Fire design in post-installed rebar applications

Design methods for lap splices and end anchorages

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1. Introduction

Fire disasters happen frequently and can occur in all types of structures, thus being a significant risk of loss of lives and assets. They may impact the stability of concrete structures with potential complete or partial collapse. Hence **structural fire safety is of critical importance** and an essential requirement that all structural building codes globally prescribe through mandatory fire resistance durations for structural elements and systems, including their connections. This helps ensure enough time for occupants to evacuate, for rescue activities to be completed, and for the fire to be safely extinguished.

Post-installed rebars (PIR) are commonly used to connect concrete structural elements cast at different times to establish a monolithic connection between the existing and new elements, as they serve as reliable, faster, and economic solutions. The need for PIRs may frequently arise out of unplanned situations or it can also be a planned activity (see Fig. 1. 1).

Building codes generally provide guidance for fire safety to design traditional reinforced concrete systems. National codes across Eurocode regions prioritize fire safety, offering clear guidance for cast-in reinforcement referencing tabulated data approach and other simplified methods. However, when it comes to alternative construction methods such as PIR, these codes call for an advanced approach requiring expert judgment due to the distinct behavior of mortars compared to concrete and steel. In these cases, it is the responsibility of the structural engineer to ensure building structures meet the mandated fire safety requirements.

Note: Post-installed rebar applications are used both in building and civil structures as lap splices and end-anchorages

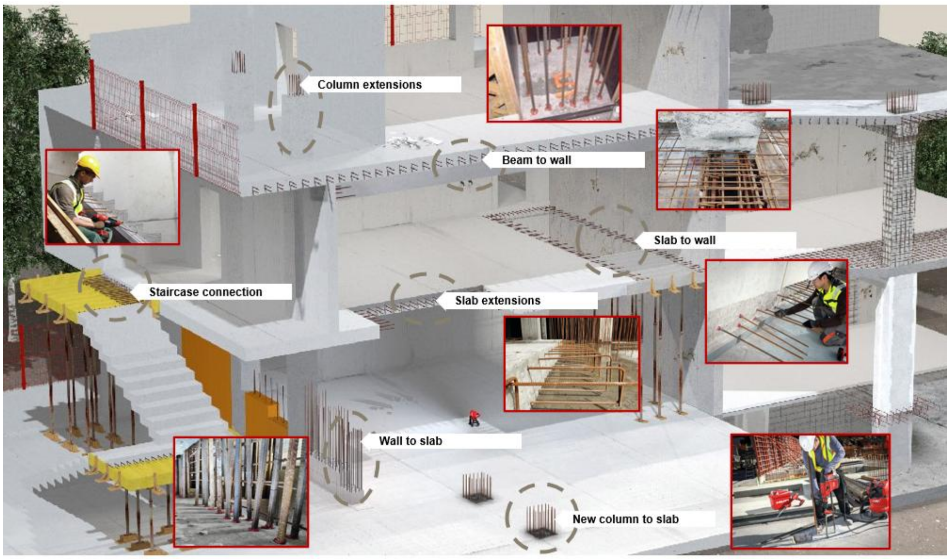
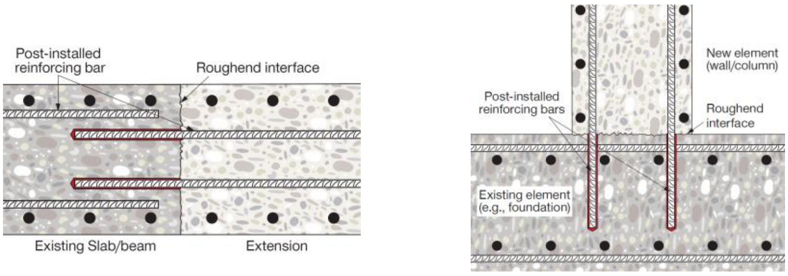


Fig. 1. 1: Typical post-installed rebar applications in building structures

1.1 Applications using PIR

The application range of post-installed rebar system connections can be broadly classified as **lap splices for member extensions** such as slab/beam/wall/column extension applications and **end anchorage applications (with/without acting moments)** for slab-to-wall, column/wall-to-slab, etc. (see Fig. 1. 2).



a) Lap splice

b) End anchorage

Fig. 1. 2: General classification of post-installed rebar applications

Simply supported end-anchorages are application cases where an element 'simply supports' onto another (e.g., slab onto a wall) without any acting moments. However, end anchorages are often, in reality, **rigid or semi-rigid connections** with acting moments arising out of partial/full fixity in concrete-to-concrete connections such as column/wall arising from foundations or a beam/slab connected onto a wall. The scope of such post-installed rigid moment-resisting applications is limited by the design method following provisions of EN 1992-1-1 [1], where such rigid joints are usually designed and executed as lap splicing. This is not always a feasible solution since in many cases the members are already constructed. For such cases, EOTA has developed a design technical report (TR) 069 [2] where rigid end anchorages can be designed and installed as straight post-installed rebar connection without the need for a splice configuration in the existing member.

2. Basics of fire exposure and PIR behaviour

2.1 Fire application input curve

PIR applications like lap splices and end-anchorages under fire exposure according to EN 1992-1-2 [3] rely on ISO 834 [4] type fire curve (see Fig. 2. 1), developed to provide a specific period of fire resistance (R). ISO 834 curve [4] is a celluloid type of fire curve utilized in the case of fires in buildings and designed based on the specifications of the owners/building authorities. However, for design of PIR infrastructure applications (e.g., tunnels), different types of fire curves like RABT are typically used. Tunnels have extraordinary volume of combustible materials to burn in the event of a fire. Hence, these fire curves are modified hydrocarbon (HC)-based which is combustible in real life situations in a tunnel.

