POST-INSTALLED REINFORCEMENT IN END ANCHORAGES

Rigid concrete-to-concrete joints

Version 1.0
July 2022

TABLE OF CONTENTS

1. ABSTRACT

Connecting structural concrete members with post-installed reinforcement (PIR) is today a trusted and reliable solution, especially considering the past 15 years have seen significant advances in the assessment and qualification of PIR solutions. Until the end of 2019, the use of injection systems qualified according to EAD 330087 was limited to simply supported end anchorages or splice connections. The only mechanism through which rigid, moment-resisting end anchorages can be addressed with EAD 330087 is if the reinforcement in the existing concrete element was detailed in a manner that created an overlap with the new bars.

Late-2019 saw the introduction of a new qualification EAD 332402 and accompanying design method TR 069 to specifically address this gap in EAD 330087, capturing the behaviour and design of moment-resisting end anchorages without overlapping bars. This enables, for the first time, regulation of the design and execution of PIR connections at a European level. This article introduces the new EAD 332402 qualification procedure and the TR 069 design method, with the latter representing a change from the existing assumptions underpinning EN 1992-1-1 design provisions for anchorage length. Furthermore, this article briefly explains the relevance of installation of epoxy mortar systems that have a direct impact on design assumptions and vice-versa.

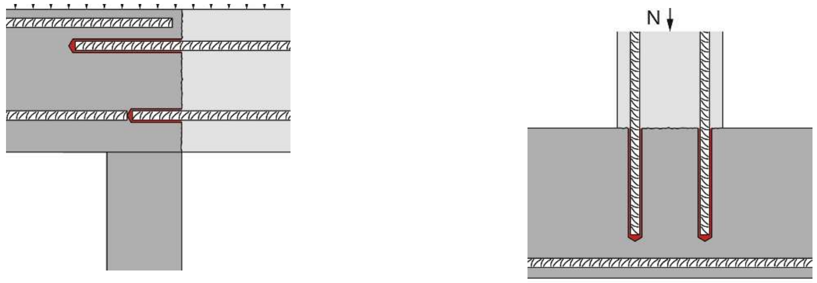
2. THE STATUS QUO: AN OVERVIEW ON ASSESSMENT & DESIGN OF POST-INSTALLED REBAR

Over the past decades, connecting structural concrete members with post-installed rebars (PIR) connections has gradually become a widespread practice in the global construction industry with its use extending to both new and existing construction. Assessing the epoxy mortar system's fitness for use through a robust qualification procedure gives confidence to designers and contractors that post-installed bars will behave like straight cast-in bars if appropriate design and installation are undertaken. In 2006, the European Organisation for Technical Assessment (EOTA) published the first assessment for Post-installed Rebar – Technical Report 023 – which was superseded in 2018 by the European Assessment Document (EAD) 330087 [1].

Building on the previous TR 023, this EAD introduced the criteria for assessing PIR systems to establish their equivalence to cast-in rebars (CIR) in terms of load-displacement behaviour, bond-splitting resistance, and robustness under differing installation, environmental, and loading conditions such as static, seismic, and fire exposure. The EAD 330087 first derives the average bond strength of an epoxy mortar system using a series of basic confined tension test and then subjects this to the variations found in real conditions to assess robustness.

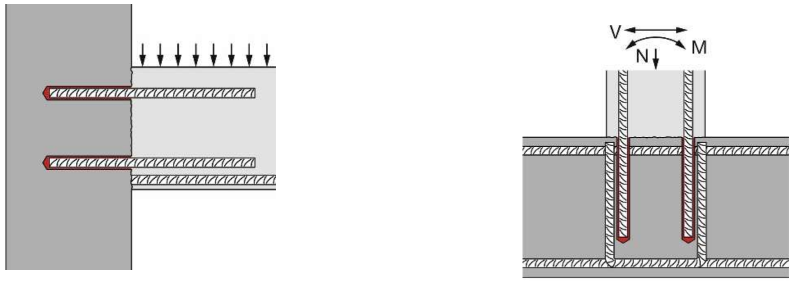
An EAD 330087-qualified epoxy mortar system can then be designed using the straight bar anchorage length design provisions of EN 1992-1-1 [2] for simply supported or compression-only end anchorages and splices, as illustrated by Figure 1.

Figure 1
Execution of post-installed moment resisting connection slab-to-slab and column or wall by splicing as required by EAD 330087 [1]



(a) **Overlap joint for rebar connections of slabs and beams**

(b) **Overlap joint at a foundation of a column or wall**



(c) **End anchoring of slabs or beams (simply supported)**

(d) **Components stressed primarily in compression**

Once designed, installation of post-installed bars introduces changes in the construction workflow, economics, and safety measures when compared to laying cast-in bars, particularly if the requirement of post-installed bars is unplanned and arises from errors in execution or changes in design. Additional steps and competencies are required of installers to ensure design translates into appropriate installations on site. A major challenge for designers and contractors is accommodating the anchorage length of straight post-installed bars within the existing section's thickness. For splices, installing post-installed bars is possible to execute despite deep anchorage lengths since the existing section is sufficiently thick to accommodate the required anchorage length. Ensuring drilling remains perpendicular to the surface is the biggest challenge that can be overcome through use of drilling aids.

