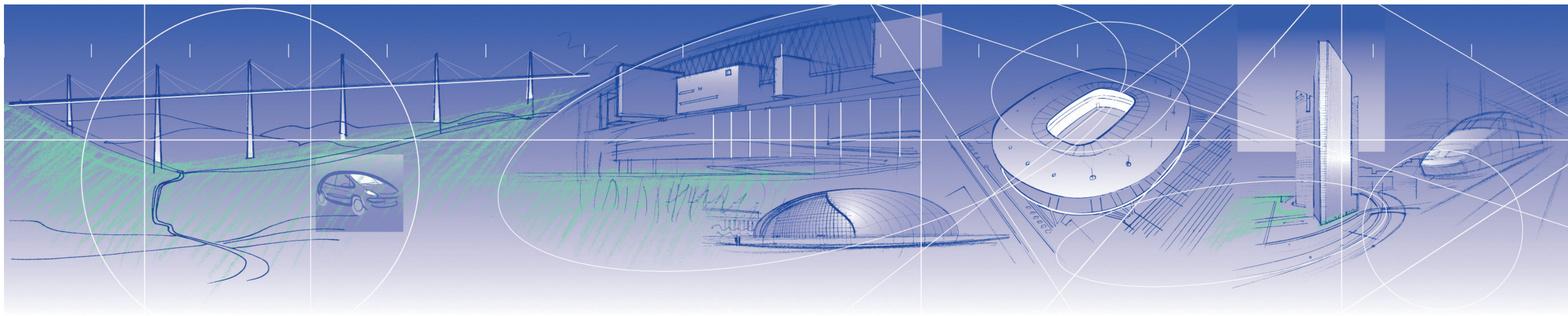

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Autorisé et notifié conformément à l'article 10 de la directive 89/106/EEC du Conseil, du 21 décembre 1988, relative au rapprochement des dispositions législatives, réglementaires et administratives des Etats membres concernant les produits de construction.

REPORT No 26028160 – HIT-CT 1

on

HILTI HIT-CT 1 injection systems
in conjunction with concrete reinforcing bar (ϕ 8 to 25mm)
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 37 pages numbered from 1/37 to 37/37

CONTENT

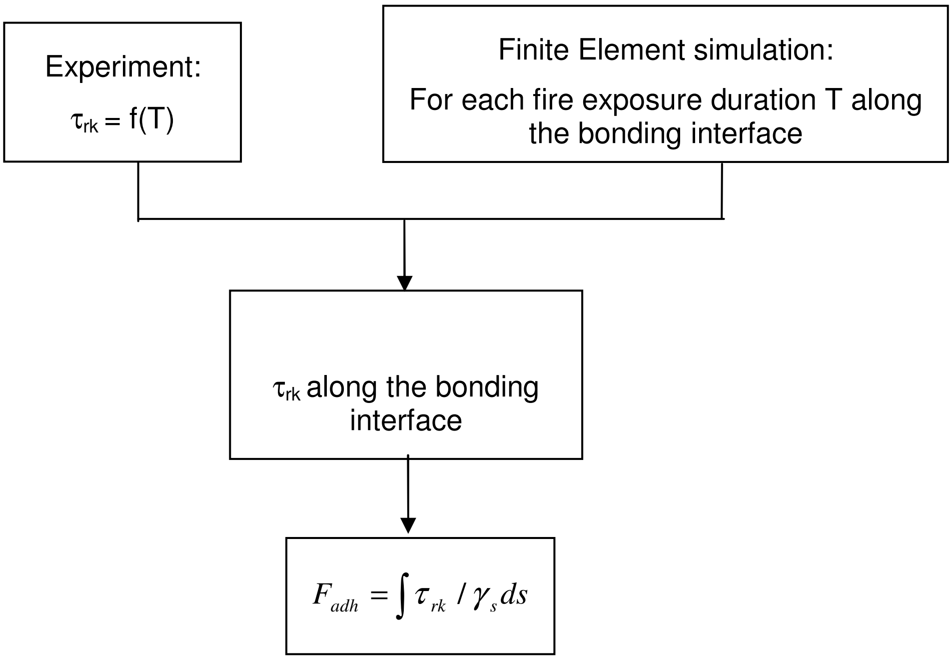
1 SCOPE

When subjected to fire exposure, construction elements performances are reduced by the effect of the temperature increase. At the HILTI 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 (RE 500; ϕ 8 to 25 mm).

The maximum loads applicable through a rebar in conjunction with HILTI HIT-CT 1 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 HILTI HIT-CT 1 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 HILTI HIT-CT 1 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 HILTI HIT-CT 1 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 HILTI HIT-CT 1 under fire exposure. These tests are carried out from 15/05/2011 to 30/06/2011 in the fire resistance laboratory of the CSTB at the MARNE-LA-VALLEE Research Centre.

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 calibrated springs which kept constant the load level or by means of hydraulic jack.

figure 1: Monitoring device

figure 2: Loading device

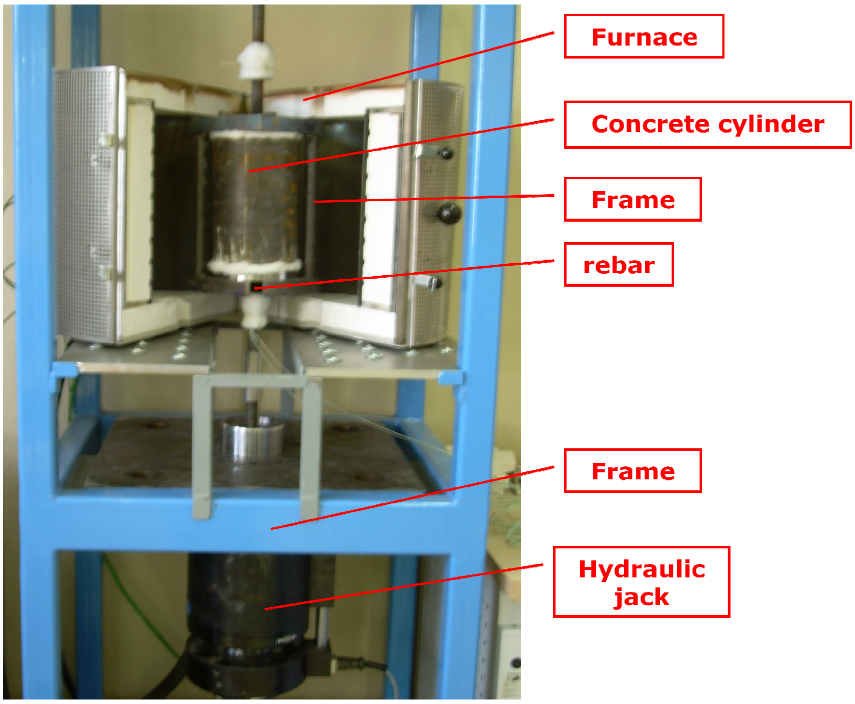


figure 3: high temperature, regulated, furnace

3.3 Test specimen

The HILTI HIT-CT 1 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 25mm, grade b500 is then inserted into the resin.

figure 4: Mortar Hilti HIT-CT 1 (foil pack 330ml and 500ml), static mixer Hilti HIT RE-M

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.

