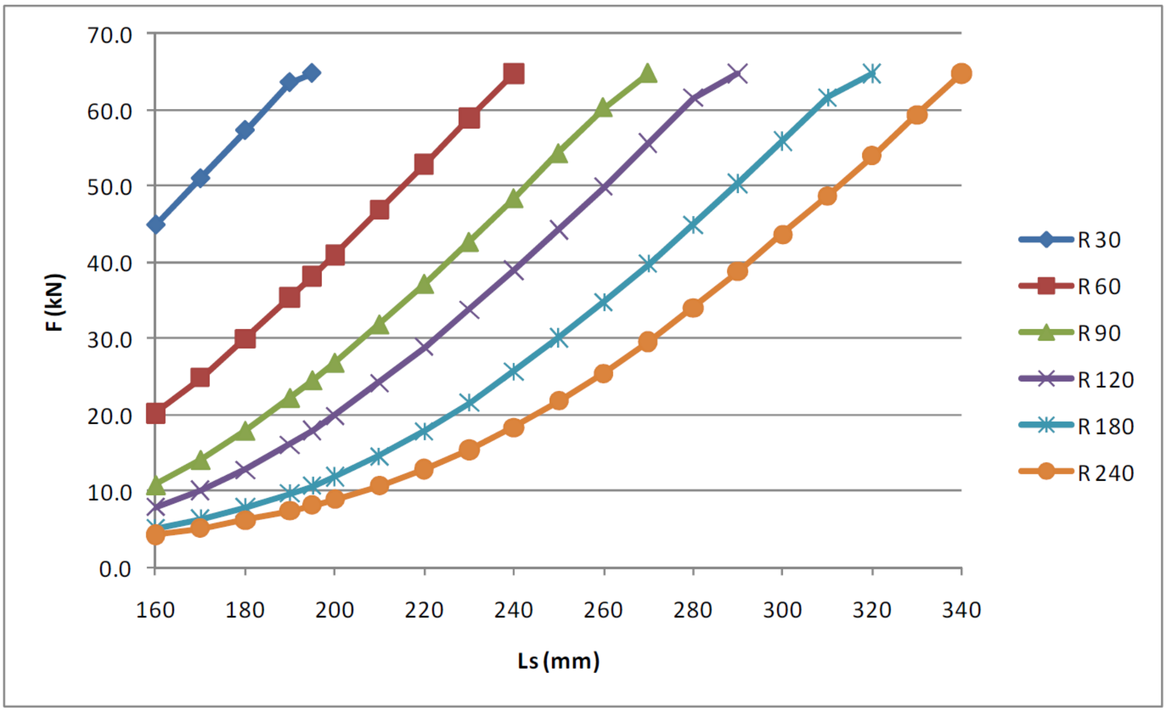


Figure 29: Maximum force of rebar (ϕ=16mm) in conjunction with Ripple R-fix.

Ripple R-fix									
Rebar diameter	Drill hole diameter	Rebar maximum load	Rebar anchorage depth	Maximum force in the rebar (kN)					
ϕ (mm)	D (mm)	F (kN)	Ls (mm)	R 30	R 60	R 90	R 120	R 180	R 240
8	12	16.2	80	3.4	1.1	0.6	0.4	0.3	0.3
			95	6.4	2.0	1.0	0.7	0.6	0.5
			110	10.2	3.5	1.7	1.2	0.8	0.8
			125	14.5	6.0	2.8	1.9	1.3	1.1
			135	16.2	8.1	3.9	2.6	1.6	1.3
			140		9.3	4.6	3.0	1.8	1.5
			155		13.2	7.2	4.7	2.7	2.0
			170		16.2	10.5	7.1	3.9	2.7
			185			14.3	10.1	5.5	3.7
			195			16.2	12.4	7.0	4.5
			200				13.6	7.8	5.0
			210				16.2	9.6	6.0
			215					10.7	6.6
			230					14.0	8.8
			240					16.2	10.5
			245						11.5
			260						14.6
			270						16.2
10	14	25.3	100	8.5	2.7	1.4	1.1	0.8	0.7
			115	13.2	4.6	2.3	1.7	1.2	1.0
			130	18.5	7.8	3.7	2.6	1.7	1.4
			145	24.1	11.8	6.0	4.0	2.4	2.0
			150	25.3	13.4	7.0	4.6	2.8	2.2
			160		16.6	9.2	6.2	3.5	2.7
			175		21.8	13.3	9.2	5.0	3.7
			185		25.3	16.4	11.6	6.3	4.5
			190			18.0	13.0	7.1	4.9
			205			23.1	17.3	9.8	6.6
			215			25.3	20.6	12.1	8.1
			220				22.2	13.3	8.9
			230				25.3	16.0	10.7
			235					17.4	11.8
			250					21.9	15.4
			265					25.3	19.4
			280						23.8
			285						25.3