For end anchorages, EAD 330087 only permits such connections to resist bending if overlap bars are provided in a manner illustrated by Figure 1(d), otherwise these connections may only transfer shear (i.e., they are simply supported as in Figure 1(c)). A structural engineer wishing to transfer moment and comply with EAD 330087 for a new construction must undertake additional planning to both provide and position the appropriate reinforcement at the right location in the existing member to accommodate the new post-installed bars. At site, this translates to exposed bars that often impede access and disrupt workflow in already congested spaces, leading to heightened safety risks. The exposed bars also run the risk of damage from construction equipment. In existing construction where these overlap bars are unavailable, transferring bending from the new to existing concrete may require partial demolition to accommodate new bars, as illustrated by Figure 2 [3]. In both situations, execution at site is hampered and prone to further errors, and the use of overlap bars is best avoided.

The inability to assess the behaviour and design of post-installed end anchorages without overlap bars, however, is not the only limitation of the EAD 330087, which also caps the design bond strength, f_{bd}, used in calculating the anchorage length to that of concrete. For example, the chemical must achieve a design bond strength, f_{bd}, of at least 2.3 MPa in C20/25 concrete. The bond strength of industry-leading epoxy mortars used in post-installed rebar connections far surpasses that of concrete and the inability to meaningfully use a more realistic performance in well-confined concrete renders many post-installed end anchorages unfeasible (i.e., the anchorage length often exceeding the existing concrete's thickness).

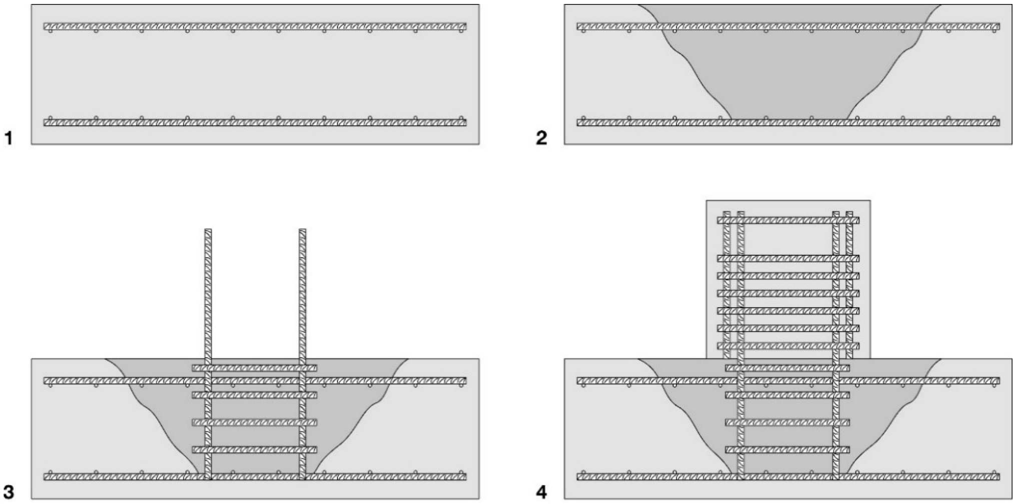


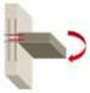
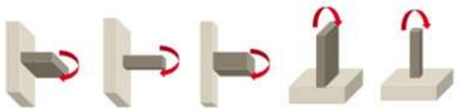
Figure 2
Typical process to demolish existing member to place a new reinforcement system followed by concrete cast-in [3]

The consequence of EAD 330087 being unable to assess the behaviour of moment-resisting end anchorages considering the bond-splitting performance of epoxy mortar in unconfined concrete necessitated a large experimental campaign in the late-2010s [4], [5], culminating in a new European Assessment Document (EAD) 332402 [6] and the accompanying Technical Report TR069 [7] published by EOTA (European Organization for Technical Assessment).

3. A BREAKTHROUGH IN PIR: NEW ASSESSMENT & DESIGN CONCEPT WITH EAD 332402 & TR 069

First published in 2019, the new Technical Report EOTA TR069 entitled “*Design method for anchorages of post-installed reinforcing bars (rebar) with improved bond-splitting behaviour as compared to EN 1992-1-1*” allows for the design of post installed, moment-resisting reinforced concrete connections under static and quasi-static loading conditions without using an overlap splice configuration. Design with TR 069 requires that the epoxy mortar system be assessed to the requirements of EAD 332402, and the subsequently published ETA contains specific factors unique to the epoxy that govern the bond-splitting behaviour of the moment-resisting connections illustrated in Table 1.

Table 1
Extension in scope of post-installed reinforcement connection with EOTA TR069 design method.

	Splices	Simply supported	Compression load only	Rigid connection with overlap	Rigid connection (without overlap bars)
					
Load	**Static**		**Fire**	**Seismic**	**Static**
Product qualification	EAD 330087				EAD 332402
Technical data	ETA I				ETA II
Design method	EC2		EC2	EC8	TR069

3.1 Overview of EAD 332402 – “Post-installed Reinforcing Bar (Rebar) Connections with improved Bond-splitting Behaviour under static loading”

While EAD 330087 assesses the equivalence of epoxy mortar to cast-in-situ concrete, the new EAD 332402 goes a step beyond and enables evaluation of the epoxy mortar’s sensitivity to several influencing factors that govern the design bond-splitting resistance of the epoxy mortar system when used with EOTA TR 069.

