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The revolution of concrete to concrete connections with post-installed rebar

Revolução das ligações betão-betão em selagens com varões nervurados pós-instalados

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Abstract

Post-installed rebar connections have become a trusted, everyday solution in recent years for reinforced concrete structures.

They are used in both retrofit work and in new construction for a wide range of applications like slab-to-wall connections, anchoring of stair landings, connecting cantilever slabs with slabs or anchoring columns in existing foundations.

Until as recently as 2018, post-installed rebar was assessed through Technical Report 023, which was then superseded by the European Assessment Document EAD 330087.

After several years of intense research, the Technical Report TR 069, broadens the scope of post-installed rebar applications to moment resisting reinforced concrete connections without the necessary execution as splice.

Hilti can now offer you a revolutionary system for moment resisting post-installed rebar connections, consisting of:

- A brand-new design method – TR 069;
- A new product – Hilti HIT-HY 200-R V3 injectable mortar;
- New software – PROFIS Rebar.

Keywords: Normalization / Project / Rehabilitation / Post-installed / New construction

Resumo

Cada vez se torna mais comum a utilização de ligações pós-instaladas na conexão de elementos de betão existente a elementos de betão novo através da selagem de varões nervurados.

Esta solução pode ser encontrada tanto em obras de construção nova como de reabilitação, em diversas aplicações – ligações parede-laje, varões para arranque de escadas, prolongamento de lajes ou arranque de pilares em fundações.

Até 2018, o dimensionamento de ligações pós-instaladas com selagem de varões nervurados era avaliado através do Relatório Técnico TR 023 que foi depois substituído pelo EAD 330087.

Após intensivos anos de investigação, surge o novo Relatório Técnico TR 069, que amplia o espectro de soluções onde as ligações pós-instaladas poderão ser aplicadas.

A Hilti pode agora oferecer um sistema revolucionário para este tipo de ligações, consistindo em:

- Um novo método de dimensionamento – TR 069;
- Um novo produto – a ancoragem química HIT-HY 200-R V3;
- Um novo software – PROFIS Rebar.

Palavras-chave: Normalização / Projeto / Reabilitação / Pós-instalado / / Construção nova

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1 Introduction

Until as recently as 2018, post-installed rebar was assessed through Technical Report 023, which was then superseded by the EAD 330087. Under EAD 330087 / TR 023, the design of post-installed rebar connections was carried out following the provisions of the valid European reinforced concrete standard – Eurocode 2. The assessment process in Eurocode 2 intends to verify the equivalency of the load-displacement behavior between cast-in and post-installed rebar. Furthermore, products could be qualified for post-installed rebar applications within the EOTA (European Organization for Technical Assessment) framework through an ETA (European Technical Approval) assessment. However, the application range was significantly limited.

To this day, post-installed rebar connections according to EAD 330087 can only be executed with straight rebar, which are permitted in accordance with EN 1992-1-1. Therefore, moment-resisting connections need to be executed with splices (i.e. planned overlap of a cast-in rebar with a post-installed rebar). This, however, is not feasible in many cases where advance planning is required and imposes a significant limitation on post-installed rebar design.

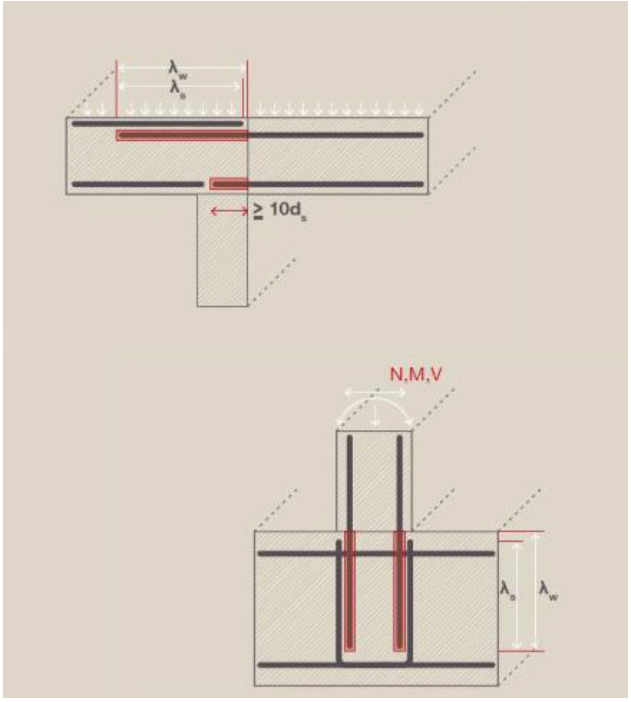

Figure 1 Execution of a post-installed, moment-resisting concrete rebar connection, slab-to-slab and column or wall by splicing, as required by EAD 330087 (schematic drawing)

