CSTB
le futur en construction

**DEPARTEMENT SECURITE, STRUCTURES et FEU**

Division Etudes et Essais Résistance au feu

# REPORT No 26046213/B

# MUNGO BEFESTIGUNGSTECHNIK AG

# MIT 600RE

on

MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE injection systems
in conjunction with concrete reinforcing bar ($\phi$ 8 to 32mm)
and subjected to fire exposure

**REQUESTED BY:**

**MUNGO BEFESTIGUNGSTECHNIK AG**
**Bornfeldstrasse**
**CH-4603 Olten**
**Schweiz**

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 <u>SCOPE</u>

When subjected to fire exposure, construction elements performances are reduced by the effect of the temperature increase. At the MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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; $\phi$ 8 to 32 mm).

The maximum loads applicable through a rebar in conjunction with MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE mortar is then calculated by integrating this bonding stress over the interface area.

Experiment:

$\tau_{rk} = f(T)$

Finite Element simulation:

For each fire exposure duration T along the bonding interface

↓

$\tau_{rk}$ along the bonding interface

↓

$$F_{adh} = \int \tau_{rk} / \gamma_s ds$$

Where:

$\tau_{rk}$ is the characteristic bonding stress

T is the temperature

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

$\gamma_S$ 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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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**

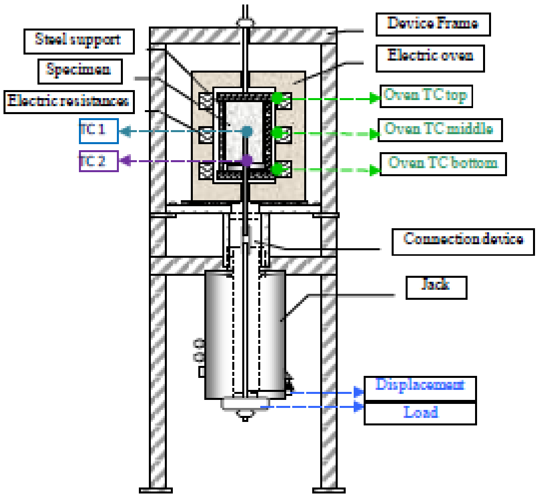



**Figure 2: Loading device**

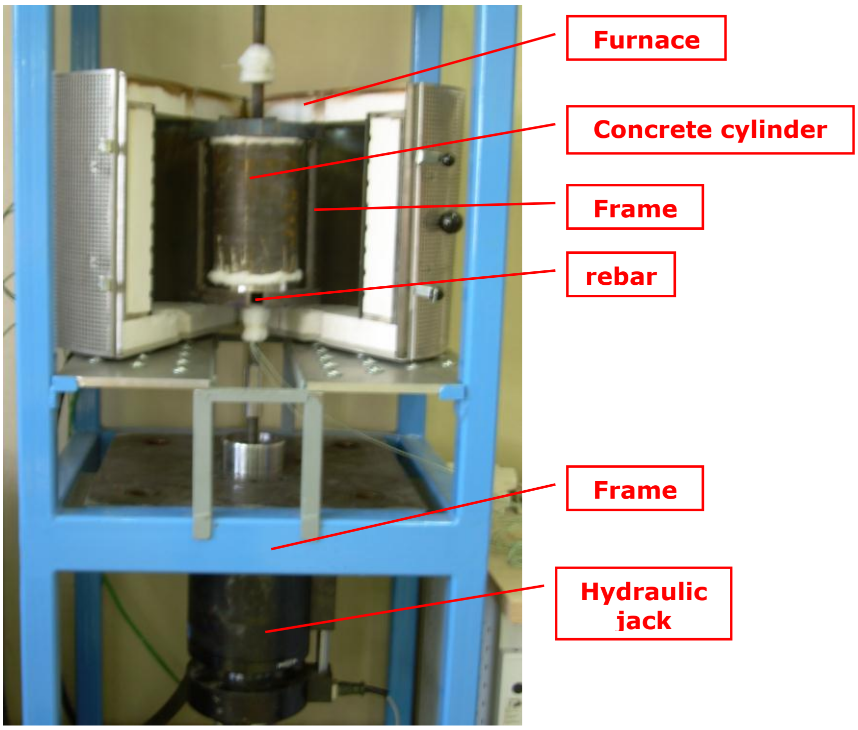
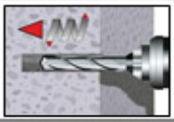
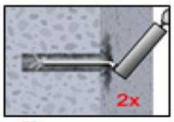
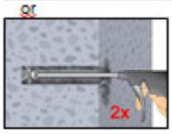
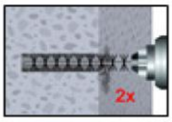
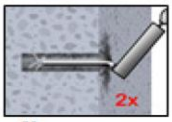
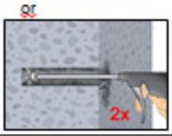
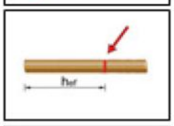
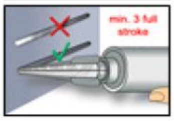



**Figure 3: high temperature, regulated, furnace**

### 3.3 Product presentation and test specimen

The MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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). |
| <br>or<br> | **Attention! Standing water in the bore hole must be removed before cleaning.**<br>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.<br>The hand-pump can be used for anchor sizes up to bore hole diameter 20 mm.<br>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 > $d_{b,min}$ (Table 5) a minimum of two times.<br>If the bore hole ground is not reached with the brush, a brush extension shall be used (Table 5). |
| <br>or<br> | 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.<br>The hand-pump can be used for anchor sizes up to bore hole diameter 20 mm.<br>For bore holes larger then 20 mm or deeper 240 mm, compressed air (min. 6 bar) **must** be used.<br>**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.<br>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. |

