Design of concrete overlay according European Standard EOTA TR066

Diseño de recrecido de hormigón según la norma europea EOTA TR66

Jörg APPL 1[a], Antonio Cardo Fernández 2[b]

[a] Ph. D. Structural Engineer. Hilti Germany. E3 Technical Marketing. dr.joerg.appl@hilti.com

[b] MSc. Civil Engineer. Hilti Española S.A. ECC Manager. antonio.cardo@hilti.com

RESUMEN

La instalación de capas de hormigón nuevas y reacondicionadas (recrecido de hormigón) es cada vez más importante debido a la creciente necesidad de reparación y refuerzo de las estructuras existentes. El nuevo concepto de diseño según EOTA TR 066 «Conector para el refuerzo de estructuras de hormigón existentes mediante recrecidos de hormigón» permite diseñar y dimensionar estas conexiones y la interfaz teniendo en cuenta todos los componentes de carga (cohesión/fricción, enclavamiento y acción de los pasadores) y otros factores específicos del producto.

ABSTRACT

The installation of new, retrofitted concrete layers (concrete overlay) is becoming increasingly important due to the growing need for repair and reinforcement of existing structures. The new design concept according to EOTA TR 066 "Connector for strengthening of existing concrete structures by concrete overlay" allows the design and dimensioning of these connections and the interface taking into account all load-bearing components (cohesion/friction, interlocking and dowel action) and other product-specific factors.

PALABRAS CLAVE: renovación, recrecido de hormigón, conectores para esfuerzo cortante, anclaje, TR066.

KEYWORDS: renovation, concrete overlay, shear connectors, anchors, TR066.

1. Introduction

EOTA TR 066 [1] reflects the current state of the art in the design of overlay applications with post-installed shear connectors. This contrasts with EN 1992-1-1 (EC2) [7], which does not take into account the individual load- bearing behavior of post-installed shear connectors.

The main difference of this method compared to previous ones is the verification of shear resistance of the installed post connector according to the different failure modes of the classical anchor theory and not only considering the failure mode of steel of the connector. There is also a verification of the connector as an embedded connector in the area of the new concrete.

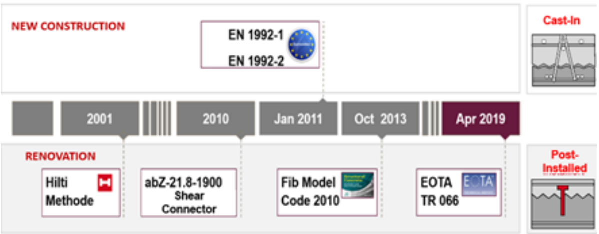

Figure 1. The "long way" of post-installed shear connectors to the final design according to EOTA TR 066 [1].

The implementation of a construction measure with concrete overlay can be roughly simplified and divided into several work steps: The demolition or exposure of the existing, damaged concrete layer, the roughening of the surface, the installation of the post-installed shear connectors, the insertion of the new reinforcement and finally the placement of the new concrete layer. (Figure 2)

Figure 2. Simplified overview of the execution steps of a construction measure with overlay

The implementation of a construction measure with concrete overlay can be roughly simplified and divided into several work steps: The demolition or exposure of the existing, damaged concrete layer, the roughening of the surface, the installation of the post-installed shear connectors, the insertion of the new reinforcement and finally the placement of the new concrete layer. (Figure 2)

2. Preparation of the surface and installation of the post-installed shear connectors

Roughening of the surface is usually carried out by high-pressure water jetting. Other methods than high-pressure water jetting are not permitted, referencing on local or additional guidelines. This derives for example of Micro-cracks which can occur during roughening by milling and lead to damage of the concrete structure. Exposed aggregates that are well anchored in the concrete must be clearly visible [1]. The required average roughness depth Rt must correspond to the specified minimum value.

The average roughness depth itself can be determined according to the Kaufmann sand surface method or by means of an electronic, optical measurement [1]. The principal suitability of the roughened old concrete is to be checked by measuring the bond strength perpendicular to the interface (adhesive tensile strength) fh, whereby at least the value of fh≥ min (1.5 N/mm²; fctm) must be achieved [1]. The scope of testing for the measurement of the roughness depth and the tensile strength shall be carried out in accordance with EOTA TR 066 [1], taking into account additional guidelines, building codes or regulations, whereby in particular for the measurement of the roughness depth the obviously least roughened areas shall be used.

