SHEAR-FRICTION APPLICATIONS AND CONCRETE OVERLAYS

Design and Construction

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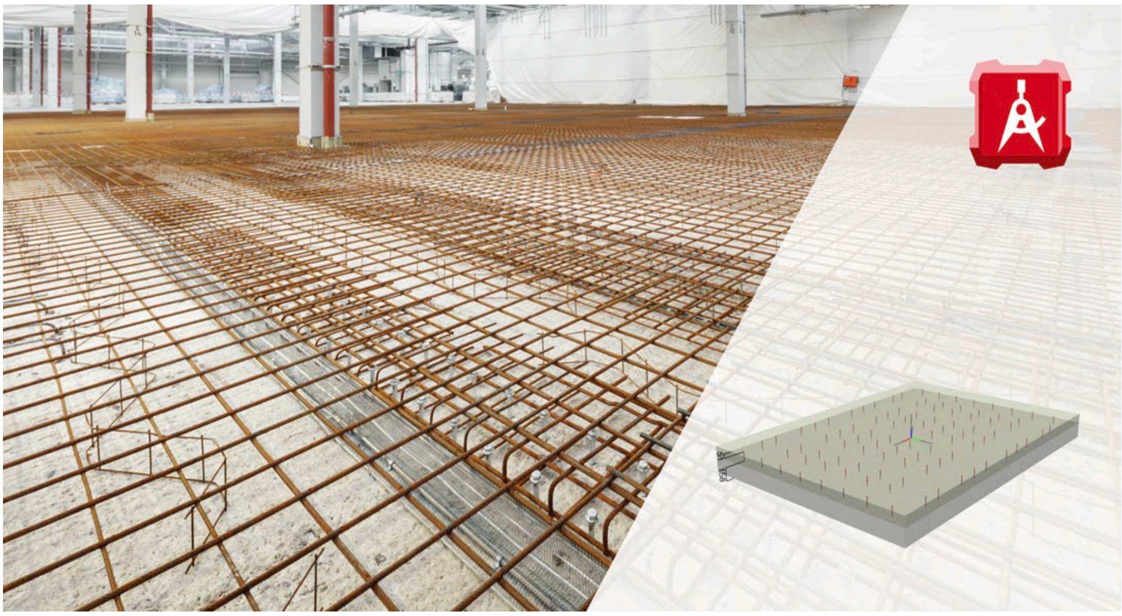


1. INTRODUCTION AND SCOPE OF THIS ARTICLE

Reinforced concrete structures require interventions in terms of structural strengthening and/or functional repurposing due to factors like deterioration through age, damage due to accidental loads, improvement in codes and regulations, functionality changes, etc. Hence, retrofitting existing concrete layers with new structural overlays in buildings and bridges such as slabs/decks, beams/girders, and walls/piers is becoming increasingly necessary and popular (see examples in Fig. 1). These **shear-friction applications (concrete overlays)** require code-compliant, efficient design and reliable construction as per design assumptions.

Note | Shear connectors are more efficient than post-installed rebars for thin overlays (150-200 mm)

Both shear connectors and rebars can be installed into existing concrete structures to ensure reliable connections with new concrete overlays. This article discusses the working mechanism and different established design methods for shear friction applications as per Eurocode 2-1-1 (EC2-1-1 [1]), EOTA TR 066 [2], and the Hilti method for static, seismic, and fatigue load actions. Important construction procedures and detailing rules for such applications involving concrete overlays are also highlighted. The use of the design software PROFIS Engineering with its “concrete overlay module” for quicker and more efficient design of applications is also briefly presented.

a) Increasing RC beam depth b) Increasing industrial slab thickness c) Increasing shear wall thickness

Fig. 1: Shear friction applications (structural overlays) in buildings & infrastructure

2. REGULATORY FRAMEWORK FOR DESIGN & QUALIFICATION

Structural connection systems in shear-friction applications using post-installed rebars/shear connectors, including the material and installation method employed, shall be assessed, and proven in terms of load/displacement performance under different influencing parameters. Only such proven structural systems can be designed according to the established design standards. The **European Organisation for Technical Assessment (EOTA)** is a regulatory body which has developed the performance assessment guidelines and specifications for structural connection systems through the establishment of **European Assessment Documents (EADs)**. The assessed construction systems according to a particular EAD are approved with **European Technical Assessments (ETAs**) that showcase the assessed performance.

Note | Eurocodes are enforced in CEN member states jointly with applicable national regulations.

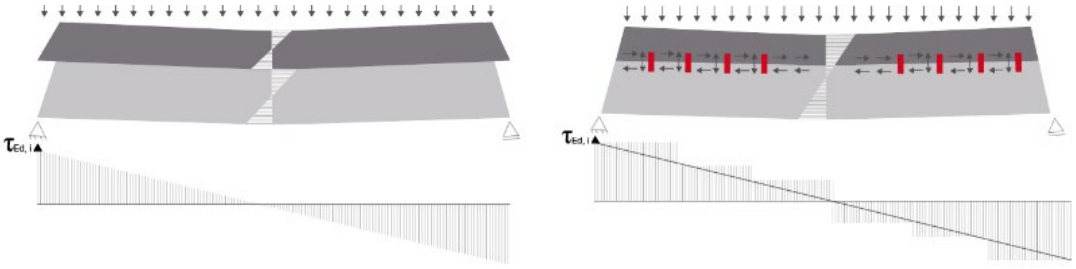
In addition and supplementary to the European codes and standards enforced by the **European Committee for Standardization (CEN)** in its member states, EOTA Technical reports (TR) are developed as supporting documents to EADs. These contain detailed information on newly developed design methods, plus the execution and evaluation of performance tests.

The design of shear friction connections between two concrete layers cast at different times is ruled by the provisions of EC2-1-1 [1], section 6.2.5. However, the design provisions in EC2-1-1 [1] require full anchorage of interface rebars (based on steel yielding) used as dowels on both sides of the interface. This condition cannot be fulfilled in many interventions, where reinforced concrete members are strengthened by adding a thin layer of concrete overlay and/or an existing thin layer of base concrete.

For overcoming this limitation, EOTA has developed a specific design guideline to address such applications, i.e., **EOTA TR 066** “*Design and Requirements for construction works of post-installed shear connection for two concrete layers* " [2].