This requirement to construct moment-resisting rebar connections using a splice can have a crucial impact on the construction workflow, economics and safety:

- A splice in new construction needs to be planned and be in place. This is not always the case;

- As concrete-pouring is done bit by bit, rebar can be exposed, which can lead to different issues such as complex logistics, damaged rebar and safety hazards;
- The load-bearing capacity of a splice consisting of two rebars with different properties is dependent of the lowest capacity of the rebar, i.e. the one that is cast-in. This limits the ability to fully leverage the higher capacity of the bond of post-installed rebar compared to cast-in rebar, thus resulting in overlap lengths that are uneconomical;
- In renovation, a rebar connection with splice needs to be executed by partial demolition to expose the existing rebar, weld the new rebar onto it and then close the connection with concrete again, all of which is very time- and thus cost-intensive.

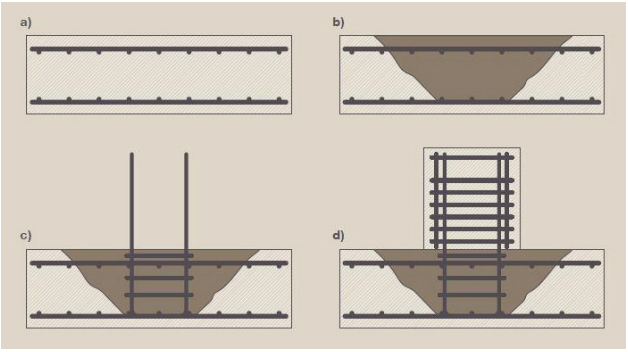

Figure 2 Schematic depiction of executing a rebar connection with partial demolition

After several years of intense research and testing, the Technical Report TR 069, published by EOTA (European Organization for Technical Assessment), broadens the scope of post-installed rebar applications. Hilti can now offer a revolutionary system for post-installed rebar connections, consisting of: a brand-new design method (TR 069), a new product with a wide range of ETAs for post-installed rebar applications (HY 200-R V3) and a new software updated with the new design method (PROFIS Rebar).

2 A milestone in post-installed rebar

2.1 The New Design Concept: TR069

The new technical report TR 069 – "Design method for anchorages of post-installed reinforcing bars (rebar) with improved bond-splitting behavior as compared to EN 1992-1-1" significantly broadens the scope of post-installed rebar applications, by giving us the possibility to start designing moment resisting structural joints without the need of execution as splice. The new report covers post-installed rebar connections in reinforced or unreinforced, normal weight, non-carbonated C20/25 to C50/60 concrete.

According to EN 1992-1-1 we need straight reinforcing steels to overlap as shown in Figure 3 in order to establish connections capable of bearing moments. Depending on the jobsite this it is not always easy to guarantee either because cast-in rebars are non-existing, a common scenario in rehabilitation projects, or because the rebar has been misplaced or forgotten as discussed above. With this new technical report, we can now consider the concrete tensile strength to transfer the loads and start designing it also as a rigid (moment-resisting) connection. The load transfer between new and existing concrete members shall be verified in accordance with EC2 (e.g., shear transfer at the interface and shear resistance of connecting member as well as nodal panel). Furthermore, the safety concept (i.e. partial safety factors) adopted in TR 069 is the same as in EC2-1 (for steel yielding) and EC2-4 (for concrete cone and bond-splitting failure modes), ensuring a high level of compatibility of the design output of TR 069 in accordance with EC2.

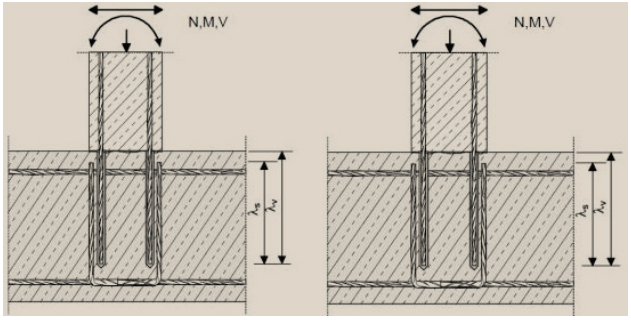

Figure 3 Example of the overlapping of the reinforcement steel (left) and without the reinforcement steel (right)

TR 069 considers the bond-splitting behavior of assessed injection systems in combination with rebars, which can happen depending on the existing concrete cover. Consequently, the qualification of the injection system (i.e. the product ETA) is an absolute mandatory requirement to design on European level according to this technical report. The product used for the post-installed rebar and designed with TR 069 must be assessed following the EAD 332402 "Post-Installed reinforcing bar (rebar) connections with improved bond-splitting behavior under static loading". Note that an EAD 330087 for "normal" post-installed rebar connections is not sufficient.