table 9 : Maximum load applicable to a rebar bonded with Ripple R-fix mortar in case of fire. 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.

Ripple R-fix									
Rebar diameter	Drill hole diameter	Rebar maximum load	Rebar anchorage depth	Maximum force in the rebar (kN)					
ϕ (mm)	D (mm)	F (kN)	Ls (mm)	R 30	R 60	R 90	R 120	R 180	R 240
12	16	36.4	120	16.8	5.8	3.0	2.2	1.6	1.5
			135	23.0	9.5	4.7	3.3	2.2	2.0
			150	29.7	14.2	7.4	4.8	3.2	2.7
			165	36.4	19.8	11.2	7.1	4.6	3.7
			180		25.9	16.0	10.2	6.4	5.0
			195		32.4	21.4	14.2	8.9	6.7
			205		36.4	25.3	17.3	11.1	8.1
			210			27.4	19.0	12.3	8.9
			225			33.8	24.4	16.5	11.7
			235			36.4	28.3	19.7	14.1
			240				30.3	21.4	15.4
			255				36.4	26.8	19.7
			270					32.6	24.6
			280					36.4	28.1
			285						30.0
			300						35.7
			305						36.4
14	18	49.6	140	29.0	11.7	6.0	4.4	2.8	2.6
			150	34.2	15.3	8.1	5.7	3.5	3.2
			160	39.4	19.3	10.7	7.4	4.4	3.8
			170	44.9	23.7	13.8	9.5	5.5	4.7
			180	49.6	28.3	17.5	12.2	6.8	5.6
			190		33.2	21.5	15.4	8.5	6.8
			200		38.3	25.9	19.0	10.5	8.2
			210		43.5	30.5	23.0	13.0	9.9
			220		48.9	35.3	27.2	15.9	11.9
			225		49.6	37.8	29.4	17.6	13.1
			230			40.3	31.7	19.3	14.3
			240			45.5	36.4	23.0	17.2
			250			49.6	41.4	27.0	20.4
			260				46.4	31.2	23.9
			270				49.6	35.6	27.7
			280					40.2	31.7
			290					45.1	35.9
			300					49.6	40.3
			310						44.9
			320						49.6

table 10 : Maximum load applicable to a rebar bonded with Ripple R-fix mortar in case of fire. 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.

Ripple R-fix									
Rebar diameter	Drill hole diameter	Rebar maximum load	Rebar anchorage depth	Maximum force in the rebar (kN)					
ϕ (mm)	D (mm)	F (kN)	Ls (mm)	R 30	R 60	R 90	R 120	R 180	R 240
16	20	64.8	160	44.9	20.2	10.9	7.9	5.1	4.3
			170	51.0	24.9	14.2	10.1	6.3	5.1
			180	57.3	30.0	18.0	12.8	7.8	6.2
			190	63.6	35.4	22.3	16.1	9.7	7.4
			195	64.8	38.2	24.6	18.0	10.7	8.2
			200		41.0	26.9	19.9	11.9	8.9
			210		46.9	31.9	24.2	14.6	10.7
			220		52.9	37.2	28.9	17.9	12.9
			230		59.0	42.7	33.8	21.6	15.4
			240		64.8	48.4	39.0	25.7	18.4
			250			54.3	44.3	30.1	21.8
			260			60.3	49.9	34.8	25.5
			270			64.8	55.7	39.8	29.6
			280				61.6	45.0	34.1
			290				64.8	50.4	38.8
			300					55.9	43.7
			310					61.7	48.8
			320					64.8	54.0
			330						59.4
			340						64.8
20	25	101.2	200	87.2	45.3	29.0	21.3	13.1	10.5
			215	99.1	55.7	37.7	28.6	17.5	13.6
			220	101.2	59.3	40.7	31.3	19.2	14.8
			230		66.6	47.2	36.9	23.3	17.5
			245		78.0	57.3	46.1	30.2	22.5
			260		89.6	67.9	55.9	38.2	28.7
			275		101.2	79.0	66.2	47.0	35.9
			290			90.4	77.0	56.3	44.0
			305			101.2	88.1	66.3	52.7
			320				99.5	76.9	62.1
			325				101.2	80.5	65.4
			335					87.8	72.1
			350					99.0	82.4
			355					101.2	86.0
			365						93.1
			380						101.2