Note: Contact Hilti for support on assessment of fire curves and fire design of specific applications

Based on the specific fire curve analysis/simulations (like ISO 834, RABT, etc.) and requirements of the applications, the temperature along the position of post-installed rebar can be estimated. This information can then be used to design the fire-safe anchorage depths using the temperature degradation data of qualified injection mortars. For PIR connections that are a part of fire-rated assemblies in a structure (floor, roof, etc.), it is important that the fire resistance of these connections is evaluated considering the fire exposure time (according to EN 1992-1-2 [3], between 30 and 240 minutes), geometrical boundary conditions and temperature distribution due to fire exposure.

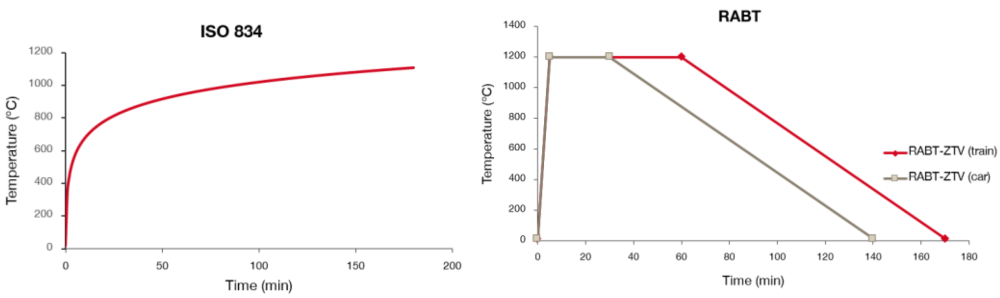


Fig. 2. 1: Typical fire curves

2.2 Behavior of PIR under fire exposure

The behavior of cast-in rebars (CIR) under fire exposure is different from post-installed rebars because properties of injection mortars are different from that of concrete (see Fig. 2. 2). The chemistry and mechanical properties of organic mortars used in PIR applications are significantly affected by high temperatures. The bond-strength degradation due to temperature is highly product dependent and different mortars behave differently at elevated temperatures. Consequently, it is important to know this time-temperature dependent reduction in bond strength to properly design the connection.

The composition of the injection mortars could be organic, inorganic or hybrid systems. All organic mortars and hybrid mortars lose their strength at lower temperatures compared to steel and concrete (see Fig. 2. 2). To overcome this challenge, Hilti's HIT-FP 700-R was developed as an injectable inorganic calcium-aluminate-based cement for post-installed rebar connections. Compared to organic mortar systems, which show no residual capacity at 500°C, Hilti HIT-FP 700-R is assessed up to 500°C and experiences a very low reduction of its bond capacity compared to concrete for which a reduction of approximately 30% is assumed at 500°C.

Note: Behavior of PIR is different and more critical than CIR under fire exposure

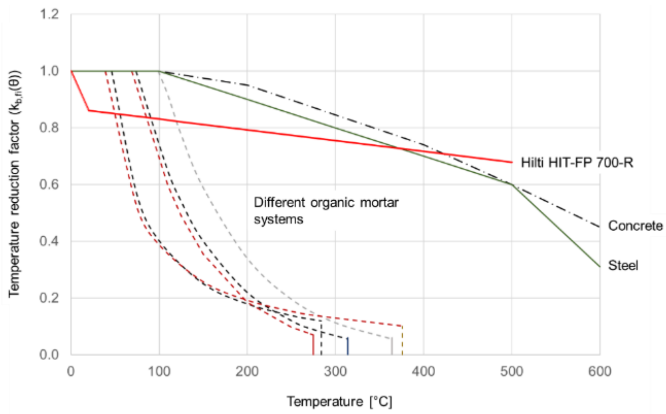
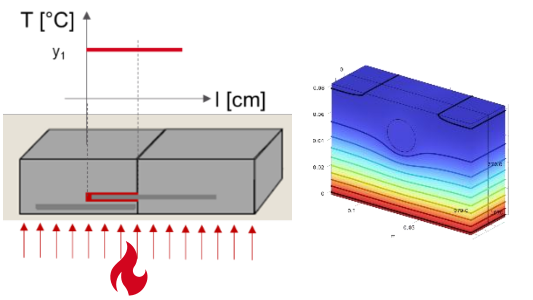


Fig. 2. 2: Performance reduction curves of injection mortars, concrete and steel under fire exposure

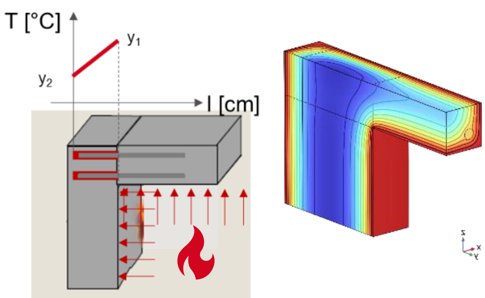
2.3 Temperature profile of PIR applications under fire exposure

For PIR applications using lap splices, the temperature distribution along the lap splice length is usually constant, for most common scenarios (see Fig. 2. 3a). In end-anchorage applications, temperature distribution usually varies along the embedment depth of the post-installed rebar (see Fig. 2. 3b).