3. LOAD BEARING MECHANISM

The perpendicular loads acting on a concrete structure like a slab/beam are transferred as longitudinal forces along the length of the member. It is critical to ensure the activation of transfer of these resulting longitudinal shear stresses through the shear connectors at the interface to establish a composite cross-section. In this case, the structural resistance of the increased cross-section using concrete overlays can be assumed. If the interface is not connected by shear connectors/dowels, even at the service loads, the adhesive resistance between the two layers is exceeded already at minor deformations of 0.03 to 0.05 mm due to cracking/delamination along the interface. This causes individual flexural bending of the two layers to behave rather independently than monolithically (compare Fig. 2 a and b).



a) Without shear connectors

b) With shear connectors

Fig. 2: Behavior of stresses at cross-section

The longitudinal shear transfer through the interface is resisted through the following three main mechanisms (see Fig. 3 a and b):

Note | The three mechanisms of shear transfer across the interface do not act simultaneously.

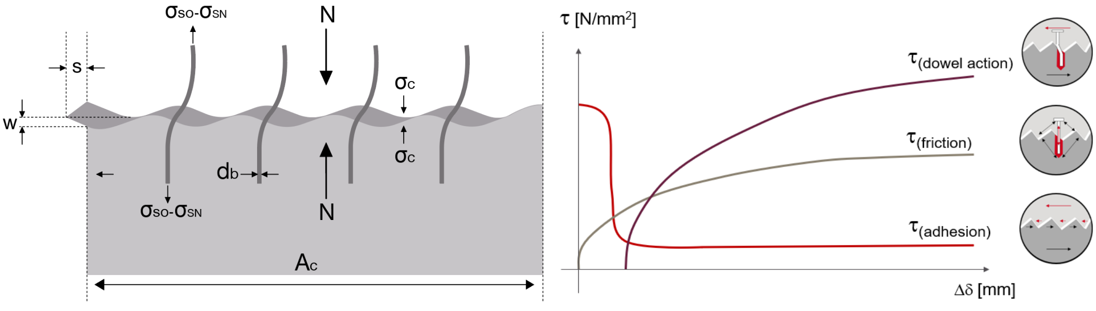
- Adhesion/interlocking
- Friction
- Dowel effect

The **adhesion** component 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 (which usually happens at service load level), detachment occurs at the interface between the concrete layers. Then the shear stresses are transferred by **mechanical interlocking** due to surface roughness.

As the relative displacement between the concrete layer increases, the shear connectors crossing the interface are stressed and the interface is subjected to compression. This transmits the shear forces by **friction**, which is again strongly dependent on interface roughness. The resulting tension forces in the shear connectors may cause failure by yielding of the material, pullout failure or other concrete related failure modes such as concrete breakout or splitting.

Due to the further relative displacement of the concrete layers, the post-installed shear connector is also subjected to shear force, which is usually referred to as the **dowel action**.

With increasing surface roughness, the shear resistance, and the shear stiffness of the composite joint increases considerably. 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.



a) Shear transfer across interface

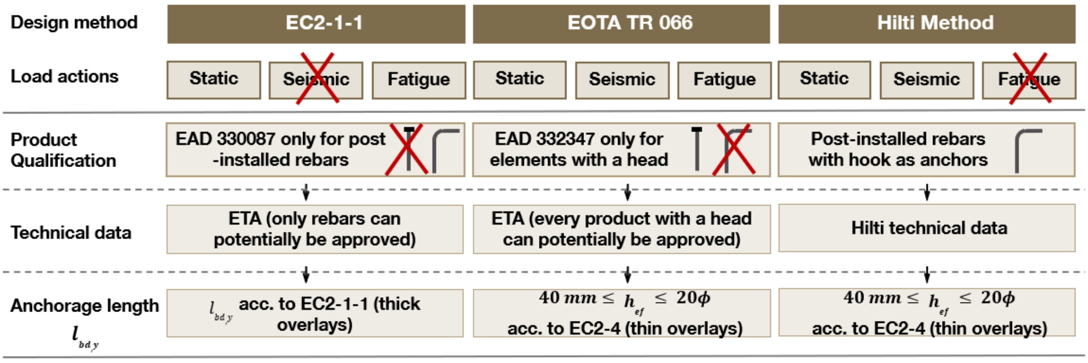
b) Contributing factors

Fig. 3: Shear transfer mechanism at the interface of concrete overlays

3.1 Design provisions for shear transfer between concrete cast at different times

The interface shear transfer needs to be verified for concrete cast at different times, using appropriate design approaches as discussed in the table below.

Table 1: Design methods & type of shear connectors for shear-friction applications (concrete overlays)



Design method	EC2-1-1	EOTA TR 066	Hilti Method
Load actions	Static ~~Seismic~~ Fatigue	Static Seismic Fatigue	Static Seismic ~~Fatigue~~
Product Qualification	EAD 330087 only for post-installed rebars	EAD 332347 only for elements with a head	Post-installed rebars with hook as anchors
Technical data	ETA (only rebars can potentially be approved)	ETA (every product with a head can potentially be approved)	Hilti technical data
Anchorage length $l_{bd\,y}$	$l_{bd\,y}$ acc. to EC2-1-1 (thick overlays)	$40\ mm \leq h_{ef} \leq 20\phi$ acc. to EC2-4 (thin overlays)	$40\ mm \leq h_{ef} \leq 20\phi$ acc. to EC2-4 (thin overlays)

Here, $l_{bd,y}$ - design anchorage length for steel yielding, h_{ef} - effective embedment depth of the shear connectors according to EC2-4 [3]

4. DESIGN OF CONCRETE OVERLAYS USING PROVISIONS AS PER EUROCODE

Conventional shear friction theory of concrete members cast at different times, as per EC2-1-1 [1] cater predominantly to applications where the longitudinal shear stresses at the interface arise due to the new layer. These include wall strengthening or slab overlays (see Fig. 4a). Load transfer of these predominant longitudinal shear stresses at the interface are defined by the following two components of shear resistance: **adhesion/interlock and friction** action from interface rebars.

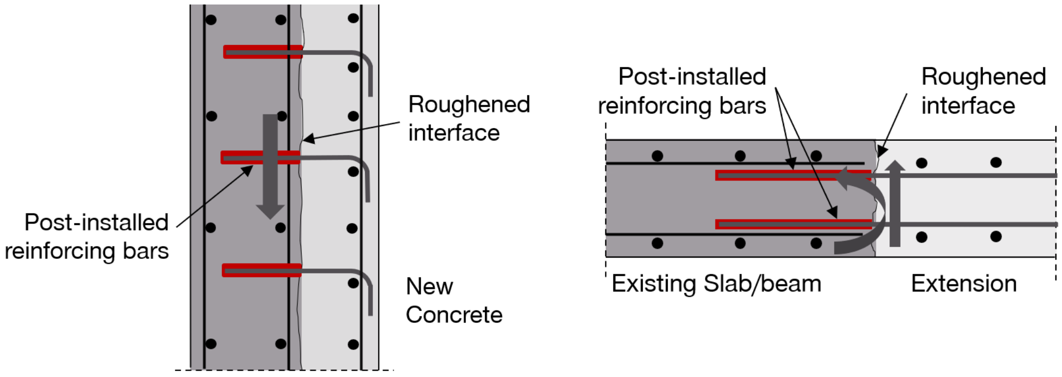
Major limitations of the design provisions by EC2-1-1 [1] include:

1) The shear rebars used as interface reinforcement need to be developed in length for yielding which might require a thick concrete section on both sides of the interface. This design requirement makes many strengthening applications unfeasible, since typical overlay thickness might range between 50 mm and 200 mm.