table 11 : Maximum load applicable to a rebar bonded with Ripple R-fix mortar in case of fire. 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.

Ripple R-fix									
Rebar diameter	Drill hole diameter	Rebar maximum load	Rebar anchorage depth	Maximum force in the rebar (kN)					
ϕ (mm)	D (mm)	F (kN)	Ls (mm)	R 30	R 60	R 90	R 120	R 180	R 240
22	27	122.4	220	113.4	65.2	44.8	34.4	21.2	16.3
			230	122.3	73.3	51.9	40.6	25.6	19.3
			235	122.4	77.4	55.5	43.9	28.0	20.9
			240		81.6	59.3	47.2	30.6	22.8
			250		90.0	66.9	54.2	36.1	26.9
			260		98.5	74.7	61.4	42.0	31.5
			270		107.1	82.8	69.0	48.4	36.7
			280		115.8	91.1	76.7	55.0	42.4
			290		122.4	99.5	84.7	62.0	48.4
			300			108.0	92.8	69.2	54.7
			310			116.6	101.1	76.8	61.4
			320			122.4	109.5	84.5	68.3
			330				118.0	92.5	75.6
			340				122.4	100.6	83.0
			350					108.8	90.7
			360					117.2	98.5
			370					122.4	106.4
			380						114.6
			390						122.4
24	29	145.7	240	145.7	87.5	56.6	45.3	29.4	22.9
			255		100.8	68.4	56.0	37.5	28.9
			270		114.5	80.7	67.5	46.8	36.3
			285		128.5	93.7	79.7	57.0	44.9
			300		142.7	107.1	92.4	68.0	54.3
			305		145.7	111.6	96.7	71.8	57.7
			315			120.7	105.5	79.7	64.6
			330			134.7	118.9	91.9	75.6
			345			145.7	132.7	104.7	87.3
			360				145.7	117.9	99.5
			375					131.4	112.0
			390					145.1	125.0
			395					145.7	129.4
			405						138.3
			415						145.7

table 12 : Maximum load applicable to a rebar bonded with Ripple R-fix mortar in case of fire. 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.

Ripple R-fix									
Rebar diameter	Drill hole diameter	Rebar maximum load	Rebar anchorage depth	Maximum force in the rebar (kN)					
ϕ (mm)	D (mm)	F (kN)	Ls (mm)	R 30	R 60	R 90	R 120	R 180	R 240
25	30	158.1	250	158.1	100.4	67.0	54.5	36.1	27.8
			260		109.7	75.4	62.2	42.2	32.5
			270		119.3	84.1	70.3	48.7	37.8
			280		129.0	93.0	78.7	55.7	43.6
			290		138.8	102.2	87.3	63.1	49.9
			300		148.7	111.5	96.2	70.8	56.6
			310		158.1	121.0	105.3	78.9	63.6
			320			130.5	114.5	87.2	71.0
			330			140.3	123.9	95.7	78.7
			340			150.2	133.4	104.6	86.8
			350			158.1	143.0	113.6	95.1
			360				152.7	122.8	103.6
			370				158.1	132.2	112.3
			380					141.6	121.2
			390					151.1	130.2
			400					158.1	139.4
			410						148.8
			420						158.1
32	40	259.0	320	259.0	223.5	160.7	129.0	98.8	82.0
			330		236.3	172.8	140.4	108.9	91.2
			340		249.1	185.0	152.0	119.5	100.9
			350		259.0	197.3	163.8	130.3	110.8
			360			209.7	175.7	141.4	121.1
			370			222.2	187.8	152.8	131.7
			380			234.8	200.0	164.4	142.6
			390			247.6	212.3	176.2	153.8
			400			259.0	224.7	188.1	165.1
			410				237.3	200.2	176.7
			420				249.9	212.4	188.4
			430				259.0	224.7	200.3
			440					237.1	212.3
			450					249.7	224.3
			460					259.0	236.5
			470						248.8
			480						259.0

table 13 : Maximum load applicable to a rebar bonded with Ripple R-fix mortar in case of fire. 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.

