MAKE YOUR CONCRETE-TO-CONCRETE CONNECTION READY FOR FIRE!

Post-installed rebar connections under fire according to EN 1992-1-2 [1] using Hilti HIT-FP 700-R cementitious injection system

07/2022

CONTENT

ABSTRACT

Exposure of concrete structures to fire leads to significant losses in mechanical and physical properties of concrete, post-installed rebars as well as the bond characteristics via mortar between them. Degradation of bond properties of post-installed rebars in fire may significantly influence the load capacity of this concrete connection. Therefore, the bond behavior of post-installed rebars needs to be considered for the structural fire engineering design of post-installed concrete to concrete connections. Up to now none of the existing post-installed rebar injection systems (resin based organic systems) is currently able to allow a one-to-one EN 1992-1-2 [1] design for concrete structures in case of fire situation. This is due to the material degradations of organic injection mortars that is much more pronounced at elevated temperature compared to the base material concrete and the bond of cast-in reinforcing steel bars.

This statement will significantly be changed with Hilti HIT-FP 700-R injection mortar (cementitious based inorganic system) for post-installed concrete-to-concrete connections showing the highest resistance concerning the response of the bond characteristic to fire... **read on to find out and how the Hilti post-installed rebar revolution continues with Hilti HIT-FP 700-R injection mortar.**

GENERAL

Concrete to concrete connection via post-installed rebars are common in daily construction practice since decades. They are used in new construction projects as well as for renovations or changes of use. Post-installed reinforcing bars consist of the installation of deformed reinforcing bars (rebars) in holes drilled in concrete and filled with injectable mortars. As shown in **Fig. 1**, the reinforcing bars are embedded in adhesive in a hole drilled into an existing concrete member and are cast-in in the new concrete on the other side. While the portion of the reinforcing bars installed in existing concrete is straight, the portion embedded in new concrete can be straight or hooked.

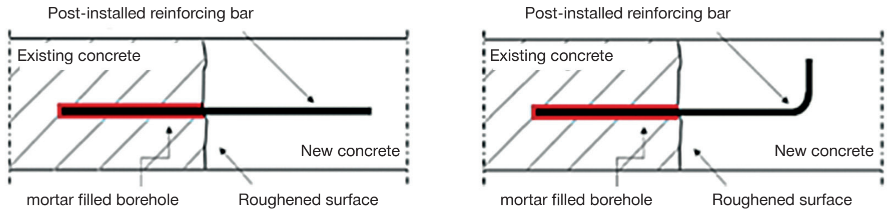


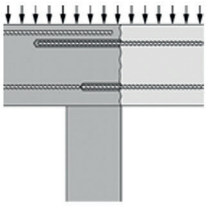
Fig. 1: *Post-installed reinforcing straight or hooked bar*

In general, two official design options for post installed concrete to concrete connections are currently available next to design options provided by manufacturers. First, post-installed rebar connections which are allowed with straight deformed cast-in rebars according to EN 1992-1-1 [2], where injection systems qualified according to EAD 330087-01-0601 [3] can be used (Cold & Fire design covered). The applications covered by EAD 330087-01-0601 [3] are limited to overlap joints, end anchorages of simply supported concrete members, end anchorage under compression loading and anchoring to cover the envelope line of acting tensile forces in bending members, see **Fig. 2**. The design of moment resisting connection must be executed as splice.

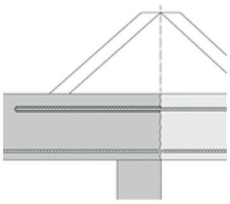
As this is sometimes not possible e.g., in rehabilitation projects [4] the rebar revolution started by introducing the technical report EOTA TR 069 [5]. This Report regulates the design and execution of reinforcement connections for rigid concrete to concrete joints on a European level without execution as overlap joint but only in case of a “cold design”.

As discussed, applications as given in Fig. 2 and executed with post-installed rebars can be theoretical designed according to EN 1992-1-2 [1] under fire consideration. Such a design is based on the understanding of both the material of reinforcing steel, injection mortar and the structural behavior of concrete exposed to fire. Although a lot of post-installed rebar system from various manufacturer are on the market, strictly speaking they cannot be used under fire consideration as the resin-based material (organic systems) whose properties changes significantly over a short temperature range can cause safety related issues [6]. This will be changed as Hilti continuous the Rebar Revolution with adding a fire-resistant injection mortar for post-installed rebar applications designed according to EN 1992-1-2 [1] for applications as given in **Fig. 2**.

Note: *Applications covered by EOTA TR 069 [5] does not cover fire action, yet and cannot therefore be used under fire. EOTA TR 069 [5] is not part of the following discussion.*



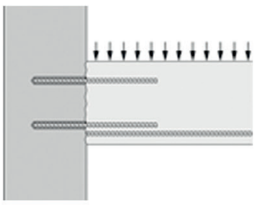
Overlap joint for rebar connections of slabs and beams



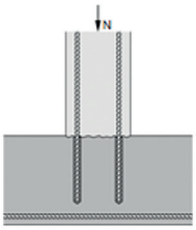
Anchoring of reinforcement to cover the line of acting tensile force

End anchoring stairs to wall

Extension of columns via splices



End anchoring of slabs or beams (simply supported)



Components stressed primarily in compression

Wall extension via splices

Slab to wall via splices or end anchorage

Fig. 2: *Examples of post-installed rebar connections which are allowed with straight deformed cast-in rebars according to EN 1992-1-1 [2] and EN 1992-1-2 [1]*

FIRE DESIGN

The Eurocode provides several procedures to design concrete structural members for the fire situation, both prescriptive as performance based. Generally, these methods may be classified into three categories which will be discussed in a later stage in conjunction with post-installed rebar systems in more detail:

a) tabulated data for well-recognized design solutions,

b) simplified engineering methods (e.g., 500°C isotherm method or zone method) for specified types of structural elements,

c) advanced thermo-mechanical or thermo-hydro-mechanical material models of steel and concrete for numerical modelling of parts of structures or for the whole structure. As advanced calculation methods, are based on a "global" structural analysis (analysis of the entire structure) for the fire situation and are in general not used for member analysis, this method will not be further discussed in that article.

