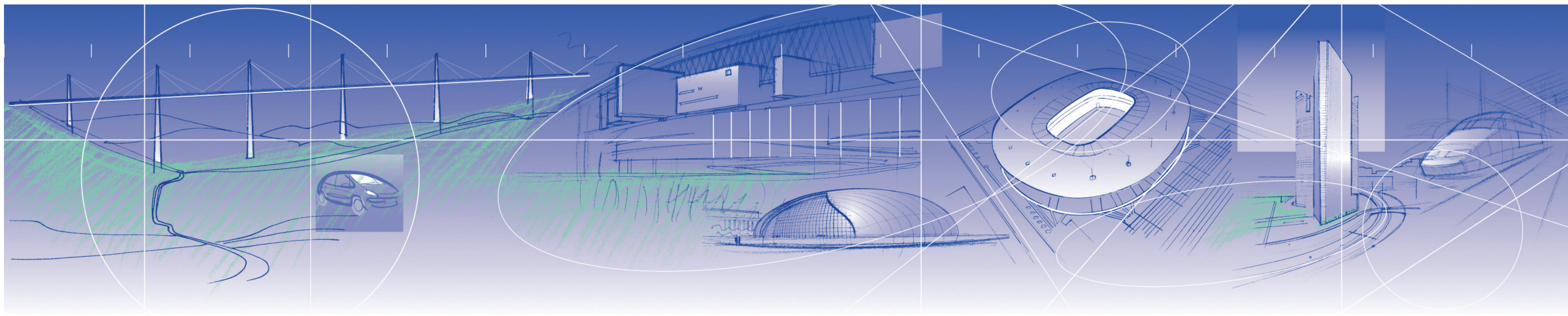

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REPORT No 26033756 – HIT-HY 200-A&R

on

HILTI HIT-HY 200-A and HILTI HIT-HY 200-R injection systems
in conjunction with concrete reinforcing bar (ϕ 8 to 32 mm)
and subjected to fire exposure

REQUESTED BY:

HILTI Aktiengesellschaft
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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

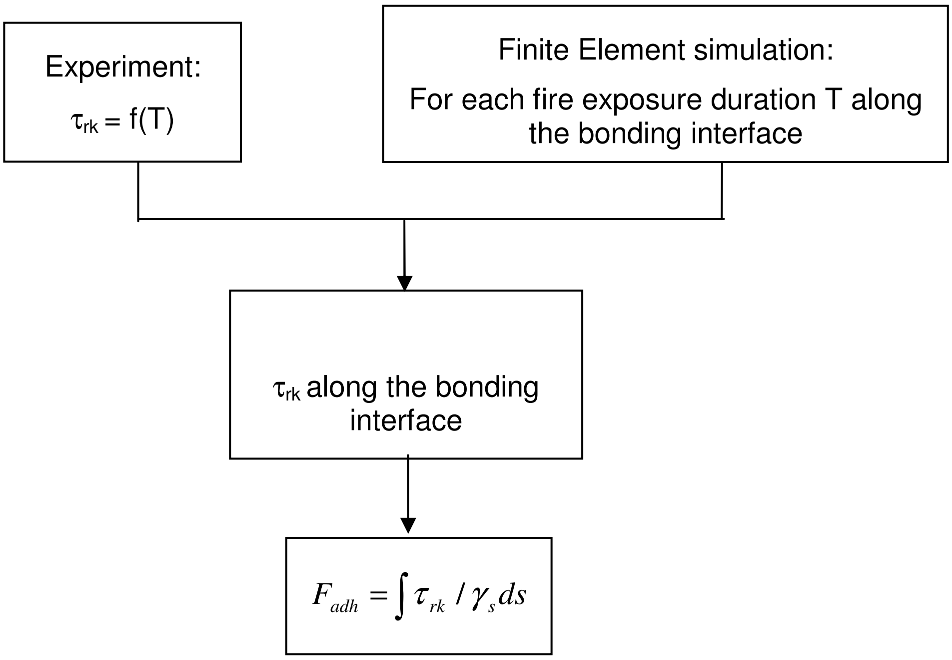
1 SCOPE

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 32 mm).

The maximum loads applicable through a rebar in conjunction with HILTI HIT-HY 200-A and HILTI HIT-HY 200-R 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 maximum loads presented hereafter are valid for HILTI HIT-HY 200-A and for HILTI HIT-HY 200-R. We will thus note HILTI HIT-HY 200-A&R in the continuation of the document.

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-HY 200-A&R 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-HY 200-A&R 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-HY 200-A&R 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-HY 200-A&R under fire exposure. These tests are carried out from 15/07/2011 to 30/09/2011 in the fire resistance laboratory of the CSTB at the MARNE-LA-VALLEE Research Centre.

Step 1: Determination of the most unfavourable mortar used with reinforcement bar (rebar):

Diameter	Embedment depth	HY 200 resin type	Applied load*
[mm]	[mm]	A and R	[kN]
12	120	A	3.0
			10.0
			20.0
			30.0
			50.0
		R	3.0
			10.0
			20.0
			30.0
			50.0

Step 2: Remaining tests necessary for fire evaluation of the most unfavorable resin determined in Step 1 used with reinforcement bar (rebar):

Diameter [mm]	Embedment depth [mm]	Applied load* [kN]
8	80	3.0
		9.0
10	100	5.0
		15.0
12	120	5.0
		7.5
		12.5
		15.0
		25.0
		35.0
		40.0
16	160	10.0
		25.0
20	200	10.0
		25.0

*: The applied loads will be adapted if necessary to the resin's characteristics.

table 1 : Test initial 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 calibrated springs which kept constant the load level or by means of hydraulic jack.

figure 1: Monitoring device

figure 2: Loading device

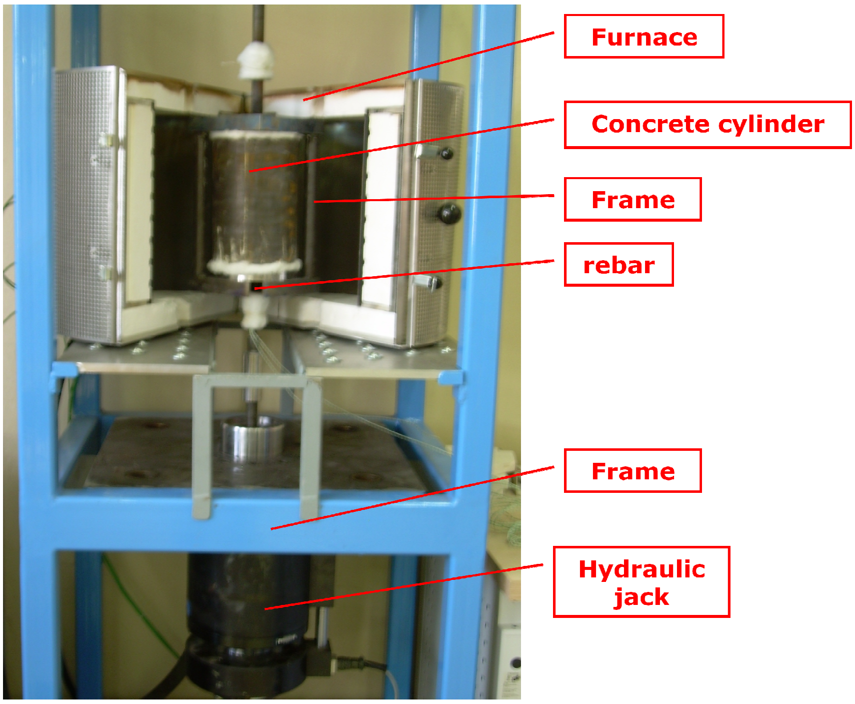


figure 3: high temperature, regulated, furnace

3.3 Test specimen

The HILTI HIT-HY 200-A and HILTI HIT-HY 200-R is a 5:1 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 8 mm and 32 mm, grade b500 is then inserted into the resin.

Hilti HIT-HY 200-A	Hilti HIT-HY 200-R

figure 4: Mortar Hilti HIT-HY 200 (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.