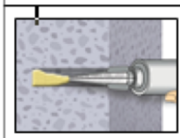
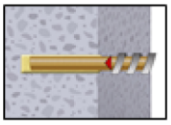
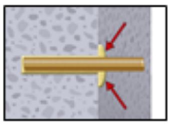
| | |
|---|---|
|  | 6. Starting from the bottom or back of the cleaned anchor hole fill the hole up to approximately two-thirds with adhesive. Slowly withdraw the static mixing nozzle as the hole fills to avoid creating air pockets. For embedment larger than 190 mm an extension nozzle shall be used. 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.<br><br>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 |

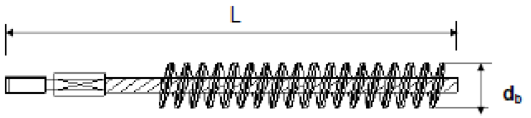



Figure 5: Brushes for cleaning the drilled holes.

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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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.

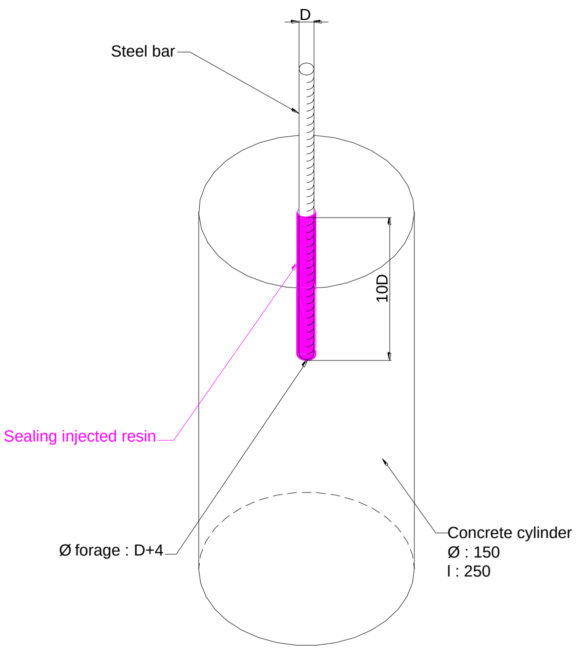



Figure 7: Steel-encased concrete cylinders

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:

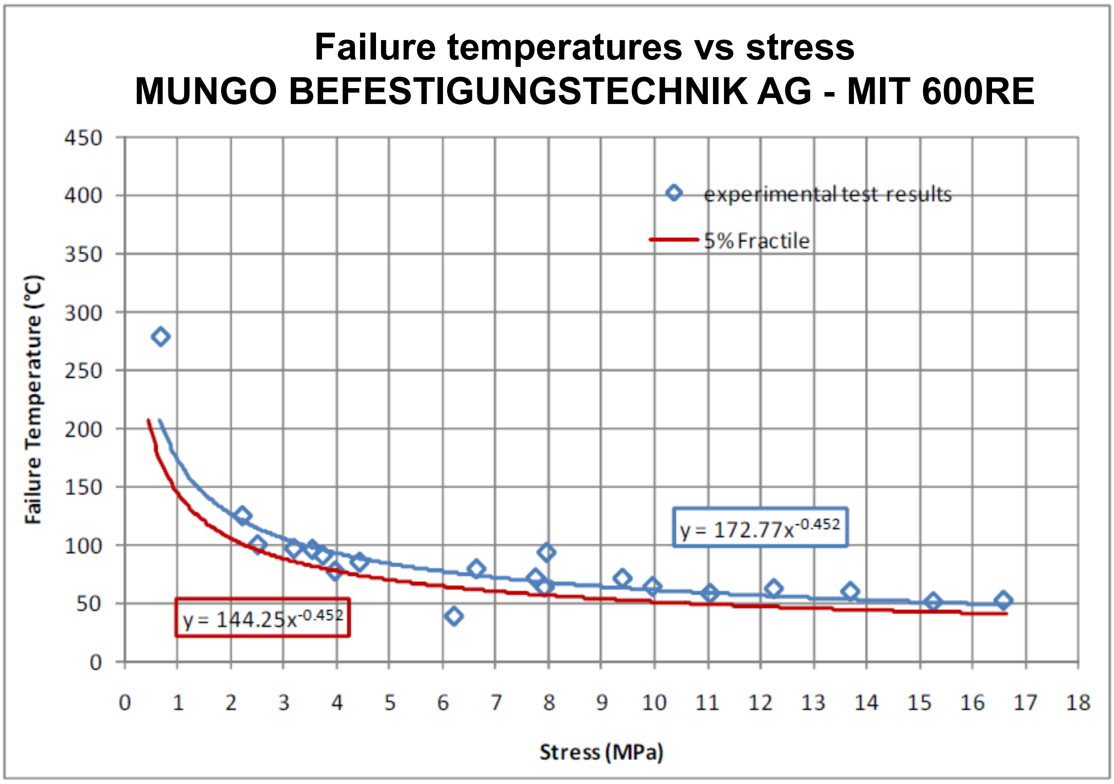



Figure 9: MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE Characteristic bonding stress – temperature relationship (red points are experimental results, black curve is the corresponding characteristic law).

# 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:

$\sigma$ is the Stefan-Boltzmann parameter

$T_s$ is the surface temperature of the heated element

$\varepsilon$ 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) | $\varepsilon$ |
|---|---|---|
| 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.