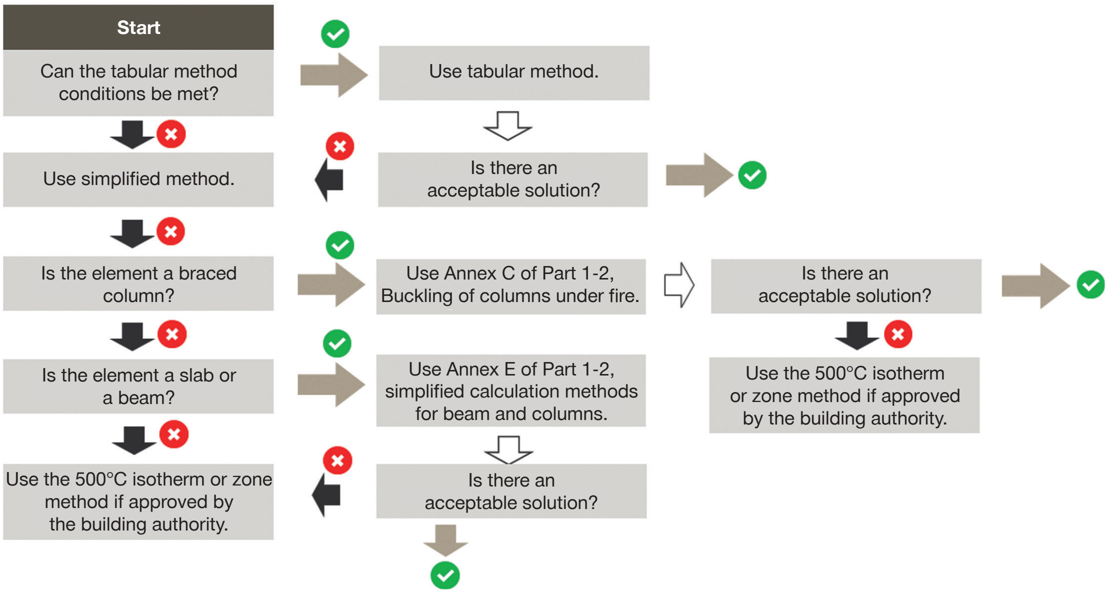


Fig. 3: *Flow chart showing fire resistance design method, tabulated data, and simplified calculation method*

In practical design, either tabulated data or simplified calculation methods are usually used for verifying structural concrete members see **Fig.3**. In general, tabulated data are the first step, as this can be assessed as a straightforward approach. Using tabulated data means taking account of the necessary boundary condition as type of member (column, beam slab), heating fire curve (ISO 834), geometrical dimension (rebar spacing, concrete cover to the flamed side) and limitations of the design as member analysis according to Eurocode ignores effects as incompatible thermal expansions which can cause high thermal stresses.

However, it should be noted that tabulated data and simplified design method may not been used without restriction for post-installed rebar systems as an understanding of the bond behavior of the post-installed rebar in relation to a cast-in rebar exposed to fire must be understood and assessed.

This will be done on the next chapters for resin based organic post-installed rebar systems and cementitious inorganic systems (Hilti HIT-FP 700-R injection mortar). Before we will provide some technical characteristics of Hilti HIT-FP 700-R and its installation process.

A NEW CHAPTER IN FIRE DESIGN

Hilti HIT-FP 700-R cementitious based injection mortar

The first injectable cement mortar

Fig. 4: Hilti HIT-FP 700-R injection system - foil pack

Hilti HIT-FP 700-R (**Fig.4**) is an injectable inorganic cement-based mortar, providing the highest fire resistance properties for post-installed rebar connections, which is superior to other available post-installed injection systems currently on the market. Due to its cementitious, inorganic characteristics, it exhibits a stable displacement and stable performance at high temperatures comparable to the behavior of concrete under fire exposure.

The injection of Hilti HIT-FP 700-R into the drilled hole is accomplished with the aid of cordless battery dispenser. In most cases, however, cementitious anchoring mortars are in general delivered in bulk form and mixed on site with a defined quantity of water. This usually limits the use to specific installation direction which are vertical down applications, in addition the installation is associated with uncertainties regarding proper mixing of the components on the construction site which is vital for the performance in service. Consequently, these products are currently not qualified by an EAD and cannot be used in conjunction with EN 1992-1-2 [1] or EN 1992-1-1 [2].

In contrary Hilti HIT-FP 700-R is characterized by its safe, flexible, and user-friendly application properties. The automatic use of predefined mixing proportions during injection, prevents the risk of erroneous or inconsistent mixing proportions and tackles limitations for the installation direction. Furthermore, Hilti HIT-FP 700-R is offered with the SAFEset technology, in which the dust is automatically extracted during the drilling process and the drill hole is additionally cleaned in compliance with ETA supporting our “executed as designed strategy”.

Changing habits for a safe fire design

Like many cementitious products and concrete, Hilti-HIT-FP 700-R shows a significant longer curing time (days) related to the curing time of standard post installed rebar systems (resin-based organic systems; minutes), see **Fig. 5**. The longer curing time should be considered regarding the construction process on-site and therefore it could be helpful to provide additional comments in the technical drawing for the contractor. In addition, small cracks and voids may be seen at mortar material expelled from the top of the borehole.