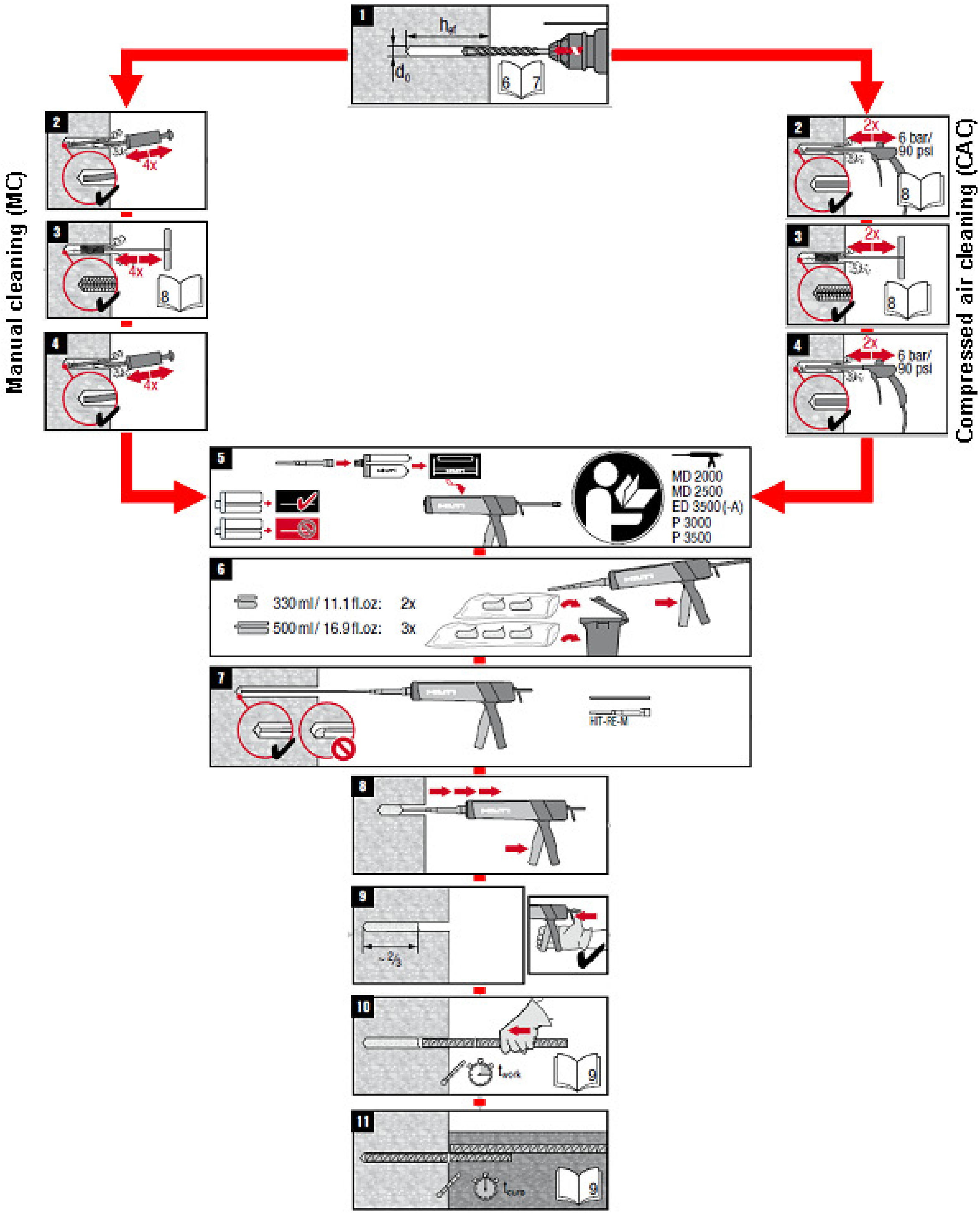


table 2 : Installation instruction, cleaning methods: manual cleaning (4x blowing, 4x brushing, 4xblowing: for rebar diameter 8 to 16 with embedment depth ≤ 250 only) or compressed air cleaning (2x blowing, 2x brushing, 2xblowing)

a) Manual cleaning

b) Compressed air cleaning

figure 4**:** Cleaning method

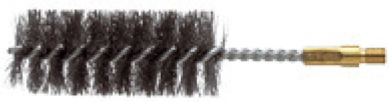


figure 5: Brushes Hilti HIT-RB for cleaning the drill holes.

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-HY 200-A&R 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.

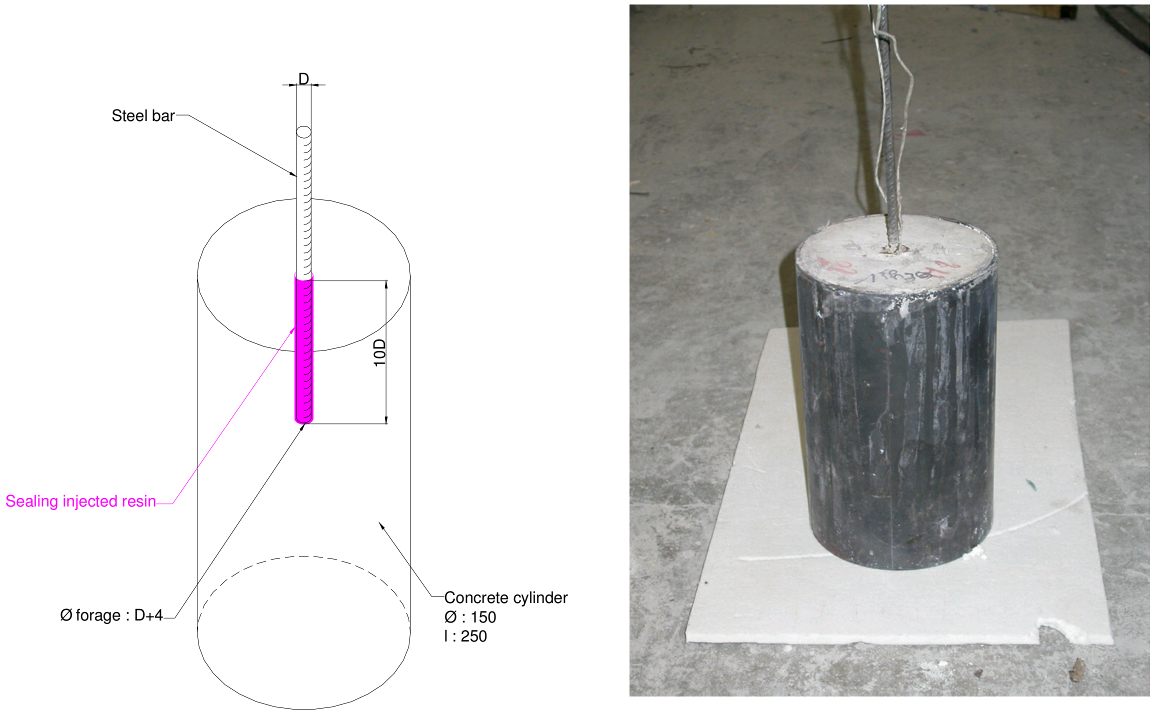


figure 7: Steel-encased concrete cylinders

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	3.0	182
		9.0	125
10	100	5.0	207
		15.0	131
12	120	3.0	272
		5.0	234
		7.5	209
		10.1	197
		12.5	180
		15.0	153
		20.0	129
		25.0	123
		30.1	104
		35.0	100
		40.1	83
		50.0	51
16	160	10.1	225
		25.0	165
20	200	10.0	267
		25.0	192

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:

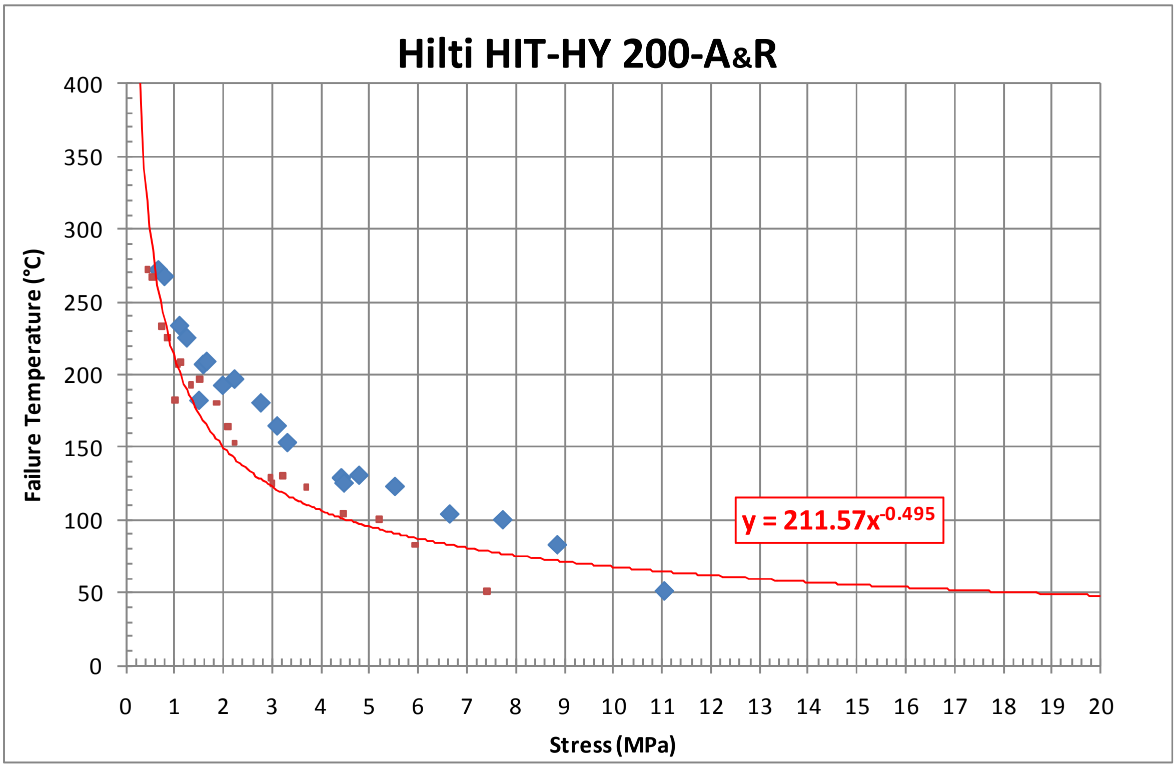


figure 9 : HILTI HIT-HY 200-A&R Characteristic bonding stress – temperature relationship (blue points are experimental results, red points are the corresponding characteristic values).