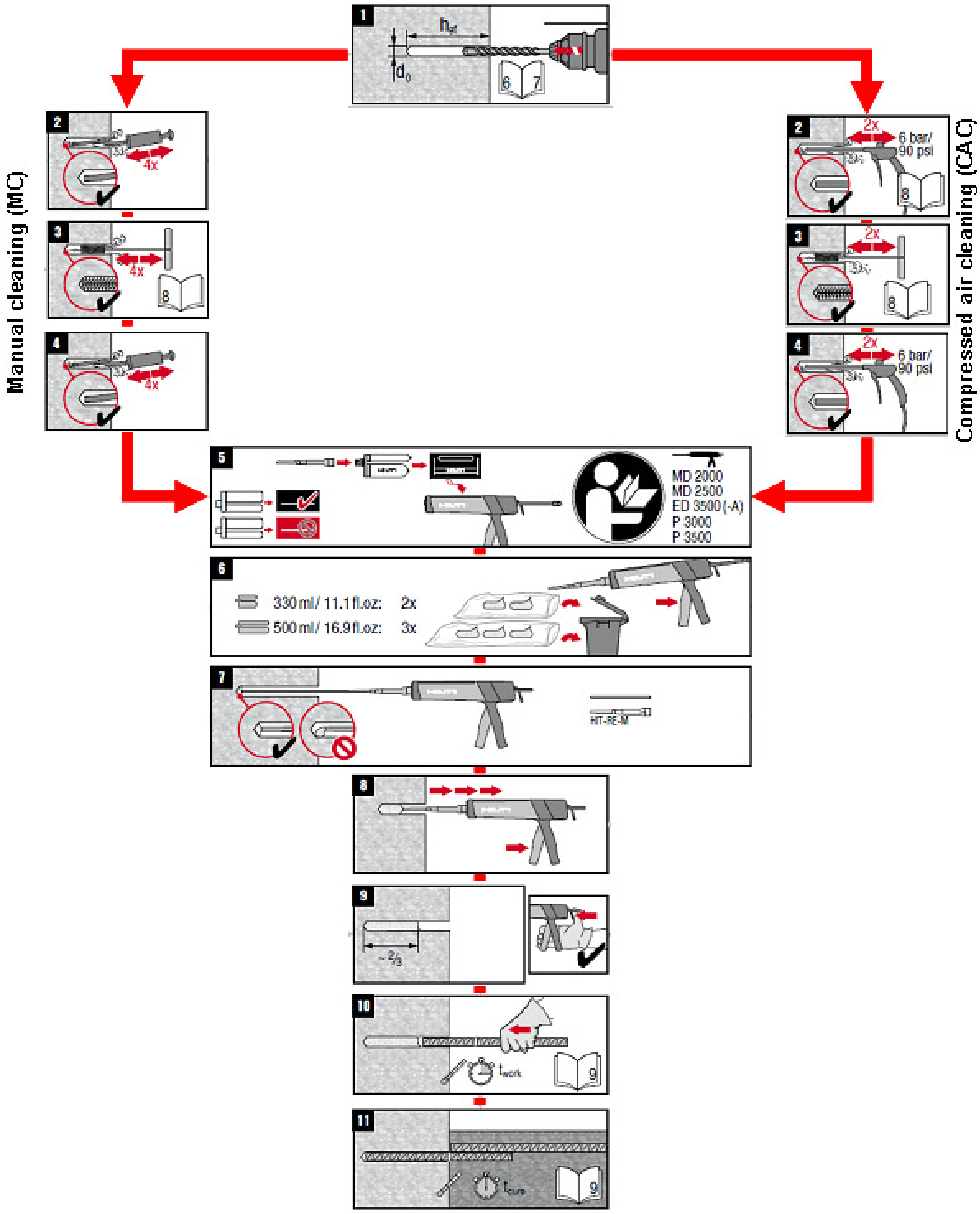


table 2 : Installation instruction, cleaning methods: manual cleaning (4x blowing, 4x brushing, 4xblowing: for rebar diameter 8 to 16 with embedment depth ≤ 250 only) or compressed air cleaning (2x blowing, 2x brushing, 2xblowing)

a) Manual cleaning

b) Compressed air cleaning

figure 4**:** Cleaning method

figure 5: Brushes Hilti HIT-RB for cleaning the drill holes.

Hilti HIT MD 2500

Hilti HIT-MD 3500-A

figure 6: Dispenser

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 HILTI HIT-CT 1 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.

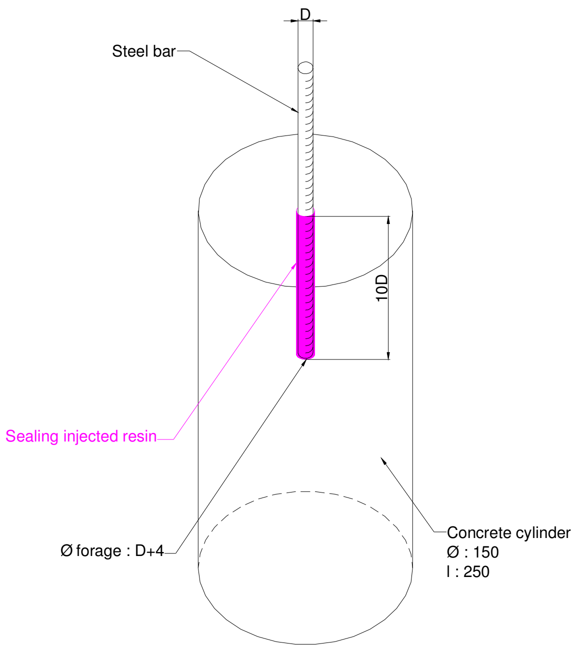


figure 7: Steel-encased concrete cylinders

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

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/m^2),
- radiation flux density: $\varphi_r = \varepsilon\sigma(T_g^4 - T_s^4)$ (W/m^2).

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.