The presence of small cracks and voids are not critical and considered in the final assessment of ETA and takes the shrinking behavior into account. To support the workflow and reduce the waiting time, two additional curing times, between the setting and the full curing have been established. This allows a partial loading of the post-installed rebar before the full design load combination can be applied comparable with concrete members where the formwork is removed before full hardening was established. The different curing times can be defined as follows and can be found in the relevant ETA, see **Fig. 5**:

ø [°C]	ø [°F]	Rebar			
		t_{work}	$t_{assembly}$	$t_{pre\text{-}loading}$ 75%	t_{cure} 100%
≥ 5 ... 10	≥ 41 ... 50	50 min	36 h	14 days	50 days
> 10 ... 15	> 50 ... 59	40 min	30 h	7 days	28 days
> 15 ... 20	> 59 ... 68	35 min	24 h	6 days	18 days
> 20 ... 30	> 68 ... 85	20 min	12 h	5 days	10 days
> 30 ... 40	> 85 ... 104	15 min	6 h	3 days	7 days
40	104	12 min	3 h	2 days	4 days

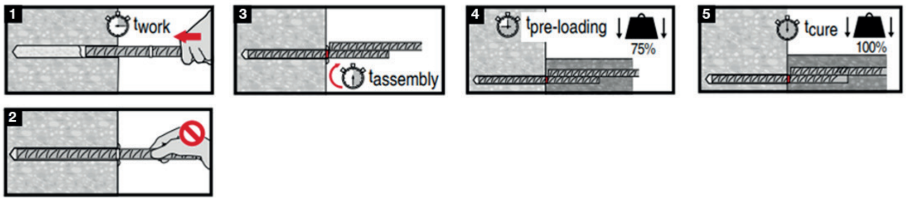
Fig. 5: *Working time t_{work}, assembly time $t_{assembly}$, pre-loading time $t_{pre\text{-}loading}$ and finally curing/hardening time t_{cure} of Hilti HIT-FP 700-R as a function of the temperature of the base material*

t_{work} describes the working time; the period in which the user can insert the rebar. The working time ranges from a maximum of 50 minutes at 5°C to a minimum of 12 minutes at 40°C.

The long working time allows an easy setting for deep embedment. Once the rebar is inserted it should not be moved see **Fig.6a**. After the minimum waiting time **$t_{assembly}$** tying new rebars to the installed/set ones is allowed, see **Fig. 6b**.

After the waiting time of **$t_{pre\text{-}loading}$**, 75% of the ultimate resistance can be applied as load to the post-installed rebar connection. The Engineer of Record must decide whether this is applicable or not, see **Fig. 6c**. When the full curing time **t_{cure}** has passed, the full design load can be applied to the post-installed rebar connection, see **Fig. 6d**.

The new Hilti mortar technology Hilti HIT-FP 700-R opens a new chapter in the qualification of injectable chemical mortars for which an update of the current EAD 330087-01-0601 [3] was needed due to its cementitious, inorganic basis.



a) t_{work} **b) $t_{assembly}$** **c) $t_{pre\text{-}loading}$** **d) t_{cure}**

Fig. 6: *Extract of installation process (incomplete), showing step 1 to step 5 of Hilti HIT-FP 700-R*

A NEW CHAPTER IN FIRE DESIGN

Verified superior fire behavior for your post-installed rebar connection using Hilti HIT-FP 700-R

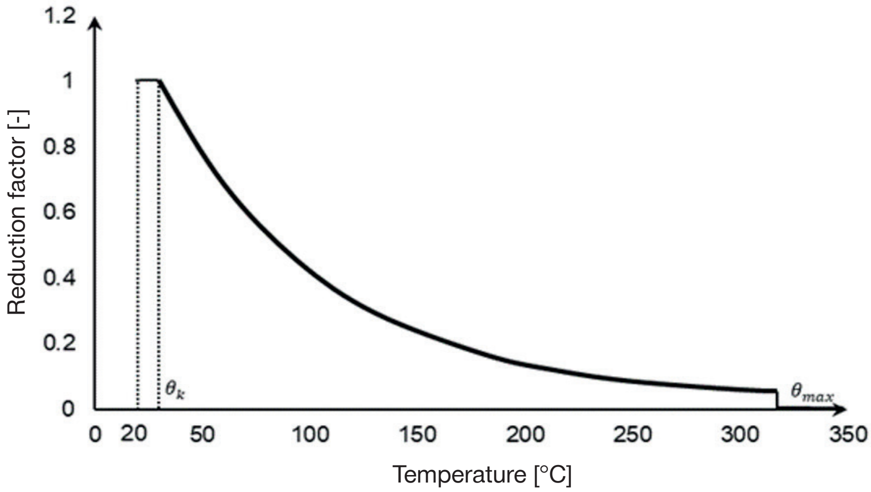


***Fig.7 Example:** Reduction factor $k_{fi}(\theta)$ for concrete strength class C20/25 as function of the temperature for a fire sensitive resin based organic post-installed rebar system*

The qualification of post-installed rebar systems under fire conditions is covered by the European Assessment Document EAD 330087-00-0601 [3], issued by EOTA and allows a design according to EN 1992-1-2. [1]. The assessment focuses on the bond strength behavior of the mortar in relation to the applied temperature. The outcome of the assessment reflected in the European Technical Assessment is given in terms of temperature reduction factor $k_{fi}(\theta)$ and is used to calculate the residual design bond strength under fire action $f_{bd,fi}$, see

Fig.7.