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.

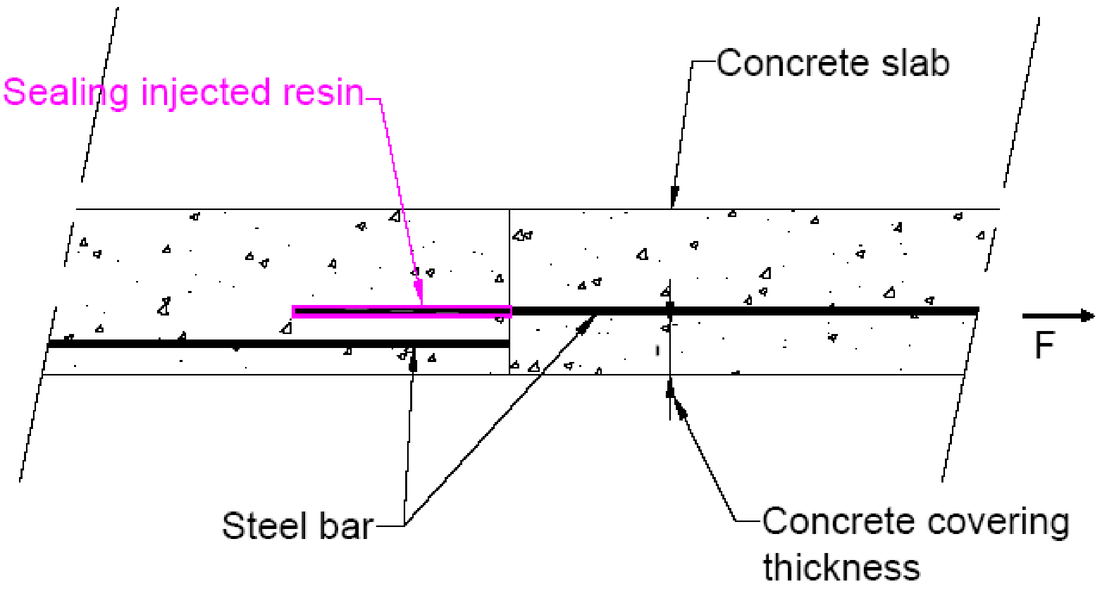


Figure 10 : Slab to slab connection

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

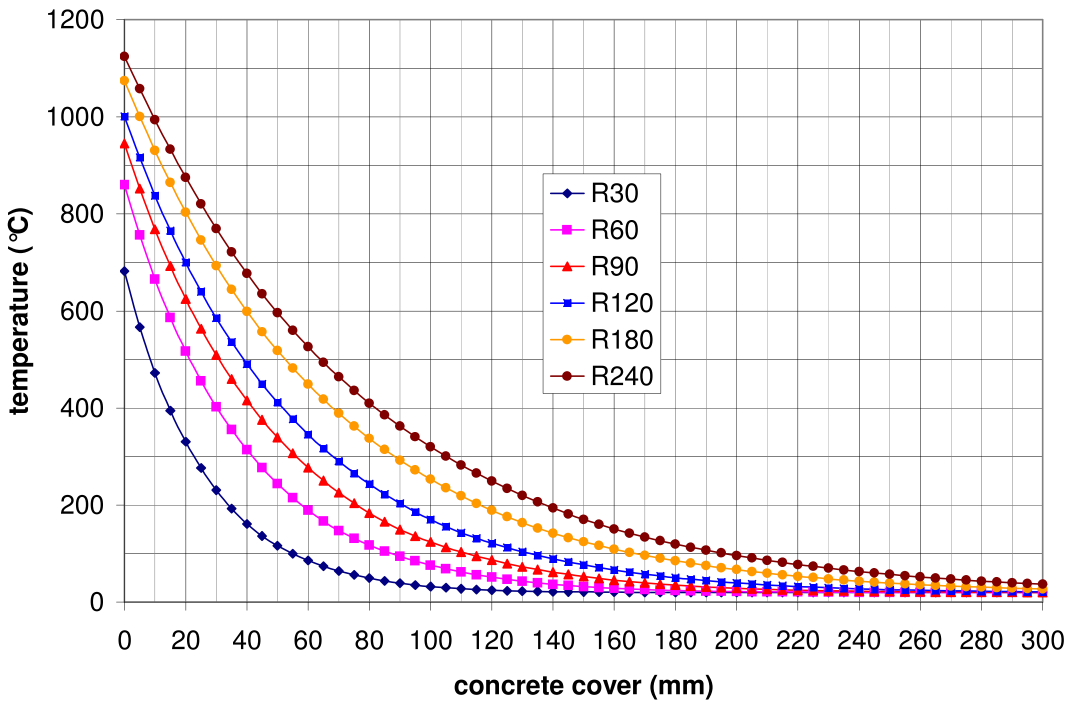


Figure 11 : Temperature at the bonding interface as a function of concrete cover.

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

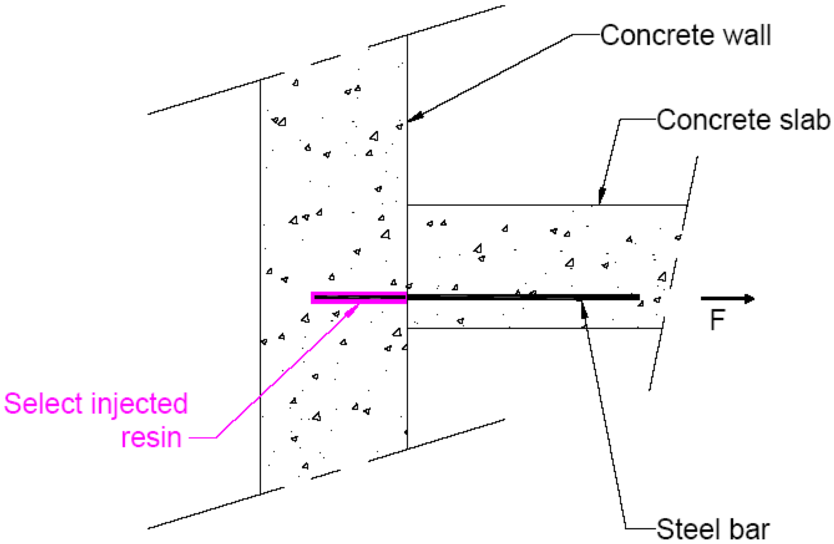


Figure 12 : Wall to slab connection

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	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*
25	30	*25*	75	*25*	75	*25*	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℃, 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.

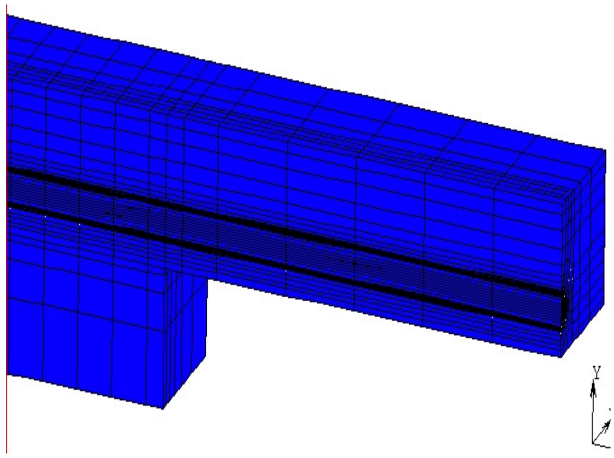


Figure 13 : Mesh used for the wall to slab connection temperature model.

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.