5.4 Beam to beam connection

The experimental temperature - bonding stress relationship is given as before by:

$$\tau = \left(\frac{\theta}{144{,}25} \right)^{-2{,}21}$$

The maximum bonding stresses for the maximum temperature in a given area of figures 17 to 25 are calculated by introducing the temperatures of contour lines in the above equation. The results are summarized in table 14.

Ripple R-fix	
Maximum temperature in area (°C)	**Bonding stress (MPa)**
40	14.0
60	6.9
80	3.7
100	2.2
120	1.5

table 14 : Maximum bonding stresses for a beam to beam connection. See figures 17 to 25 to use correctly this table.

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.

An over presentation of the results is given here after: the rebar anchorage depth that vouches for the resin adhesion strength is stronger than the tensile strength of the rebar (rebar maximum load permitted in case of fire). Rebar anchorage depths are presented in table 15.

Ripple R-fix							
Rebar diameter (mm)	**Drill hole diameter (mm)**	**Rebar maximum load (kN)**	**Rebar anchorage depth (mm) for maximum temperature in area here below**				
			40 °C	**60 °C**	**80 °C**	**100 °C**	**120 °C**
8	12	16.2	80	148	280	458	686
10	14	25.3	100	185	350	573	857
12	16	36.4	120	222	420	687	
14	18	49.6	140	259	490	802	
16	20	64.8	160	296	560	917	
20	25	101.2	200	370	700		
22	27	122.4	220	407	770		
24	29	145.7	240	444	840		
25	30	158.1	250	463	875		
32	40	259.0	320	593			

table 15 : anchorage depth applicable to a rebar bonded with Ripple R-fix mortar in case of fire. See figures 17 to 25 to use correctly this table.

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.

5.5 Wall to beam connection

In order to present results in a simple manner, we prefer present here the rebar anchorage depth that vouches for the resin adhesion strength is stronger than the tensile strength of the rebar (rebar maximum load permitted in case of fire). The presentation of the results as for the wall to slab connection would require 27 tables!

For a given rebar anchorage depth, the adhesion strength is given as before by:

$$F_{adh} = \int_0^{Ls} \frac{1}{\gamma_s} \pi * \phi * \tau_{rk}(x) dx$$

We then present in the following tables (table 16 to table 18) the rebar anchorage depths "Ls", for all layers and in each permitted configuration for beams, for which F_{adh} is higher than the corresponding "rebar maximum load" in tables.

Ripple R-fix – beam's width = 20 cm									
Rebar diameter	Drill hole diameter	Rebar maximum load		Rebar anchorage depth (mm)					
ϕ (mm)	D (mm)	F (kN)	Fire duration	R 30	R 60	R 90	R 120	R 180	R 240
			concrete cover (mm)	30	55	80			
8	12	16.2	layer 1	124	154	178			
			layer 2	113	141	166			
			layer 3	111	137	163			
10	14	25.3	layer 1	137	168	192			
			layer 2	126	155	181			
			layer 3	124	151	178			
12	16	36.4	layer 1	150	181	206			
			layer 2	139	168	195			
			layer 3	137	165	192			
14	18	49.6	layer 1	162	194	220			
			layer 2	151	181	209			
			layer 3	149	178	206			
16	20	64.8	layer 1	175	207	233			
			layer 2	163	194	222			
			layer 3	162	191	219			
20	25	101.2	layer 1	200	232	258			
			layer 2	200	217	246			
			layer 3	200	215	244			
22	27	122.4	layer 1	220	244	271			
			layer 2	220	229	258			
			layer 3	220	227	256			
24	29	145.7	layer 1	240	257	283			
			layer 2	240	242	271			
			layer 3	240	240	269			
25	30	158.1	layer 1	250	263	289			
			layer 2	250	250	276			
			layer 3	250	250	275			
32	40	259.0	layer 1	320	320	332			
			layer 2	320	320	320			
			layer 3	320	320	320			

table 16 : anchorage depth applicable to a rebar bonded with Ripple R-fix mortar in case of fire.