$$f_{bd,PIR,fi}(\theta) = f_{bd,PIR} \cdot \frac{\gamma_c}{\gamma_{M,fi}} \cdot k_{fi}(\theta)$$

where:

$f_{bd,PIR,fi}(\theta)$	=	Design value of the bond strength in case of fire in N/mm^2, for a given temperature (θ) in the mortar layer
$f_{bd,PIR}$	=	Design value of the bond strength under cold condition in N/mm^2 as given in the related ETA document considering the concrete classes
γ_C	=	Partial safety factor according to EN 1992-1-1 [2]
$\gamma_{M,fi}$	=	Partial safety factor according to EN 1992-1-2 [1]
$k_{fi}(\theta)$	=	Reduction factor of the bond strength in case of fire for a for a given temperature (θ) in the mortar layer

The reduction factor $k_{fi}(\theta)$ for the bond strength of a mortar injection systems is derived through testing under simulated fire conditions. A constant load is applied to the rebar in a confined setup, while the temperature is increased until pullout failure of the tested sample occurs, see **Fig. 8**. The applied load as a function of the temperature is then translated into the reduction factor $k_{fi}(\theta)$ by calculating the ratio of the bond strength values to the reference value for cast-in-rebar for the respective concrete class.

The reduction of the characteristic strength for several different available injection systems on the market as a function of the temperature is given In **Fig. 9** based on the published ETA documents.

In the following discussion, the reduction of bond strength at increased temperature in the mortar layer due to fire ("Fire Design") refers to the bond strength of post-installed rebar at room temperature ("Cold Design") and fully cured prior to increasing the concrete temperature as given in the described test-setup shown in **Fig.8**.

The bond strength of all post-installed rebar systems or, to be more precise, the reduction factor decreases with increasing concrete temperature, see **Fig. 8**. The relationship between concrete temperature and residual bond strength is highly mortar dependent. The bond strength of all resin-based organic systems (dotted lines) having a temperature of 200°C is only about 20% to 40% of the value recorded in tests at 20°C. At 400°C none of the resin-based organic mortars may provide any residual bond strength value. While all organic systems (dotted lines) reduce drastically its bond strength values with increasing temperature in case of fire, Hilti HIT-FP 700-R (solid line) cementitious-based inorganic mortar provides bond strength values at 200°C of approximately 80% of the residual capacity, at 500°C the residual bond strength still values >60% compared to the bond strength at room temperature. This fire behavior provides several design advantages under fire compared to resin-based organic systems.

Even if the advantage of the organic over inorganic mortars can be defined as "the faster curing time and better performance" at room temperature this advantage is completely diminishing under fire consideration.

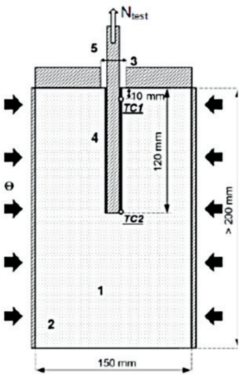


Fig. 8: Simulated fire condition test of installed post-installed rebar with lateral thermal loading and sustained loaded rebar

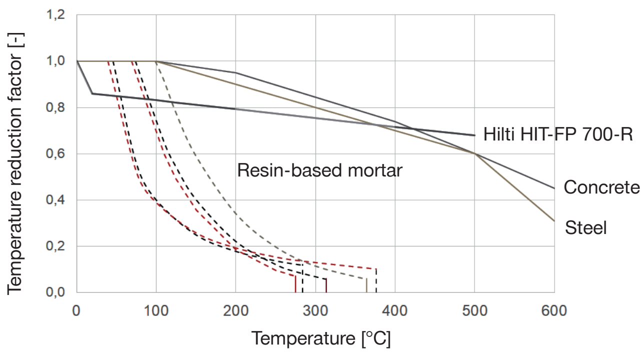


Fig. 9: Reduction of the characteristic bond strength for several different available injection systems on the market as a function of the temperature as given in the related ETA documents

Verified long-term behavior using Hilti HIT-FP 700-R

With the new Hilti technology allowing fully cementitious injectable mortars to be used for post-installed rebar connections for frequent use, several aspects of performance were investigated and are part of the assessment process according to the new version EAD 330087-02 (in preparation, 2022). These aspects are especially linked with regards to the classification of the system, porosity degree, long-term effects, and tendency to a shrinking behavior.

Classification: The new Version of the EAD document which is currently in preparation establishes a method to separate the mortar types into resin-based and cement-based mortars. This distinction was not clearly described in the previous versions, despite the presence of a few requirements dedicated to cementitious products.

The method consists of a compositional analysis based on the mass loss over temperature for the assessed product.

Shrinkage & long-term stability: Two new test protocols apply to products classified as cement-based mortars. The first aspect to be assessed is the sensitivity of the post-installed rebar system for installations in low-relative humidity concrete. This test aims at assessing the influence of dry outdoor and indoor climates and to a maximization of shrinkage effects due to potential water suction of the surrounding concrete affecting the cement hydration by altering the water-cement ratio of the mortar and consequently the bond strength.

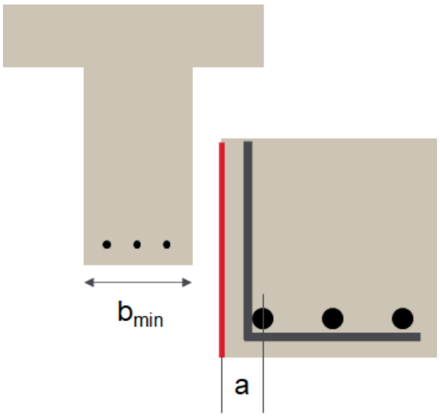
The second aspect to be assessed is the long-term stability of the mortar microstructure. This characteristic of performance is verified in an accelerated setup with severe exposure to high temperature and humidity, namely the so-called weathering conditions. This check is required to evaluate the sensitivity of the cementitious product to porosity variations, phase conversions and disjoining pressure.