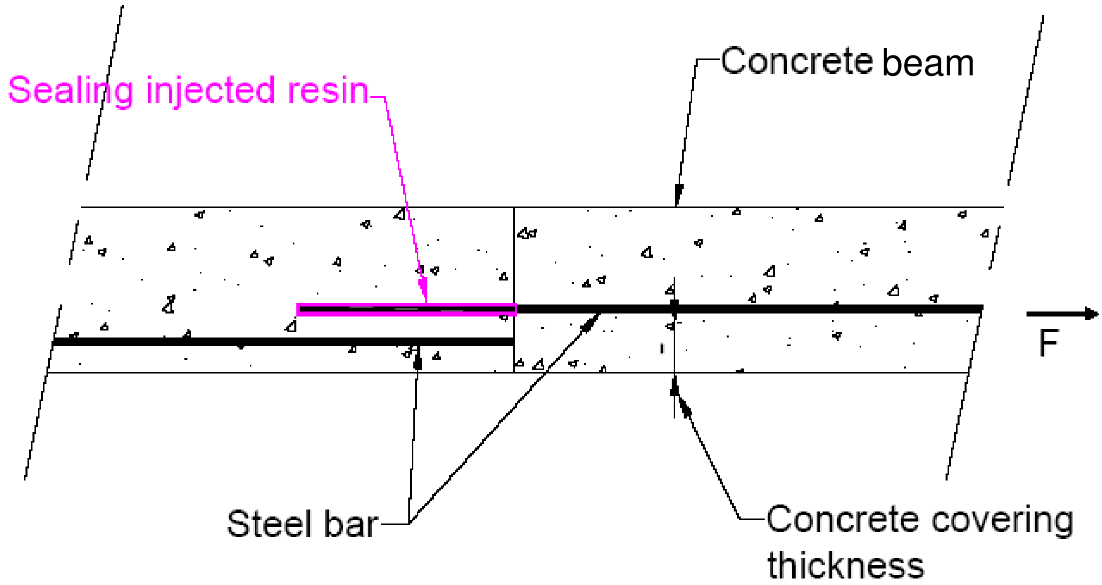


Figure 15 : beam to beam connection

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).

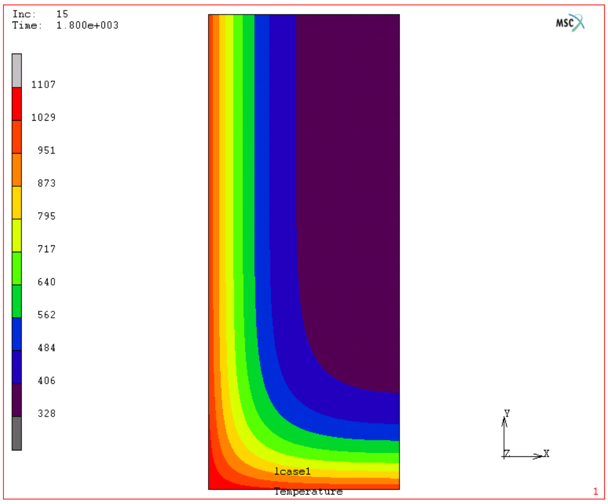


Figure 16: An example of temperature profile (T °Kelvin) – fire duration = 30 minutes – beam's width = 20 cm

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.

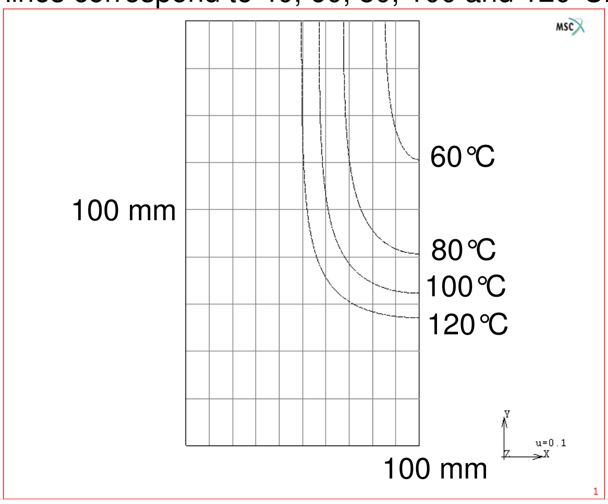


Figure 17: Temperature contour lines for beam's width = 20 cm and fire duration = 30 min

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

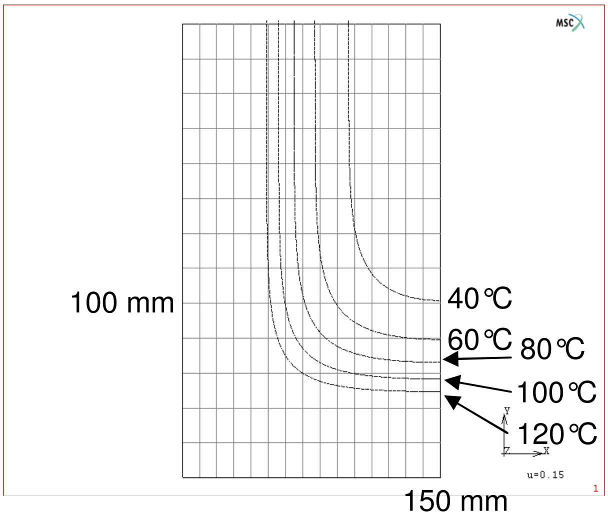


Figure 18: Temperature contour lines for beam's width = 30 cm and fire duration = 30 min

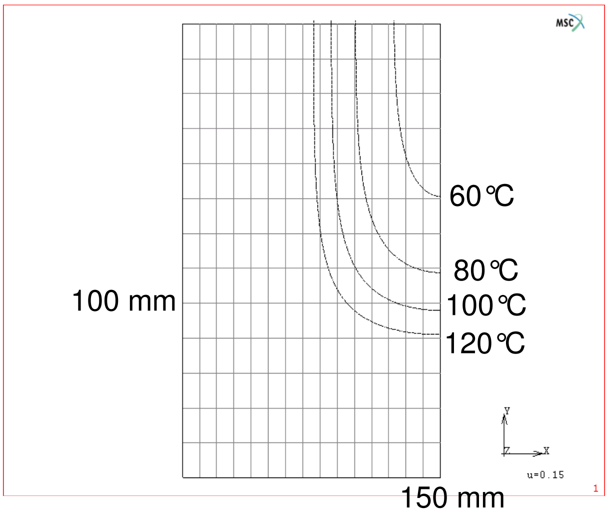


Figure 19: Temperature contour lines for beam's width = 30 cm and fire duration = 60 min

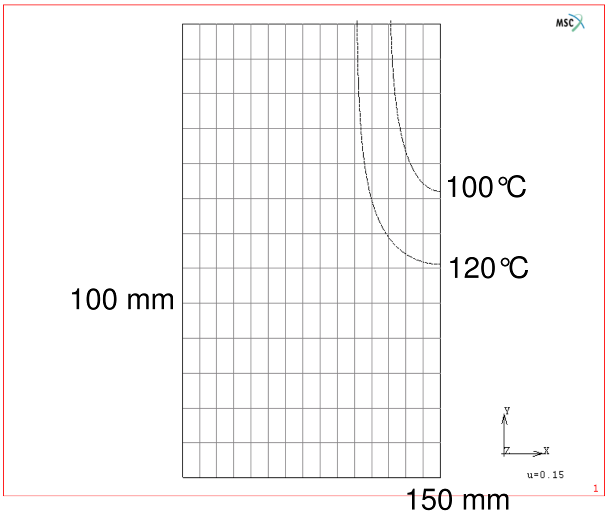


Figure 20: Temperature contour lines for beam's width = 30 cm and fire duration = 90 min

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

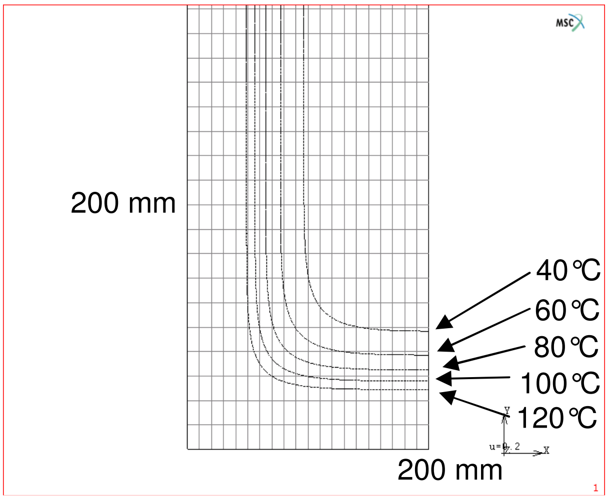


Figure 21: Temperature contour lines for beam's width = 40 cm and fire duration = 30 min

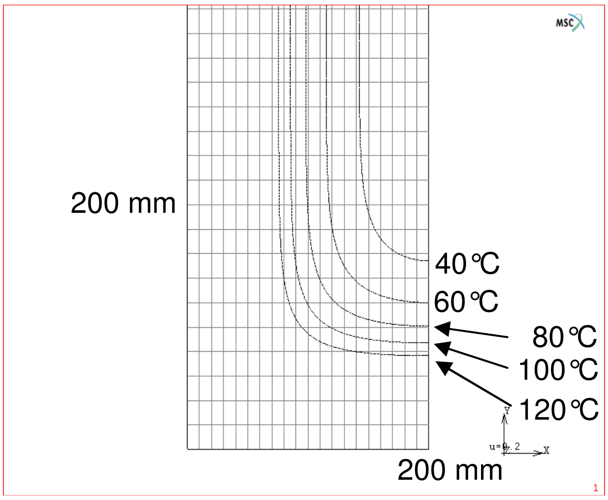


Figure 22: Temperature contour lines for beam's width = 40 cm and fire duration = 60 min