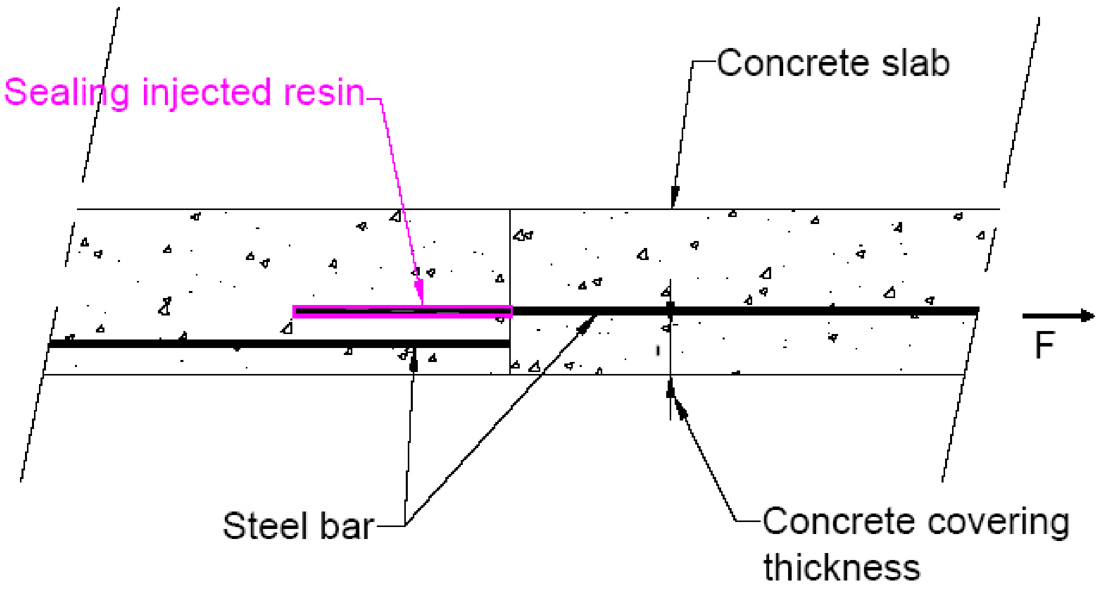


Figure 10 : Slab to slab connection

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

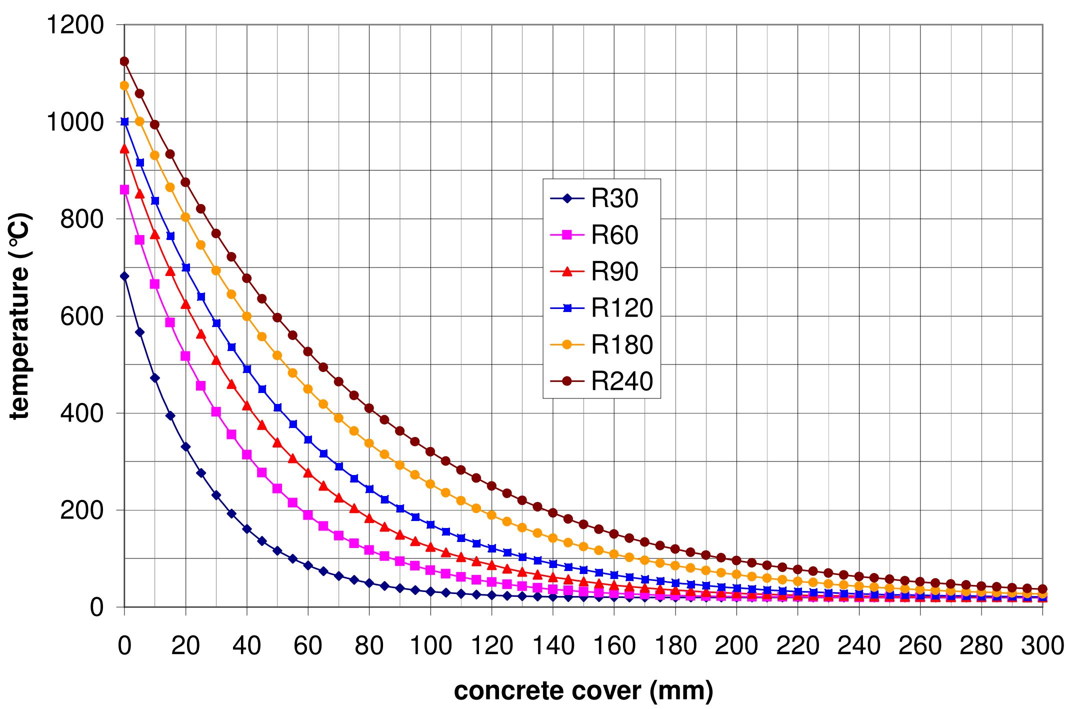


Figure 11 : Temperature at the bonding interface as a function of concrete cover.

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

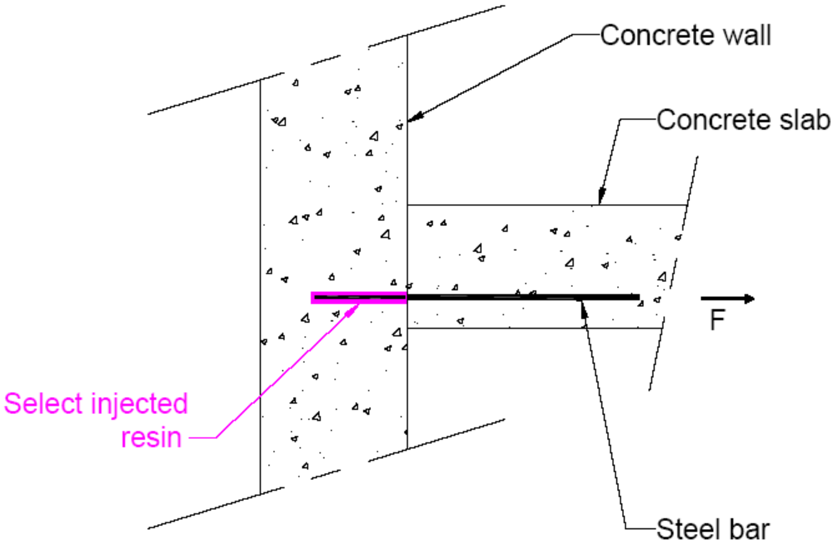


Figure 12 : Wall to slab connection

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	10	*10*	60	*20*	70	*25*	90	*35*	110	*50*	150	*70*	*175*
10	12	*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*
18	22	*18*	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*
22	27	*22*	66	*22*	70	*25*	90	*35*	110	*50*	150	*70*	*175*
24	*29*	*24*	*72*	*24*	*72*	*25*	90	*35*	110	*50*	150	*70*	*175*
25	30	*25*	75	*25*	75	*25*	90	*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℃, 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℃.

- No heat exchange condition on the other sides.

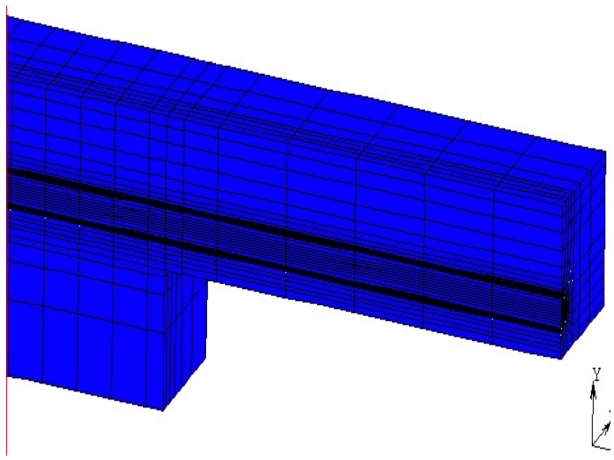


Figure 13 : Mesh used for the wall to slab connection temperature model.

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.

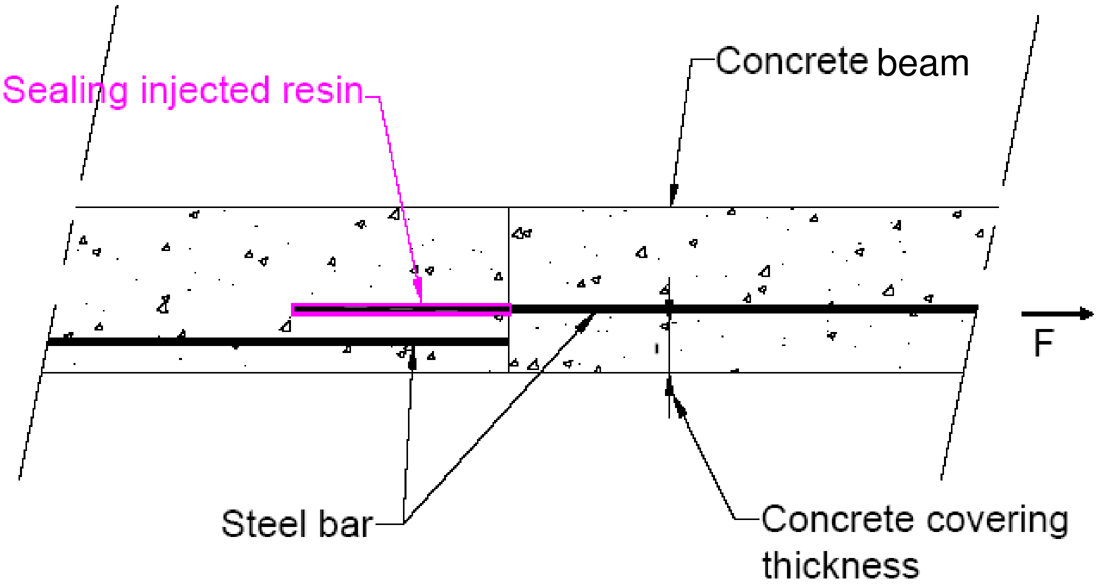


Figure 15 : beam to beam connection

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).