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.

Ripple R-fix – beam's width = 30 cm									
Rebar diameter	Drill hole diameter	Rebar maximum load		Rebar anchorage depth (mm)					
ϕ (mm)	D (mm)	F (kN)	Fire duration	R 30	R 60	R 90	R 120	R 180	R 240
			concrete cover (mm)	30	55	80	85		
8	12	16.2	layer 1	124	152	170	195		
			layer 2	113	137	151	178		
			layer 3	111	132	145	171		
10	14	25.3	layer 1	137	166	184	210		
			layer 2	126	151	166	194		
			layer 3	124	146	160	187		
12	16	36.4	layer 1	150	180	198	225		
			layer 2	138	164	181	209		
			layer 3	137	160	174	202		
14	18	49.6	layer 1	162	193	212	239		
			layer 2	151	177	194	223		
			layer 3	149	173	188	216		
16	20	64.8	layer 1	175	205	225	252		
			layer 2	163	190	208	236		
			layer 3	162	186	201	229		
20	25	101.2	layer 1	200	230	250	278		
			layer 2	200	213	230	259		
			layer 3	200	210	226	253		
22	27	122.4	layer 1	220	243	263	291		
			layer 2	220	225	242	271		
			layer 3	220	223	238	266		
24	29	145.7	layer 1	240	255	275	303		
			layer 2	240	240	255	284		
			layer 3	240	240	251	279		
25	30	158.1	layer 1	250	261	282	309		
			layer 2	250	250	259	288		
			layer 3	250	250	257	285		
32	40	259.0	layer 1	320	320	325	353		
			layer 2	320	320	320	330		
			layer 3	320	320	320	328		

table 17 : anchorage depth applicable to a rebar bonded with Ripple R-fix mortar in case of fire.

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.

Ripple R-fix – beam's width = 40 cm or more									
Rebar diameter	Drill hole diameter	Rebar maximum load		Rebar anchorage depth (mm)					
ϕ (mm)	D (mm)	F (kN)	Fire duration	R 30	R 60	R 90	R 120	R 180	R 240
			concrete cover (mm)	28	52	70	85	110	136
8	12	16.2	layer 1	125	154	175	193	223	247
			layer 2	114	139	158	174	203	228
			layer 3	112	135	151	166	193	218
10	14	25.3	layer 1	138	168	190	208	239	264
			layer 2	127	153	173	190	220	246
			layer 3	125	149	166	181	210	236
12	16	36.4	layer 1	151	181	204	223	255	281
			layer 2	140	166	187	205	236	263
			layer 3	138	162	180	196	226	253
14	18	49.6	layer 1	163	194	217	237	269	296
			layer 2	152	179	201	219	251	279
			layer 3	150	175	194	210	241	269
16	20	64.8	layer 1	176	207	230	250	283	311
			layer 2	165	192	214	232	265	294
			layer 3	163	188	207	224	255	284
20	25	101.2	layer 1	200	232	256	276	310	339
			layer 2	200	215	236	254	287	317
			layer 3	200	212	231	248	279	308
22	27	122.4	layer 1	220	244	268	289	323	352
			layer 2	220	227	248	267	301	331
			layer 3	220	225	244	260	292	322
24	29	145.7	layer 1	240	256	281	301	336	366
			layer 2	240	240	261	279	314	344
			layer 3	240	240	256	273	305	335
25	30	158.1	layer 1	250	263	287	307	343	372
			layer 2	250	250	265	283	317	348
			layer 3	250	250	262	279	310	340
32	40	259.0	layer 1	320	320	330	351	387	417
			layer 2	320	320	320	324	358	389
			layer 3	320	320	320	322	353	382

table 18 : anchorage depth applicable to a rebar bonded with Ripple R-fix mortar in case of fire.

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.