2) The design equation born out of conventional shear-friction theory is not always applicable where the bending moment that causes tension and compression is predominant in addition to the interface shear

(e.g., beam/slab extensions as shown in Fig. 4b). In such situations, regional/national regulations like the German National Annex to EC2-1-1 (DIN EN 1992-1-1 NA 2013-04) [4] provide clear guidance for the verification of this type of load transfer.

3) These provisions do not cater to seismic load actions.



a) Shear dominated application

b) Bending dominated application

Fig. 4: Conventional shear-friction theory application for interface shear as per EC2-1-1 [1]

The interface design shear resistance (V_{Rdi}) verification provision given in EC2-1-1 [1], section 6.2.5 is:

$$V_{Rdi} = \underbrace{c \cdot f_{ctd}}_{\text{Adhesion/interlock}} + \underbrace{\mu \cdot \sigma_n}_{\text{Friction}} + \rho \cdot f_{yd}(\mu \sin\alpha + \cos\alpha) \le \underbrace{0.5 \cdot \nu \cdot f_{cd}}_{\text{Strut capacity}}$$

where,

c and μ are factors for adhesion/interlock and friction depending on roughness of interface (see EC2-1-1 [1], sect. 6.2.5)

f_{ctd} & f_{cd} is the design tensile strength and the design compressive strength of concrete, respectively.

f_{yd} is the design yield strength of steel reinforcement

σ_n is stress per unit area caused by the minimum external normal force across the interface that can act simultaneously with the shear force, such that $\sigma_n < 0.6 f_{cd}$ and is negative for tension. When σ_n is tensile, $c \cdot f_{ctd}$ should be taken as 0

ρ is the ratio of area of reinforcement across the interface including ordinary shear reinforcement, with adequate anchorage at both sides of the interface (A_s) to area of the joint (A_i)

α shall be limited by 45° to 90° (refer section 6.2.5 of EC2-1-1 [1])

v is the strength reduction factor for concrete cracked in shear depending on national regulations.

The recommended value is $v = 0.6(1 - \frac{f_{ck}}{250})$

- The design resistance shall be equal to or greater than the longitudinal shear stress along the interface ($v_{Ed,i}$) caused by **external forces.** When the shear action is perpendicular to the interface ($V_{Ed,i}$) the interface stress can be calculated as following:

$$v_{Ed,i} = \beta \cdot \frac{V_{Ed,i}}{z \cdot b_i}$$

- where z is the inner lever arm and b_i is the width of the interface of the composite section.

- β is the ratio of longitudinal force in the new concrete and the total longitudinal force either in the compression or tension zone for the section considered and calculated as per sect. 6 of EC2-1-1 [1]. However, this ratio β can be taken as 1.0 to be conservative.

When the **adhesion/interlock** resistance is sufficient to resist the entire design shear load, the requirement for dowel bars at the interface can be neglected, hence only minimum embedment length ($l_{bd,min}$) can be considered, which is typically around 10-times the rebar diameter. If not, then the additional resistance from shear interface rebars **(friction)** crossing the interface is required with adequate anchorage length ($l_{bd,y}$) for yielding on both sides of the interface (this dictates the need of thicker sections).

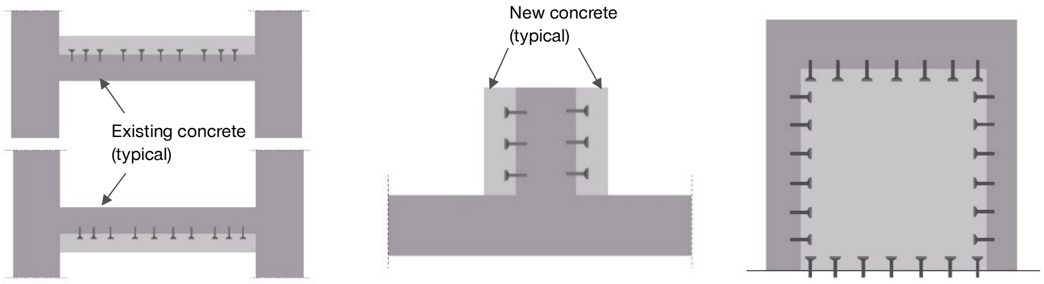
For **fatigue loading** case, the value of the roughness coefficient, *c*, reduces by 50%. While these loading cases could be designed using post-installed rebar systems, no European assessment of post-installed rebars for fatigue loading is currently available. Note that according to EN 1992-2 [15] (code for concrete bridge design), the coefficient, *c,* shall be taken as equal to zero.

5. DESIGN OF CONCRETE OVERLAYS USING PROVISIONS AS PER EOTA TR 066

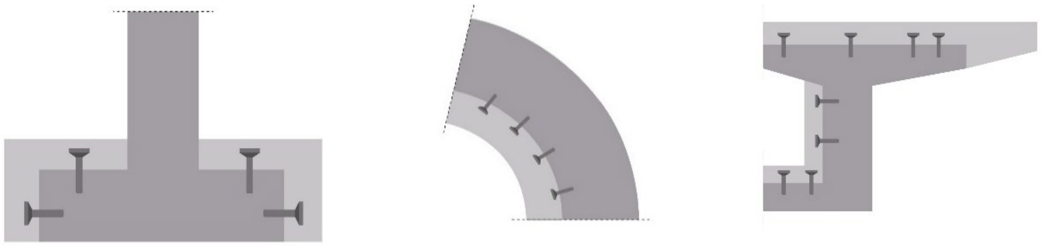
5.1 General

Note | EOTA TR 066 [2] provides solutions for thin concrete overlays.

Design of concrete using improved design provisions as per EOTA TR 066 [2] provides solutions for thin overlays, as commonly required for strengthening reinforced concrete elements using special shear connectors. EOTA TR 066 [2] allows design and dimensioning of these connections and the interface considering all load-bearing components of shear resistance (**adhesion/interlocking, friction, and dowel action**) and other product-specific factors from relevant ETA. Overcoming the limited application range (thick overlays) as per EC2-1-1 [1] provisions, with the new design method EOTA TR 066 [2] and qualified products assessed through the EAD 332347 [5], several other applications can be designed (refer Fig. 5). The provisions include two possible design approaches explained in the following section.



a) Beams/slabs **b) Columns/walls** **c) Shear walls in R.C. frame**



d) Foundations **e) Shells/arches/tunnels** **f) Bridges**

Fig. 5: Typical shear-friction applications using EOTA TR 066 [2]

Note | An unreinforced interface should be assumed only if the interface is expected to stay uncracked over the entire service life.