It should be noted that these effects are already reflected in the final bond strength values published in the related ETA document. The new requirements of EAD ensures that the published characteristic of performance in the ETA, especially the bond strength values, maintain the same reliability of the output of assessment required for resin-based mortars.

It should be also noted that Hilti HIT-FP 700-R passed the complete test-program by means of verified performance. Due to unique temperature behavior Hilti HIT-FP 700-R provides several advantages when designing post-installed rebar connections by allowing to take account of the tabulated data and simplified design methods according to Eurocode EN 1992-1-2 [1], this will be discussed in the next chapter.

A NEW CHAPTER IN FIRE DESIGN

Only Hilti HIT-FP 700-R matches with the tabulated data of EN 1992-1-2 [1]



Standard fire resistance [min]	Dimension axis distances	Minimum dimension [mm]				
		Possible combinations of a (average axis distance) and b_{min} (width of beam)				Web thickness
R 30	b_{min}	80	120	160	200	80
	a	25	15	10	20	
R 60	b_{min}	120	160	200	300	100
	a	40	35	30	25	
R 90	b_{min}	150	200	250	400	100
	...	...	...	...	...	...

Fig. 10: *Modified extract of tabulated data taken from Eurocode EN 1992-1-2 [1] as example*

The Eurocode EN 1992-1-2, Section 5 [1] fire parts give design solutions in terms of tabulated data to be used within the specified limits of the application conditions. The method is applicable for the verification of separate members for a standard fire exposure according to ISO 834 up to 240 minutes, manufactured with normal weight concrete made with siliceous aggregates using cast-in rebars. Indirect fire actions are not considered, except those resulting from thermal gradients. Depending on the required fire resistance duration and, if necessary, the utilization of the component, minimum values of the component dimensions and center distances of the reinforcement are given depending on the type of component, see **Fig. 10** exemplarily (beam).

In the tables, minimum concrete cover is expressed as the distance “a” from the axis of the main cast-in reinforcement to the closest concrete surface. The stated axis distances are nominal values. Allowance for tolerance need not be added. In part 1-1 of Eurocode 2 [2], valid for normal temperature design, the concrete cover “c” is defined as the distance from the edge of a reinforcing bar to the closest concrete surface. Hence, for a longitudinal rebar (main reinforcement) with diameter Ø, the relation between “a” and “c” typically can be written as $a = c + Ø_{stirrup} + Ø/2$.

Using tabulated data, no further checks are required concerning shear and torsion capacity and spalling, however additional detailing rules are specified for each type of structural member. The advantage of the tabulated values is that a designer can quickly verify whether the dimensions which follow from a normal temperature design (cold design), are acceptable under fire conditions. **For most common structural components in building construction, the table values represent conservative assumptions for cast-in rebars but NOT necessarily for concrete-to-concrete connections executed via post-installed rebars. This is because the minimum axis distance of reinforcement as given in the tabulated data located in tensile zones of simply supported beams and slabs, are calculated based on a critical steel temperature of θ_{krit} = 500°C.** The critical temperature is that temperature for which the steel yields under the steel stress $\sigma_{s,fi}$ occurring in the fire situation calculated for the actions $E_{d,fi}$ ($\eta_{fi} = E_{d,fi} / E_d$ = 0,7 for tabulated data). **Consequently, this straightforward approach can only be used for post-installed rebar systems if the residual bond capacity under fire exposure at 500°C related to the residual strength of concrete is known and comparable.**

The reduction of the characteristic strength of reinforcing and prestressing steel as a function of the temperature θ for use with the tabulated values is given Eurocode EN 1992-1-2, Section 5 [1]. These curves in conjunction with tabulated data refers to curves for reinforcing steel (hot rolled or cold worked: EN 10080 [7]), the values for normal weight concrete (2000 to 2600 kg/m^3, see EN 206-1 [8]) made with siliceous aggregates. At 500°C both concrete and steel provides a residual characteristic strength of ~0.7 compared to the strength at room temperature.

This is the logic when using tabulated data. In contrary as showing in **Fig. 9**, all resin-based organic injection systems provide a residual capacity of zero at a mortar temperature of 500°C. Consequently, the philosophy of the tabulated data cannot be used without restrictions for the shown resin-based organic injection systems. Following the bond reduction for the inorganic Hilti HIT-FP 700-R injection system as given in **Fig.9** the residual capacity comparable with concrete and steel.

Only Hilti HIT-FP 700-R provides the designer the advantage of using the tabulated values without restrictions where he can quickly verify whether the dimensions which follow from a normal temperature design (cold design), are acceptable under fire conditions.

A NEW CHAPTER IN FIRE DESIGN

Only Hilti HIT-FP 700-R fully comply with the simplified calculation method of EN 1992-1-2 [1]

Simplified calculation methods are used to determine the ultimate load-bearing capacity of a heated cross-section under the relevant combination of actions for concrete members executed with cast-in rebars. In the fire situation it must be verified that the design effect of actions $E_{fi,d,t}$ in the fire situation at time t is less than or equal to the corresponding design resistance $R_{d,t,fi}$ of the member at time t. The necessary temperatures profiles in the concrete cross-sections subjected to a fire standard exposure can be calculated using software and concrete thermal properties. In EN 1992-1-2 [1] and the related Annexes three simplified calculation methods are described, note that the 500°C isotherm method is not approved for use in Germany according to the national annex:

(a) The ‘500°C isotherm method is applicable for a standard fire exposure and any other heat regimes which cause similar temperature fields in the fire exposed member. It is assumed that concrete with a temperature > 500°C does not contribute to the load-bearing capacity while the remaining concrete cross-section retains its initial strength and Young's modulus. As a result, a new shape of cross-section of the element is created within the 500°C isotherm being the restricting line while the concrete properties within the new cross-section are the same as for normal temperature. At the same time, the strength of the cast-in reinforcement is reduced as a function of its temperature.