Note: The temperature distribution profile in PIR applications is influenced by the concrete cover, embedment length and fire exposure time.



a) PIR with constant temperature distribution located parallel to the flamed concrete surface (typical in lap splices)



b) PIR with uneven temperature distribution along the length of the bar (typical in end anchorages)

Fig. 2. 3: Typical temperature distribution in PIR connections

3. Framework for qualification and design

3.1 Design overview of PIR for fire exposure

Design of Post-Installed Rebars (PIR) is not directly addressed in EN 1992-1-1 [1] (static design) and EN 1992-1-2 [3] (fire design). The approaches for fire design verification for cast-in rebars (CIR) which are given in EN 1992-1-2 [3] are as follows:

Tabulated data: This method relies on keeping the required minimum concrete member dimensions and cover for different fire exposure classes. This method is based on the principle that, for certain geometrical constraints for a specific fire duration, the temperature in the rebar does not exceed 500 °C. Under these conditions the fire design case is never decisive, and the static design of the cross section and anchorage of cast-in bars is sufficient.

Simplified calculation: EN 1992-1-1 [1] assumes a ‘critical temperature’ of 500 °C in structural members and using 500 °C isotherm method, concrete above 500 °C is ignored and the cross-section is reduced for stresses to be recalculated. Alternatively, the zone method can be used for cross-section analysis.

Advanced method: Advanced thermal–mechanical finite element simulations of the entire structure are carried out. This method might be needed where unusual geometries are involved or in high-risk projects.

The above standard approaches for cast-in rebar cannot be applied directly to post-installed rebar applications. All organic mortars lose their strength rapidly at much lower temperatures compared to inorganic mortars, steel and concrete (see Fig. 2. 2), resulting from reduced bond strength under fire. This pushes the need for a significant increase in required concrete cover for post-installed rebar design to meet fire requirements, and/or deeper embedment lengths which might not be always possible due to limitations in existing member sizes and/or uneconomical solutions for design under fire exposure.

3.2 Assessment overview of PIR for fire exposure

The assessment document **EAD 330087 [5]** revolves around the concept of equivalency in performance (i.e., bond strength and load-displacement behavior) between a post-installed rebar system and cast-in rebar system under static loading. Based on the fire input curve discussed, fire duration class, concrete strength class and loading conditions, the performance degradation of the PIR systems at elevated temperatures is also assessed as per the EAD. Thus, the European Technical Assessments (ETAs) specify fire performance of injection mortars through corresponding bond strength reduction curves as a function of the temperature. PIR systems assessed using EAD 330087 [5] are thus enabled to be used in design applications using static design provisions of EN 1992-1-1 [1] and fire design provisions as per EN 1992-1-2 [3] which are generally for cast-in rebars. It is also important to note that the design provisions of **EN 1992-1-1 [1] allow only limited PIR applications** such as lap splices and end anchorages without bending moments.

Overcoming the limited application range of PIR applications as per provisions of EN 1992-1-1 [1], **EOTA TR 069 [2]** provides a design method for end-anchorage applications with acting moments (see Fig. 3. 1) based on **improved bond-splitting behavior**. This includes verification of all the possible failure modes (steel yielding, pull-out, splitting and concrete cone failure). The product-dependent performance of the specific post-installed rebar system is considered via assessment according to the EAD 332402 [6] and its variants [7] [8] [9].

Note: EOTA TR 069 allows higher bond strength of adhesive mortar than EN1992-1-1

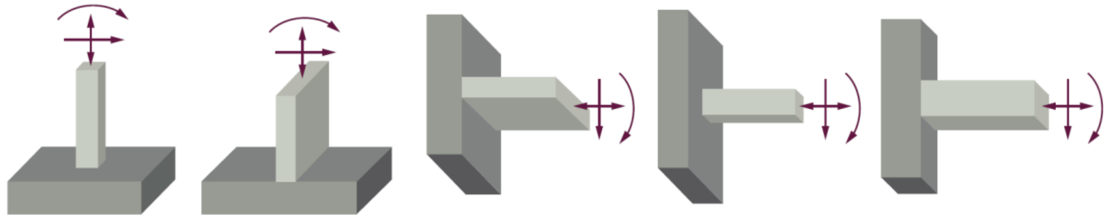


Fig. 3. 1: Typical design applications covered by EOTA TR 069

The evolution of PIR assessment and design methods (for static and fire exposure) for PIR applications over the last two decades are depicted in Fig. 3. 2.

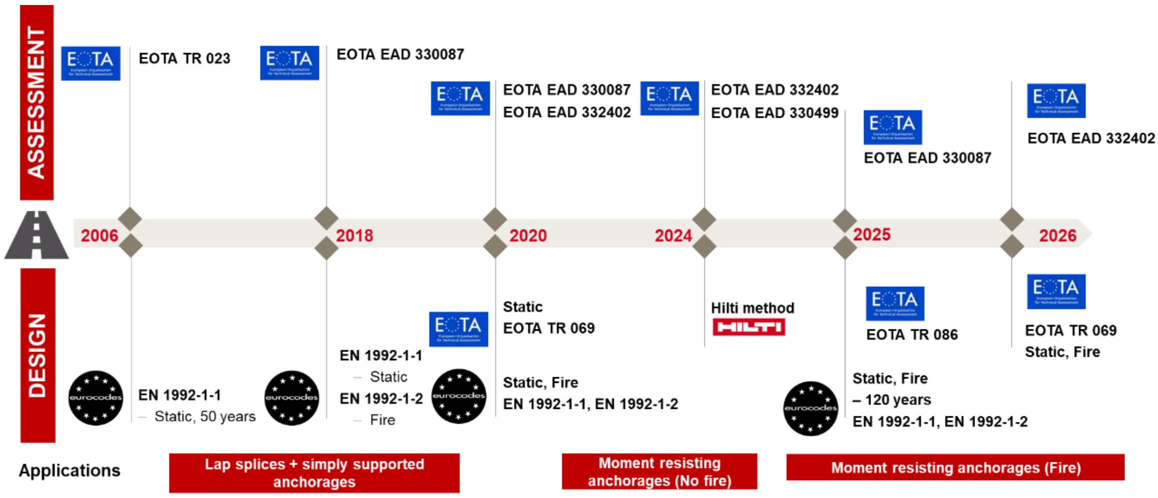


Fig. 3. 2: Evolution of post-installed rebar assessment and design methods for fire exposure