Although a “stand-alone” qualification document, EAD 332402 builds upon specific aspects of two existing EADs: 330087 (for equivalence to cast-in, covered in Section 2 of this document) & 330499 (bonded anchors) [8]. The latter does not cover small edge distances and spacing and anchorages beyond 20 times the bar diameter but does provide the characteristic pull-out resistance of the epoxy mortar that forms the upper limit of the bond-splitting resistance. The former solely assesses equivalence to cast-in bars, meaning an epoxy mortar must first be qualified to both these documents prior to an assessment with EAD 332402.

EAD 332402 implements a novel beam-end test (BET) specimen to model the bond-slip curve from the *fib* Model Code 2010 [9] for post-installed bars using epoxy mortars. This BET specimen generates a bending moment, resulting in a compression and tension zone comparable to a typical beam, but one where the concrete surrounding the post-installed epoxy mortar system is also under tension (i.e., unconfined). When compared with the pull-out specimen from EAD 330087 that uses a **confined** setup to prevent cone breakout, uniform concrete cover to all edges, and large confinement, this setup enables a comprehensive evaluation of bond-splitting behaviour under realistic boundary conditions in which concrete is **unconfined**, cover is small and not uniform to different edges, and the layout of the transverse reinforcement is included.

Figure 3 illustrates a representative BET specimen designed to evaluate the **influence** of a specific epoxy mortar on the bond-splitting behaviour of the concrete, resulting in the following mortar-specific calibration factors that influence the characteristic bond-splitting resistance:

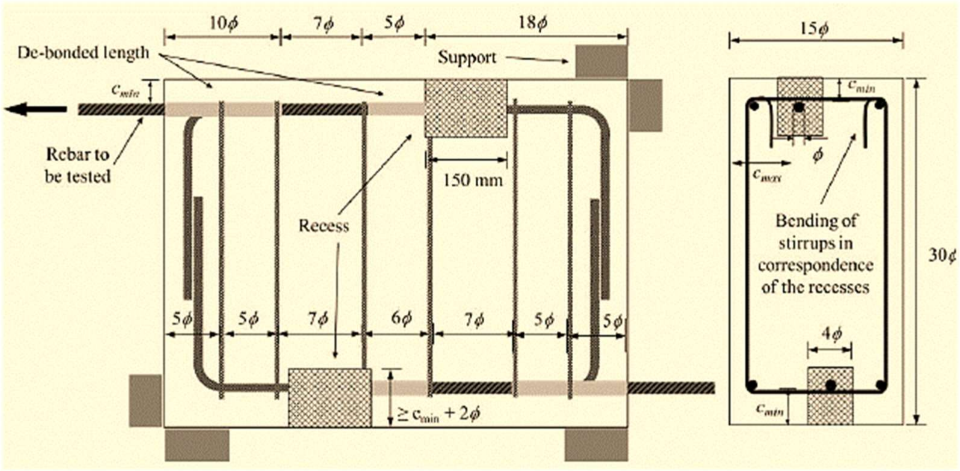


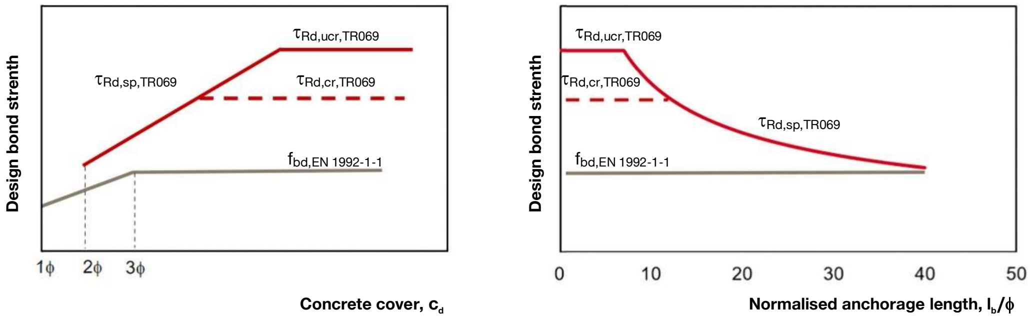
Figure 3
Elevation & Plan of Beam-end Test specimen from [6]

- Sp1 – influence of **concrete strength**
- Sp2 – influence of **bar diameter**
- Sp3 – influence of **minimum concrete cover**
- Sp4 – influence of **side concrete cover**
- Lb1 – influence of **anchorage length**
- A_k – a **fitting** or “product basic” factor
- Ω_{cr} – influence of **cracks** (up to 0.3mm in accordance with EN 1992-1-1)

Alongside the characteristic pull-out resistance of the epoxy mortar, these mortar-specific calibration factors are published in a separate European Technical Assessment (ETA). The result of this approach represents a shift in design ethos where using a different epoxy mortar will result in a different bond-splitting resistance and anchorage length, an approach that has many similarities to design of post-installed bonded anchors. Figures 4(a) and (b) show a qualitative comparison of the bond-splitting resistance when modelled with the design method TR 069 and EN 1992-1-1. The solid and dashed red lines for uncracked and cracked concrete illustrated by Figure 4(a) represent the bond stress in relation to the confinement by cover (the minimum cover-to-bar diameter) and demonstrate the increase in splitting bond stress until it reaches the pull-out resistance of the epoxy mortar, a feature not possible with the EAD 330087 and EN 1992-1-1 design approach, which does not permit increase on bond stress beyond a confinement limit of cover being thrice the bar diameter.