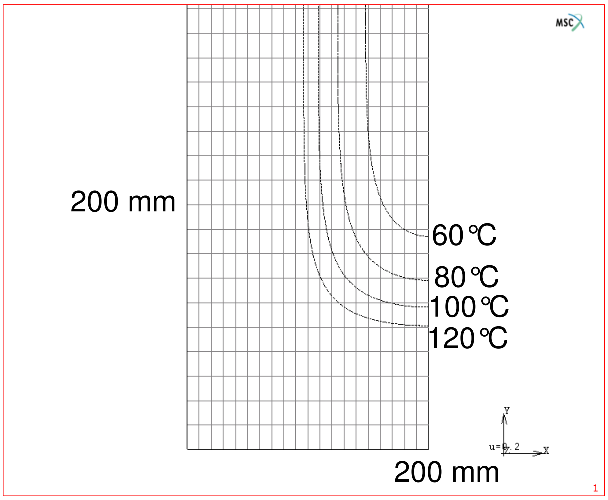


Figure 23: Temperature contour lines for beam's width = 40 cm and fire duration = 90 min

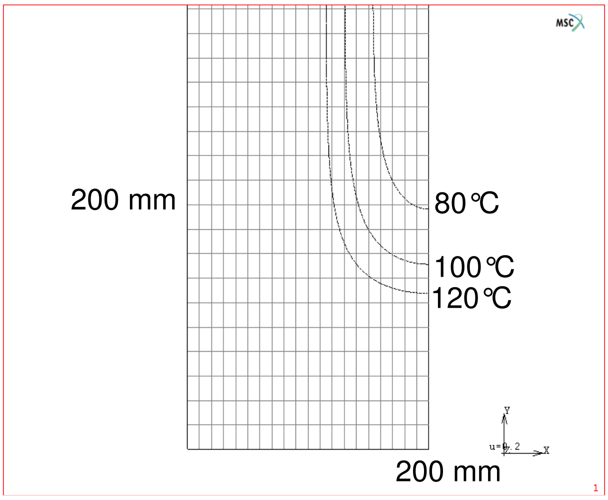


Figure 24: Temperature contour lines for beam's width = 40 cm and fire duration = 120 minutes

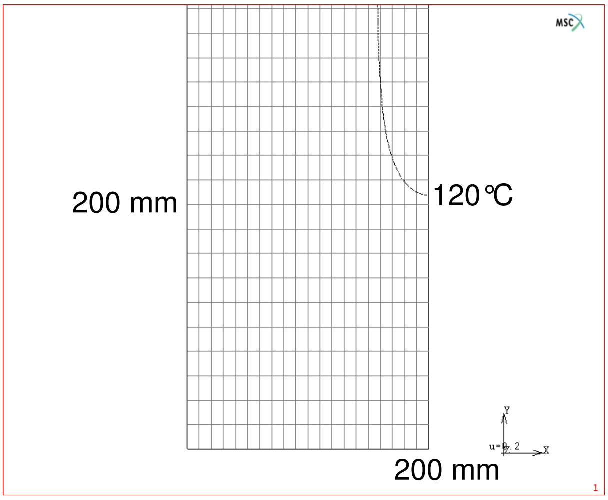


Figure 25: Temperature contour lines for beam's width = 40 cm and fire duration = 180 minutes

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

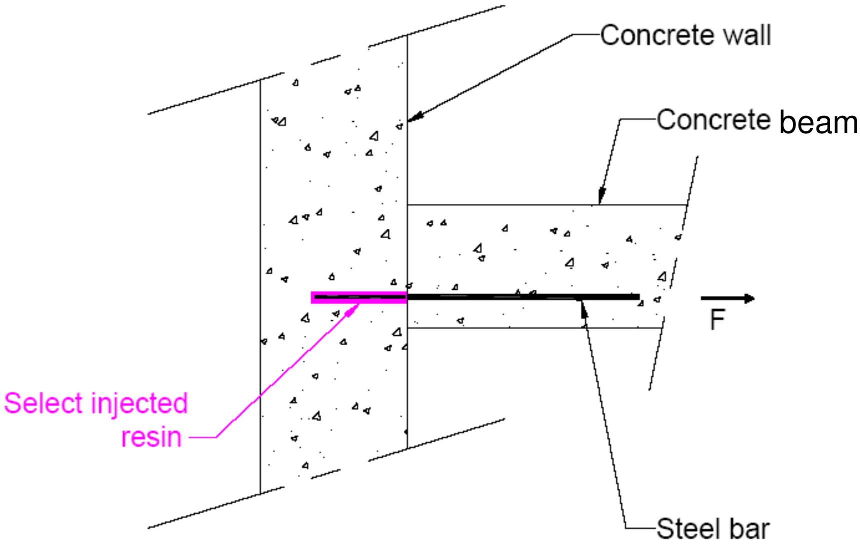


Figure 26: Wall to beam connection

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.

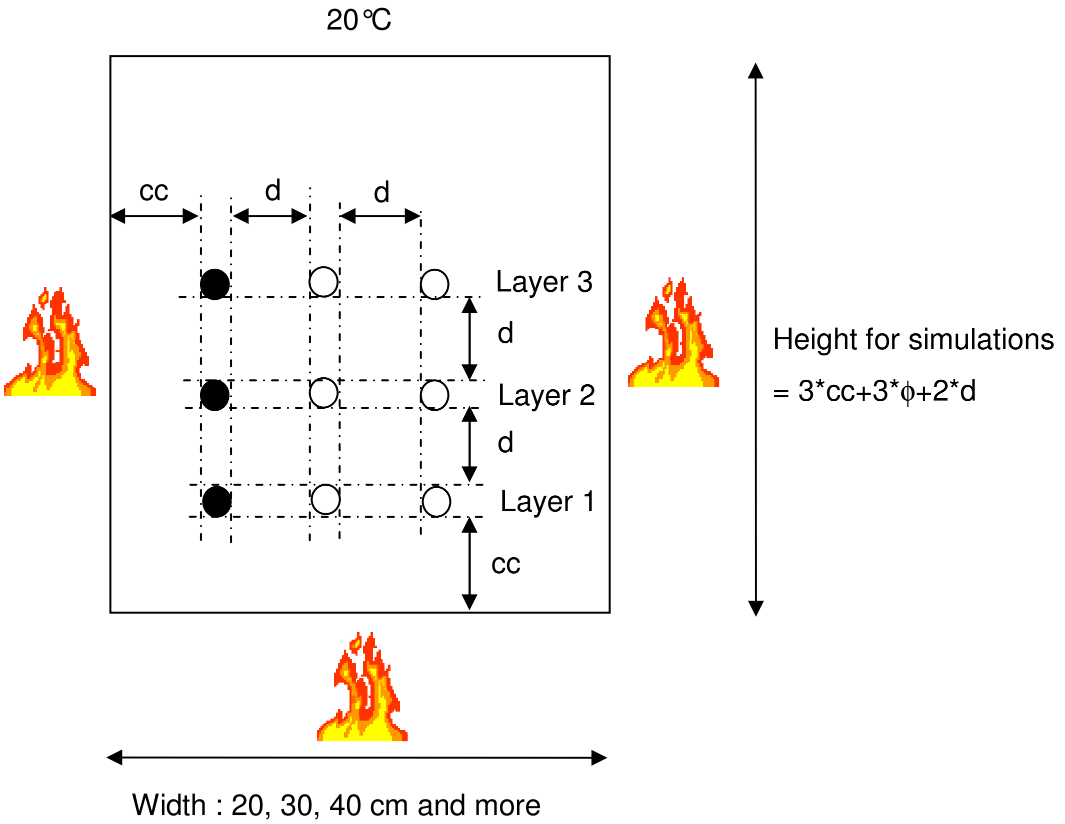


Figure 27: reinforcement frame

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	25	32
Distance between layers (mm)	60	60	60	60	60	66	75	81	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.