Unreinforced interface: monolithic behavior, i.e., **strong adhesive bond** is assumed, and no shear connectors are required.

Reinforced interface: composite behavior, i.e., **weak adhesive bond** is assumed where shear connectors are used across the shear interface to transmit the tensile forces generated by friction and dowel action between the two concrete layers.

For both approaches the most important design parameter is the **interface roughness**. EOTA TR 066 [2] recognized 4 different roughness levels i.e., **very rough, rough, smooth, and very smooth surfaces**.

EOTA TR 066 [2] distinguishes between two types of forces for design:

1) **External forces** as defined in sect. 4 of this article.

2) **Forces resulting from restraint at the perimeter ($V^*_{Ed,j}$) due to concrete shrinkage** (see Fig. 6). These forces activate **uplift forces** perpendicular to the interface ($N^*_{Ed,j}$), which are carried by the shear connectors and transferred into the two concrete layers. These forces are a function of l_e, the width of the restraint area of the interface at the perimeter, cross-section dimensions of the new concrete overlay and again importantly the **interface roughness**.

Note | The external forces and forces from perimeter restraint are not superimposed.

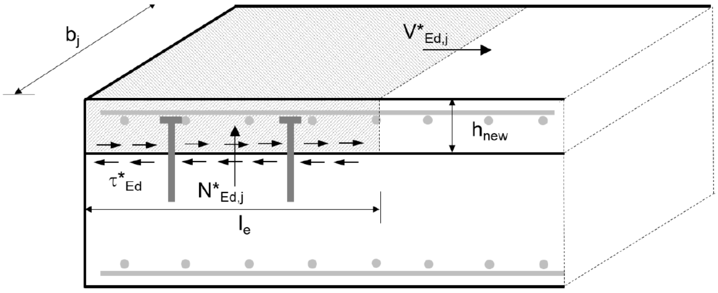


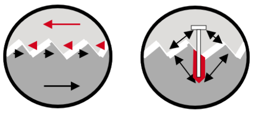
Fig. 6: Schematic representation of connectors to resist restraint forces along the perimeters (ref. EOTA TR 066 [2])

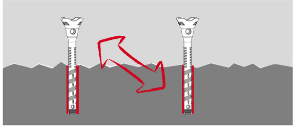
Note: **The restraint forces at the perimeter may be neglected** if other measures are taken or if the boundary conditions are such that no tension at the perimeter occurs (e.g., self-weight of a wall on its bottom side).

5.2 Design resistances of interfaces

As mentioned earlier, EOTA TR 066 [2] allows for design of the shear interface with **strong adhesive bond condition** assumption where shear connectors are not required. The design resistance is a sum of only two components of the shear transfer mechanism: **adhesion resistance** and **friction resistance**. The design resistance is limited by the compressive strut capacity of the concrete. An unreinforced interface may be assumed to resist static/fatigue loads only as shown by the equation as follows:

$$\tau_{Rd} = \underbrace{c_a \cdot f_{ctd}}_{\text{① Adhesion}} + \underbrace{\mu \cdot \sigma_n}_{\text{② Friction}} \leq \underbrace{0.5 \cdot \upsilon \cdot f_{cd}}_{\text{③ Strut capacity}}$$





Note: Even in the case of an unreinforced interface, **a minimum constructive reinforcement** should be provided to support the new concrete layer as per the relevant local codes of construction. A minimum of two shear connectors per m^2 with a spacing not larger than 700 mm is recommended.

When the total design resistance of the unreinforced interface is not enough to account for the design shear stress, and where relative slip at the interface is expected (e.g., under seismic actions), the design resistance equation given by EOTA TR 066 [2] is modified as shown below. It now includes the additional contribution from the **friction resistance** and **dowel action** by the installed shear connectors (**reinforced interface**). This design resistance of reinforced interface assumes **weak adhesive bond condition.**

$$\tau_{\mathrm{Rd}} = \underbrace{c_r \cdot f_{ck}^{\frac{1}{3}}}_{①\ \text{Interlock}} + \underbrace{\mu \cdot (\sigma_n + \kappa_1 \cdot \alpha_{\kappa 1} \cdot \rho \cdot \sigma_s)}_{②\ \text{Friction}} + \underbrace{\kappa_2 \cdot \alpha_{k2} \cdot \rho \cdot \sqrt{\frac{f_{y,k}}{\gamma_s} \cdot \frac{0.85 \cdot f_{ck}}{\gamma_c}}}_{③\ \text{Dowel action}} \leq \underbrace{\beta_c \cdot \nu \cdot \frac{0.85 \cdot f_{ck}}{\gamma_c}}_{④\ \text{Concrete strut resistance}}$$

Where c_r, μ, κ_1, κ_2 and β_c are factors dependent on surface roughness given table 2 below:

Table 2: Coefficients and parameters for different surface roughness (ref. EOTA TR 066 [2])

Surface characteristics of interface	c_a	c_r	κ_1	κ_2	β_c	μ	
						$f_{ck} \geq 20$ MPa	$f_{ck} \geq 35$ MPa
Very rough (including shear keys[1]) $R_t \geq 3.0$ mm	0.5	0.2	0.5	0.9	0.5	0.8	1.0
Rough $R_t \geq 1.5$ mm	0.4	0.1	0.5	0.9	0.5	0.7	
Smooth (concrete surface without treatment after vibration or slightly roughened when cast against formwork)	0.2	0	0.5	1.1	0.4	0.6	
Very smooth (steel, plastic, timber formwork)	0.025	0	0	1.5	0.3	0.5	

[1] Shear keys should satisfy the geometrical requirements given in EOTA TR 066 [2]

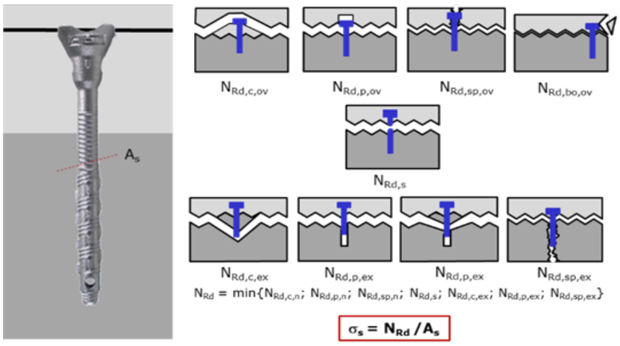


Fig. 7: Anchor verifications to be carried out to determine σ_s

For the calculation of σ_s all possible failure modes in the new and existing concrete layers should be calculated according to the provisions of EC2-4 [3] (see Fig. 7). The smallest resistance is decisive. These hand calculations may be quite laborious. However, they can be done very quickly with PROFIS Engineering software suite. Refer section 8 of this article.