Additionally, concrete design standards such as EN 1992-1-1 use the “uniform bond model” that uses a mean bond stress along the entire length of the bar to simplify the design procedure for cast-in bars with post-installed bars also following suit. However, bond stress is known to degrade with increasing anchorage length and Figure 4(b) represents this scenario where the EN 1992-1-1 line represents the uniform bond model and the solid and dashed red lines represent the non-linear degradation of bond stress with TR 069.

Figure 4
Qualitative comparison of the bond-splitting resistance of a system evaluated according to EAD 332402 and EOTA TR069 with a system according to EAD 330087 and EN 1992-1-1 [10]



(a) Bond stress curve dependence on concrete cover (c_d)

(b) Bond stress curve dependence on anchorage length

3.2 Design concept of TR069 – “Design method for post-installed reinforcing bars (rebars) with improved bond-splitting behaviour as compared to EN 1992-1-1”

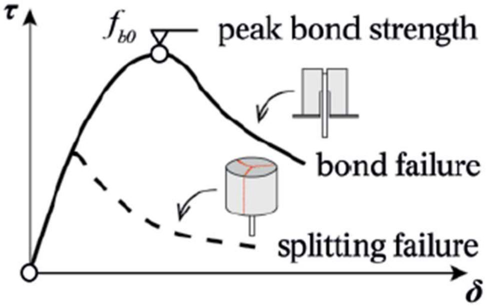
Structural concrete relies on the force transfer between reinforcement and concrete – denoted by “bond” and “anchorage” – which governs the behaviour at the serviceability (SLS) and ultimate limit states (ULS). Fundamentally, however, bond is not a property of the bar; rather, the geometry of the bar and concrete section, material characteristics, stress state, and the surface characteristics of the steel all combine to influence bond and, by extension, structural concrete [11].

For cast-in and post-installed bars, bond may fail in one of two ways:

1. **Splitting** – relying on the concrete’s tensile strength as well as adhesion and friction at the interface, splitting is typified by cracks forming along the concrete’s surface parallel to the bar. Radial, or hoop, stresses give rise to such cracks that develop at the surface of the nearest edge along the length of the bar and may cause the concrete to spall if the stress is sufficiently high and confinement low. Therefore, increasing the confinement, particularly through increasing concrete cover and spacing, in turn increases the splitting resistance.
2. **Pull-out** – with increasing confinement and stress, the force transfer increasingly relies on the ribs of the bar bearing against the concrete. Failure is marked when the force in bar exceeds the concrete’s shear strength, resulting in the bar shearing off along the tops of the ribs.

Figure 5 typifies the concept of splitting being weaker than pull-out, but more ductile since splitting cracks become visible on the surface and does not result in a sudden, brittle failure as with pull-out.

Figure 5
Bond-slip laws for pull-out (solid line) and splitting (dashed line) failures [12].



Consequently, design provisions such as those in EN 1992-1-1 and other standards specifically limit the positive impact of higher confinement to induce a more ductile behaviour in the section. However, these provisions assume that concrete will not be subject to direct tension, as is the case for a cast-in or post-installed anchors, due to sufficient confinement provided by the concrete strength, clear cover and spacing, transverse reinforcement, bar diameter and geometry, pressure perpendicular to the bar axis (lateral pressure), or a combination of these. This confined model also ensures that any formation of concrete cone does not occur as the bars are embedded at sufficient depth to preclude such a failure.

TR 069 represents a shift in the design approach to engage the higher strength of modern inorganic epoxy mortars used with post-installed bars, thereby allowing a more realistic and detailed evaluation of bond-splitting resistances. When coupled with the mortar-specific calibration factors from the EAD 332402 assessment, the design method allows a strength assessment of post-installed bars in unconfined concrete – i.e., concrete subject to direct tension caused by a bending moment – while engaging the epoxy mortar to influence the bond-splitting resistance of the system. Many aspects of TR 069 connect to the existing understanding of bond behaviour and design of structural concrete:

- The hierarchy of resistances follows limit state principles, where the weakest design resistance governs the design anchorage length.
- The detailing arrangements must still respect EN 1992-1-1 provisions.
- Roughening the contact interface between new and existing concrete must be undertaken to transfer shear in line with Section 6.2.5 of EN 1992-1-1.
- Durability requirements must be satisfied in line with EN 1992-1-1.

However, the nature of the epoxy mortar assessment, with its unconfined setup, implies design must consider the possibility of concrete cone breakout and, consequently, requires the evaluation of its resistance similar to bonded anchor design when connecting a baseplate to a concrete substrate. Here, TR 069 draws upon the logic of EN 1992-4, but without limitations in anchor group configurations while maintaining that bars in structural concrete are not subject to direct shear.

3.3 Design verification according to EOTA TR 069

Using the limit state design logic, TR 069 requires evaluation of three design resistances using the appropriate material partial safety factors from Table 3.1 of TR 069, replicated below in Table 2. The three failure modes are:

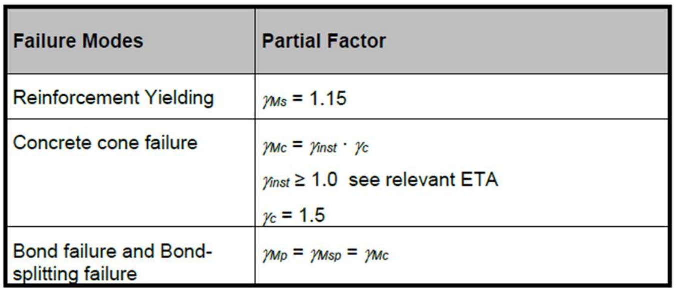
- Design resistance to yielding of the bars ($N_{Rd,y}$), evaluated for the **highest loaded bar** in tension.
- Design resistance to concrete cone breakout ($N_{Rd,c}$), evaluated for the **group of bars** in tension.
- Design resistance to bond-splitting ($N_{Rd,sp}$), evaluated for **highest loaded bar** in tension.