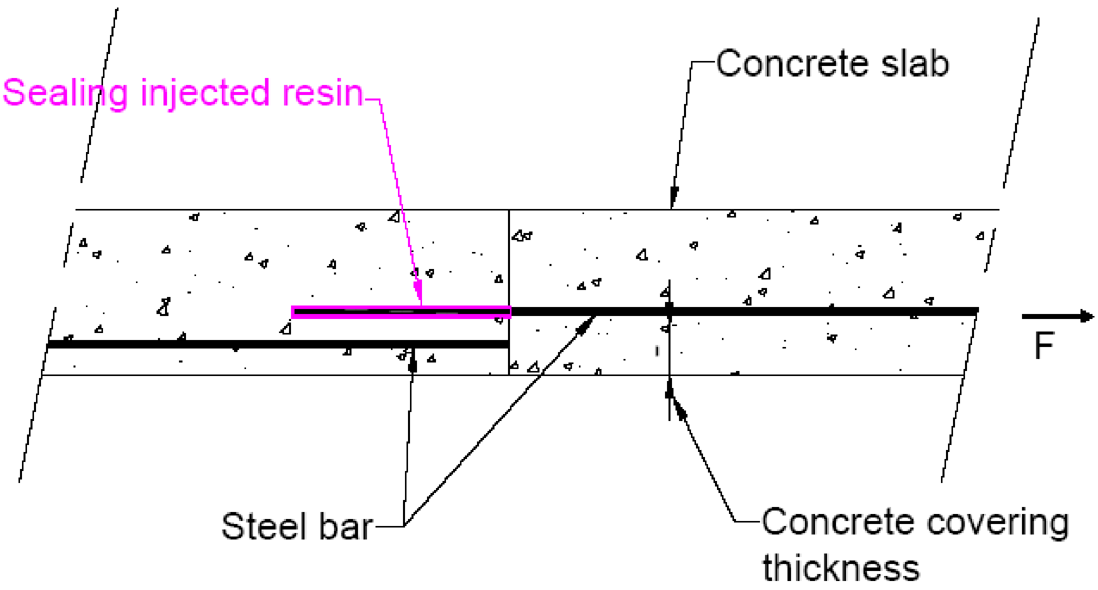



Figure 10: Slab to slab connection

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

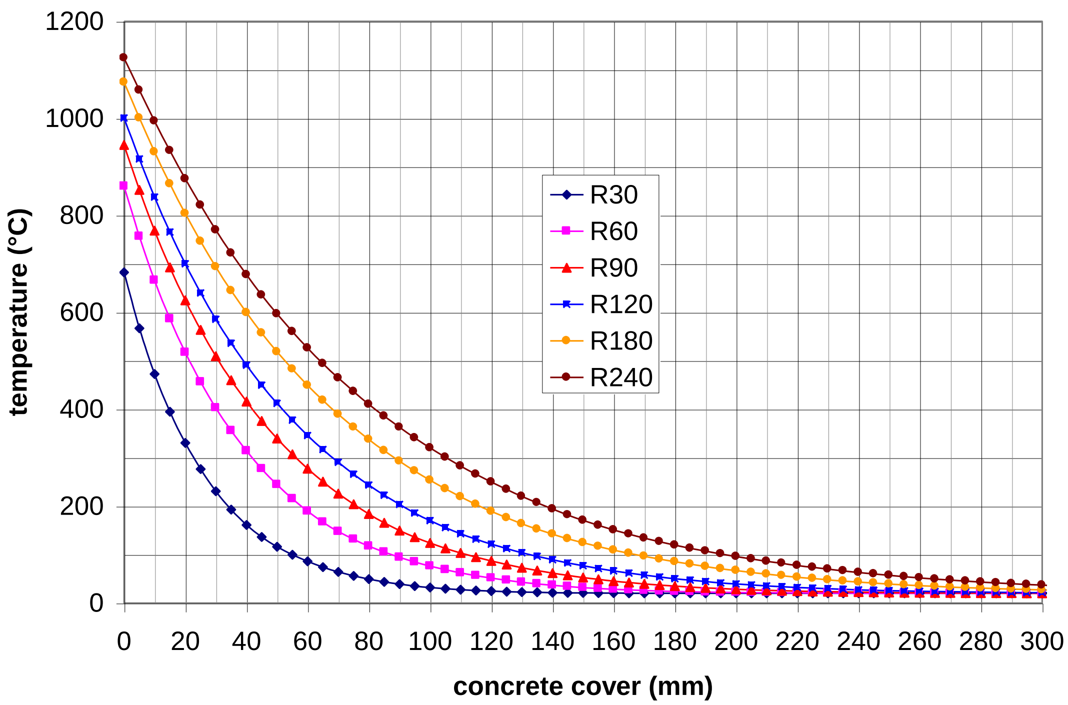



Figure 11: Temperature at the bonding interface as a function of concrete cover.