2.1 Post-installed shear connectors

There is a wide range of post-installed shear connectors available. A distinction can be made between concrete screw systems and mortar systems.

The installation of the shear connector type "concrete screw", HCC-HUS3, takes place in three steps. First, a hole is drilled in the existing concrete, ideally dust-free, using a hollow drill bit. The standard hammer drilling method with corresponding ETA (European Technical Assessment)-compliant cleaning can also be carried out.

The concrete screw is driven in with a special impact screwdriver. The drilling depth is typically chosen slightly greater than the screw-in depth to create space for the dust and debris of the thread cutting process in the concrete.

The tensile load-bearing behavior of this system depends on the tolerance of the drilled hole, which is regulated in the ETA for the product. Due to the thread cut into the concrete, this shear connector is adjustable in height to a certain degree.

The post-installed shear connectors of the "bonded anchor" type are special elements or standard elements equipped with additional accessories, e.g. HCC-B (special element, optimized for positioning the reinforcement and installation (Figure 3)), HCC-K (reinforcement bar with headed end (special element)) and HCC-HAS U (threaded rod with washer and nut (standard element)).

Regardless of the element, a borehole is drilled in the existing concrete and the drilling dust must be removed during drilling as described above. The epoxy mortar is injected into the borehole with an automatic or pneumatic dispenser before the element is inserted into the borehole.

Figure 3. Installation of Hilti HCC shear connectors with and without overlying reinforcement layer

3. Load-bearing behavior of the interface

The behavior of interface subjected to longitudinal shear stresses can be described using the shear-friction theory. It should be noted, however, that the term "shear-friction theory" may be misleading as it includes several different stages of development.

The original "shear-friction theory" assumes that the transmission mechanism of shear stresses in an interface that is simultaneously subjected to shear and compression forces is only ensured by friction. Generally, a simple sawtooth model is used to illustrate the basic principles of this theory (Figure 4).

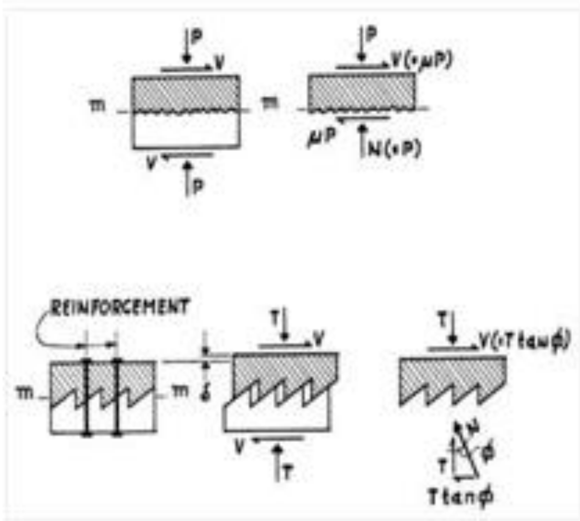

Figure 4. "Shear-friction theory" as sawtooth model 1960 by Birkeland and Birkeland [2]

This theory was developed around 1960 by Birkeland and Birkeland [2]. In 1972, it was extended by Mattock and Hawkins [3] to include the load-bearing component of cohesion. In 1978, concrete compressive strength was included in the theory as proposed by Loov [4]. Finally, Randl [5] describes that the shear transfer in the reinforced composite joint consists of three main mechanisms: cohesion, friction and dowel action. The three main mechanisms can be clearly described in Figure 5. Figure 6 shows the shear stress curve as a function of the relative displacement of the individual load-bearing mechanisms (adhesion/interlock τ adh, friction τ sf and shear reinforcement τ sr (Zilch and Reinecke [6]).

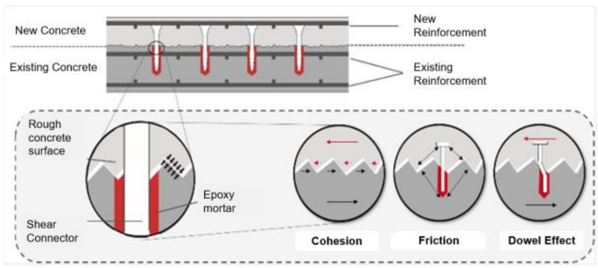

Figure 5. Shear transfer in the reinforced composite joint: cohesion / interlocking, friction and dowel effect using the example of the shear connector HCC-K.