The decisive design resistance, R_d, governing the anchorage length is provided by:

$$R_d \leq \min\left(N_{Rd,y}; N_{Rd,c}; N_{Rd,sp}\right)$$

To prevent failure at the ultimate limit state, $E_d \leq R_d$, where E_d is the design action.

Table 2:
Partial safety factors for different failure modes, from Table 3.1 of TR069 [7]



Failure Modes	Partial Factor
Reinforcement Yielding	$\gamma_{Ms} = 1.15$
Concrete cone failure	$\gamma_{Mc} = \gamma_{inst} \cdot \gamma_c$ $\gamma_{inst} \geq 1.0$ see relevant ETA $\gamma_c = 1.5$
Bond failure and Bond-splitting failure	$\gamma_{Mp} = \gamma_{Msp} = \gamma_{Mc}$

3.3.1 Design resistance to yielding (Section 4.2, TR 069):

Resistance to yielding of the bars is based on the bar diameter and yield strength of the bar using the following relationship:

$$N_{Rd,y} = \frac{N_{Rk,y}}{\gamma_{Ms}} = \frac{A_s f_{yk}}{\gamma_{Ms}}$$

Where:

A_s – cross-sectional area of highest loaded bar in tension.

f_{yk} – characteristic yield strength of the bar.

γ_{Ms} – See Table 2 of this paper.

3.3.2 Design concrete cone breakout resistance (Section 4.3, TR 069)

As elaborated in earlier sections of this paper, evaluating the resistance of concrete breakout is necessary considering the assumption that concrete will be subject to direction tension. Evaluating the resistance is similar to EN 1992-4 [13] for bonded anchors:

$$N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}$$

with:

γ_{Mc} = See Table 2 of this paper.

$$N_{Rk,c} = \left(k_1 \cdot \sqrt{f_{ck}} \cdot l_b^{1.5}\right) \cdot \frac{A_{c,N}}{A_{c,N}^0} \cdot \psi_{s,N} \cdot \psi_{ec,N} \cdot \psi_{re,N} \cdot \psi_{M,N}$$

Where:

k_1 = 7.7 or 11.0 for cracked or uncracked concrete, respectively, from the ETA

f_{ck} = concrete compressive strength (in cylinder)

l_b = anchorage length of the bar not limited to 20 times the bar diameter as in EN 1992-4

$\frac{A_{c,N}}{A_{c,N}^0}$ = factor for geometric effect of axial spacing and edge distance

$\psi_{s,N}$ = factor for the disturbance of the distribution of stresses in the concrete due to the proximity of an edge of the concrete member

$= 0.7 + 0.3 \frac{c}{c_{cr,N}} \leq 1.0$

$\boldsymbol{\psi_{re,N}}$ = effect of dense reinforcement in existing concrete when anchorage, $\boldsymbol{l_b}$, is less than 100mm

= $\mathbf{0.5} + \frac{l_b}{\mathbf{200}} \leq \mathbf{1}$

$\boldsymbol{\psi_{ec,N}}$ = for the effect of tension acting eccentric to the group of bars.

= $\frac{\mathbf{1}}{\mathbf{1+2}e_N/s_{cr.N}} \leq \mathbf{1}$

$\boldsymbol{\psi_{M,N}}$ = the positive effect of a compression force between fixture and concrete in cases of bending moments, with or without axial force. and is expressed in below equation:

= $\mathbf{2} - \frac{z}{\mathbf{1.5}l_b} \geq \mathbf{1}$, where *z* represents the lever arm.

A lack of experimental evidence suggests that $\boldsymbol{\psi_{M,N}}$ should be assumed as 1.0 when the concrete cover is less than 1.5 times the anchorage length (i.e., near edge conditions) [14].

3.3.3 Design bond splitting resistance (Section 4.4, TR 069)

The design bond-splitting resistance, *N_{Rd,sp}*, is a factor of the anchorage length (l_b), bar diameter (ϕ), and the bond-splitting strength ($\tau_{Rk,sp}$) is based on the analytical formulation found in the *fib* Model Code 2010 [9]:

$$N_{Rk,sp} = \frac{\boldsymbol{\tau_{Rk,sp}} \cdot l_b \cdot \phi \cdot \pi}{\gamma_{Mp}}$$

$$\boldsymbol{\tau_{Rk,sp}} = \boldsymbol{\eta_1} \cdot \boldsymbol{A_k} \cdot \left(\frac{\boldsymbol{f_{ck}}}{\mathbf{25}}\right)^{sp1} \cdot \left(\frac{\mathbf{25}}{\boldsymbol{\phi}}\right)^{sp2} \cdot \left[\left(\frac{\boldsymbol{c_d}}{\boldsymbol{\phi}}\right)^{sp3} \cdot \left(\frac{\boldsymbol{c_{max}}}{\boldsymbol{c_d}}\right)^{sp4} + \boldsymbol{k_m K_{tr}}\right] \cdot \left(\frac{\mathbf{7}\boldsymbol{\phi}}{\boldsymbol{l_b}}\right)^{lb1} \cdot \boldsymbol{\Omega_{p,tr}}$$