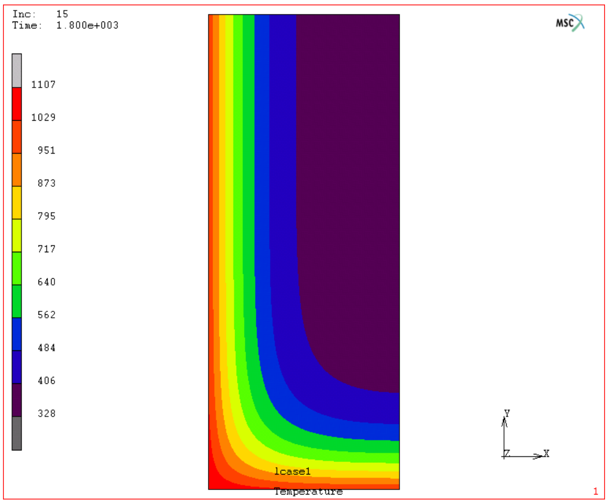


Figure 16: An example of temperature profile (T °Kelvin) – fire duration = 30 minutes – beam's width = 20 cm

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 equal to 500-600 mm (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.

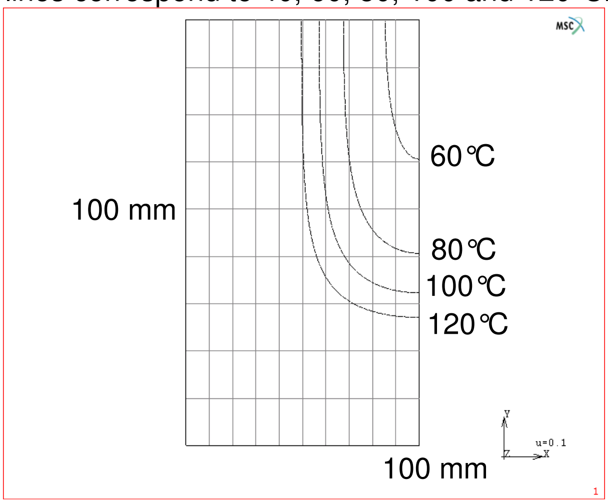


Figure 17: Temperature contour lines for beam's width = 20 cm and fire duration = 30 min

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

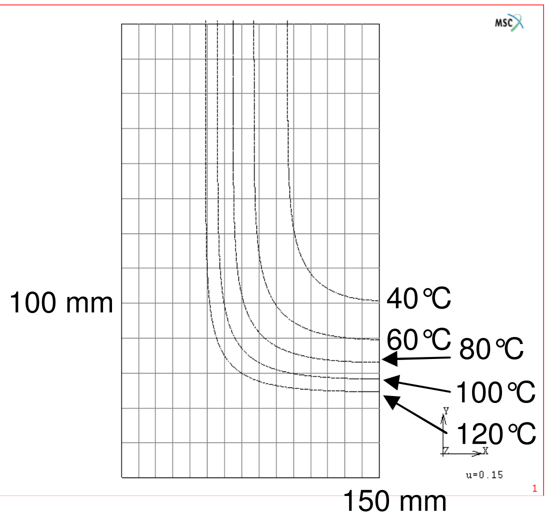


Figure 18: Temperature contour lines for beam's width = 30 cm and fire duration = 30 min

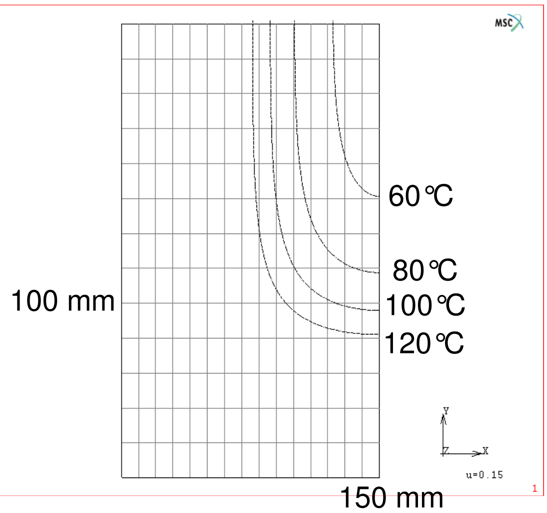


Figure 19: Temperature contour lines for beam's width = 30 cm and fire duration = 60 min

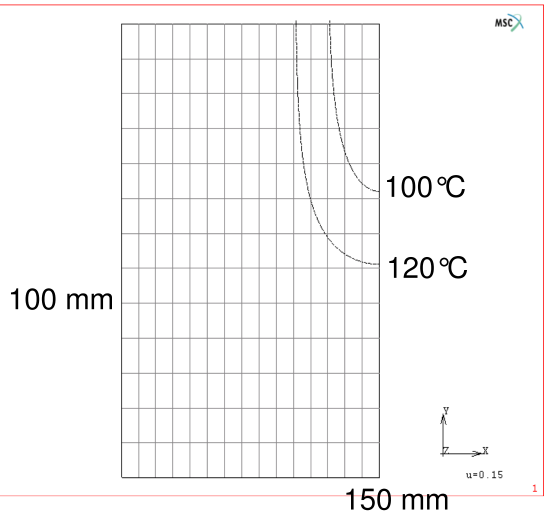


Figure 20: Temperature contour lines for beam's width = 30 cm and fire duration = 90 min

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

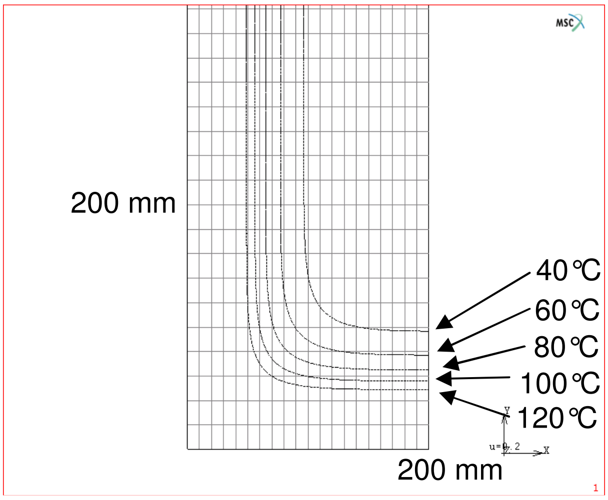


Figure 21: Temperature contour lines for beam's width = 40 cm and fire duration = 30 min

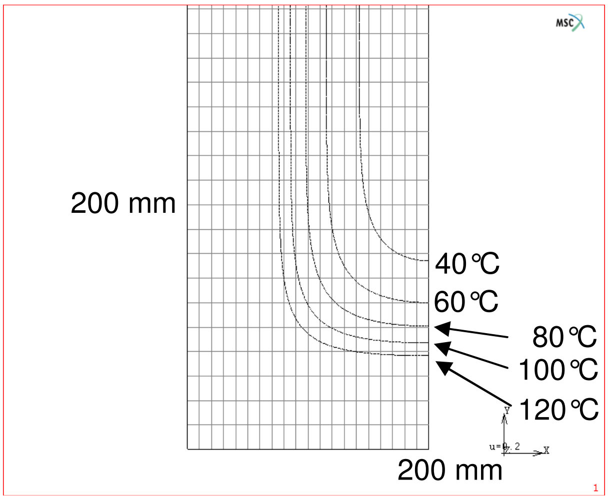


Figure 22: Temperature contour lines for beam's width = 40 cm and fire duration = 60 min

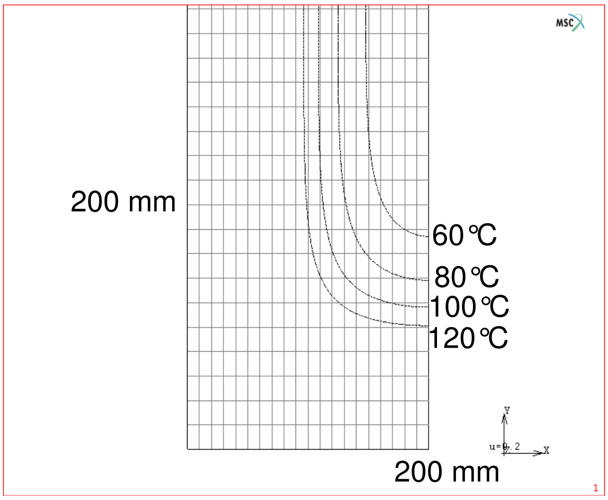


Figure 23: Temperature contour lines for beam's width = 40 cm and fire duration = 90 min