Having determined the reduced cross-section dimensions and the reduced level of yielding stress for the cast-in rebar, the load bearing capacity in fire situation for element R_{fi} at time t is calculated based on the commonly accepted methods for reinforced concrete elements analysis under normal temperature conditions, see **Fig. 11**. As discussed, **reduction of yielding stress of reinforcing steel for cast-in rebars is conducted as the function of temperature level at the center of each bar despite their location regarding the 500°C isotherm. However, even if some of the cast-in reinforcing bars may fall outside the reduced cross-section, they may be included in the calculation of the ultimate load-bearing capacity of the fire exposed cross-section. This is because a significant**

bond-loss is not assumed of cast-in rebars until 500°C. As indicated in **Fig. 10** this approach cannot be applied to the resin based organic systems, since bond-loss is happening already at an earlier temperature stage. Consequently, we would have to re-write the sentence of the '500°C isotherm method valid for cast-in rebar systems as follows for resin based organic post-installed rebars systems:

"Concrete properties within the new cross-section are the same as for normal temperature. Reduction of yielding stress and bond strength of post installed reinforcing is conducted as the function of temperature level at the center of each post-installed bar. In addition, if the temperature of the post-installed rebar exceeds the value where the temperature reduction factor of the post-installed rebar system values $k_{fi}(\theta) = 0.7$, the steel cross section of the post-installed rebar cannot be included when calculating the load bearing capacity. According to **Fig. 10** the temperature level where the load bearing capacity of the post-installed rebar system of resin-based organic systems should be neglected ranges between 75°C to 150°C for the plotted systems."

In contrary to cementitious-based inorganic system, Hilti HIT-FP 700-P delivers, so no need for designers to take the above paragraph into account and follow the relatively simple method if allowed by you building authorities.

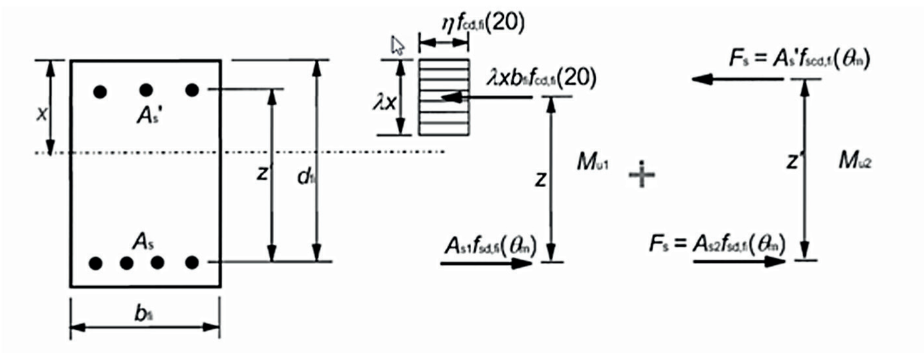


Fig. 11: *Calculation of load-bearing capacity of a cross-section with tension as well as compression reinforcement according to [1]*

(b) The Zone method provides more accurate results compared to the previous one. In this method, the cross-section is divided into several parallel zones (n>3) of equal thickness where the mean temperature, the corresponding mean compressive strength and modulus of elasticity of each zone are assessed. The fire damaged cross-section is represented by a reduced cross-section ignoring a damaged zone of thickness a_z at the fire exposed sides found via equation or diagrams as given in
EN 1992-1-2 [1]. When the reduced cross-section is found and the strength and E-modulus of elasticity are determined for the fire situation, the fire design follows the normal temperature design procedure, see **Fig.10**.

The strengths of concrete and reinforcing cast-in rebars are calculated as a function of temperature using reduction factors $k_c(\theta_M)$ (the temperature in the center of the remaining zone applies) or $k_s(\theta)$. Also, for that method a direct one-to-one approach for post-installed rebar connection in case of resin-based organic mortars as shown in **Fig. 6** is NOT possible as the residual bond strength of the post-installed rebar system next to the concrete strength and steel strength must also be calculated as a function of the temperature. In addition, the max. temperature in the mortar layer should be limited between 150 and 350°C – depending on the product and the orientation of the rebars to the fire – as the resin-based organic systems do not have any residual bond capacity.

In contrary to resin-based organic systems, Hilti HIT-FP 700-P delivers, so no need to modify the zone methods up to 500°C steel temperature.

Note: In Germany, this method may be used for members subjected to bending with or without normal force. The description of the Zone Method in EN 1992-1-2 [1] is incomplete, especially for concrete columns. Hence, the use of the Zone Method in Germany is only allowed by building authorities if the comments and interpretations by Zilch et al. [9] or Cyllok and Achenbach [10] are considered.

(c) The method based on estimation of curvature deals with columns where second order effects under fire are significant, assessing a reinforced concrete cross-section exposed to bending moment and axial load. This method is based on the estimation of the curvature (EN 1992-1-1, Sec-5 [2]). This method will not be further discussed here in conjunction with this article as it may be assessed as a simplified general calculation method but requires a correspondingly large amount of effort to implement. When using this method thermal strains must be considered (even if not explicitly mentioned in EN 1992-1-2 [1]).