The adhesion component τadh results from chemical adhesive bonds between the particles of the old and new concrete. When the maximum load-bearing capacity of the adhesive bond is reached, detachment occurs at the interface between the concrete layers and the shear stresses are transferred by mechanical interlocking due to surface roughness.

As the relative displacement between the concrete layers increases, the shear connectors crossing the interface are stressed and the shear connectors may fail by yielding of the steel, pullout failure or other possible failure modes. As a result of the resistance of the shear connectors, the interface is subjected to compression and the shear forces are transmitted by friction (τsf). Due to the relative displacement of the concrete layers, the post-installed shear connector is also subjected to shear force, which is usually referred to as dowel action (τsr).

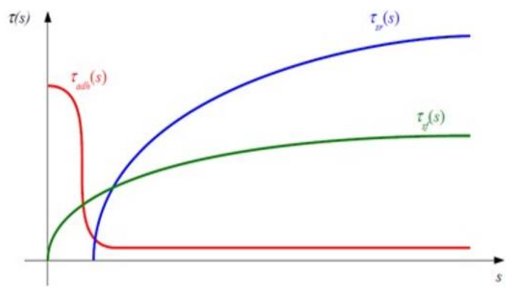

Figure 6. Shear stress curve as a function of relative displacement for the individual load-bearing mechanisms (adhesion/interlock τadh, friction τsf and shear reinforcement τsr (dowel action) (Zilch and Reinecke [6]).

With increasing surface roughness, the shear resistance and the shear stiffness of the composite joint increase considerably. In addition, the distribution of the total resistance between the three load-bearing components changes. In the extreme case, when the interface is very rough, the connectors at the joint are mainly subjected to tensile stress, whereas with a smooth interface the dowel stress on the connectors in shear is predominant.

4. Design of the shear joint according to EOTA TR 066

4.1 Static and quasi-static actions

4.1.1 External Forces

To determine the acting shear stress, the applied external shear force VEd,i is converted by the following equation into a shear stress τEd,i acting parallel to the interface in a given section I (Figure 7):

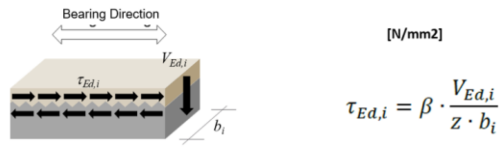

Figure 7. Conversion of the external shear force VEd,i into a shear stress τEd,i acting in parallel in the interface of the composite joint

$$\tau_{Ed,i} = \beta \cdot \frac{V_{Ed,i}}{z \cdot b_i} \qquad \textbf{(1)}$$

With:

β = ratio between longitudinal force in the new concrete and the total longitudinal force in either the compression or tension zone, for the section number consideration.

$V_E d, i$ = acting external shear force

bi = width of the zone under consideration

z = lever arm of the internal forces

These areas or zones of length li can be defined based on the shear stress distribution due to external loading (shear force distribution), whereby the maximum shear stress within the zone is decisive. The ratio of the longitudinal forces related to the total longitudinal force b depends on the height of the new concrete layer related to the height of the concrete compression zone.

4.1.2. Forced forces

EOTA TR 066 [2] also considers constraint forces at the edge of the concrete layer due to shrinkage under static and quasi- static actions. This generates shear stresses parallel to the bond joint, τ*Ed and uplift forces N*Ed,j (Figure 8). These uplift forces are considered within a certain influence length le along the edge area depending on the surface roughness and the height of the new concrete layer.

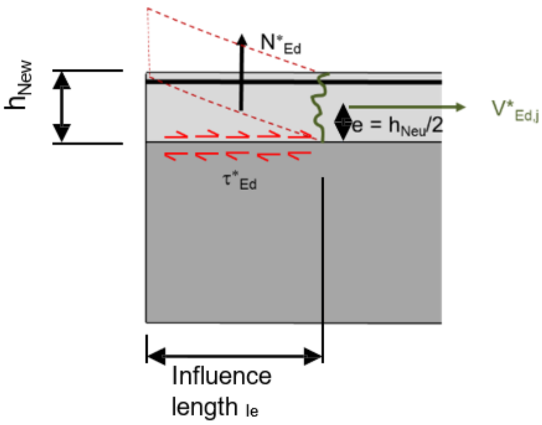

Figure 8. Lifting forces due to shrinkage according to EOTA TR066 [2], schematic

These must be smaller than the tensile resistance NRd of the shear connector taking into account the governing failure mode. The higher the new concrete layer and the rougher the concrete surface, the greater the length le that must be taken into account.