The equation for $\boldsymbol{\tau_{Rk,sp}}$ models the influence of the epoxy mortar on concrete strength, bar diameter, minimum and maximum cover, transverse reinforcement, and transverse pressure (this pressure applies only to uncracked concrete), and anchorage length, thereby providing the bond-splitting strength ($\tau_{Rk,sp}$). The splitting bond stress then is capped by the pull-out resistance of the epoxy mortar influenced by cracks and anchorage length as shown below:

$$\tau_{Rk,sp} \leq \boldsymbol{\tau_{Rk,ucr}} \cdot \boldsymbol{\Omega_{cr}} | \boldsymbol{\Omega_{p,tr}} \cdot \boldsymbol{\psi_{sus}} \qquad \rightarrow for\ 7\phi \leq l_b \leq 20\phi$$

$$\tau_{Rk,sp} \leq \boldsymbol{\tau_{Rk,ucr}} \cdot \left(\frac{\mathbf{20}\boldsymbol{\phi}}{\boldsymbol{l_b}}\right)^{lb1} \cdot \boldsymbol{\Omega_{cr}} | \boldsymbol{\Omega_{p,tr}} \cdot \boldsymbol{\psi_{sus}} \rightarrow for\ l_b \geq 20\phi$$

In the above equations:

$\boldsymbol{\gamma_{Mc}}$ = See Table 2 of this paper.

$\boldsymbol{A_k}$ = Basic epoxy mortar fitting parameter, evaluated by the EAD 332402 & published in the ETA, represents the basic splitting resistance.

$\boldsymbol{\eta_1}$ **=** **f**rom EN 1992-1-1, this factor accounts for the quality of good (1.0) or poor (0.7) bond conditions and bar position while casting the new section. For post-installed bars, good bond conditions may be assumed in most scenarios as the upward flow of water during hardening, or bleeding, occurs in freshly cast concrete, and does not impact the post-installed bar embedded into existing concrete.

$(\boldsymbol{f_{ck}}/\mathbf{25})^{sp1}$ = with Sp1 from epoxy mortar's ETA, the combined term accounts for the influence of the epoxy mortar on the concrete strength. While strength classes above C25/30 increase the splitting resistance, the epoxy mortar too will modify this increase.

$(\mathbf{25}/\boldsymbol{\phi})^{sp2}$ = with Sp2 from the epoxy mortar's ETA, the combined term accounts for the diameter-dependent size effect on the splitting bond strength. For cast-in scenarios, larger bar sizes lower the splitting resistance, and this is no different to post-installed bars with reductions starting with bar sizes larger than 25mm.

$(\boldsymbol{c_d/\phi})^{\boldsymbol{sp3}}$ = with Sp3 from the epoxy mortar's ETA, the combined term accounts for the influence of epoxy mortar on confinement from small concrete covers. Similar to EN 1992-1-1, the minimum cover, c_d, is lowest of the cover to the nearest edge and half the clear spacing between the bars. The ETA also sets the minimum concrete cover to be not less than 2ϕ and the design equation sets ϕ as 12mm in the denominator when using bar sizes less than 12mm.

$(\boldsymbol{c_{max}/c_d})^{\boldsymbol{sp4}}$ = The ratio of the largest (c_{max}) to the smallest cover (c_d) is modified with the factor Sp4 from the epoxy mortar's ETA and models the influence of the epoxy mortar on confinement from large concrete covers. c_{max} is the large of the cover to the farthest edge and half the bar spacing. Smaller ratios of c_{max} & c_d represent bars positioned near corners where low confinement from cover reduces the splitting bond resistance. While the lower limit cannot be lower than 1.0, TR 069 sets the upper limit of c_{max}/c_d as 3.5.

$\boldsymbol{k_m K_{tr}}$ = the combination of $\boldsymbol{k_m}$ and $\boldsymbol{K_{tr}}$ highlights the positive impact of transverse reinforcement on splitting by increasing ductility. While $\boldsymbol{K_{tr}}$ – the amount of reinforcement crossing a potential splitting surface – is limited to an upper value of 0.05 by TR 069 and EN 1992-1-1, $\boldsymbol{k_m}$ can only take values of 0, 6, or 12 based on the effectiveness of transverse reinforcement. The effectiveness reduces the further transverse reinforcement is from the concrete edge and the longitudinal reinforcement. In end anchorages such as connecting a new beam to an existing column, transverse reinforcement in the existing concrete column will be parallel to the post-installed longitudinal bars of the new beam, and therefore cannot improve the splitting bond resistance, hence this combined term may be ignored in design.

$(\boldsymbol{7\phi/l_b})^{\boldsymbol{lb1}}$ = covered in earlier sections and by Figure 5, the **splitting** bond strength degrades with increasing anchorage length, and the factor lb1 – from the epoxy mortar's ETA – influences this degradation. Since all design anchorage lengths, $\boldsymbol{l_b}$, will exceed $\boldsymbol{7\phi}$ as required by the minimum anchorage length rules in Section 3.4 of this paper, an epoxy mortar with a lower lb1 factor proves beneficial for deeper anchorages ($\boldsymbol{7\phi} \ll \boldsymbol{l_b}$).