4. Fire design of post-installed rebars

4.1 Design verification format and principles

A fire rating for the post-installed rebar connection (duration during which the structural functionality and stability of the post-installed rebar connection to be ensured) can only be established if the capacity corresponding to that rating is equal to or greater than the demand. At ultimate limit state during fire exposure of a member, the design load effects, $E_{d,fi}$, shall not be larger than the design fire resistance, $R_{d,fi}$, outlined by the equation below:

$E_{d,fi} \leq R_{d,fi}$ EN 1992-1-2, eq. (2.3)

where,

$E_{d,fi} = \eta_{fi} \cdot E_d$ EN 1992-1-2, eq. (2.4)

$R_{d,fi} = R_{k,fi}/\gamma_{M,fi}$

Here, E_d accounts for the design load actions (force or moment) under normal ambient ('cold') conditions, η_{fi} is the load reduction factor and $\gamma_{M,fi}$ is the material safety factor for fire exposure. Design loads determined from static actions are used for fire design with modifications based on partial safety factors for loads as well as material (section 4.1.1).

The decisive fire design resistance ($R_{d,fi}$), expressed as the total tension force in the post-installed reinforcement used for PIR connections, shall be the minimum of the calculated resistance for each failure mode (steel yielding, pull-out, splitting and concrete cone breakout). This design verification format and principles are applicable for fire design of all PIR applications.

4.1.1 Partial safety factors

The partial safety factors for materials and general partial factors for load actions follow the principles of EN 1992-1-1 [1] and EN 1992-1-2 [3] for static and fire loading cases, respectively, as shown in Table 4. 1 below:

Table 4. 1: Material partial safety factors

Strength Verification	Partial factor-Static	Partial factor-Fire	Remark
Rebar steel yielding	$\gamma_{Ms} = 1.15$	$\gamma_{s,fi} = 1.0$	Reduction in material safety factors for fire exposure
Concrete cone breakout	$\gamma_{Mc} = \gamma_{inst} \cdot \gamma_c$ where, γ_{inst} as per ETA, $\gamma_c = 1.5$	$\gamma_{Mc,fi} = \gamma_{inst} \cdot \gamma_{c,fi}$ where, γ_{inst} as per ETA, $\gamma_{c,fi} = 1.0$	
Bond-splitting failure & pull-out	$\gamma_{Mp} = \gamma_{Msp} = \gamma_{Mc}$		
Design load actions E_d	$E_d = \gamma_G \cdot G_k + \gamma_Q \cdot Q_k \approx \gamma_f \cdot E_k$ where, $\gamma_f = 1.4$	$E_{d,fi} = \eta_{fi} \cdot E_d$ where, $\eta_{fi} = 0.7$	Reduction of design loads for fire exposure

4.2 Design of lap splice length under fire exposure

Note: For more details on design of post-installed rebar applications, refer Hilti's Concrete-to-concrete connections Handbook

The design of splice length can be calculated using the same design provisions for a static load case in Section 8 of EN 1992-1-1 [1]. However, the reduced bond strength capacity from the relevant ETA for fire ($f_{bd,fi}$) shall be used instead of $f_{bd,PIR}$. The design bond strength under fire ($f_{bd,fi}$) reduces with increasing temperature. This curve 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 (see Fig. 2. 2).

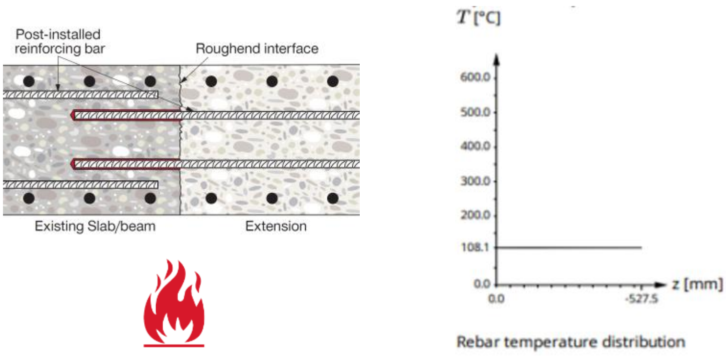


Fig. 4. 1: Typical temperature distribution in lap splice connection

The design procedure for splice length under fire exposure assuming a constant temperature distribution (see Fig. 4. 1) is summarized using steps shown below:

Step 1	Determine the temperature in rebar for which the splice length must be calculated
Step 2	Determine the temperature reduction factor $k_{fi}(\theta)$ from relevant ETA
Step 3	Calculate the design bond strength $(f_{bd,fi})$ using the reduction factor
Step 4	Calculate the splice length using the design bond strength $(f_{bd,fi})$