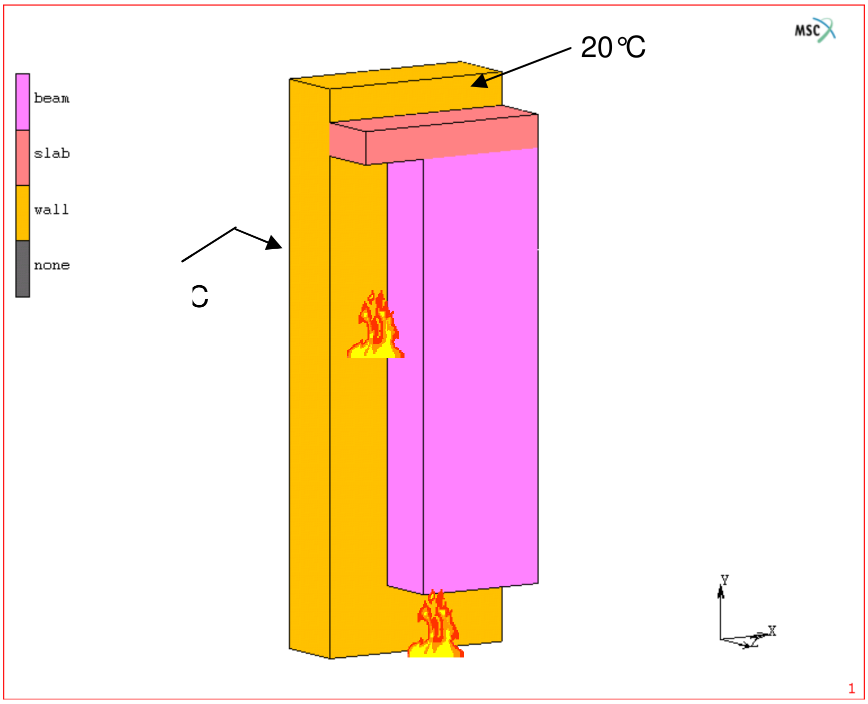


Figure 28: Mesh used for the wall to beam connection temperature model.

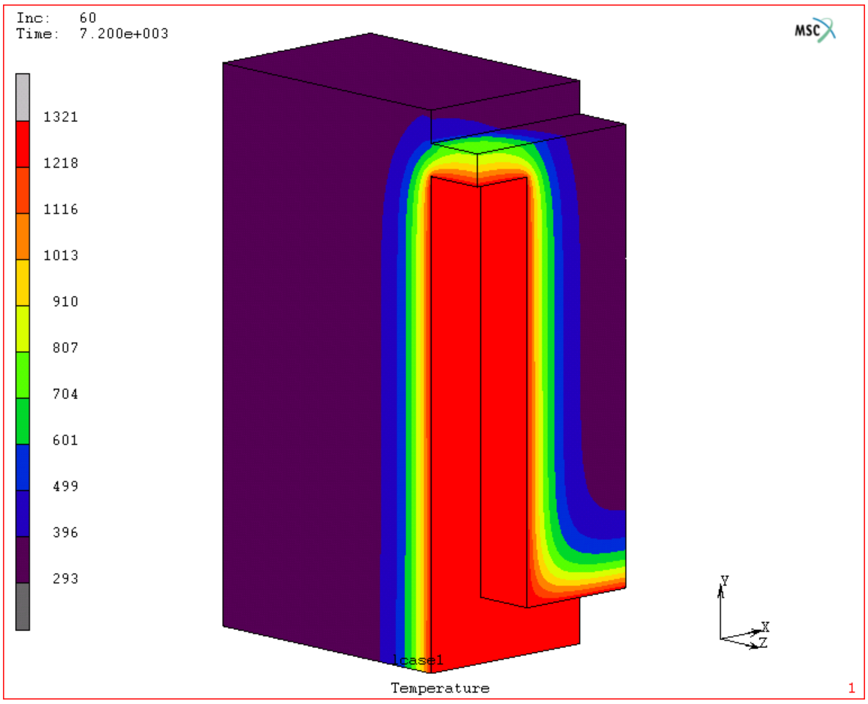


Figure 29: An example of temperature profile (T °Kelvin) – fire duration = 2 hours – beam's width = 40 cm.

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:

$$\tau = \left(\frac{\theta}{211{,}57} \right)^{-2{,}02} \qquad (1)$$

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.

<table>
<tr><th>HILTI HIT-HY 200-A&R</th><th colspan="6">Bonding stress (MPa)</th></tr>
<tr><th>Concrete cover (mm)</th><th>R 30</th><th>R 60</th><th>R 90</th><th>R 120</th><th>R 180</th><th>R 240</th></tr>
<tr><td>10</td><td>0.2</td><td></td><td rowspan="2"></td><td rowspan="3"></td><td rowspan="4"></td><td rowspan="6"></td></tr>
<tr><td>20</td><td>0.4</td><td>0.2</td></tr>
<tr><td>30</td><td>0.8</td><td>0.3</td><td>0.2</td></tr>
<tr><td>40</td><td>1.7</td><td>0.5</td><td>0.2</td><td>0.2</td></tr>
<tr><td>50</td><td>3.3</td><td>0.8</td><td>0.4</td><td>0.3</td><td>0.2</td></tr>
<tr><td>60</td><td>6.4</td><td>1.2</td><td>0.6</td><td>0.4</td><td>0.2</td></tr>
<tr><td>70</td><td>9.7</td><td>2.0</td><td>0.9</td><td>0.5</td><td>0.3</td><td>0.2</td></tr>
<tr><td>80</td><td>12.0</td><td>3.3</td><td>1.3</td><td>0.8</td><td>0.4</td><td>0.3</td></tr>
<tr><td>90</td><td>13.5</td><td>5.2</td><td>1.9</td><td>1.1</td><td>0.5</td><td>0.3</td></tr>
<tr><td>100</td><td>14.5</td><td>7.8</td><td>2.8</td><td>1.5</td><td>0.7</td><td>0.4</td></tr>
<tr><td>110</td><td>15.2</td><td>9.9</td><td>4.1</td><td>2.2</td><td>1.0</td><td>0.6</td></tr>
<tr><td>120</td><td>15.7</td><td>11.6</td><td>5.9</td><td>3.0</td><td>1.3</td><td>0.7</td></tr>
<tr><td>130</td><td>16.0</td><td>12.8</td><td>8.0</td><td>4.2</td><td>1.7</td><td>0.9</td></tr>
<tr><td>140</td><td>16.2</td><td>13.7</td><td>9.8</td><td>5.8</td><td>2.2</td><td>1.2</td></tr>
<tr><td>150</td><td>16.3</td><td>14.4</td><td>11.1</td><td>7.7</td><td>2.9</td><td>1.5</td></tr>
<tr><td>160</td><td>16.4</td><td>15.0</td><td>12.3</td><td>9.3</td><td>3.8</td><td>2.0</td></tr>
<tr><td>170</td><td>16.5</td><td>15.4</td><td>13.1</td><td>10.6</td><td>5.0</td><td>2.5</td></tr>
<tr><td>180</td><td>16.5</td><td>15.7</td><td>13.8</td><td>11.7</td><td>6.4</td><td>3.2</td></tr>
<tr><td>190</td><td>16.5</td><td>15.9</td><td>14.4</td><td>12.6</td><td>7.9</td><td>4.0</td></tr>
<tr><td>200</td><td rowspan="28">16.6</td><td>16.1</td><td>14.8</td><td>13.3</td><td>9.2</td><td>5.0</td></tr>
<tr><td>210</td><td>16.2</td><td>15.2</td><td>13.9</td><td>10.3</td><td>6.2</td></tr>
<tr><td>220</td><td>16.3</td><td>15.5</td><td>14.4</td><td>11.3</td><td>7.6</td></tr>
<tr><td>230</td><td>16.4</td><td>15.7</td><td>14.9</td><td>12.1</td><td>8.7</td></tr>
<tr><td>240</td><td>16.4</td><td>15.9</td><td>15.2</td><td>12.8</td><td>9.8</td></tr>
<tr><td>250</td><td>16.5</td><td>16.0</td><td>15.5</td><td>13.3</td><td>10.7</td></tr>
<tr><td>260</td><td>16.5</td><td>16.2</td><td>15.7</td><td>13.8</td><td>11.5</td></tr>
<tr><td>270</td><td>16.5</td><td>16.2</td><td>15.9</td><td>14.3</td><td>12.2</td></tr>
<tr><td>280</td><td>16.5</td><td>16.3</td><td>16.0</td><td>14.6</td><td>12.8</td></tr>
<tr><td>290</td><td rowspan="19">16.6</td><td>16.4</td><td>16.2</td><td>14.9</td><td>13.3</td></tr>
<tr><td>300</td><td>16.4</td><td>16.3</td><td>15.2</td><td>13.8</td></tr>
<tr><td>310</td><td>16.5</td><td>16.4</td><td>15.4</td><td>14.2</td></tr>
<tr><td>320</td><td rowspan="16">16.6</td><td>16.4</td><td>15.6</td><td>14.5</td></tr>
<tr><td>330</td><td>16.5</td><td>15.8</td><td>14.8</td></tr>
<tr><td>340</td><td>16.5</td><td>15.9</td><td>15.1</td></tr>
<tr><td>350</td><td rowspan="13">16.6</td><td>16.1</td><td>15.3</td></tr>
<tr><td>360</td><td>16.2</td><td>15.5</td></tr>
<tr><td>370</td><td>16.2</td><td>15.7</td></tr>
<tr><td>380</td><td>16.3</td><td>15.9</td></tr>
<tr><td>390</td><td>16.4</td><td>16.0</td></tr>
<tr><td>400</td><td>16.4</td><td>16.1</td></tr>
<tr><td>410</td><td>16.5</td><td>16.2</td></tr>
<tr><td>420</td><td>16.5</td><td>16.3</td></tr>
<tr><td>430</td><td rowspan="5">16.6</td><td>16.4</td></tr>
<tr><td>440</td><td>16.4</td></tr>
<tr><td>450</td><td>16.5</td></tr>
<tr><td>460</td><td rowspan="2">16.6</td></tr>
<tr><td>470</td></tr>
</table>

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.