Note: **A minimum interface reinforcement is required** (when weak adhesion bond condition is assumed) to prevent brittle failure and to allow for redistribution of stresses and to ensure composite behavior of the new combined section (see EOTA TR066 [2], section 2.3.4).

5.3 Design of shear interfaces for fatigue action

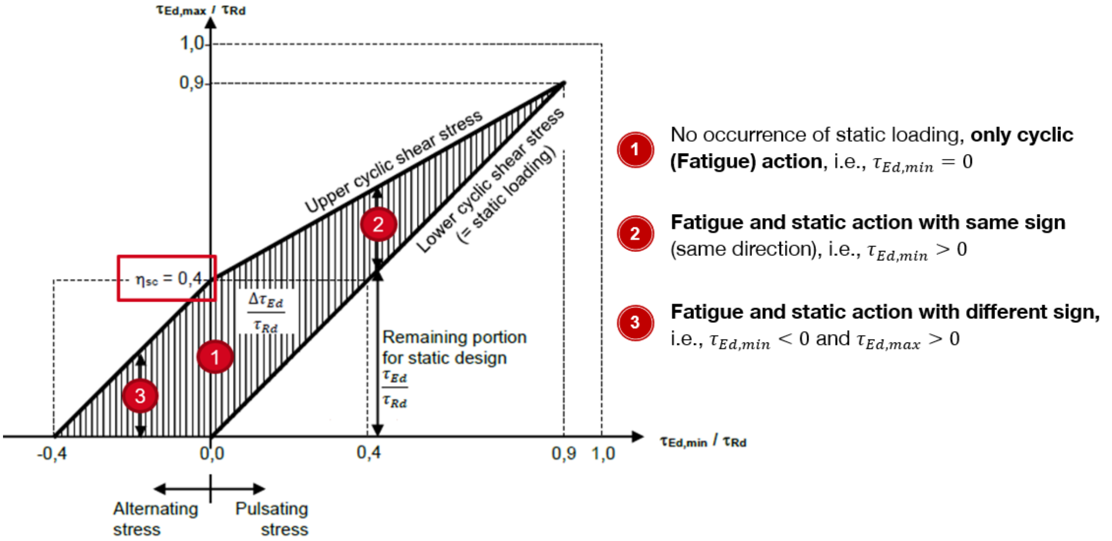
The design provisions as per EOTA TR 066 [2] for fatigue loads are only applicable when the following requirements are fulfilled:

- The interface surface is limited to very rough.
- Only shear connectors with an ETA according to EAD 332347 [5] covering fatigue case may be used.
- Concrete strength classes of both existing and new concrete layers as per relevant ETA(s).
- The following verification condition shall be satisfied for the shear design resistance for fatigue loads:

$$\Delta\boldsymbol{\tau}_{\boldsymbol{Ed}} \leq \eta_{sc} \cdot \boldsymbol{\tau}_{\boldsymbol{Rd}}$$

Note | According to EOTA TR 066 [2], no fatigue design of connectors is required.

η_{sc} is the factor for fatigue loading of shear connectors depending upon on superimposition of cyclic (fatigue) stress & its direction on the static action. This value is to be taken from relevant ETA(s). The limits of cyclic (Fatigue) stresses and design resistance ratios are shown in Fig. 8, in which $\eta_{sc} = 0.4$ is taken as a cornerstone for the Goodman Diagram. EOTA TR 066 [2] covers the design of three different situations that might occur, as shown in Fig. 8



① No occurrence of static loading, **only cyclic (Fatigue) action**, i.e., $\tau_{Ed,min} = 0$

② **Fatigue and static action with same sign** (same direction), i.e., $\tau_{Ed,min} > 0$

③ **Fatigue and static action with different sign,** i.e., $\tau_{Ed,min} < 0$ and $\tau_{Ed,max} > 0$

Fig. 8: Constant life diagram (Goodman diagram, ref. EOTA TR 066 [2])

5.4 Design of shear interfaces for seismic action

Note | The seismic forces are usually not superimposed with static forces as well as forces from perimeter restraint.

The derivation of the seismic forces acting perpendicular to the interface activates tensile forces and their transfer mechanism through the shear connectors and subsequently through both the layers of concrete need to be verified. **The forces required to be transferred at the vertical/horizontal interface depend upon the type of shear-friction strengthening application** chosen for beam/slab strengthening, column/wall strengthening, or infill of a seismic frame.

The design provisions are similar to the provisions given for static load cases, but an unreinforced shear interface is not allowed for seismic load cases. Verification of resistances as per different failure modes shall be calculated assuming seismic performance category C1 or C2 according to EC2-4 [3] depending on the design assumption and application.

Design resistances

Note | The upper limit for $\tau_{\mathrm{Rd,seis}}$ shall be equal to τ_{Rd}.

The design shear resistance at the interface between concrete cast at different times for seismic load case is given by:

$$\tau_{Rd} = \alpha_{seis} \cdot \left[\underbrace{\boldsymbol{\mu} \cdot \sigma_{\mathrm{n}} + \alpha_{k1} \cdot \boldsymbol{k_1} \cdot \rho \cdot \sigma_{s,eq} \cdot \boldsymbol{\mu}}_{\text{① Friction}} + \underbrace{\alpha_{k2} \cdot \boldsymbol{k_2} \cdot \rho \cdot \sqrt{f_{yd} \cdot f_{cd}}}_{\text{② Dowel action}} \right] \leq \underbrace{\boldsymbol{\beta_{\mathrm{c}}} \cdot v \cdot f_{cd}}_{\text{③ Concrete strut resistance}}$$

where,

$\sigma_{s,eq}$ = min ($N_{Rd,s,eq}$; $N_{Rd,c,eq}$; $N_{Rd,p,eq}$; ...)/$A_s \leq f_{yk}/\gamma_s$ (steel stress as per relevant failure mode under seismic conditions, i.e., category C1 or C2 as per EC2-4 [3])

α_{seis} is product dependent seismic factor to be taken from relevant ETA (value ≤ 1.0).