Hence the following equation in the basic lap length design calculations for fire is modified as,

$$\boldsymbol{l_{b,rqd,fi} = (\phi/4)\cdot(\sigma_{sd}/f_{bd,fi})}$$ EN 1992-1-2, eq. (8.3) + EAD 330087

where, σ_{sd} is the design stress in rebar

4.2.1 Steel yielding verification

The design also considers the residual stress in the steel reinforcement in fire exposure with strength reduction factor $k_s(\theta)$ considering the maximum temperature along the anchorage length, using the verification equation as follows:

$$\boldsymbol{F_{Ed,fi} \leq F_{yd,fi} = k_s(\theta)\cdot A_s \cdot f_{y,k}/\gamma_{s,fi}}$$

where, $\gamma_{s,fi}$ is the material safety factor for steel for fire condition, A_s is the cross-sectional area of rebar(s) and $k_s(\theta)$ is taken from EN 1992-1-2, Figure 5.1.

> Note: The temperature θ to calculate the reduction factors for mortar $k_{fi}(\theta)$ and steel $k_s(\theta)$ can be taken from EN 1992-1-2 [3], Annex A for standard structural elements based on design fire temperature. Alternatively, it can be also taken from a suitable finite element model simulation.

4.3 Design of end anchorages (without acting moments) under fire exposure as per Eurocode

The principles of design for fire exposure are similar to what is discussed in previous section for lap splices. However, for end anchorages/intersection connections, the temperature distribution usually varies along the embedment length of the rebar (see Fig. 4. 2).

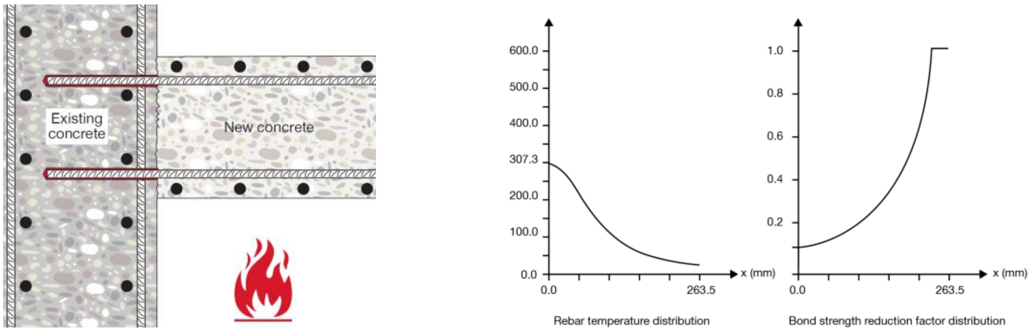


Fig. 4. 2: Typical temperature distribution in end anchorage connection

Note: The Eurocode provisions for fire design of end-anchorages are only valid for simply supported anchorage connections (without acting moments) and not for applications with acting moments. Engineering judgement is required to consider the effect of partial fixity in concrete connections on the top rebar in such simply supported end-anchorage applications.

4.3.1 Design anchorage length calculation under fire exposure

The design anchorage length can be calculated using the same design provisions mentioned for design of lap splices, using a similar approach of reduced bond strength capacity from the relevant ETA. The fire bond resistance $(N_{Rd,fi})$ assuming a non-constant temperature distribution (refer to Fig. 4. 2) is determined using following steps shown:

Step 1	Determine the temperature profile in the rebar for the specific application
Step 2	Use the relevant mortar reduction factor vs. temperature curve
Step 3	Determine bond strength vs. temperature degradation curve
Step 4	Determine the fire bond capacity using resistance integration method

The design bond stress at a position 'x' along the anchorage length from the interface under fire $(f_{bd,fi})$ is calculated using the equation below**:**

$$f_{bd,fi} = k_{fi}(\theta(x)) \cdot f_{bd,\,PIR} \frac{\gamma_c}{\gamma_{c,fi}} \qquad \text{EAD 330087}$$

where**,**

$k_{fi}(\theta(x))$ is the reduction factor at a position 'x' along the anchorage length dependent on exposure temperature taken from ETA.

The fire bond resistance $(N_{Rd,fi})$ for an assumed design anchorage length of post-installed rebars $(l_{bd,fi})$ is given by the equation:

$$N_{Rd,fi} = \pi \cdot \phi \cdot \frac{\gamma_c}{\gamma_{c,fi}} \frac{f_{bd,fi}}{\alpha_2 \cdot \alpha_3 \cdot \alpha_5} \int_0^{lbd,fi} k_{fi}(\theta(x))dx$$

All $'\alpha'$ coefficient values are provided in EN 1992-1-1 [1] and their design calculations for fire remain the same as for static. The fire bond resistance $(N_{Rd,fi})$ calculated according to this integration method shall not be smaller than $N_{Ed,fi}$, requiring an iterative design process.

4.3.2 Steel yielding verification

Steel yielding verification is carried out in the same way as for lap splices (refer section 4.2.1). Here the strength reduction factor for maximum temperature along the rebar anchorage length $k_s(\theta_{max})$ is utilized.

4.4 Design of end anchorages with acting moments under fire exposure as per EOTA TR 069

The new provisions of EOTA TR 069 [2] allow fire design of end anchorage with acting moments (rigid joints) based on the bond-splitting behavior of post-installed rebars at elevated temperatures.

4.4.1 Fire design resistance to yielding of steel rebar

See section 4.2.1 for verification procedure for resistance to yielding of rebar under fire.