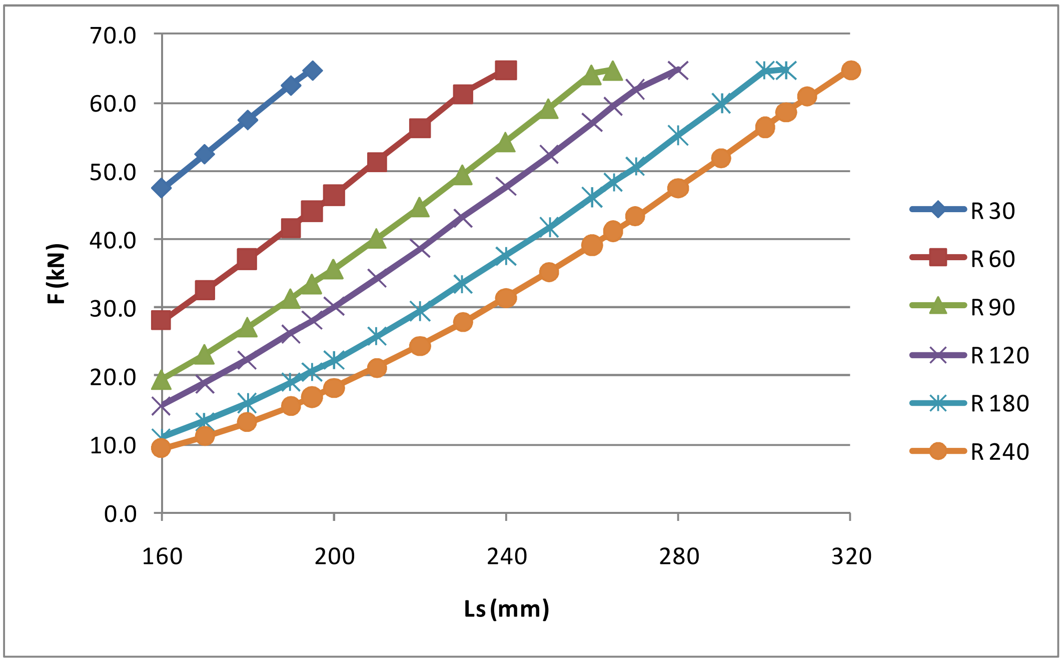


Figure 30: Maximum force of rebar (ϕ=16mm) in conjunction with HILTI HIT-HY 200-A&R.

HILTI HIT-HY 200-A&R									
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	10	16.2	80	5.8	2.4	1.4	1.2	1.0	1.0
			90	7.8	3.4	2.0	1.6	1.3	1.3
			100	9.9	4.8	2.7	2.1	1.6	1.6
			110	12.2	6.4	3.7	2.8	2.1	1.9
			120	14.6	8.3	5.0	3.7	2.6	2.3
			130	16.2	10.3	6.5	4.9	3.3	2.8
			140		12.4	8.2	6.2	4.1	3.4
			150		14.7	10.1	7.8	5.2	4.1
			160		16.2	12.1	9.5	6.4	4.9
			170			14.2	11.4	7.8	5.9
			180			16.2	13.4	9.4	7.1
			190				15.6	11.1	8.4
			195				16.2	12.0	9.1
			200					13.0	9.9
			210					14.9	11.5
			220					16.2	13.2
			230						15.0
			240						16.2
10	12	25.3	100	11.8	5.6	3.2	2.6	2.0	1.9
			110	14.6	7.5	4.3	3.4	2.5	2.3
			120	17.5	9.6	5.8	4.4	3.2	2.8
			130	20.5	12.0	7.5	5.7	3.9	3.4
			140	23.5	14.6	9.6	7.3	4.9	4.1
			150	25.3	17.4	11.8	9.2	6.1	5.0
			160		20.2	14.2	11.3	7.5	6.0
			170		23.2	16.8	13.6	9.2	7.2
			180		25.3	19.6	16.0	11.0	8.6
			190			22.4	18.6	13.1	10.2
			200			25.3	21.3	15.3	12.0
			210				24.1	17.7	14.0
			215				25.3	18.9	15.1
			220					20.2	16.1
			230					22.8	18.4
			240					25.3	20.8
			250						23.3
			260						25.3
12	16	36.4	120	20.5	10.7	6.5	5.0	3.7	3.5
			130	24.0	13.4	8.4	6.3	4.6	4.3
			140	27.7	16.4	10.7	8.0	5.7	5.2
			150	31.3	19.5	13.2	10.0	7.1	6.2
			160	35.1	22.9	16.0	12.2	8.7	7.4
			165	36.4	24.6	17.5	13.4	9.7	8.1
			170		26.3	19.0	14.7	10.7	8.9
			180		29.8	22.2	17.4	12.8	10.6
			190		33.5	25.5	20.2	15.2	12.6
			200		36.4	28.9	23.3	17.8	14.7
			210			32.4	26.4	20.6	17.1
			220			35.9	29.7	23.5	19.6
			225			36.4	31.4	25.0	20.9
			230				33.1	26.6	22.3
			240				36.4	29.7	25.1
			250					33.0	28.1
			260					36.4	31.1
			265						32.7
			270						34.3
			280						36.4

table 9 : Maximum load applicable to a rebar bonded with HILTI HIT-HY 200-A&R 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.

HILTI HIT-HY 200-A&R									
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
14	18	49.6	140	32.5	18.4	12.0	9.3	6.3	5.9
			150	36.7	21.9	14.9	11.7	7.8	7.1
			160	41.1	25.7	18.1	14.3	9.5	8.5
			170	45.5	29.6	21.5	17.3	11.6	10.1
			180	49.6	33.7	25.1	20.5	14.0	12.0
			190		37.8	28.8	23.9	16.7	14.2
			200		42.1	32.8	27.5	19.6	16.6
			210		46.4	36.8	31.2	22.7	19.3
			220		49.6	40.9	35.1	26.0	22.2
			230			45.1	39.1	29.5	25.3
			240			49.4	43.2	33.1	28.5
			245			49.6	45.3	35.0	30.2
			250				47.4	36.9	31.9
			260				49.6	40.7	35.5
			270					44.7	39.1
			280					48.7	42.9
			285					49.6	44.8
			290						46.8
			300						49.6
16	20	64.8	160	47.4	28.1	19.4	15.7	11.0	9.4
			170	52.4	32.5	23.2	18.9	13.4	11.2
			180	57.5	37.0	27.1	22.4	16.0	13.2
			190	62.6	41.7	31.3	26.2	19.0	15.6
			195	64.8	44.1	33.5	28.1	20.6	16.9
			200		46.5	35.7	30.1	22.3	18.3
			210		51.3	40.1	34.3	25.8	21.2
			220		56.3	44.8	38.6	29.5	24.4
			230		61.3	49.5	43.1	33.4	27.8
			240		64.8	54.3	47.7	37.5	31.4
			250			59.2	52.3	41.8	35.2
			260			64.1	57.1	46.2	39.2
			265			64.8	59.5	48.4	41.2
			270				61.9	50.6	43.3
			280				64.8	55.2	47.5
			290					59.9	51.9
			300					64.6	56.3
			305					64.8	58.6
			310						60.9
			320						64.8
18	22	82.0	180	65.5	41.7	30.5	25.2	18.0	14.9
			190	71.3	46.9	35.2	29.4	21.4	17.5
			200	77.0	52.3	40.1	33.9	25.1	20.6
			210	82.0	57.7	45.2	38.6	29.0	23.9
			220		63.3	50.4	43.5	33.2	27.5
			230		68.9	55.7	48.5	37.6	31.3
			240		74.6	61.1	53.6	42.2	35.4
			250		80.3	66.6	58.9	47.0	39.6
			255		82.0	69.4	61.5	49.4	41.8
			260			72.1	64.2	51.9	44.1
			270			77.8	69.7	56.9	48.7
			280			82.0	75.2	62.1	53.5
			290				80.7	67.3	58.4
			295				82.0	70.0	60.9
			300					72.7	63.4
			310					78.1	68.5
			320					82.0	73.7
			330						78.9
			340						82.0

table 10 : Maximum load applicable to a rebar bonded with HILTI HIT-HY 200-A&R 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.