The adhesion/interlock mechanism of shear resistance in case of seismic loading (reversible) is not relied upon. The design coefficients of the above equation require modifications for the seismic case as per the relevant ETAs and EOTA TR 066 [2] as seen in Table 3 below:

Table 3: Factors related to surface roughness under seismic loading from EOTA TR 066 [2]

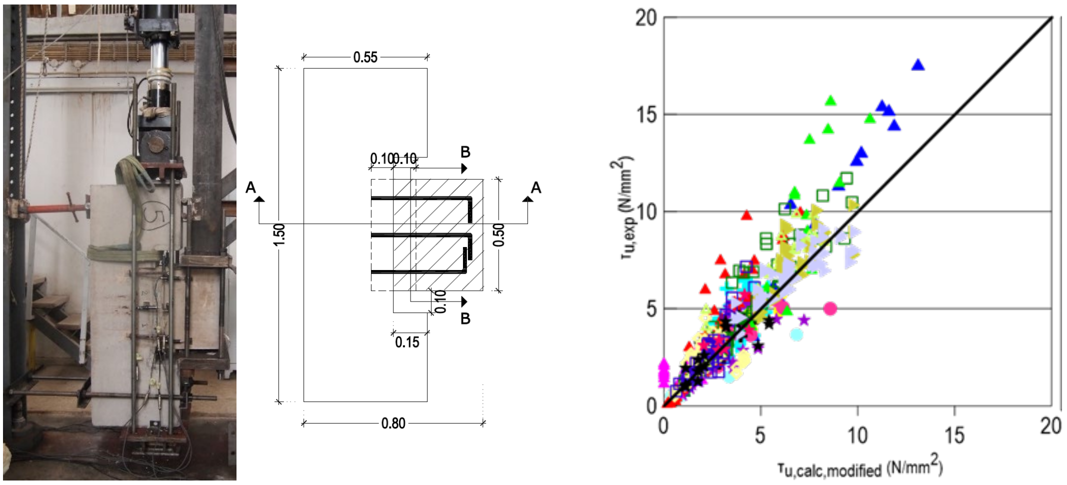
Surface characteristics of interface	C_r	κ_1	κ_2	β_c	μ	
					$f_{ck} \geq 20$ MPa	$f_{ck} \geq 50$ MPa
Rough $R_t \geq 1.5$ mm	0	0.5	0.9	0.5	$\mu = 0.4 \sqrt[3]{\left(\frac{f_{cd}}{\sigma_c + \sigma_n}\right)^2}$	$\mu = 0.27 \sqrt[3]{\left(\frac{f_{cd}}{\sigma_c + \sigma_n}\right)^2}$
Smooth $R_t < 1.5$ mm	0	0.5	1.1	0.4	$\mu = 0.27 \sqrt[3]{\left(\frac{f_{cd}}{\sigma_c + \sigma_n}\right)^2}$	$\mu = 0.135 \sqrt[3]{\left(\frac{f_{cd}}{\sigma_c + \sigma_n}\right)^2}$

6. DESIGN OF CONCRETE OVERLAYS AS PER HILTI METHOD

A traditional alternative solution is the employment of post-installed rebars with bent-ends on the cast-in side as shear connectors in concrete overlays. For this purpose, Hilti and research partners have developed a method that can be used to allow a safer and more reliable design of interfaces using post-installed rebars, which follows the principles of EOTA TR 066 [2]. The anchorage lengths designed using the Hilti method are significantly smaller than as per EC2-1-1 [1].

This design method is based on the research work by Palieraki et al. [6], [7] that has demonstrated that the static and cyclic strength of the shear friction interface can be accurately described as the sum of **friction and dowel action** shear transfer mechanisms (see Fig. 9).

However, due to the lack of radial symmetry of the heads of rebars, the minimum anchorage lengths are longer than according to EOTA TR066 [2], which needs to be considered by the designer/engineer.



a) Typical test specimen and setup used to derive the shear-friction model (dimensions are in m)

b) Prediction of static and cyclic interface shear plotted against test results

Fig. 9: Derivation of shear-friction Hilti design method [6] [7]

Design equation of shear resistance at the interface as per Hilti method is based on modification of the equation of EOTA TR 066 [2] for static load case (seen as below), and is applicable when certain conditions are satisfied as follows:

- Central and perimetral zones are defined as per provisions in EOTA TR 066 [2]
- Only reinforced interfaces (weak adhesive bond assumption) are allowed
- The minimum h_{ef} shall be 6 times the diameter of shear connectors
- Bent rebars in the overlay concrete shall be conforming to EC2-1-1 [1]

$$\tau_{\mathrm{Rd}} = \underbrace{\boldsymbol{\mu_h} \cdot (\sigma_n + \boldsymbol{\kappa_{1h}} \cdot \rho \cdot \sigma_s)}_{\text{① Friction}} + \underbrace{\boldsymbol{\kappa_{2h}} \cdot \rho \cdot \sqrt{\frac{f_{yk}}{\gamma_s} \cdot \frac{\alpha_{cc} \cdot f_{ck}}{\gamma_c}}}_{\text{② Dowel action}} \leq \underbrace{\beta_c \cdot \nu \cdot \frac{\alpha_{cc} \cdot f_{ck}}{\gamma_c}}_{\text{③ Concrete strut resistance}}$$

Where Hilti method's influencing factors (refer Table 4): - ***k_{1h}*** is dependent on the surface roughness, loading type (static/seismic) and h_{ef} and ***k_{2h}*** is dependent on h_{ef}. **Provisions of static load case shall apply for seismic as well**, however the **minimum *h_{ef}* shall be 10 times the diameter of shear connectors** and σ_s is replaced by $\sigma_{s,eq}$ calculated according to EOTA TR 066 [2].

Table 4: Values for factors *k_{1h}* and *k_{2h}* (Hilti Method)

Interface characteristics for *k_{1h}* factor	*k_{1h}* value for static loading 6d < *h_{ef}* < 20d	*k_{1h}* value for seismic loading 10d < *h_{ef}* < 20*d*
Mechanically roughened (≥ 1.5 mm)	**0.6**	**0.02 *h_{ef}*/*d* + 0.2**
Smooth surface (< 1.5 mm)	**0.4**	**0.2**

Normalized embedment Depth for *k_{2h}*	*k_{2h}* value
***h_{ef}* / *d* > 8**	**0.7**
6 ≤ *h_{ef}* / *d* ≤ 8	**0.1 *h_{ef}* / *d* – 0.1**
***h_{ef}* / *d* = 8**	**0.5**

7. CONSTRUCTION REQUIREMENTS OF CONCRETE OVERLAYS

Note | Contact Hilti for application in different concrete types (e.g., high grades or light weight concrete).