### 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

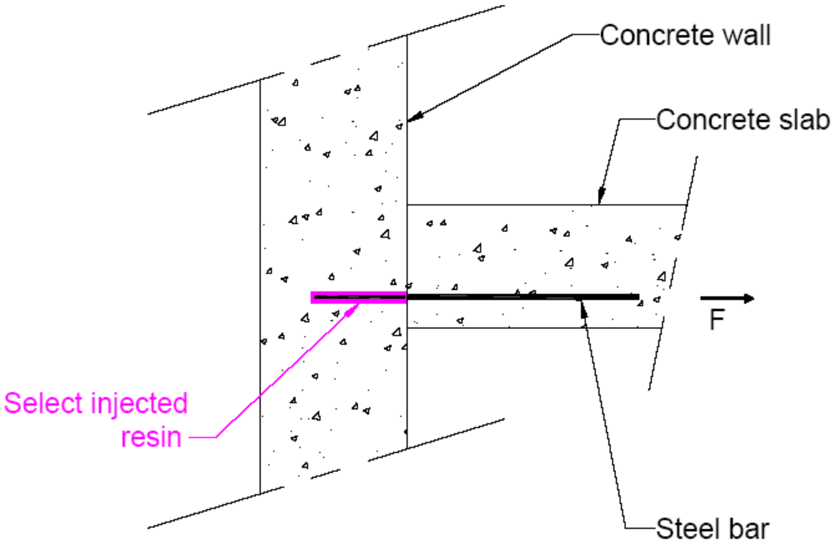



Figure 12: Wall to slab connection

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.

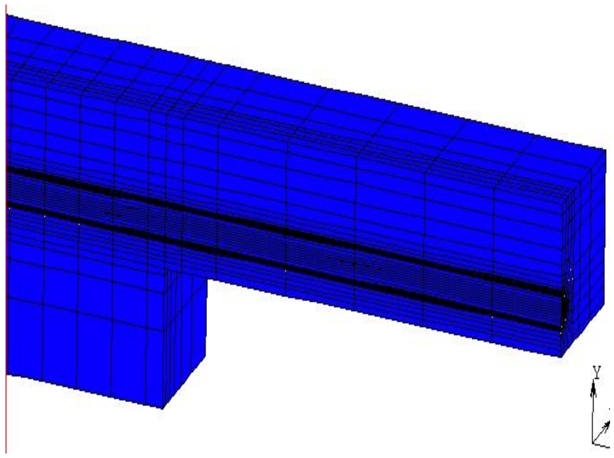


Figure 13: Mesh used for the wall to slab connection temperature model.

### 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.

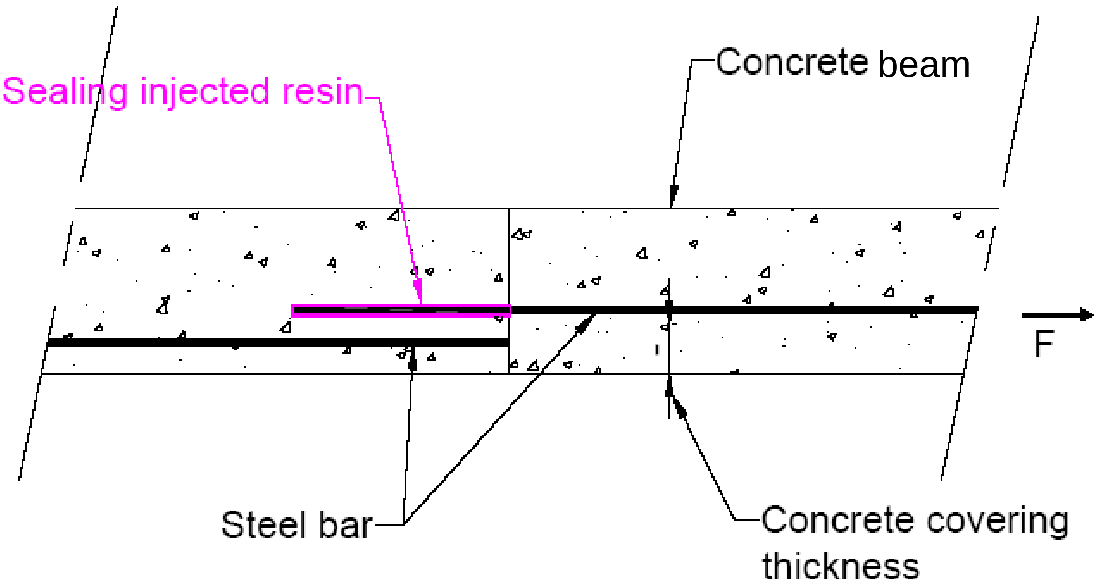



Figure 14: beam to beam connection

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).

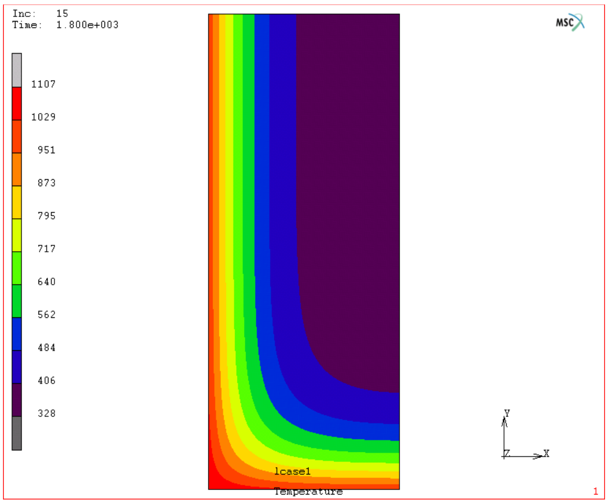



Figure 15: An example of temperature profile (T °Kelvin) – fire duration = 30 minutes – beam's width = 20 cm

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.