$(\boldsymbol{20\phi/l_b})^{\boldsymbol{lb1}}$ = similar to the reduction in splitting bond strength, **pull-out** bond strength (of the epoxy mortar) also declines in a non-linear manner with increasing anchorage length, but this effect only becomes noticeable at anchorages beyond $\boldsymbol{20\phi}$. The same factor lb1 from the epoxy mortar's ETA further influences this degradation and wherever $\boldsymbol{l_b} > \boldsymbol{20\phi}$ epoxy mortars with a lower lb1 factor slightly reduce the combined term.

$\boldsymbol{\psi_{sus}}$ = applied to the pull-out resistance, the sustained load ratio accounts for the influence of creep and relaxation on the epoxy mortar caused by sustained tension. Since post-installed bars are always under tension, mortar-specific sustained load factor (ψ^0_{sus}) will reduce the pull-out resistance. Therefore, as with bonded anchors, a higher sustained load ratio is beneficial.

$\boldsymbol{\Omega_{cr}}$ = the presence of cracks parallel to the bond length of the post-installed bar reduce the pull-out resistance of the epoxy mortar and this factor, alongside the sustained load ratio, reduces the upper limit of the bond-splitting resistance. The dashed red lines in Figure 5 demonstrate schematically this reduced upper limit, and this is diameter-dependent with larger bar sizes exhibiting lower values of $\boldsymbol{\Omega_{cr}}$ for certain epoxy mortars, while other mortars do not exhibit such reductions.

$\boldsymbol{\Omega_{p,tr}}$ = in instances of concrete where cracks in concrete have not yet arisen or can be proven never to arise during the structure's service life, a compressive transverse pressure contributes to a higher bond-splitting resistance, or a lower resistance if the transverse pressure is tensile. The pressure is based on compressive or tensile stress in concrete perpendicular to the bar axis averaged over a volume of 3ϕ around the bar.

3.4 Additional Requirements for the Connection

In line with EN 1992-1-1 provisions, TR 069 also specifies the minimum anchorage length required to satisfy detailing requirements. The design anchorage length $\boldsymbol{l_b}$, must at least satisfy the minimum anchorage length, $\boldsymbol{l_{b,min}}$.

Apart from durability requirements for such as concrete cover and service life, the existing member must have sufficient reinforcement to sustain the loads imposed by the new member and the shear transfer from new to existing concrete through the cross-section must be verified by EN 1992-1-1, Clause 6.2.5 for concrete cast at different times. For certain members, a punching shear check of the existing concrete may also be required.

4. SIGNIFICANT ADVANTAGES WITH QUALIFIED INJECTABLE EPOXY MORTARS

Hilti offers designers a choice of two high performing epoxy mortars, **HY 200R V3** and the new **RE 500 V4**, both qualified to EAD 332402 and ready for use in moment-resisting end anchorages designed to TR 069. Both have unique characteristics based on the epoxy mortar chemistry and perform excellently under different conditions.

- **HY 200R V3** specialises where a faster curing time is dictated by overall project timelines. From a TR 069 design perspective, this epoxy mortar provides high performance in scenarios where confinement is small.
- **RE 500 V4** provides a longer curing time but superlative performance in the widest of project requirements. This latest epoxy mortar from Hilti outperforms HY 200R V3 in scenarios where confinement is large.

As a note to designers, it difficult to provide a straightforward comparison on which epoxy mortar is “always better” without a comparative design, since their mortar-specific factors influence merely the bond-splitting resistance in the design flow. If a design is governed by steel failure or by concrete cone breakout rather than bond-splitting, then the choice of epoxy mortar matters little from a design perspective, assuming both met the initial project requirements.

5. SAFETY IN DESIGN AND EXECUTION

PROFIS Software: Planning, designing, and documenting in one tool.

Design with TR 069, like bonded anchor design and unlike traditional post-installed rebar design to EN 1992-1-1, is ill suited to hand calculations. The calculation cycle starts with assuming a design anchorage length and a particular epoxy mortar system that will satisfy the cone breakout and bond-splitting resistances. A hand calculation would require several iterations to arrive at a feasible solution.

For a fast and optimised design, the Hilti **PROFIS** software enables engineers to design & resolve any post-installed reinforced concrete connection, from simply supported to moment-resisting to splice. PROFIS offers you flexibility and efficiency, always according to the latest regulations and standards (EOTA TR069 and EN 1992-1-1).

Figure 6:
A typical SafeSet system for concrete-to-concrete connections

SAFESET: Consistent safety during installation

The resistance of post-installed rebar connections is significantly influenced by the installation process. A clean borehole is key to ensuring void-free installations during the adhesive injection to guarantee, in turn, that the installation behaves as designed. Inserting the rebar up to the necessary anchorage length within the working time of the epoxy mortar is another crucial factor in the installation process.

To minimise installation errors, HIT-RE 500 V4 and HIT-HY 200-R V3 injection epoxy mortars are compatible with the SafeSet system. When hammer drilling, the Hilti SafeSet system relies on hollow drill bits (HDB) connected to a vacuum cleaner (e.g., Hilti VC 40-U or VC 20-U vacuums) to drill and clean the hole in one step. Hilti HDBs use the same state-of-the art carbide drilling technology as Hilti TE-CX and Hilti TE-YX bits for optimal drilling performance. The Hilti SafeSet system performs equally well in dry and wet concrete and eliminates a most important and time-consuming step in the installation process, which is cleaning the borehole before injecting the adhesive.