It should be noted that in EOTA TR 066 [1], the constraint forces are not superimposed with the acting forces from external loading, as the required verification is carried out separately by a verification against external loading and a verification against constraint forces. For the verification against constraint forces, either the shear stress from the constraint forces or the applied shear stress from external actions in the interface is taken into account, whereby the maximum value of the applied shear stress is decisive:(τEd=max.(τEd,i; τ*)).

4.2 Static and quasi-static resistance of the shear joint

4.2.1. Shear capacity of the shear joint without shear connectors (rigid composite)

Application condition 1 applies to rigid bond without subsequently installed shear connectors, where a good bond can be assumed and no tensile stresses occur perpendicular to the shear joint. In this case, the design of the shear resistance of the interface is carried out via the adhesive bond (No.1 in Figure. 9) and friction due to external normal stresses (No.2 in Fig. 8) without considering shear connectors. The corresponding coefficients depend on the roughness of the joint and are given in EOTA TR 066 [1].

$$\tau_{Rd} = \underbrace{c_a \cdot f_{ctd}}_{1} + \underbrace{\mu \cdot \sigma_n}_{2} \leq \underbrace{0{,}5 \cdot \nu \cdot f_{cd}}_{3}$$

Figure 9. Application condition I: Shear capacity of the composite joint without shear connector (rigid composite)

The shear strength is limited by the concrete compression strut (No. 3 in Fig. 8). The maximum shear strength of the bonded joint is approximately 30% of the design value of the concrete's cylindrical compressive strength.

If the condition τEd ≤ τRd is fulfilled, post-installed shear connectors are only required at the edge due to shrinkage (cf. chapter 4.1.2). If the condition τEd ≤ τRd is not fulfilled, post-installed shear connectors are required in the edge area along the interface.

4.2.2. Shear capacity of the shear joint with post-installed shear connector (reinforced interface)

Application condition 2 applies to non-rigid bond where relative displacement is allowed in the interface and post-installed shear connectors are used. Consequently, the design of the shear capacity of the interface includes the mechanisms of interlock (No. 1 in Fig. 10), friction (No. 2 in Fig. 10) and dowel action (No. 3 in Fig.10).

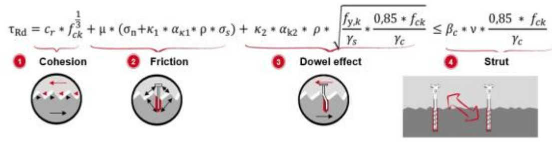

Figure 10. Application condition II: Shear strength of the reinforced interface according to EOTA TR 066 [2].

Mechanical interlock not adhesion is described by the expression "cr·fck 1/3" in the case of an interface with shear connectors and takes into account the concrete compressive strength and the surface roughness. For a reinforced composite joint, the coefficient cr takes values between 0 and 0.2. Note that compared to application condition 1, the bond resistance ca is replaced by a coefficient for mechanical interlock cr.

With increasing relative displacement of the concrete layers, the concrete layers want to separate further. The post-installed shear connectors counteract this separation and are subjected to tensile stress, causing compressive forces to develop between the surfaces, resulting in friction. In addition, the compressive forces can also be caused by external forces, which are taken into account by σN. However, the post-installed shear connectors can only be loaded up to the point where they fail in tension. The failure mode with the lowest resistance values determines the steel stress σS (Fig. 11).

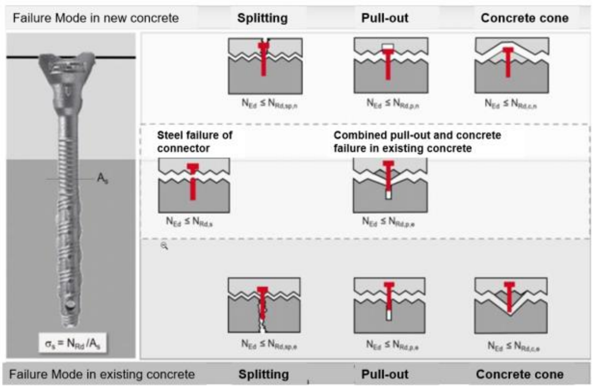

Figure 11. Specific resistance of the shear connector σs under tension depending on all possible failure modes