HILTI TEAM STRENGTH FOR YOUR NEXT CONSTRUCTION PROJECT

Hilti injection systems for post installed rebar connection and Hilti design Software

The importance of fire resistance depends on the size of the building the occupancy of the building related to the number of occupants, type of activities and the fire safety objectives. To provide life safety, fire resistance is essential in buildings where a fire could grow large before all occupants have time to escape. It should be noted that even if the general context and general notions of fire safety are the same everywhere in Europe, the requirements are non-uniform, in general, all fire relevant structural / bracing Walls, columns and slabs which can be executed with post-installed rebars (see **Fig. 12**) must fulfill the structural integrity for a certain time.

However, not all post-installed rebar connections are temperature critical under fire considerations and consequently the application can maybe also be executed more economical using resin-based mortar compared to cementitious based mortar. To determine the level of influence on the temperature distribution on post-installed rebar connections, a distinction can be made between three different connection types where the significant parameters are the orientation of the post-installed rebar to the flamed surface and the number of the flamed surfaces, see **Fig. 13**.

In case of the first connection type, the bond strength is affected by the fire along the whole length of the rebar with the same impact due to a constant temperature distribution as the distance from the structural post-installed reinforcing bars to the one flamed surface is constant. Consequently, for such a connection there is no possibility to transfer the applied load into colder regions. The reduction factor must be applied along the whole embedment depth/splice length. Such conditions are in general be found where post installed rebars are used for extension of slabs or walls via splices.

In case of the second connection type, the bond strength is NOT necessarily affected along the whole anchorage length causing a NOT constant temperature distribution as the distance from the structural post-installed reinforcing bars to the flamed surface is NOT constant. The load is maybe transferred to colder region within the connection, utilizing higher bond strength values. Such conditions are in general present in case of end-anchorages of slab to wall connection. For such applications resin-based mortars may also provide an acceptable fire resistance solution.

If we keep this application in mind but transfer the slab to wall connection into a beam to column connection, we will end up with the connection type 3 in **Fig. 13**.

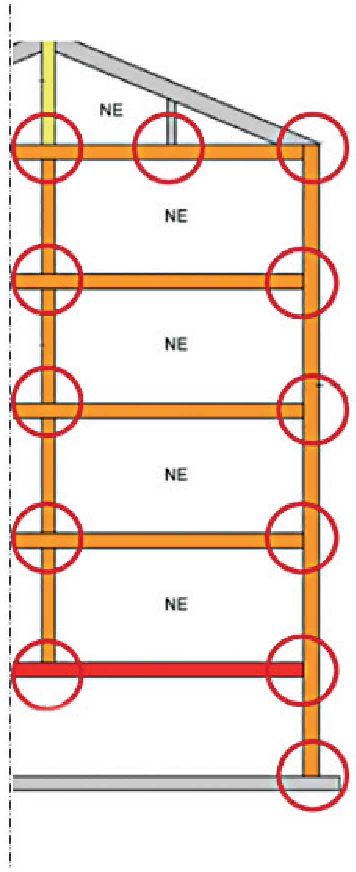
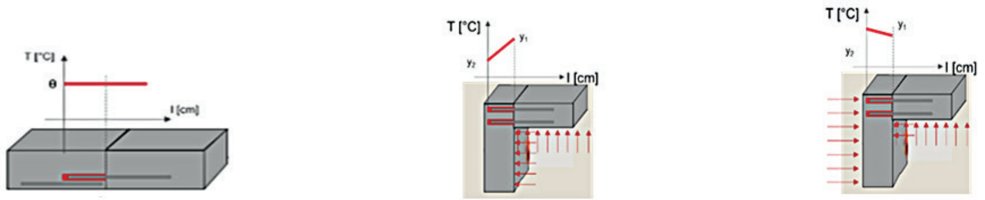


Fig. 12: *Possible positions of post-installed rebar connections*

In that case the post-installed rebar is also not orientated parallel to the flames surface however due to the number of flamed surfaces already for short fire resistance times the temperature in the mortar layer maybe assessed as relatively high. This can be seen in **Fig. 13** where the calculated splice length, anchorages length are given for a resin based and system (Hilti Hit RE 500 V4) and cement based system (Hilti HIT-FP 700-R) for a fire duration time of R30.



	SLAB TO SLAB flamed surface from the bottom[1]	**SLAB TO WALL** flamed surface from the bottom and one side[1]	**BEAM TO COLOUMN** flamed from bottom and 4 sides[2]
R30	Cold: $f_{bd,pi}$ = 2,3 N/mm², $l_{0,pi}$ = 1135 mm	Cold: $f_{bd,pi}$ = 2,3 N/mm², $l_{0,pi}$ = 567 mm	Cold: $f_{bd,pi}$ = 2,3 N/mm², $l_{0,pi}$ = 567 mm
	Resin based mortar: Hot: $f_{bd,pi,R30}$ = 0,85 N/mm², $l_{0,pi,R30}$ = 2150 mm	Resin based mortar: Hot: $l_{0,pi,R30}$ = 290 mm	Resin based mortar: Hot: $l_{0,pi,R30}$ = 1380 mm
	Hilti HIT-FP 700-R, hot: $f_{bd,pi,R30}$ = 2,83 N/mm², $l_{0,pi,R30}$ = 650 mm	Hilti HIT-FP 700-R, hot: $l_{0,pi,R30}$ = 320 mm	Hilti HIT-FP 700-R, hot: $l_{0,pi,R30}$ = 330 mm