4.4.2 Fire design resistance to concrete cone breakout

Two analytical approaches are available for evaluating concrete cone failure resistance under fire conditions. **One is time-based method**, following provisions of EN 1992-4 [10], Annex D referred by EOTA TR 069 [2] for concrete cone breakout strength in fire $N_{Rd,c,fi}$. **The second approach is a temperature-based method** that enhances design flexibility by evaluating anchor performance based on its thermal profile. Unlike the time-based method, this approach is not limited by fire duration and remains valid for arbitrary fire exposure times, including those exceeding 120 minutes (refer Table 4.2 for differences between the two concrete cone models). The determination of concrete cone design resistance $N_{Rd,c,fi}$ for a specific fire exposure duration shall be established following steps 1 to 5 as follows:

Step 1	Determine concrete cone resistance at ambient temperature
Step 2	Determine the temperature profile in the rebar for the specific application
Step 3	Determine the temperature θ_c at the end of the anchorage length
Step 4	Calculate the temperature reduction factor $k(\theta c)$
Step 5	Determine fire concrete cone resistance by applying reduction factor

Table 4. 2: Difference between concrete cone models (Eurocode model limitations vs. EOTA TR 069 model advantages)

Time-based model	Temperature-based model
Calculation of resistance only for fixed fire duration classes R90 & R120, and applied to lower exposure times	Optimized calculations available for any fire exposure time (e.g., R15, R160, R240) and potentially beyond
Model valid only for standard ISO fire curve	Model valid for different fire curves
Fire exposure is one sided and if additional fire exposure side is considered, then cover ‘c’ shall be ≥ min(300 mm and $2l_{b,fi}$)	Removes all geometrical constraints for fire exposure
Larger characteristic spacing and edge distance than for static design	Same characteristic spacing and edge distance as for static design
C20/25 strength class only shall be used	C20/25 – C50/60 strength classes can be utilized
Benefits of using fire protection solutions are available only via physical testing	Benefits of using fire protection solutions are available with simple thermal simulations

4.4.3 Fire design resistance to pull-out and splitting failure

The following steps are to be followed to determine the design resistance corresponding to pull-out and splitting failure $N_{Rk,sp,fi}$.

Step 1	Determine pull-out and splitting resistances at ambient temperature
Step 2	Determine resistance vs. temperature degradation curves for splitting and pull-out
Step 3	Boundary temperature at splitting and pull-out intersection is calculated
Step 4	Temperature profile is determined along the embedment length
Step 5	Determine embedment lengths for splitting and pull-out resistances
Step 6	Calculate the fire load capacity using resistance integration method

Using the pull-out and splitting reduction factors (as functions of temperature) from the relevant ETAs, resistance degradation curves are derived and from these resulting curves, the boundary temperature (θ_b) is determined (see Fig. 4. 3). θ_b is defined as the point where failure shifts from splitting to pull-out (intersection of the pull-out and splitting resistance degradation curves).

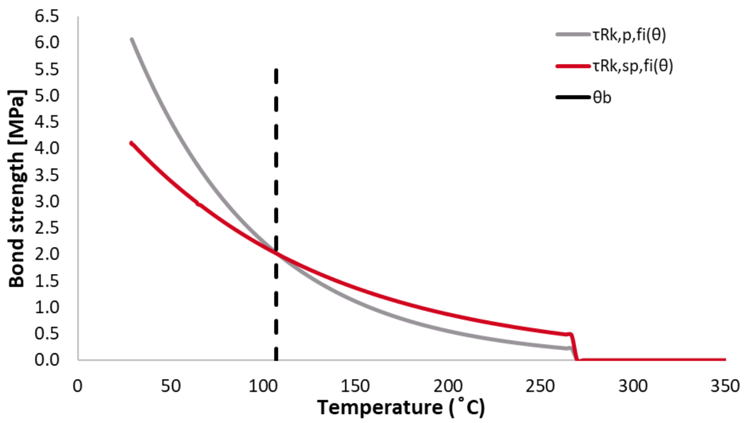


Fig. 4. 3: Boundary temperature at intersection of pull-out and splitting resistance degradation curves.

Note:

1) In some cases this boundary may not exist (no intersection between the two curves) as failure can be exclusively pull-out (favoured by higher concrete cover c_d) or splitting (favoured by smaller cover concrete c_d). In such cases, only the lower degradation curve shall be used for design.

2) If the fire rating requirements are not met, a redefinition of the geometric parameters is required and a redesign of the connection following steps 1 to 6 is needed (an iterative process).

5. Hilti product solutions

For the entire application range of post-installed rebar systems (lap splices and end anchorages), Hilti's portfolio of solutions (assessed as per applicable EADs) for various load actions and other critical performance attributes are presented in table 5.1.