To use qualified shear connectors and solutions as per EOTA TR 066 [2], the construction of shear-friction applications (concrete overlays) should satisfy the requirements of material and procedure for construction described in section 4 of EOTA TR 066 [2]. Normal weight concrete shall be used according to the requirements of applicable Eurocodes, standards, and national regulations. Reinforcement material shall also satisfy the requirements and fulfill detailing requirements as per EC2-1-1 [1].

7.1 Construction procedure

Implementation of concrete overlays involves the following simple process steps (see Fig. 10):

1) Demolition of the existing concrete member or damaged concrete layer (if any)

Deteriorated/damaged concrete material and loose concrete material shall be removed by suitable means to the required depth as specified by the Engineer of Record (EoR). If the surface layer of existing concrete is carbonated, the carbonated layer should be removed in areas that are to receive post-installed rebars or shear connectors.

2) Proper roughening & post-treatment of the exposed concrete surface – crucial step

Roughening of the existing concrete surface is a crucial step in the process of construction of the concrete overlays. The design resistance of the shear interface as per any design method depends dominantly on the surface roughness parameters of the interface (coefficients of cohesion and friction). Refer to the design examples in section 9 to see the impact of changing the surface roughness category.

Roughening of the surface is usually carried out by high-pressure water jetting. Proper roughening should result in the exposure of aggregates (clear visibility) that are well anchored in the concrete.

Post-treatment of the roughened concrete surface involves two steps. The first step is **cleanliness** – the work sequence must be designed in such a way that the interface always remains clean of any dust, debris, and oil from the time of roughening until the new concrete is placed. Secondly, the clean interface must be kept at the **saturated surface dry condition** to support the hydration of the fresh concrete.

The required average roughness depth R_t must correspond to the specified minimum value as per EOTA TR 066 [2]. The principal suitability of the roughened concrete surface shall be checked by measuring the bond strength perpendicular to the interface (adhesive tensile strength) as per EOTA TR 066 [2]. Additional guidelines and specifications by the Engineer of Record shall also be fulfilled.

Demolition | Surface machining | Installation of the shear connectors | Laying the Reinforcement | Placement of the Concrete

Fig. 10: Construction of concrete overlays

3) Installation of the post-installed shear connectors (rebars/shear connectors)

There is a wide range of post-installed shear connectors available, from mechanical screw systems to adhesive mortar systems. For installation of post-installed shear connectors, qualified shear connectors (such as HILTI's HUS4-H or HCC-B, see Fig. 11) shall follow the manufacturer's IFU (Instructions for Use) which usually follow three steps. The first step is to drill boreholes in the existing concrete. The second step consists of cleaning the boreholes using the recommended procedure in the product's IFU. The last step is installation of the shear-connector system (mechanical or adhesive-mortar bonded).

HCC-HAS-U **HCC-K** **HUS4-H** **HCC-B**

Fig. 11: Qualified shear connectors for concrete overlay

4) Laying and placement of the new required reinforcement layers

The reinforcement bars for the new concrete overlay layer are placed in position as per the working drawings and technical specifications provided by the EoR.

5) Final placement of the new concrete overlay of the required thickness

The new overlay concrete shall be poured as per the project specifications. In addition to the reinforcement detailing and construction requirements for post-installed shear connection systems given by the Eurocodes, national regulations, and EOTA TR 066 [2], the following additional requirements shall be fulfilled for the new concrete layer:

- The compressive strength of the new concrete should be higher than that of the existing concrete.
- The new concrete should have low shrinkage properties.
- Pouring of fresh concrete should satisfy the requirements as per EOTA TR 066 [2].
- The new concrete should be consolidated with a vibratory screed. If the new overlay thickness is more than 100 mm, appropriate internal vibratory needles are recommended.

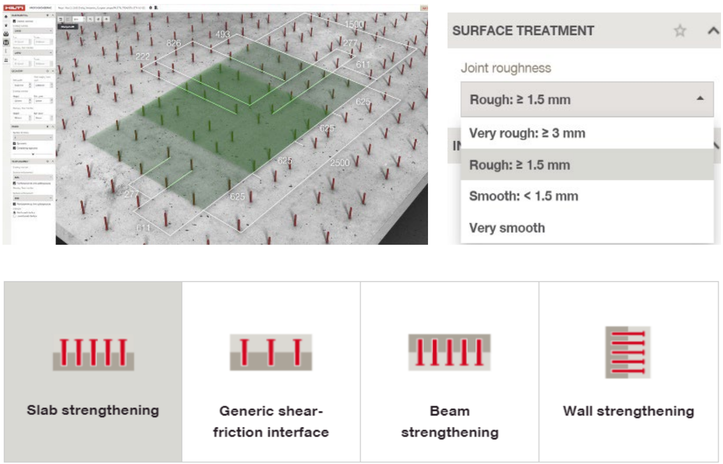
8. PRACTICAL DESIGN USING PROFIS ENGINEERING

Solving the shear-friction application cases through the various design methods discussed, then comparing them to choose the most suitable and optimal solution, can be very time consuming, especially when using manual calculations. Hilti's cloud-based design software PROFIS Engineering helps designers to quickly create code-compliant designs, thereby ensuring a safer and more efficient workflow. PROFIS Engineering helps in choosing the right solution for **different load actions (static, fatigue & seismic**) and qualified products (shear connectors & adhesive mortar systems). Some key benefits of using PROFIS Engineering concrete overlay module include:

- Choosing the most appropriate application type tailored for slab strengthening, beam strengthening, wall or column strengthening or generic shear-friction interface option for solving custom cases (i.e., per 1 m^2) using sectional forces or interface shear stresses.
- Choosing and instantly visualizing the zonal segmentation of the overlay application solutions as per guidelines of EOTA TR 066 [2]. PROFIS Engineering does **design optimization** either by solving the minimum number of shear connectors required or the number of shear connectors required for user-input embedment depth.
- PROFIS Engineering displays the utilization ratios for shear interface verification and the tensile resistances for the various failure modes of the post-installed shear connectors.

- PROFIS Engineering produces an instant comprehensive design report for documentation, with detailed calculation steps.

PROFIS Engineering



SURFACE TREATMENT

Joint roughness

Rough: ≥ 1.5 mm

Fig. 12: PROFIS Engineering software suite-concrete overlay design module

9. DESIGN EXAMPLES

Comparison of design examples using different design methods such as EOTA TR 066 [2], Hilti method, and provisions as per EC2-1-1 [1] for different load actions and types of product solutions are discussed in this section. These design examples have been worked out using PROFIS Engineering software. For standardization of comparisons, the following design parameters are considered (unless otherwise noted):

Concrete class of existing concrete and overlay concrete are kept as C25/30 and C30/37 respectively. The characteristic strength of steel is $500\ N/mm^2$. The thickness of the existing slab and overlay concrete are kept as 200 mm and 100 mm, respectively. The design shear stress is taken as $0.35\ N/mm^2$.