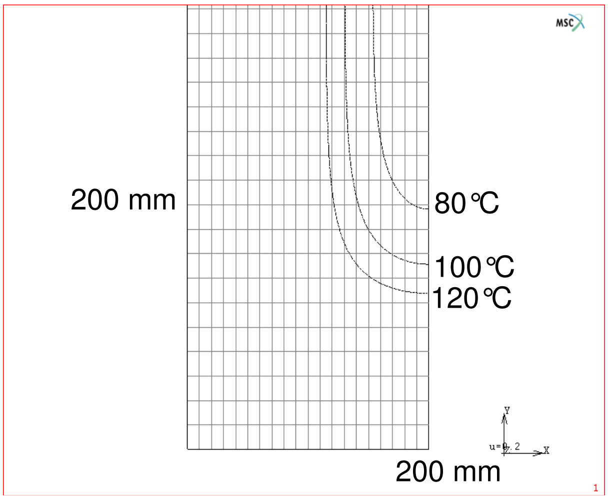


Figure 24: Temperature contour lines for beam's width = 40 cm and fire duration = 120 minutes

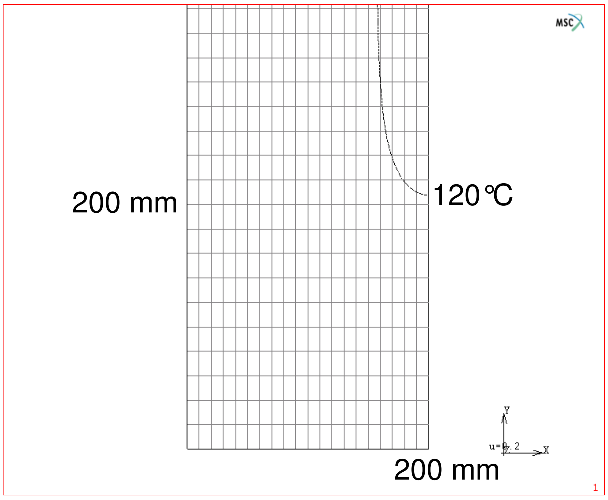


Figure 25: Temperature contour lines for beam's width = 40 cm and fire duration = 180 minutes

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

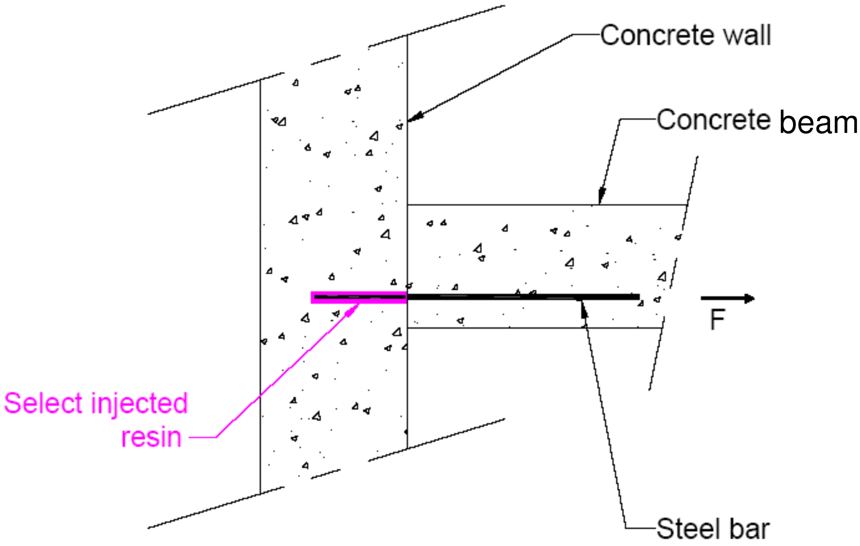


Figure 26: Wall to beam connection

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.

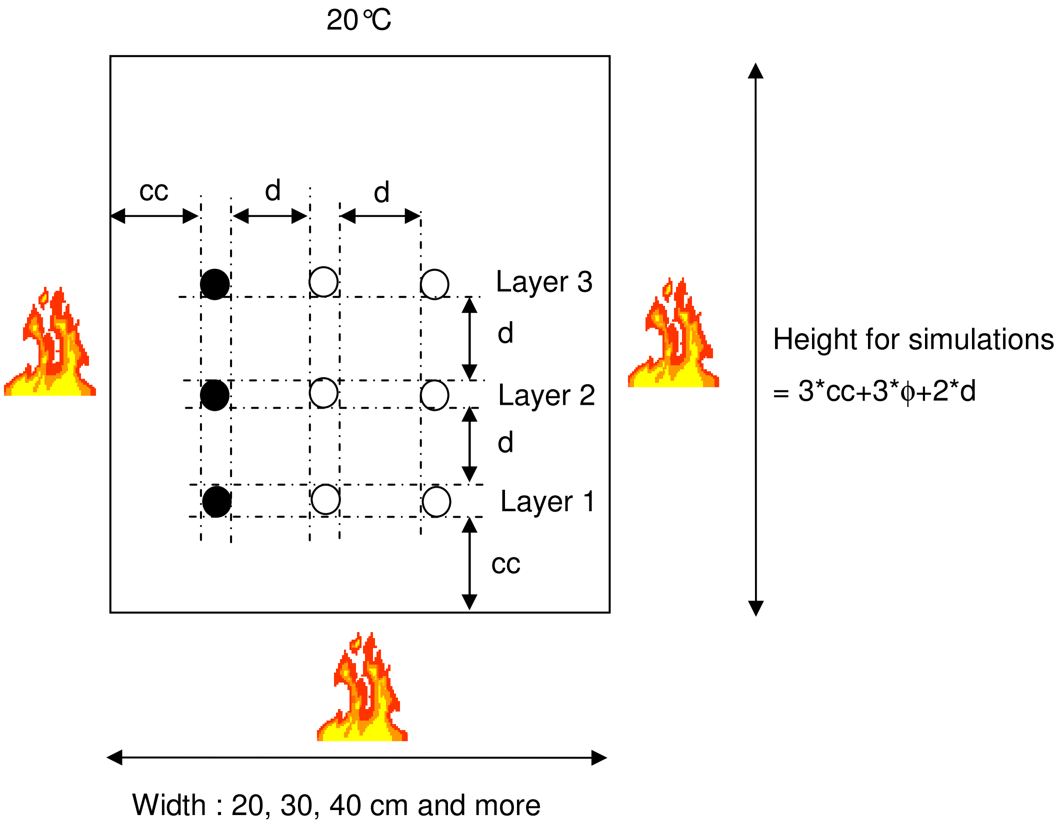


Figure 27: reinforcement frame

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:

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

The following values are then obtained:

Rebar diameter (mm)	8	10	12	14	16	18	20	22	24	25
Distance between layers (mm)	60	60	60	60	60	66	75	81	87	90

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.