[1] Application conditions: C20/25; Ø 12/200 mm, c = 40 mm, α_2 = 1, α_6 = 2, σ_{Sd} = 435 N/mm², $\sigma_{Sd,fi}$ = 0.7 · 435 N/mm² = 305 N/mm²
[2] Application conditions: C20/25; Ø 12/100 mm, c = 40 mm, α_2 = 1, α_6 = 2, σ_{Sd} = 435 N/mm², $\sigma_{Sd,fi}$ = 0.7 · 435 N/mm² = 305 N/mm²

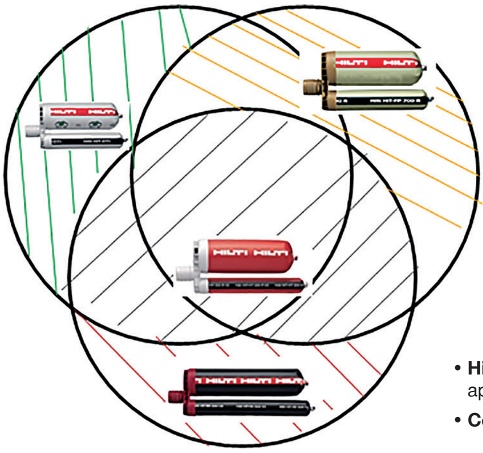
***Fig. 13:** Temperature critical and less temperature critical post-installed rebar connections and its related splice and anchorage length for two different injection systems*

Under cold conditions all bond strength values are the same as reported in the ETA of the product for concrete strength class C20/25. In best case the upper limit corresponds to the bond strength of a cast-in rebar under the same boundary condition. In case of fire, we see a significant difference between a resin-based mortar and the cement-based mortar Hilti HIT-FP 700-R already for a fire resistance time of R30. In case of connection type 1 and 3 Hilti HIT-FP 700-R is the right solution while application type 2 maybe also executed with HIT-RE 500-V4.

However, fire is not the only design conditions which may have to be followed consequently Hilti is providing a team of injection systems for post-installed rebar connections as the “egg-laying, milk-bearing woolly sow” mortar which is a synonym for “do-it all mortar” is not yet existing, see **Fig. 12**. The easiest was of selecting the right system is by inputting all application conditions into the Hilti PROFIS software and perform the design. Using the Hilti PROFIS software, you can design and resolve all possible application types mentioned in EAD330087 [3] under “cold” and “hot” design and all possible applications mentioned in conditions and EAD 332402-01-0601 [11] (cold design only), which helps an engineer to quickly relate to the best solution. If a fire relevant connection should be designed PROFIS Engineering allows you also to enter the constant temperature distribution if known, or alternately gives the output of the temperature distributions along the whole anchorage length for the selected applications, depending on the required fire resistance time and position of the rebar related to the fire selected.

The design is summarized in a clear and comprehensible design report and information on the “cold” and “hot design” for your project documentation.

• **Hilti HIT-CT 1:** Fast cure for standard application range or application where particularly environmentally friendly connection should be executed, EC2 design only.



• **Hilti HIT-FP 700-R:** Developed for temperature critical applications as fire, long curing time compared to resin-based systems, EC2 design only

• **Hilti HIT-HY 200-R V3:** Fast cure for standard application range, EC2 design & EOTA TR 069

• **Covers 80%** of PIR applications

80/20

• **Hilti HIT-RE 500 V4, the solution finder:** Slow cure for standard application range and applications where very large rebar diameter and deep boreholes or many boreholes are needed (pneumatic dispenser). EC2 design & TR 069

Fig. 14: *Hilti Team strength for post-installed rebar connections by providing specific feature*

However, if you want to pre-select a mortar system, we can provide a rule of thumb as general application characteristic and application conditions including static loading in combination with normal rebar diameters are anyhow covered by all system:

- **Hilti HIT-FP 700-R:** Developed for temperature critical applications as discussed above, longer curing time compared to resin-based systems.
- **Hilti HIT-RE 500 V4:** Slow cure for standard application range and applications where very large rebar diameter and deep boreholes or many boreholes are needed.
- **Hilti HIT-HY 200-R V3:** Fast cure for standard application range in general 80% of all possible post-installed may be covered with this system if no specific design conditions apply.
- **Hilti HIT-CT 1:** Fast cure for standard application range or application where particularly environmentally friendly connection should be executed (label free).

SUMMARY

The analysis of cast-in concrete-to-concrete connections subjected to fire action may be performed by several methods with different levels of complexity and accuracy. On the simplest practical level, descriptive methods in the form of tabulated data may be applied, taking account of the specific conditions covered by these values.

Due to its straightforward approach this is the first method applied in practical design for concrete members. As second step or a second option simplified calculation methods maybe used where the fire damaged cross-section is represented by a reduced cross-section ignoring a damaged zone of thickness at the fire exposed sides. Both tabulated data and simplified calculation methods have in common that they assume that until 500°C the reduction of the concrete compressive strength (bond between cast-in rebar), related to the design actions is not significant. In contrary the relationship between the bond of post-installed rebar system is highly mortar dependent while at 500°C none of the investigated resin-based systems provides any residual bond strength. Consequently, applying the logic of tabulated data and simplified calculation method in combination with these systems may lead to safety issues regarding the fire behavior.

To overcome that challenge Hilti can now provide a cementitious based injection mortar showing a related reduction in bond strength which is much lower compared to resin-based mortars and even concrete at 500°C. Consequently, Post-installed rebar connections under fire according to EN 1992-1-2 [1] using tabulated data and simplified calculation methods can now be realized using Hilti HIT-FP 700-R. In combination with other Hilti injection systems, we believe that we can nearly satisfies all design needs coming along with building construction projects, while Hilti Profis engineering supports the choice of the right product in a simple way.

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