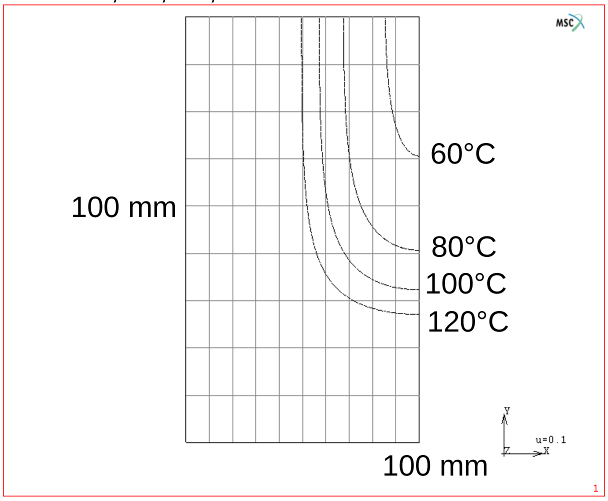



Figure 16: Temperature contour lines for beam's width = 20 cm and fire duration = 30 min

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

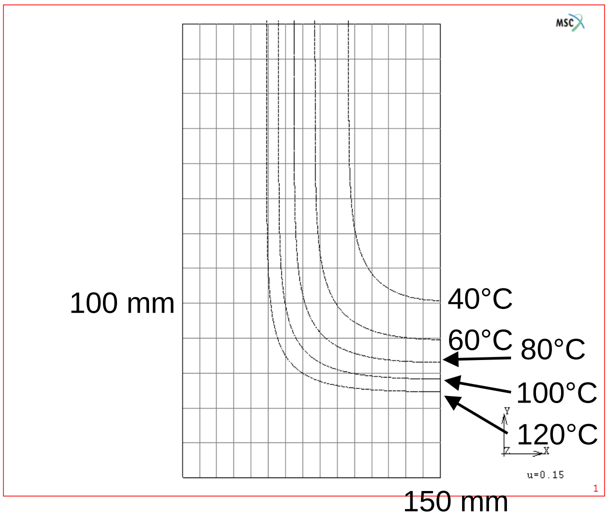



Figure 17: Temperature contour lines for beam's width = 30 cm and fire duration = 30 min

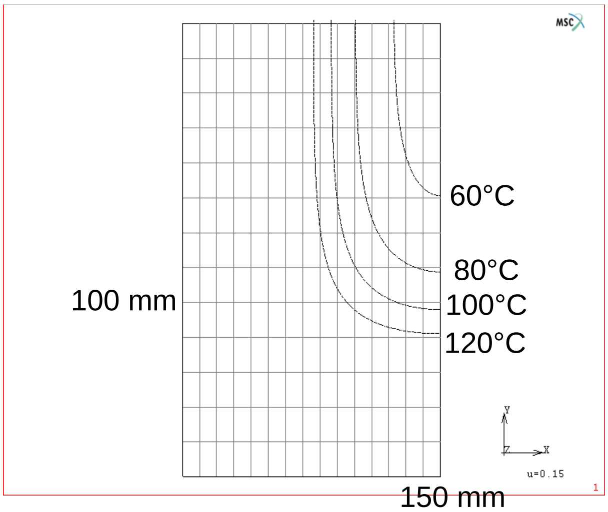



Figure 18: Temperature contour lines for beam's width = 30 cm and fire duration = 60 min

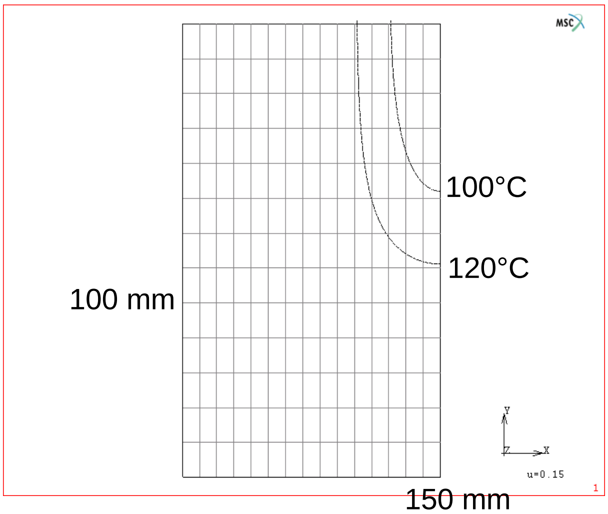



Figure 19: Temperature contour lines for beam's width = 30 cm and fire duration = 90 min

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

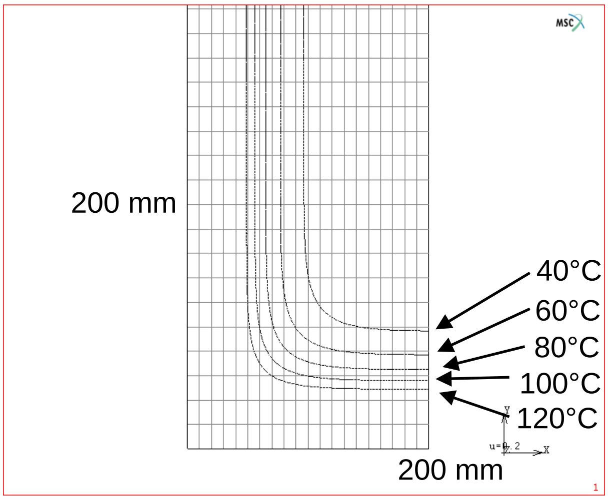



Figure 20: Temperature contour lines for beam's width = 40 cm and fire duration = 30 min