Extensive research has shown that the bond-splitting behavior of qualified mortars like Hilti's HY 200 R V3 is significantly better than cast-in rebar, i.e. the design value of the bond stress is higher than for embedded rebar for different thickness of concrete covers, thus allowing for optimized design.

2.1.1 Design principles with TR069

The EOTA TR 069 combines reinforced concrete design principles (EN 1992-1-1) with anchoring to concrete principles (EN 1992-4). The individual failure modes of the system connection are rebar steel yielding, concrete cone and bond/splitting. The design is based on the hierarchy of strength design principals, i.e. the lowest resistance of the individual failures model is decisive in addiction. The requirements of EN 1992-1-1 in terms of minimum anchorage length must be fulfilled.

$$R_d \leq \min\left(N_{Rd,y}; N_{Rd,c}; N_{Rd,sp}\right) \quad (1)$$

Where:

$N_{Rd,y}$ design resistance to yielding

$N_{Rd,c}$ design concrete cone break out resistance

$N_{Rd,sp}$ design bond splitting resistance

Design resistance to yielding

The resistance to yielding is a function of rebar diameter and steel strength and can be obtained from the following equation:

$$N_{Rd,y} = N_{Rk,y} / \gamma_{Ms} \quad (2)$$

$$N_{Rk,y} = A_s \cdot f_{yk} \quad (3)$$

Where:

A_s cross sectional area of all tensioned post-installed rebars within the connection

f_{yk} yield strength

Design concrete cone break out resistance

The embedment depth is calculated from the interface between the old and the new concrete. This is where the concrete cone can occur, Figure 4.

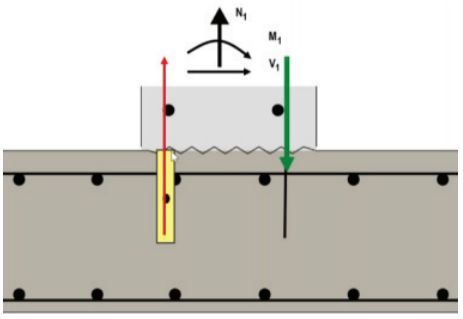

Figure 4 The yellow rectangle represents from where the embedment length is being considered

The characteristic resistance for the group of reinforcement under tension action resulting from the moment resisting mechanism shall be obtained as per the equation below:

$$N_{Rk,c} = N^0_{Rk,c} \cdot A_{c,N} / A^0_{c,N} \cdot \Psi_{s,N} \cdot \Psi_{re,N} \cdot \Psi_{ec,N} \cdot \Psi_{M,N} \quad (4)$$

Where:

$N^0_{Rk,c}$ characteristic resistance for a single reinforcement post-installed in the concrete and not influenced by any adjacent reinforcement or edge

$A^0_{c,N}$ projected area of a single reinforcement post-installed in the concrete with large spacing and edge distance with the concrete cone idealized as a pyramid of height lb and base length $s_{cr,N} = 3\ l_b$ [mm]

$\Psi_{re,N}$ the shell spalling factor accounts for the reduced strength of rebars with an anchorage length $l_b < 100$ mm inserted in concrete elements with closely spaced reinforcement

$\Psi_{ec,N}$ this factor account for the eccentricity between the point of application of the axial force and the center of gravity of the tensioned rebars

$\Psi_{M,N}$ this factor represents a compression force resulting from the bending moment for concrete cone failure

Design bond splitting resistance

The characteristic resistance for the group of reinforcement under tension shall be obtained as given below. If the load on the tensioned bars is applied eccentrically and/or the values c_{min} and c_{max} are different for each tensioned bar, the resistance $N_{Rk,sp}$ shall be calculated separately for each rebar.

$$N_{Rk,sp} = \tau_{Rk,sp} \cdot l_b \cdot \varnothing \cdot \pi \quad (5)$$

Table 1 Five new possibilities to design structural joints as rigid connections: column to foundation, wall to foundation, slab to wall, beam to wall and beam to column