Table 5. 1: Qualified product solutions for post-installed rebar applications

PRODUCTS	HIT-RE 500	HIT-HY 200 R	HIT-HY 170	HIT-RE 100	HIT- CT 100	HIT-FP 700 R
						
Rebar diameters	8 to 40 mm	8 to 40 mm	8 to 32 mm	8 to 40 mm	8 to 25 mm	8 to 40 mm
Design	Eurocode & EOTA TR 069	Eurocode & EOTA TR 069	Eurocode	Eurocode	Eurocode	Eurocode
Approval	ETAs 20/0539, 20/0540, 25/0448	ETAs 19/0600, 19/0665, 25/0534	ETA 15/0297	ETA 15/0883	ETA 24/0147	ETA 21/0624
Performance attributes	Static, seismic & fire	Static, seismic & fire	Static, seismic & fire	Static & fire	Static & fire	Static, seismic & fire
Max. working life	120 years	120 years	100	50 years*	50 years**	100 years
Min. / Max inst. temperature	-5°C / +40°C	-10°C / +40°C	-5°C / +40°C	+5°C / +40°C	-5C / +40°C	+5°C / +40°C
Work. time @ 20°C	30 min.	9 min.	5 min.	25 min	4 min.	20 min.
Curing time @ 20°C	7 hours	60 min.	1.5 hours	12 hours	3.5 hours.	10 days
Drilling method	HD, HDB, DD+RT, DD, CA	HD, HDB, DD+RT, CA	HD, HDB, CA	HD, HDB, DD, CA	HD, HDB, CA	HD, HDB, DD+RT, CA
Moisture condition	Dry and wet (all drilling methods), Water-filled (only HD)	Dry and wet	Dry and wet	Dry and wet	Dry and wet	Dry and wet
Max. embedment	3200 mm	1300 mm	1250 mm	3200 mm	700 mm	2500 mm

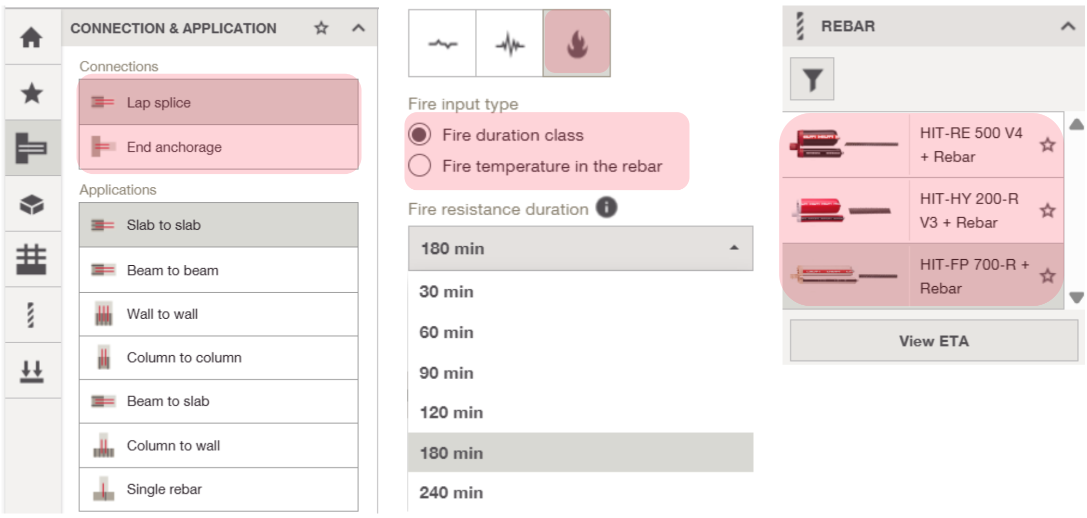
Note: HD – Hammer Drilling, HDB – Hammer Drilling with hollow drill bit, CA - Compressed air drilling, DD- Diamond wet coring method, (DD+RT) Diamond wet coring method combined with hole roughening
* 100 years working life coming soon in 2026
** 120 years working life coming soon in 2026

6. Design using PROFIS Engineering

6.1 Efficient and value-engineered design solutions

Solving different post-installed rebar (PIR) application cases using state-of-the-art design methods and then comparing the solutions with different qualified injection mortars to choose the most suitable solution can be very time-consuming when using manual calculations. Hilti's cloud-based design software PROFIS Engineering streamlines this process by supporting fast, code-compliant designs that ensure safety, efficiency, and transparency (see Fig. 6. 1).

With its advanced PIR module, PROFIS now incorporates the latest fire simulations with various parameters allowing designers to evaluate more realistic rebar and injection mortar performances under elevated temperatures. PROFIS allows the choosing of fire exposure durations up to 240 min for any PIR application, or the user is allowed to give manual input of rebar temperature as well. The choice of fire exposure sides for different applications will also be made available soon. The software enables quick comparison of different qualified injection mortars under multiple load actions (static, seismic, and fire), and instantly shows the governing case, saving time and improving accuracy. Additional key benefits include design optimization, clear utilization ratios, flexible adjustment of design parameters, and comprehensive design reports with detailed calculation steps.



a) PIR application selection b) Fire duration/temperature selection c) Qualified product selection

Fig. 6. 1: Benefits of using PROFIS Engineering software for fire design of PIR applications

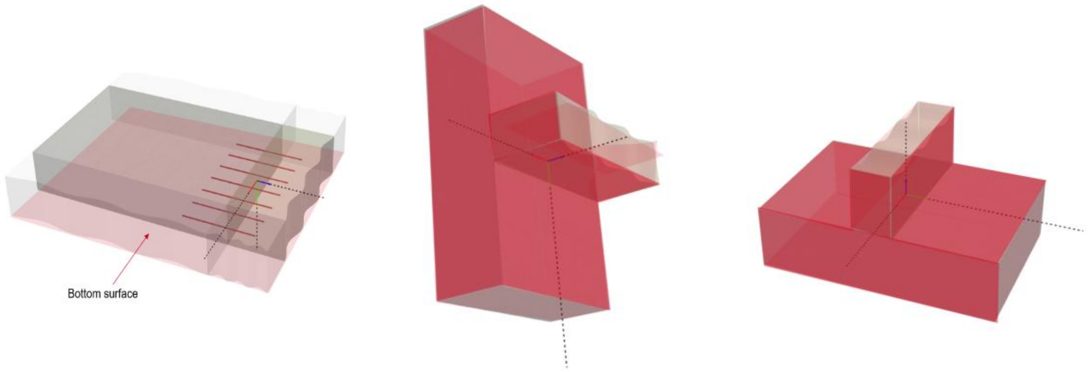
6.2 Background on finite element simulations for fire design in PROFIS

Fire simulations play an essential role in structural fire design, particularly in predicting temperature distribution within critical components - such as along the anchorage length of post-installed reinforcing bars. In this context, simulation work was carried out to generate temperature profile databases which are implemented in PROFIS Engineering for a range of predefined structural applications (e.g., slab-to-slab connections, beam-to-wall interfaces) under various boundary conditions (e.g., duration and direction of fire exposure).