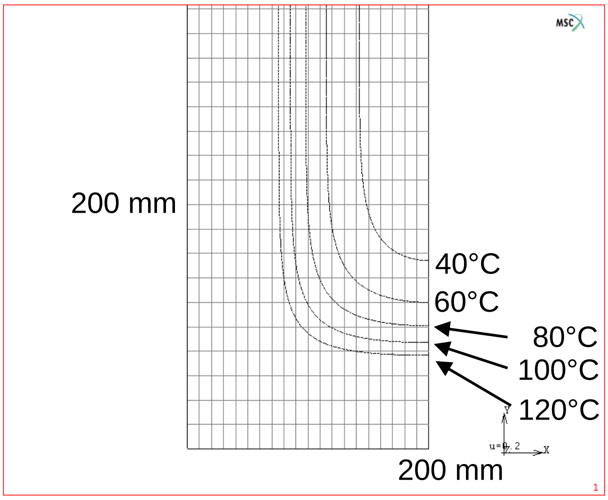



Figure 21: Temperature contour lines for beam's width = 40 cm and fire duration = 60 min

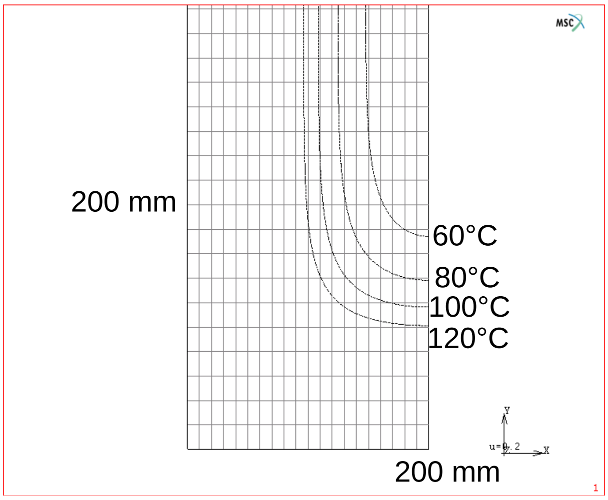



Figure 22: Temperature contour lines for beam's width = 40 cm and fire duration = 90 min

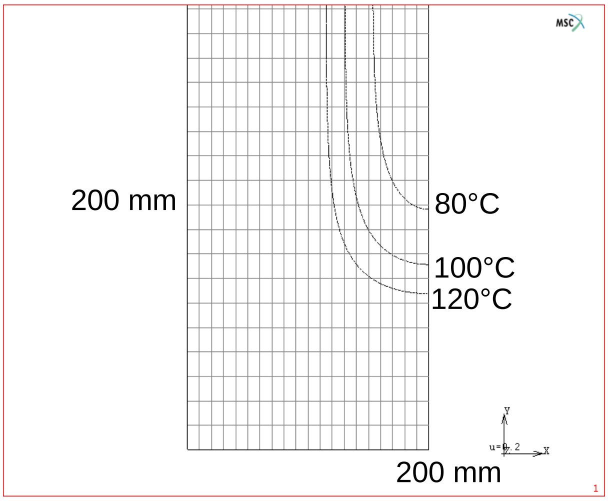



Figure 23: Temperature contour lines for beam's width = 40 cm and fire duration = 120 minutes

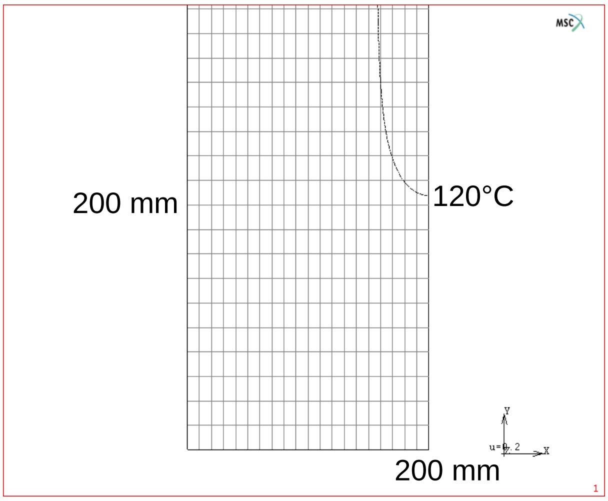



Figure 24: Temperature contour lines for beam's width = 40 cm and fire duration = 180 minutes

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**

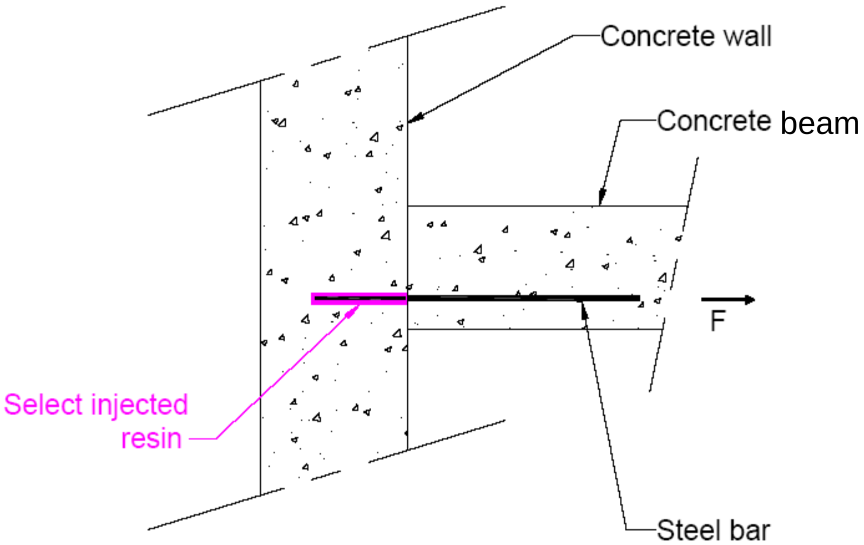



Figure 25: Wall to beam connection

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.