Connection type	Supported	Supported	Simply supported	Rigid	Rigid	Rigid	Rigid	Rigid
Members connected	Slab to wall	Beam to wall	Beam to column	Column to foundation	Wall to foundation	Slab to wall	Beam to wall	Beam to column
Current design method	EC2	EC2	EC2	x	x	x	x	x
Design with beyond CI	EC2	EC2	EC2	Beyond CI	Beyond CI	Beyond CI	Beyond CI	Beyond CI

$$\tau_{Rk,sp} = \eta_1 \cdot A_k \cdot (f_{ck}/25)^{sp1} \cdot (25/\varnothing)^{sp2} [(c_d/\varnothing^{sp3}) \cdot (c_{max}/c_d)^{sp4} + \\ + k_m \cdot k_{tr}] \cdot (7\varnothing/l_b)^{lb1} \cdot \Omega_{p,tr} \quad (6)$$

$$\leq \tau_{Rk,ucr} \,.\, \Omega_{cr} / \Omega_{p,tr} \,.\, \Psi_{sus} \text{ for } 7\varnothing \leq l_b \leq 20\varnothing \quad (7)$$

$$\leq \tau_{Rk,ucr} \,.\, (20\, l_b/\varnothing)^{lb1} \,.\, \Omega_{cr} / \Omega_{p,tt} \,.\, \Psi_{sus} \text{ for } l_b > 20\varnothing \quad (8)$$

Where:

A_k fitting factors; sp1, sp2, sp3, sp4 and lb1 = fitting exponents according to ETA

$\varnothing$ diameter of the rebar

l_b embedment length of the post-installed rebar

$\tau_{Rk,sp}$ bond resistance in non-cracked concrete (upper value)

More details can be found in reference [2].

2.1.2 Key advantages with TR 069

There are three key advantages when designing according to TR 069: compliance, optimization and productivity.

The new design method provides a code compliant solution on European level for structural joints. It is now possible to design post-installed moment resisting connections subjected to bending moments broadening the range of post-installed rebar design without the need of execution as a splice. There are five additional applications that can be designed as a rigid connection as detailed in Table 1.

Secondly, with TR 069 we can now utilize the full bond strength of the injection mortar. This is only possible if the product to be used has been tested and qualified with the appropriate ETAs. When the higher bond strength is being considered (for example in the case of HY 200-R V3 close to the level of anchor approvals) we can achieve a reduction of the anchorage length, thus allowing design optimization compared to EC2. This optimization will depend on geometrical conditions, loads and spacing.

At last, the new method will allow for productivity gains both when designing and when building. On the design side, the new method allows to design every type of concrete-to-concrete connection using a single methodology, while before it was common to revert to steel-concrete design for moment resisting connections. This productivity in design can be more easily captured when using a software solution that fully incorporates TR 069 (for example PROFIS Rebar). On the jobsite, productivity gains can be obtained through the design optimization – shorter embedments will translate into a reduction of materials needed and a reduction of installation time.

2.1.3 TR 069 limitations

There are a few limitations to the applicability of the norm TR 069. It is limited to the verification of the length of the post-installed rebar so the loads transferred into the surrounding must be verified separately.

Furthermore, the new norm is only applicable to moment-resisting connections subjected to static and quasi-static loads and does not yet cover seismic, fatigue action and fire exposure.

One important point to highlight is that the connecting joint between the existing and the new reinforced concrete shall be roughened, and the carbonated layer should be removed. The verification of the joint resistance to shear force shall be carried out according to EN 1992-1-1.

2.2 Products Innovation: HIT-HY 200-R V3

Extensive research has shown that HY 200-R V3 has increased performance compared to cast-in rebar as shown in Figure 5. Now with TR 069 we can leverage this increased performance and achieve design optimization, i.e. reduce embedment depth of many post-installed rebar connections.

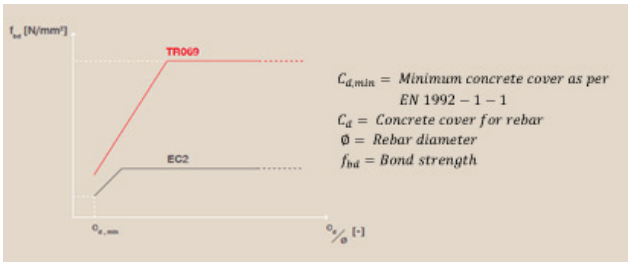

Figure 5 Comparation of allowed bond strength for HY 200-R V3 with different thickness of concrete under EC2 and under TR069

The product HIT-HY 200-R V3 has the first ETA approved "Rebar Performance System", ETA 19/0665, under EAD 332402 "Post--Installed reinforcing bar (rebar) connections with improved bond-splitting behavior under static loading", with up to three times higher bond strength for rebar applications, from 2,3 N/mm² to > 7,0 N/mm².