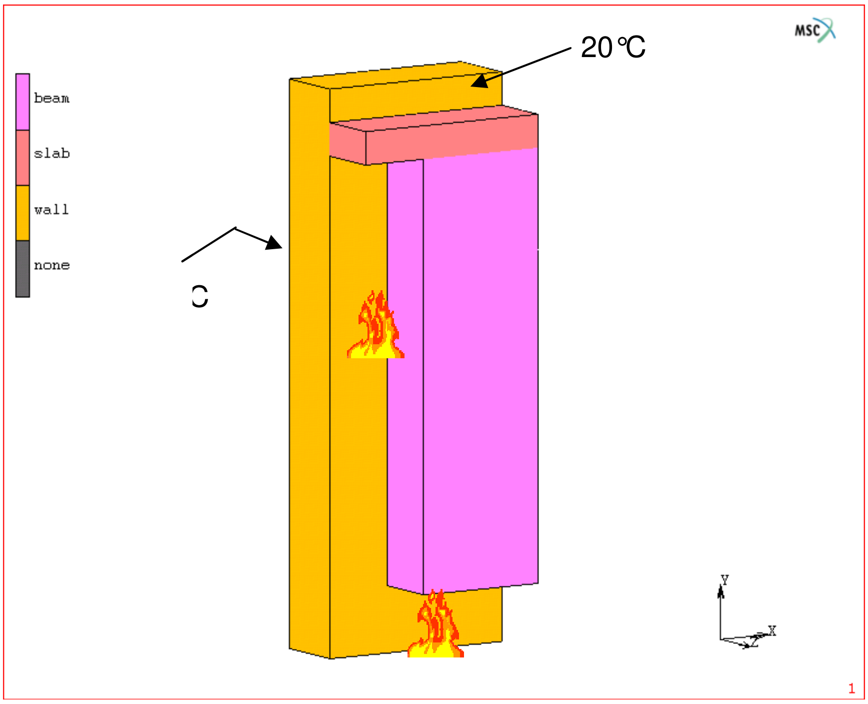


Figure 28: Mesh used for the wall to beam connection temperature model.

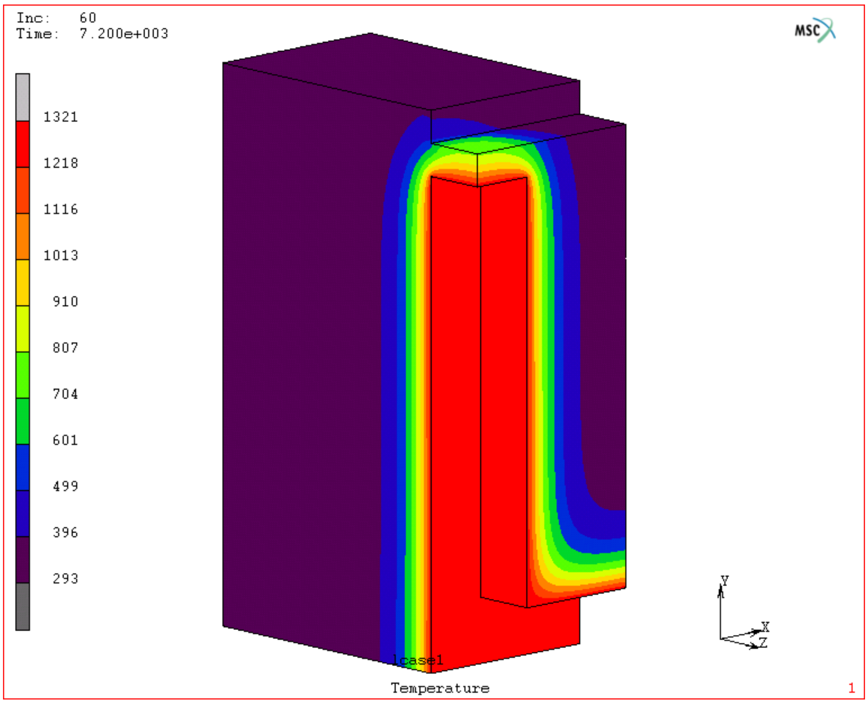


Figure 29: An example of temperature profile (T °Kelvin) – fire duration = 2 hours – beam's width = 40 cm.

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:

$$\tau = \left(\frac{\theta}{241{,}97}\right)^{-1{,}202} \qquad (1)$$

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.

HIT-CT 1	Bonding stress (MPa)					
Concrete cover (mm)	R 30	R 60	R 90	R 120	R 180	R 240
10	0.4					
20	0.7	0.4				
30	1.1	0.5	0.4			
40	1.6	0.7	0.5	0.4		
50	2.4	1.0	0.7	0.5	0.4	
60	3.5	1.3	0.8	0.7	0.5	
70	5.0	1.8	1.1	0.8	0.6	0.5
80	6.8	2.4	1.4	1.0	0.7	0.5
90	8.8	3.1	1.7	1.2	0.8	0.6
100	10.9	4.0	2.2	1.5	1.0	0.7
110	12.9	5.1	2.7	1.9	1.1	0.8
120	14.7	6.4	3.4	2.3	1.4	1.0
130	16.1	7.8	4.1	2.8	1.6	1.1
140	17.2	9.2	5.0	3.3	1.9	1.3
150	18.1	10.7	6.0	4.0	2.2	1.5
160	18.7	12.2	7.1	4.7	2.6	1.8
170	19.1	13.5	8.2	5.6	3.1	2.0
180	19.4	14.7	9.4	6.5	3.5	2.3
190		15.8	10.6	7.5	4.1	2.7
200		16.6	11.8	8.5	4.7	3.1
210		17.4	12.9	9.6	5.4	3.5
220		18.0	13.9	10.7	6.1	3.9
230		18.4	14.9	11.8	6.9	4.5
240		18.8	15.7	12.9	7.7	5.0
250		19.1	16.4	13.9	8.5	5.6
260		19.3	17.1	14.8	9.4	6.3
270			17.6	15.7	10.3	7.0
280			18.0	16.5	11.2	7.7
290			18.4	17.2	12.1	8.5
300			18.7	17.8	12.9	9.3
310			19.0	18.3	13.7	10.1
320			19.2	18.8	14.5	10.9
330	20.0		19.3	19.2	15.2	11.7
340				19.6	15.9	12.5
350				19.8	16.6	13.3
360					17.1	14.1
370		20.0			17.6	14.8
380					18.1	15.5
390					18.5	16.2
400			20.0		18.9	16.8
410				20.0	19.2	17.4
420						17.9
430						18.4
440					20.0	18.9
450						19.3
460						19.7
470						20.0

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 12.

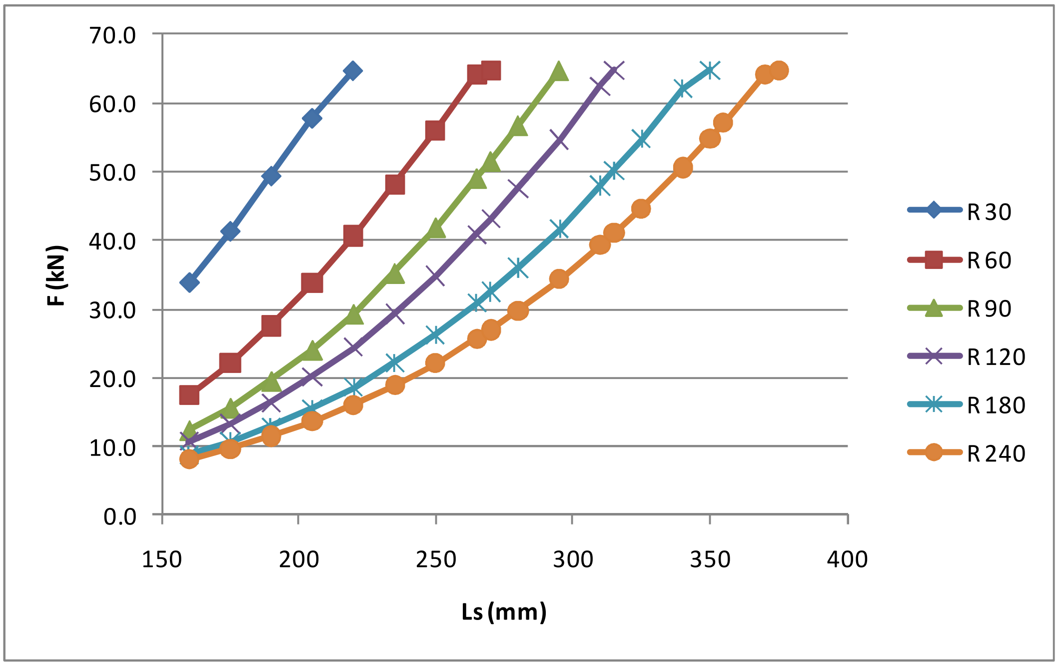


Figure 30: Maximum force of rebar (ϕ=16mm) in conjunction with HILTI HIT-CT 1.