6.2.1 Finite element modelling and boundary conditions

Numerical thermal analyses were conducted using finite element (FE) modeling, incorporating material mechanical and thermal properties for concrete and steel as specified in EN 1992-1-1 [1] and EN 1992-1-2 [11]. For each application type (see some examples in Fig. 6. 2), a comprehensive set of simulations was performed, covering multiple scenarios by varying key parameters including:

- fire exposure sides (see Table 6.1)
- fire durations
- rebar diameters
- concrete covers
- cross-sectional geometry of the concrete member
- rebar embedment length



a) Slab extensions b) Slab to wall connection c) Wall to slab connection

Fig. 6. 2: Examples of fire exposure sides in PROFIS Engineering design software

For each application type and every combination of rebar diameter, embedment depth, and concrete cover, the transient heat transfer equations are solved for a maximum of 240 minutes fire exposure duration using proprietary finite element software. The ISO 834 fire curve [4] was used for simulations. To predict the temperature field in a structure, the transient heat transfer equation is solved together with appropriate convective and radiative boundary conditions and material data according to EN 1992-1-2 [11]. The flux over the boundary is the sum of the convective flux and the radiative flux. Finally, for each simulation case, thermal profiles are extracted at predefined fire exposure duration intervals (R30, R60, R90, R120, R180, and R240). These temperature distributions are systematically compiled into a structured database for subsequent analysis and model development.

Table 6. 1: Fire exposure sides for different applications used for simulations in PROFIS Engineering

Application	Fire exposure sides simulated in PROFIS Engineering
Slab to slab / Wall to wall	1) Both sided 2) One sided – either side (coming soon)
Beam to beam	All four sides
Column to column	All four sides
Beam to slab / Column to wall	No simulations available. Users need to input temperature of rebar
Single rebar	No simulations available. Users need to input temperature of rebar
Slab to wall/ Wall to slab	1) Slab: either top side or bottom side + Wall: near side (coming soon) 2) Slab: both top and bottom side + Wall: near side
Column to slab	Column: fire from all four sides; Slab: fire from top surface
Beam to wall	Beam: fire from all four sides; Wall: fire from front surface
Beam to column	Beam: fire from all four sides; Column: fire from all four sides

7. SPEC2SITE™ solutions

Since Hilti offers a wide range of qualified solutions for structural connections, we want to make it easy for our users to navigate through and select the best solution which is value engineered for their application conditions. We do this by offering our SPEC2SITE™ solutions (with injection mortar) that help ensure improvement in the construction workflow for all PIR applications, from engineering design to installation on the jobsite, by making the projects more productive, safer and more sustainable through the offerings shown in Fig. 7. 1:

Fig. 7. 1: Hilti's SPEC2SITE™ offering for post-installed rebar applications

For Engineers, Hilti helps with improving design specifications for structural connections using post-installed rebar solutions, and **for Contractors,** Hilti helps in making structural connections faster, simpler, safer, and more sustainable through the following benefits:

Table 7.1: Hilti's SPEC2SITE™ offering benefits for engineers and contractors

FOR ENGINEERS	FOR CONTRACTORS
Higher performing structural connection solutions, for a wide variety of application requirements including fire resistance like HIT-FP 700-R, HIT-RE 500, etc. up to 240 min	**Faster** installation of fire qualified PIR systems with fewer steps such as automatic cleaning of drilled holes and no need for additional materials like fire sprays/boards for further installation
Value engineered and code-compliant designs for fire load action, quickly and seamlessly created using PROFIS Engineering	**Simpler** intuitive installation process that requires less skilled labor, reduced installation steps without requiring fire sprays/boards
More peace of mind with design methods and software to design for fire safety and knowledge-sharing that help ensure you get what you specify	**Safer,** smarter systems and job-site presence help ensure installations comply with the fire design specifications, safer with auto-cleaning and accurate dosing
More sustainable designs for fire safety with quantified and reduced CO_2 and no need for alternate solutions like fire sprays, boards, etc.	**More sustainable** projects for fire safety with quantifiable reductions in CO_2 and less jobsite wastage and no need for additional materials

8. Summary

The paper introduces the importance of structural fire safety focusing on behaviour and design of post-installed rebar (PIR) applications under fire load actions. Fundamental information on fire exposure, fire application input curve, behaviour of both CIR and PIR under fire exposure, and performance reduction curves are explained. It presents the European framework for qualification and design requirements for fire, and assessment principles for PIR, followed by detailed fire design approaches for lap splices and end anchorages, both with and without acting moments, in line with Eurocode [1], [3] and the new EOTA TR 069 [2] design methods. The article also gives a brief introduction on Hilti's qualified PIR product portfolio, highlights the role of finite element simulations of applications under fire and how they have been implemented in PROFIS Engineering to assist in quick and efficient design. The article ends with how Hilti's SPEC2SITE™ solutions help engineers as well as contractors improve productivity.

9. References

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