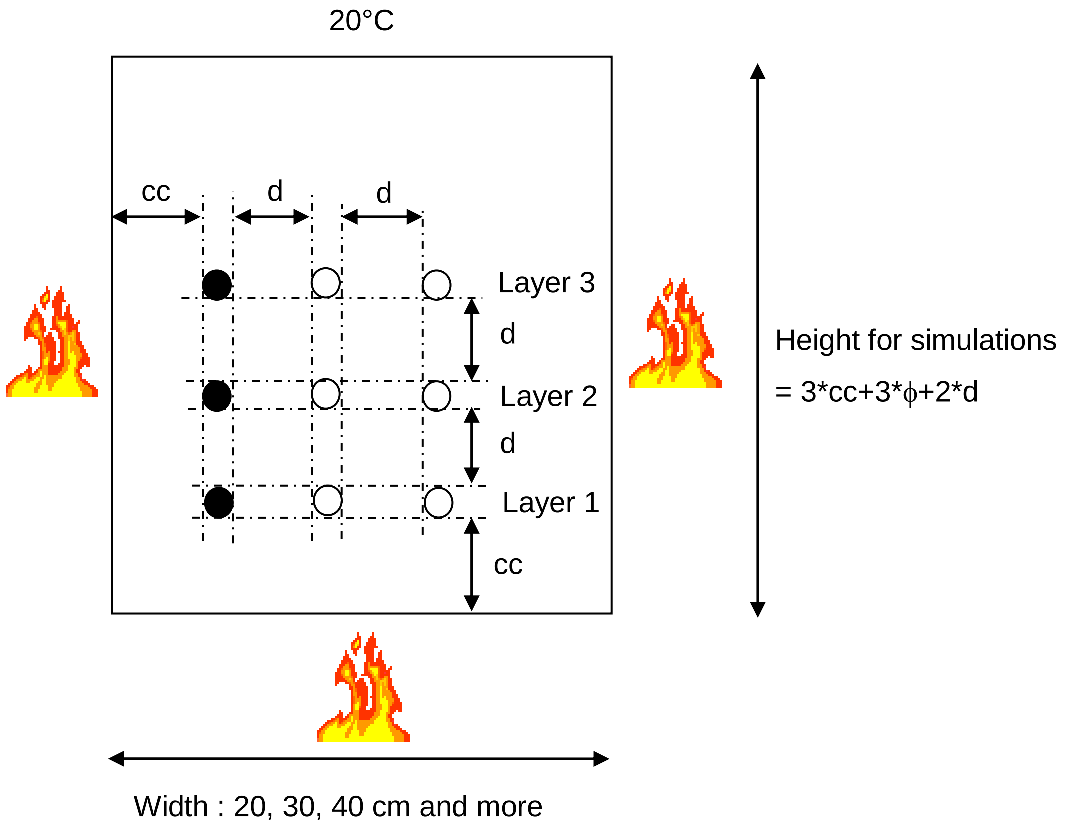



Figure 26: reinforcement frame

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:

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

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.

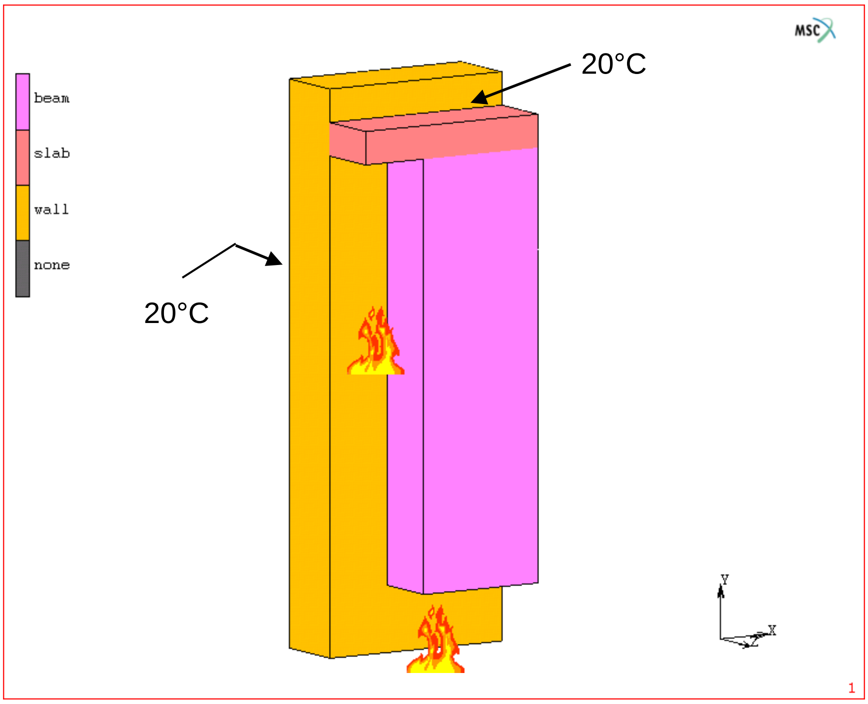



Figure 27: Mesh used for the wall to beam connection temperature model.