HIT-CT 1									
Rebar diameter	Drill hole diameter	Rebar maximum load (kN)	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	10	16.2	80	3.6	2.0	1.5	1.4	1.3	1.3
			95	5.5	2.9	2.1	1.9	1.7	1.7
			110	8.0	4.1	2.9	2.5	2.2	2.1
			125	11.1	5.8	3.9	3.3	2.8	2.6
			140	14.8	7.8	5.3	4.4	3.5	3.2
			150	16.2	9.5	6.3	5.2	4.0	3.6
			155		10.4	6.9	5.6	4.4	3.9
			170		13.5	9.0	7.2	5.4	4.7
			185		16.2	11.5	9.1	6.7	5.6
			200			14.4	11.3	8.2	6.7
			210			16.2	13.0	9.4	7.6
			215				13.9	10.0	8.0
			230				16.2	12.1	9.5
			245					14.5	11.2
			255					16.2	12.4
			260						13.1
			275						15.3
			285						16.2
10	12	25.3	100	7.3	3.9	2.9	2.6	2.3	2.2
			115	10.4	5.5	3.9	3.4	2.9	2.8
			130	14.1	7.5	5.2	4.4	3.7	3.4
			145	18.5	10.0	6.8	5.7	4.6	4.2
			160	23.6	13.2	8.9	7.3	5.7	5.1
			165	25.3	14.4	9.7	7.9	6.1	5.4
			175		16.9	11.5	9.3	7.0	6.1
			190		21.1	14.6	11.6	8.6	7.3
			205		25.3	18.1	14.5	10.4	8.8
			220			22.2	17.7	12.6	10.4
			235			25.3	21.4	15.1	12.4
			250				25.3	18.0	14.6
			265					21.3	17.1
			280					25.0	19.9
			285					25.3	21.0
			295						23.1
			305						25.3
12	16	36.4	120	13.1	6.9	5.0	4.4	3.7	3.7
			135	17.5	9.3	6.5	5.6	4.7	4.5
			150	22.6	12.2	8.5	7.1	5.8	5.5
			165	28.2	15.8	11.0	8.9	7.2	6.6
			180	34.2	20.1	14.0	11.0	8.8	8.0
			190	36.4	23.2	16.3	12.7	10.0	9.0
			195		24.9	17.5	13.6	10.7	9.5
			210		30.4	21.6	16.6	13.0	11.3
			225		36.3	26.2	20.1	15.6	13.4
			230		36.4	27.9	21.4	16.6	14.1
			240			31.4	24.0	18.7	15.7
			255			36.4	28.5	22.1	18.4
			270				33.4	26.0	21.5
			280				36.4	28.9	23.7
			285					30.4	24.9
			300					35.2	28.7
			305					36.4	30.1
			315						33.0
			330						36.4

table 9 : Maximum load applicable to a rebar bonded with HILTI HIT-CT 1 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.

HIT-CT 1									
Rebar diameter	Drill hole diameter	Rebar maximum load (kN)	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
14	18	49.6	140	22.0	11.4	8.2	7.0	5.7	5.6
			155	27.9	14.9	10.6	8.9	7.1	6.8
			170	34.5	19.1	13.5	11.2	8.7	8.1
			185	41.6	24.0	17.0	14.0	10.6	9.7
			200	49.1	29.6	21.2	17.3	12.8	11.5
			205	49.6	31.6	22.7	18.5	13.6	12.2
			215		35.8	26.0	21.1	15.4	13.7
			230		42.5	31.4	25.5	18.5	16.1
			245		49.6	37.3	30.5	22.0	18.9
			260			43.7	36.1	26.0	22.1
			275			49.6	42.0	30.5	25.7
			290				48.4	35.5	29.7
			295				49.6	37.2	31.2
			305					40.9	34.2
			320					46.8	39.0
			330					49.6	42.5
			335						44.4
			350						49.6
16	20	64.8	160	33.8	17.4	12.4	10.7	8.7	8.1
			175	41.3	22.1	15.7	13.3	10.6	9.7
			190	49.3	27.5	19.6	16.4	12.9	11.5
			205	57.8	33.7	24.1	20.1	15.5	13.6
			220	64.8	40.7	29.3	24.4	18.6	16.1
			235		48.2	35.3	29.3	22.2	18.9
			250		56.0	41.9	34.8	26.3	22.1
			265		64.1	49.1	40.9	30.8	25.7
			270		64.8	51.6	43.1	32.5	27.0
			280			56.8	47.5	35.9	29.7
			295			64.8	54.7	41.6	34.3
			310				62.4	47.9	39.3
			315				64.8	50.1	41.0
			325					54.7	44.7
			340					62.0	50.6
			350					64.8	54.8
			355						57.0
			370						64.0
			375						64.8
18	22	82.0	180	49.8	26.8	19.0	16.1	12.8	11.6
			195	59.1	33.2	23.6	19.8	15.4	13.7
			210	68.7	40.5	29.0	24.2	18.5	16.2
			225	78.7	48.5	35.1	29.2	22.2	19.1
			230	82.0	51.3	37.4	31.1	23.5	20.1
			240		57.1	42.1	35.0	26.4	22.4
			255		66.0	49.8	41.4	31.2	26.1
			270		75.3	58.0	48.4	36.5	30.3
			285		82.0	66.9	56.1	42.5	35.1
			300			76.1	64.3	49.1	40.4
			310			82.0	70.2	53.9	44.2
			315				73.2	56.4	46.2
			330				82.0	64.3	52.4
			345					72.5	59.3
			360					81.1	66.7
			365						69.4
			375						74.7
			390						82.0

table 10 : Maximum load applicable to a rebar bonded with HILTI HIT-CT 1 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.

HIT-CT 1									
Rebar diameter	Drill hole diameter	Rebar maximum load (kN)	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
20	25	101.2	200	67.0	35.3	25.7	21.7	17.3	15.7
			220	80.8	45.3	33.2	28.0	21.8	19.4
			240	95.4	56.7	42.1	35.4	27.3	23.8
			250	101.2	62.9	47.0	39.6	30.4	26.3
			260		69.3	52.2	44.1	33.7	29.0
			280		82.6	63.6	54.0	41.3	35.1
			300		96.6	76.2	64.9	49.9	42.2
			310		101.2	82.8	70.8	54.7	46.1
			320			89.5	77.0	59.8	50.3
			340			101.2	89.9	70.8	59.4
			360				101.2	82.6	69.5
			380					95.2	80.5
			390					101.2	86.3
			400						92.2
			415						101.2
22	27	122.4	220	88.9	49.8	36.5	30.8	24.0	21.3
			235	100.9	59.1	43.7	36.8	28.4	24.9
			250	113.1	69.2	51.7	43.5	33.4	28.9
			265	122.4	79.8	60.4	51.1	39.1	33.5
			280		90.9	70.0	59.3	45.4	38.6
			295		102.4	80.3	68.3	52.4	44.4
			310		114.3	91.1	77.9	60.2	50.7
			320		122.4	98.5	84.7	65.8	55.3
			325			102.2	88.2	68.7	57.7
			340			113.9	98.9	77.9	65.3
			355			122.4	110.1	87.5	73.6
			370				121.8	97.6	82.3
			375				122.4	101.1	85.4
			385					108.4	91.7
			400					119.3	101.4
			405					122.4	104.7
			415						111.5
			430						122.0
			435						122.4
24	29	145.7	240	120.0	66.3	45.6	39.2	30.9	27.6
			255	133.3	76.5	53.5	46.0	36.0	31.8
			270	145.7	87.5	62.2	53.7	41.8	36.6
			285		99.0	71.7	62.1	48.2	42.0
			300		111.1	82.1	71.2	55.3	47.8
			315		123.6	92.8	81.0	63.1	54.3
			330		136.7	104.4	91.5	71.6	61.4
			345		145.7	116.6	102.5	80.9	69.2
			360			129.2	113.9	90.9	77.7
			375			141.8	125.8	101.4	86.6
			380			145.7	129.9	105.0	89.8
			390				138.2	112.3	96.2
			400				145.7	119.8	102.9
			405					123.6	106.4
			420					135.4	117.3
			435					145.7	128.6
			450						140.3
			460						145.7

table 11 : Maximum load applicable to a rebar bonded with HILTI HIT-CT 1 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.