Furthermore, this product has an additional ETA rebar (ETA 19/0600) qualifying it for the most challenging conditions. This ETA covers seismic rebar approval, fire rebar approval, and SafeSet System approval for high reliability in jobsite conditions. SafeSet System allows for automatic cleaning of the borehole during drilling ensuring always proper borehole cleaning, a key pain point of chemical anchors technology. Currently HY 200-R V3 has the standard ETA approval of 50 years of service life but is in the process of qualifying for ETA approved 100 years service life. Such requirement might be very relevant for post-installed rebar applications on civil projects like bridges or tunnels. HY 200-R V3 is also qualified for anchoring applications with ETA 19/0601.

The HY 200-R V3 solution offers specifiers and general contractors the following advantages:

- Significant increase of application range for post-installed rebar connections;
- Flexibility during planning and detailing of moment-resisting reinforced concrete connections;
- Less interruption of the construction process due to partial demolition;

- Less health and safety risks related to cast-in rebar sticking out of the concrete;
- Ability to use the performance of the injection mortar to its fullest extent, optimizing the design solution, with significant productivity gains;
- Project planning, design and documentation of the calculation process for post-installed rebar using the Hilti PROFIS Rebar design software.

2.3 Tools for an Efficient and Accurate Design: Hilti PROFIS Rebar

By using the Hilti PROFIS Rebar design software, you can perform every type of post-installed reinforced concrete connection: from simply supported to moment resisting to splice. PROFIS Rebar offers you flexibility and efficiency, always according to the latest regulations and standards that were discussed before (TR 069 and EC2).

With simple and easy-to-use tools for designing, you can calculate:

- Tension and compression lap splice lengths;
- Anchorage lengths for starter bars;
- Anchorage lengths for special rigid connections;
- Different loads – static, seismic, fire resistance and fatigue resistance;
- For different conditions – dry or wet concrete;
- For different drilling methods – hammer drilling or diamond drilling with or without a roughening tool.

In addition, it generates an easy-to-use design report for your project documentation with relevant information that includes the following verifications: steel flow of the subsequent reinforcement; concrete excavation; composite/gap failure (based on qualification in ETA) and minimum anchorage length.

Hilti PROFIS Rebar can even go beyond the code with Hilti design methods, based on internal Hilti research work, allowing specifiers to design applications which are not covered by Eurocode 2 or TR 069. For load cases which are not yet regulated, the Hilti design method, incorporated in PROFIS Rebar can be used as an engineering judgement providing additional engineering solutions, e.g. post-installed reinforced concrete connections under fatigue loading.

3 Main conclusions

The new technical report TR 069 is a new approach to the design of structural joints. This new approved design concept on European level gives us an improved method to calculate different post--installed rebar applications with more flexibility (i.e. covering a broader range of applications compared to EN 1992-1-1, namely moment-resisting connections) and higher productivity (i.e. with potential for design optimization, namely embedment reduction).

From now on it is possible according to TR 069, to leverage the bond strength of injection systems which carry an ETA according to EAD 332402. Hilti offers the first product qualified under the new EAD 332402, HIT-HY 200-R V3, with significantly higher rebar performance and qualified for the most challenging conditions namely seismic and fire, designed according to EN 1992-1-1.

Combined with this new regulation, the software Hilti PROFIS Rebar can give a complete perspective of calculation with the certainty that the design complies with the latest regulations and standards.

This revolutionary system of improved code, product innovation and efficient design software allows for more economical and safer solutions for a wide range of post-installed rebar applications.

Referências

[1] EN 1992-1-1:2014 – Eurocode 2: Design of concrete structures – Part1-1: General rules and rules for buildings.

[2] EOTA TR069 – Design Method for Anchorage of post-installed reinforcing bars (rebars) with improved bond-splitting behavior as compared to EN 1992-1-1. European Organization for Technical Assessment, October 2019.

[3] EAD 332402-00-0601 – Post-installed reinforcing bar (rebar) connections with improved bond-splitting behavior under static loading.

[4] EN 1992-4:2018 – Eurocode 2 – Design of concrete structures – Part 4: Design of fastenings for use in concrete.

[5] fib Model Code 2010 – Fib Model Code for Concrete Structures 2010.

[6] fib Bulletin 72 – Bond and Anchorage of embedded reinforcement: Background to the fib Model Code for Concrete Structures 2010.