The coefficient αk1 considers the percentage of the tensile force acting on the shear connector. For smooth surfaces αk1= 0. The dowel effect is caused by the relative displacement of both concrete layers. Under these conditions and depending on the value of the relative displacement, the shear connectors are subjected to shear stresses (in addition to tensile stresses due to friction) and bending stresses. As the load increases, the concrete near the surface within the interface is damaged so that the resultant of the resistance is redistributed deeper into the concrete. This increases the eccentricity between the shear force and the resultant compression at the shear connector, resulting in bending stresses in the shear connector. The factor αk2 takes this into account as the product-specific bending load capacity of the shear connector.

5. Applications

This reinforcement technique can be applied to all types of structure: buildings, industry and civil engineering. On industrial slabs or in buildings, reinforcement is generally used to adapt the structure to changes in operating conditions (change of use) or to increase its load-bearing capacity. As part of the rehabilitation of a structure, vertical load-bearing elements may also require an increase in cross-section. Finally, as far as engineering structures are concerned, the reinforcement and repair of bridges and tunnels is becoming increasingly common, and often requires the reinforcement or repair of structural elements (decks, caissons, etc.). Figures 12,13,14.

Figure 12. Example of the use of Hilti HCC-HUS4 concrete screw connectors on the underside of a slab.

Figure 13. Attic reinforcement in a residential building with Hilti HCC-HUS4 concrete screw connectors

Figure 14. Reinforcement of a bridge deck with Hilti HCC-B connectors

6. Conclusions

EOTA TR 066 [1] is a state-of-the-art design concept for the design of the shear capacity of interface with post-installed shear connectors.

EOTA TR 066 [1] considers the three main load transfer mechanisms: cohesion/mechanical interlock, friction and dowel action under static action, quasi-static action, fatigue action and seismic action. In this paper, there is a focus over static and quasi-static action.

The load-bearing behavior of the post-installed shear connectors is product- specific and cannot be determined theoretically. It is determined in accordance with the European Assessment Document depending on the type of shear connector by EAD 330232-00-0601 (concrete screw as anchor), EAD 330499- 00-0601 (bonded anchor as anchor) and EAD 332347-00-0601 (shear connector). Qualification as a fastening element or anchor is therefore not sufficient for a design according to EOTA TR 066.

Paper introduces by outlining the implementation stages of the application, which can be broken down into a few simple steps on site: demolition or exposure of the existing damaged concrete layer, bush-hammering of the surface, installation of the post-installed connectors, placement of the new reinforcing bars and, finally, pouring of the new concrete layer. It should be noted that the preparation of the surface and the depth of roughness Rt are essential parameters in the design.

It should also be remembered that there are many types of connectors available: mechanical systems such as concrete screws (mechanical connectors) and systems with injection mortar. These are generally compared with traditional methods using cross-linked reinforcing bars.

References

[1] EOTA TR 066: EOTA Technical Report, Design and requirements for construction works of post-installed shear connection for two concrete layers, Amended 2020

[2] Birkeland, P.W. and Birkeland, H.W. - Connections in precast concrete construction, American Concrete Institute, Journal of the American Concrete Institute, Vol. 63, No. 3, pp. 345-368, March 1966.

[3] Mattock, A.H. and Hawkins, N.M. - Shear transfer in reinforced concrete - recent research, Precast/Prestressed Concrete Institute, PCI Journal, Vol. 17, No. 2, pp. 55-75, March-April 1972.

[4] Loov, R.E. - Design of precast connections, Paper presented at a seminar organized by Compa International Pte, Ltd, 8 p., Singapore, September 1978.

[5] Randl, N.: Investigation of force transmission between old and new concrete at different joint roughnesses. Innsbruck, Leopold-Franzens-University Innsbruck, Dissertation 1997

[6] Zilch, K. and Reinecke, R. - Capacity of shear joints between high-strength precast elements and normal-strength cast-in-place decks, FIB International Symposium on High Performance Concrete, Orlando, USA, 25-27 September 2000.

[7] EN1992-1-1:2020-01 - Eurocode 2: Design of reinforced and prestressed concrete structures - Part 1-1: General design rules

[8] FIB ModelCode for Concrete Structures 2010

[9] EOTA TR 066: EOTA Technical Report, Design and requirements for construction works of post-installed shear connection for two concrete layers, April 2019.