HIT-CT 1									
Rebar diameter	Drill hole diameter	Rebar maximum load (kN)	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	134.2	76.0	52.9	45.5	35.7	31.6
			265	148.1	87.2	61.7	53.1	41.4	36.4
			280	158.1	99.1	71.3	61.7	47.9	41.8
			295		111.5	81.8	70.9	55.1	47.7
			310		124.4	92.9	80.9	63.0	54.3
			325		137.8	104.6	91.6	71.6	61.4
			340		151.7	117.1	102.9	81.0	69.3
			350		158.1	125.8	110.7	87.7	75.0
			355			130.2	114.7	91.2	77.9
			370			143.3	126.9	102.0	87.1
			385			156.8	139.6	113.2	96.8
			390			158.1	144.0	117.0	100.2
			400				152.7	124.8	107.2
			410				158.1	132.8	114.6
			415					136.9	118.4
			430					149.4	130.0
			445					158.1	142.1
			460						154.5
			465						158.1

table 12 : Maximum load applicable to a rebar bonded with HILTI HIT-CT 1 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:

$$\tau = \left(\frac{\theta}{241{,}97} \right)^{-1{,}202}$$

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 13.

HIT-CT 1	
Maximum temperature in area (°C)	Bonding stress (MPa)
40	8.7
60	5.3
80	3.8
100	2.9
120	2.3

table 13 : 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 14.

HIT-CT 1 - Rebar anchorage depth (mm)							
Rebar diameter (mm)	Drill hole diameter (mm)	Rebar maximum load (kN)	Maximum temperature in area (°C)				
			40	60	80	100	120
8	10	16.2	118	193	272	356	444
10	12	25.3	148	241	341	445	554
12	16	36.4	178	289	409	534	665
14	18	49.6	207	337	477	624	
16	20	64.8	237	386	545		
18	22	82.0	266	434	613		
20	25	101.2	296	482	681		
22	27	122.4	326	530			
24	29	145.7	355	578			
25	30	158.1	370	603			

table 14 : anchorage depth applicable to a rebar bonded with HILTI HIT-CT 1 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 15 to table 17) 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.

HIT-CT 1 - 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	10	16.2	Layer n°1	139	171	195			
			Layer n°2	129	159	185			
			Layer n°3	127	156	182			
10	12	25.3	Layer n°1	153	188	213			
			Layer n°2	143	176	203			
			Layer n°3	141	173	200			
12	16	36.4	Layer n°1	167	203	230			
			Layer n°2	157	191	220			
			Layer n°3	155	188	217			
14	18	49.6	Layer n°1	180	217	245			
			Layer n°2	170	205	235			
			Layer n°3	169	202	232			
16	20	64.8	Layer n°1	194	230	259			
			Layer n°2	183	219	250			
			Layer n°3	182	216	247			
18	22	82.0	Layer n°1	207	244	273			
			Layer n°2	196	232	264			
			Layer n°3	195	229	261			
20	25	101.2	Layer n°1	219	257	287			
			Layer n°2	208	244	276			
			Layer n°3	208	242	274			
22	27	122.4	Layer n°1	232	270	300			
			Layer n°2	221	257	289			
			Layer n°3	220	255	287			
24	29	145.7	Layer n°1	245	283	313			
			Layer n°2	240	270	302			
			Layer n°3	240	268	301			
25	30	158.1	Layer n°1	252	289	320			
			Layer n°2	250	276	308			
			Layer n°3	250	275	307			

table 15 : anchorage depth applicable to a rebar bonded with HILTI HIT-CT 1 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.

HIT-CT 1 - 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	10	16.2	Layer n°1	139	170	188	213		
			Layer n°2	129	156	172	198		
			Layer n°3	127	152	166	191		
10	12	25.3	Layer n°1	153	186	206	232		
			Layer n°2	143	172	190	217		
			Layer n°3	141	168	185	211		
12	16	36.4	Layer n°1	167	201	222	250		
			Layer n°2	157	187	207	235		
			Layer n°3	155	183	201	229		
14	18	49.6	Layer n°1	180	215	238	266		
			Layer n°2	170	202	222	251		
			Layer n°3	168	198	217	245		
16	20	64.8	Layer n°1	193	229	252	281		
			Layer n°2	183	215	237	267		
			Layer n°3	181	211	231	260		
18	22	82.0	Layer n°1	206	242	266	295		
			Layer n°2	196	229	251	281		
			Layer n°3	194	225	246	275		
20	25	101.2	Layer n°1	219	255	280	309		
			Layer n°2	208	240	262	292		
			Layer n°3	207	237	258	287		
22	27	122.4	Layer n°1	232	268	293	323		
			Layer n°2	221	253	275	306		
			Layer n°3	220	251	271	301		
24	29	145.7	Layer n°1	245	281	306	336		
			Layer n°2	240	266	288	319		
			Layer n°3	240	264	285	315		
25	30	158.1	Layer n°1	252	288	313	343		
			Layer n°2	250	271	294	324		
			Layer n°3	250	270	291	321		

table 16 : anchorage depth applicable to a rebar bonded with HILTI HIT-CT 1 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.

HIT-CT 1 - 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	10	16.2	Layer n°1	140	171	193	211	239	261
			Layer n°2	130	158	178	194	221	244
			Layer n°3	128	153	171	186	212	234
10	12	25.3	Layer n°1	154	187	211	230	262	286
			Layer n°2	144	174	196	214	244	269
			Layer n°3	142	170	190	206	235	260
12	16	36.4	Layer n°1	168	202	227	248	281	308
			Layer n°2	158	189	212	231	264	291
			Layer n°3	156	185	206	224	255	282
14	18	49.6	Layer n°1	181	216	242	264	299	327
			Layer n°2	171	203	228	248	283	311
			Layer n°3	169	199	221	240	274	302
16	20	64.8	Layer n°1	194	230	257	279	315	345
			Layer n°2	184	217	242	263	299	329
			Layer n°3	183	213	236	256	290	321
18	22	82.0	Layer n°1	207	243	271	293	331	362
			Layer n°2	197	230	256	278	315	347
			Layer n°3	196	226	250	270	306	338
20	25	101.2	Layer n°1	220	257	284	307	346	378
			Layer n°2	209	241	267	288	326	359
			Layer n°3	208	239	262	282	318	350
22	27	122.4	Layer n°1	233	270	298	321	361	393
			Layer n°2	222	254	280	302	341	374
			Layer n°3	221	252	276	296	333	366
24	29	145.7	Layer n°1	246	283	311	334	375	408
			Layer n°2	240	267	293	315	355	389
			Layer n°3	240	265	289	310	347	381
25	30	158.1	Layer n°1	252	289	317	341	382	416
			Layer n°2	250	273	298	320	359	394
			Layer n°3	250	272	295	316	353	387

table 17 : anchorage depth applicable to a rebar bonded with HILTI HIT-CT 1 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.