The resistance of post-installed rebar connections is significantly influenced by the installation process. A clean borehole is key to ensuring void-free installations during the adhesive injection to guarantee, in turn, that the installation behaves as designed. Inserting the rebar up to the necessary anchorage length within the working time of the epoxy mortar is another crucial factor in the installation process.

To minimise installation errors, HIT-RE 500 V4 and HIT-HY 200-R V3 injection epoxy mortars are compatible with the SafeSet system. When hammer drilling, the Hilti SafeSet system relies on hollow drill bits (HDB) connected to a vacuum cleaner (e.g., Hilti VC 40-U or VC 20-U vacuums) to drill and clean the hole in one step. Hilti HDBs use the same state-of-the art carbide drilling technology as Hilti TE-CX and Hilti TE-YX bits for optimal drilling performance. The Hilti SafeSet system performs equally well in dry and wet concrete and eliminates a most important and time-consuming step in the installation process, which is cleaning the borehole before injecting the adhesive.

With diamond coring with roughening, Hilti SafeSet uses the TE-Y RT “Flex fork” roughening tool. This creates a rough surface within the cored hole, helping to increase the mechanical interlock between epoxy mortar and concrete. The result ensures the epoxy mortar behaves as designed with fewer and simpler cleaning steps. Hilti SafeSet helps to minimise installation errors, contributing to a construction that performs as designed on the jobsite.

6. SUMMARY

The state-of-the-art EAD 332402 & TR 069 introduce a new assessment and design approach for post-installed bars to the industry and fill the gap of the existing EAD 330087 assessment and EN 1992-1-1 design standard. The ability to design moment-resisting, post-installed reinforced concrete connections while simultaneously modelling the impact of the epoxy mortar system on the bond-splitting behaviour is revolutionary in concept, since no two epoxy mortar systems can be considered comparable without design.

This paper gave a short glimpse inside the qualification programme of the EAD 332402 and a detailed look at the design verification required by TR 069. With Hilti’s PROFIS software, the engineer’s time is freed up to undertake the several other verifications that are required beyond the anchorage length calculation – for instance, the shear transfer, stability checks for the existing member, and so on. Translating these designs into a productive and error-free installation at site is possible with the Hilti SafeSet systems.

7. REFERENCES

1. **EOTA.** *EAD 330087-01-0601 - "Systems for post-installed rebar connections".* Brussels : EOTA, 2020.

2. **CEN.** *Eurocode 2: Design of Concrete Structures - Part 1-1: General rules and rules for buildings.* Brussels : European Committee for Standardization, 2004.

3. *The revolution of concrete to concrete connections with post-installed rebar.* **Barbara Campelo, Joana Correia, Jorg Appl.** 18, March 2022, Revista Portuguesa de Engenharia de Estructuras, Vol. 3, pp. 89-94.

4. *A new test specimen to investigate the bond behavior.* **Rex, Justus, Sharma, Akanshu and Hofmann, Jan.** 2, s.l. : Wiley, 2019, Structural Concrete, Vol. 20, pp. 583-596. ISSN 1751-7648.

5. *Cast-in and post-installed rebar anchorage systems in RC column foundation joints: Experimental investigations.* **Mahadik, Vinay, Sharma, Akanshu and Hofmann, Jan.** s.l. : Elsevier, 2021, Engineering Structures, Vol. 238. ISSN 0141-0296.

6. **EOTA.** *EAD 332402-00-0601 - "Post-installed reinforing bar (rebar) connections with improved bond-splitting behavior under static loading" (Pending citation).* Brussels : EOTA.

7. —. *TR 069 - "Design method for anchorage of post-installed reinforcing bars (rebars) with improved bond-splitting behavior as compared to EN 1992-1-1".* Brussels : EOTA, 2019.

8. —. *EAD 330499-01-0601 - "Bonded fasteners for use in concrete".* Brussels : EOTA, 2018.

9. **fib.** *Model Code for Concrete Structures 2010.* Lausanne : Ernst & Sohn, 2013. ISBN 978-3-433-60408-3.

10. *Bewehrungsanschlüsse für momententragfähige Verbindungen nach EOTA TR 069.* **Wörle, Patrick, Appl, Jörg and Genesio, Giovacchino.** 11, s.l. : Wiley, 2020, Beton- und Stahlbetonbau, Vol. 115, pp. 887-896. ISSN 1437-1006.

11. *Bond and anchorage of embedded steel reinforcement in fib Model Code 2010.* **Cairns, John.** 1, s.l. : Wiley, 2015, Structural concrete, Vol. 16, pp. 45-55. ISSN 1751-7648.

12. *Bond behaviour of straight, hooked, U-shaped and headed bars in cracked concrete.* **Brantschen, F, et al.** 5, s.l. : Wiley, 2016, Structural Concrete, Vol. 17, pp. 799-810. ISSN 1751-7648.

13. **CEN.** *Eurocode 2 - Design of concrete structures - Part 4: Design of fastenings for use in concrete.* Brussels : European Committee for Standarization, 2018.

14. *Design of anchorages in connections using post-installed reinforcing bars.* **Catteneo, Sara, Genesio, Giovacchino and Piccinin, Roberto.** Naples : Italian Concrete Days 2020, 2021.

Hilti Asia Pacific Pte Ltd
80 Pasir Panjang Road
#16-83/84 Mapletree Business City
Singapore 117372

www.facebook.com/hiltigroup
www.hilti.group