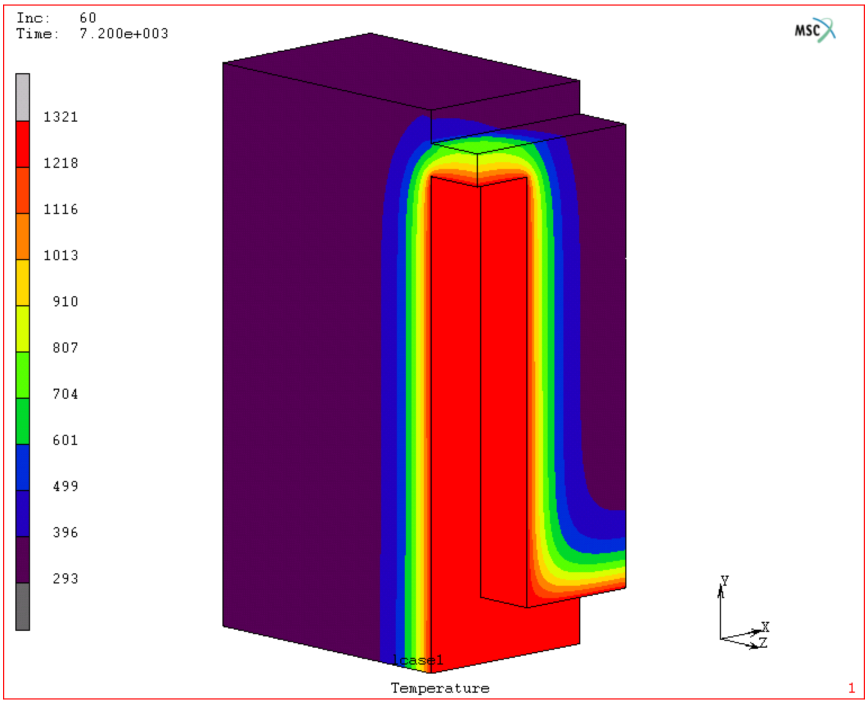



Figure 28: An example of temperature profile (T °Kelvin) – fire duration = 2 hours – beam's width = 40 cm.

## 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 ($\gamma_s$) is the product of partial safety factors:

- $\gamma_c$ partial safety factor on concrete compressive strength (1,3)
- $\gamma_t$ partial safety factor on concrete tensile strength variability (1,0)
- $\gamma_f$ partial safety factor on field realisation variability (1,2)

The global safety factor is $\gamma_s$ = 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:

- $\theta$ is the temperature in °C
- $\tau$ 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.

| MIT RE600 | 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
- $\phi$ 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.

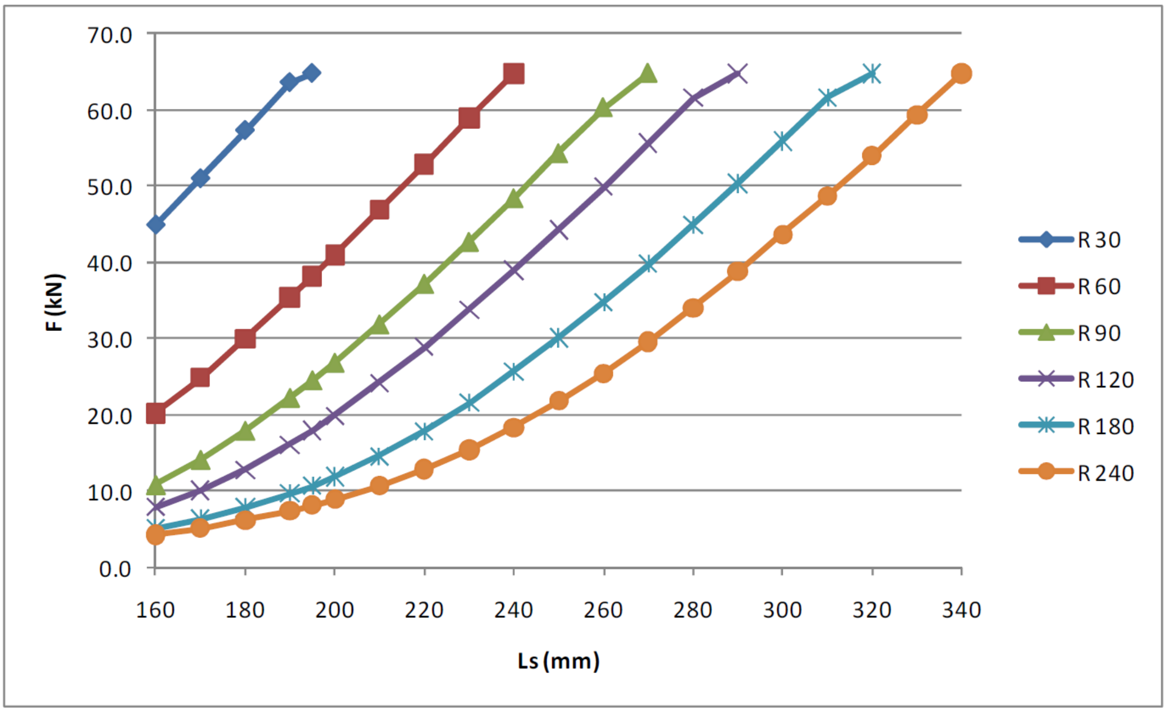



Figure 29: Maximum force of rebar ($\phi$=16mm) in conjunction with MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE.

| MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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.

| MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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.

| MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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.

| MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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.

| MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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.

| MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE | |
|---|---|
| **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.

| MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE | | | | | | | |
|---|---|---|---|---|---|---|---|
| **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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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.

| MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE – 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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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.

| MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE – 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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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.

| MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE – 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 MUNGO BEFESTIGUNGSTECHNIK AG - MIT 600RE 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.