HILTI HIT-HY 200-A&R									
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**
20	25	101.2	200	86.0	54.5	41.4	34.7	25.7	21.7
			210	92.4	60.4	46.7	39.7	29.7	25.2
			220	98.8	66.4	52.3	44.9	34.1	28.9
			225	101.2	69.4	55.1	47.5	36.4	30.9
			230		72.5	58.0	50.2	38.8	32.9
			240		78.7	63.8	55.7	43.6	37.2
			250		84.9	69.7	61.4	48.7	41.8
			260		91.2	75.7	67.1	53.9	46.5
			270		97.5	81.8	73.0	59.3	51.4
			280		101.2	88.0	79.0	64.9	56.6
			290			94.2	85.1	70.5	61.8
			300			100.5	91.2	76.3	67.2
			305			101.2	94.3	79.2	70.0
			310				97.4	82.2	72.8
			320				101.2	88.2	78.4
			330					94.2	84.2
			340					100.3	90.0
			345					101.2	93.0
			350						96.0
			360						101.2
22	27	122.4	220	108.6	73.0	57.5	49.3	37.5	31.8
			230	115.7	79.7	63.8	55.2	42.6	36.2
			240	122.4	86.5	70.2	61.3	48.0	41.0
			250		93.4	76.7	67.5	53.6	45.9
			260		100.3	83.3	73.9	59.3	51.1
			270		107.3	90.0	80.3	65.3	56.6
			280		114.2	96.8	86.9	71.4	62.2
			290		121.3	103.6	93.6	77.6	68.0
			295		122.4	107.1	96.9	80.7	71.0
			300			110.6	100.3	83.9	74.0
			310			117.5	107.1	90.4	80.0
			320			122.4	114.0	97.0	86.3
			330				120.9	103.6	92.6
			335				122.4	107.0	95.8
			340					110.4	99.0
			350					117.1	105.5
			360					122.4	112.1
			370						118.8
			380						122.4
25	30	158.1	250	156.0	107.0	81.6	72.2	57.4	49.8
			255	158.1	110.9	85.2	75.7	60.5	52.6
			260		114.7	88.9	79.2	63.6	55.4
			270		122.5	96.2	86.3	70.1	61.4
			280		130.4	103.8	93.6	76.8	67.5
			290		138.3	111.4	101.0	83.6	73.9
			300		146.2	119.1	108.5	90.6	80.4
			310		154.2	126.8	116.1	97.7	87.0
			315		158.1	130.7	119.9	101.3	90.4
			320			134.6	123.7	104.9	93.9
			330			142.5	131.4	112.3	100.9
			340			150.4	139.2	119.8	108.0
			350			158.1	147.0	127.3	115.2
			360				154.9	135.0	122.6
			365				158.1	138.8	126.3
			370					142.7	130.0
			380					150.4	137.5
			390					158.1	145.0
			400						152.7
			410						158.1

table 11 : Maximum load applicable to a rebar bonded with HILTI HIT-HY 200-A&R 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.

HILTI HIT-HY 200-A&R									
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
32	40	259.0	320	259.0	218.1	172.1	148.1	126.5	114.8
			330		228.3	182.0	157.7	135.6	123.4
			340		238.6	192.0	167.4	144.8	132.2
			350		248.9	202.0	177.1	154.2	141.2
			360		259.0	212.0	187.0	163.6	150.3
			370			222.1	196.9	173.2	159.6
			380			232.3	206.9	182.9	169.0
			390			242.5	216.9	192.7	178.5
			400			252.7	226.9	202.6	188.0
			410			259.0	237.0	212.5	197.7
			420				247.2	222.4	207.5
			430				257.4	232.4	217.3
			435				259.0	237.5	222.2
			440					242.5	227.2
			450					252.6	237.1
			460					259.0	247.0
			470						257.0
			475						259.0

table 12 : Maximum load applicable to a rebar bonded with HILTI HIT-HY 200-A&R 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:

$$\tau = \left(\frac{\theta}{211{,}57} \right)^{-2{,}02}$$

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.

HILTI HIT-HY 200-A&R	
Maximum temperature in area (°C)	**Bonding stress (MPa)**
40	13.4
60	10.3
80	7.1
100	4.5
120	3.1

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.

HILTI HIT-HY 200-A&R - 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	80	100	145	227	328
10	12	25.3	100	125	181	284	410
12	16	36.4	120	150	217	340	492
14	18	49.6	140	175	253	397	574
16	20	64.8	160	200	289	454	656
18	22	82.0	180	225	325	510	
20	25	101.2	200	251	362	567	
22	27	122.4	220	276	398	624	
25	30	158.1	250	313	452		
32	40	259.0	320	401	579		

table 14 : anchorage depth applicable to a rebar bonded with HILTI HIT-HY 200-A&R 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.

HILTI HIT-HY 200-A&R - 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	121	143	160			
			Layer n°2	108	128	147			
			Layer n°3	107	125	144			
10	12	25.3	Layer n°1	137	160	178			
			Layer n°2	125	145	165			
			Layer n°3	123	142	162			
12	16	36.4	Layer n°1	153	177	195			
			Layer n°2	141	162	183			
			Layer n°3	139	159	179			
14	18	49.6	Layer n°1	168	193	212			
			Layer n°2	156	178	199			
			Layer n°3	155	175	196			
16	20	64.8	Layer n°1	184	208	228			
			Layer n°2	172	194	216			
			Layer n°3	170	191	212			
18	22	82.0	Layer n°1	199	224	244			
			Layer n°2	187	210	232			
			Layer n°3	186	207	228			
20	25	101.2	Layer n°1	215	240	260			
			Layer n°2	202	224	246			
			Layer n°3	201	222	244			
22	27	122.4	Layer n°1	230	255	275			
			Layer n°2	220	239	261			
			Layer n°3	220	238	260			
25	30	158.1	Layer n°1	254	279	299			
			Layer n°2	250	262	284			
			Layer n°3	250	261	283			
32	40	259.0	Layer n°1	320	333	353			
			Layer n°2	320	320	338			
			Layer n°3	320	320	337			

table 15 : anchorage depth applicable to a rebar bonded with HILTI HIT-HY 200-A&R 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.

HILTI HIT-HY 200-A&R - 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	121	141	152	174		
			Layer n°2	108	125	132	155		
			Layer n°3	107	120	126	148		
10	12	25.3	Layer n°1	137	158	170	192		
			Layer n°2	124	142	151	174		
			Layer n°3	123	138	145	167		
12	16	36.4	Layer n°1	153	175	187	210		
			Layer n°2	140	158	168	192		
			Layer n°3	139	154	162	185		
14	18	49.6	Layer n°1	168	191	204	227		
			Layer n°2	156	175	185	209		
			Layer n°3	155	170	179	202		
16	20	64.8	Layer n°1	184	207	220	243		
			Layer n°2	172	190	201	226		
			Layer n°3	170	186	195	219		
18	22	82.0	Layer n°1	199	223	236	260		
			Layer n°2	187	206	217	242		
			Layer n°3	186	202	211	235		
20	25	101.2	Layer n°1	215	238	252	276		
			Layer n°2	202	219	230	254		
			Layer n°3	201	217	226	250		
22	27	122.4	Layer n°1	230	254	267	291		
			Layer n°2	220	235	246	270		
			Layer n°3	220	233	242	265		
25	30	158.1	Layer n°1	254	277	291	315		
			Layer n°2	250	257	268	292		
			Layer n°3	250	256	265	289		
32	40	259.0	Layer n°1	320	332	345	370		
			Layer n°2	320	320	321	345		
			Layer n°3	320	320	320	343		

table 16 : anchorage depth applicable to a rebar bonded with HILTI HIT-HY 200-A&R 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.

HILTI HIT-HY 200-A&R - 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	122	143	159	172	193	209
			Layer n°2	110	127	140	151	171	188
			Layer n°3	108	123	134	143	161	177
10	12	25.3	Layer n°1	138	160	177	190	213	230
			Layer n°2	126	144	158	170	192	209
			Layer n°3	124	140	152	162	181	199
12	16	36.4	Layer n°1	154	177	194	208	232	250
			Layer n°2	142	161	175	188	211	230
			Layer n°3	140	157	169	180	200	219
14	18	49.6	Layer n°1	169	193	210	225	250	269
			Layer n°2	158	177	192	205	229	249
			Layer n°3	156	173	186	197	219	238
16	20	64.8	Layer n°1	185	209	227	241	267	287
			Layer n°2	173	193	208	222	246	267
			Layer n°3	172	189	202	214	236	257
18	22	82.0	Layer n°1	200	225	243	258	284	304
			Layer n°2	189	209	224	238	263	284
			Layer n°3	187	205	218	230	253	274
20	25	101.2	Layer n°1	216	240	258	274	300	321
			Layer n°2	203	222	237	250	275	296
			Layer n°3	203	220	233	244	266	288
22	27	122.4	Layer n°1	231	256	274	290	316	338
			Layer n°2	220	237	252	266	291	313
			Layer n°3	220	235	248	260	283	304
25	30	158.1	Layer n°1	255	279	298	313	340	362
			Layer n°2	250	260	274	287	312	335
			Layer n°3	250	259	272	283	306	327
32	40	259.0	Layer n°1	320	333	352	368	395	418
			Layer n°2	320	320	327	340	364	388
			Layer n°3	320	320	326	338	360	381

table 17 : anchorage depth applicable to a rebar bonded with HILTI HIT-HY 200-A&R 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.