Example 1) Concrete overlay design solution using EOTA TR 066 [2] with mechanical shear connectors of 14 mm diameter (HUS4-H – refer sect. 10) under static & seismic loads is compared for cases of different surface roughness (see Fig. 13). Design solutions are compared keeping the minimum effective embedment in the existing member as h_{ef} = 65 mm. This design example shows the influence and **importance of different roughness characteristics** which can lead to an optimized number of shear connectors.

Note | Design comparisons show that increasing the surface roughness, gives optimized design solutions.

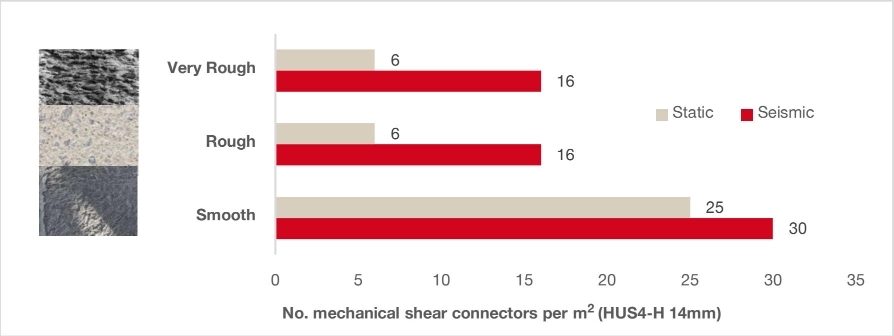


Fig. 13: Example 1 - Influence of interface roughness on design as per EOTA TR 066 [2]

Example 2) Concrete overlay design solution using EOTA TR 066 [2] with qualified bonded shear connectors of 10 mm diameter (HCC-K + HIT RE 500 V4 – refer sect. 10) under static loads compared with hooked rebar + HIT RE 500 V4 using Hilti method (see Fig. 14). Both design cases have the minimum effective embedment in the existing member as h_{ef} = 60 mm. The interface roughness has been considered as “rough”. This example highlights the **higher efficiency of connectors with a radial symmetric head** such as the Hilti HCC-K, i.e., smaller amount of connects per m^2 for the same design conditions and performance level as with hooked bars.

Example 3) Shows design comparison of bonded-shear connectors using EOTA TR 066 [2] method (HCC-K d10 mm + HIT RE 500 V4 – refer sect. 10) where **thin overlay sections** are only required against thicker section requirement (i.e., larger embedment depth) arising out of design provisions as per EC2-1-1 [1] (rebar d10 mm + HIT RE 500 V4) (see Fig. 15). The interface was assumed as ‘rough’ category.

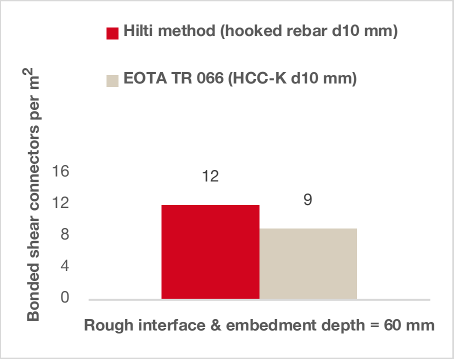


Fig. 14: Example 2- EOTA TR 066 [2] vs. Hilti method

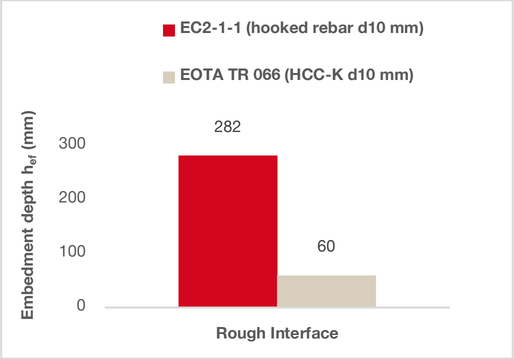


Fig. 15: Example 3- EOTA TR 066 [2] vs. EC2-1-1 [1]

Example 4) Compares the concrete overlay design of effective embedment depths of mechanical shear connectors using EOTA TR 066 [2] and bonded rebars using Hilti method for seismic load case (14 mm diameter shear connectors was assumed) (see Fig. 16). For 100% utilization of design shear capacities, four number of rebars are required as per Hilti method and 20 numbers of HUS4-H shear connectors are required as per EOTA TR 066 [2] method. This design example shows the possibility of concrete overlay design using special mechanical shear connectors **(quicker & efficient solution)** against using hooked rebars **(a cost-effective alternative)**.

Example 5) Shows the possibility of concrete overlay design using EOTA TR 066 [2] for fatigue load case (see Fig. 17). Here Hilti’s qualified shear connectors HCC-B + HIT RE 500 V4 (refer sect. 10) are used for a) fatigue design stresses (minimum | maximum) of $0.2\ N/mm^2$ | $0.4\ N/mm^2$ respectively, and b) fatigue design stresses (minimum | maximum) of $0\ N/mm^2$ | $0.4\ N/mm^2$ respectively. It is evident that not only the maximum stress value of fatigue loading but also (and more importantly) the cycle’s amplitude is decisive.

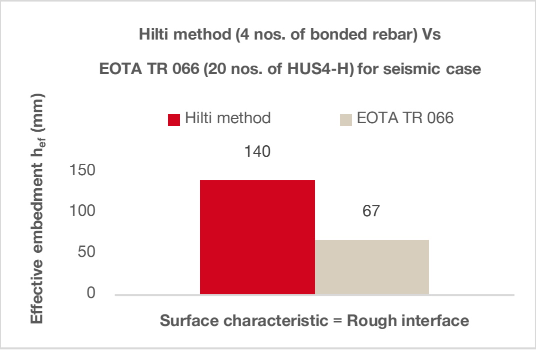


Fig. 16: Example 4 – HUS4-H vs. post-installed rebar (seismic)

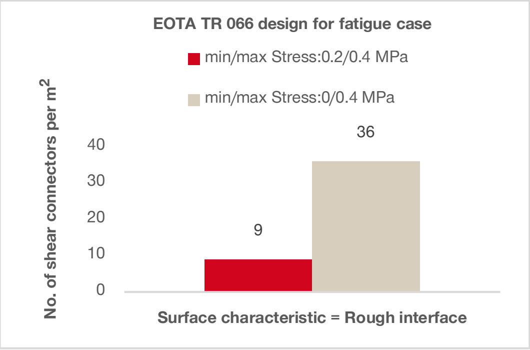


Fig. 17: Example 5 - Fatigue design as per EOTA TR 066 [2]

10. HILTI'S QUALIFIED SOLUTIONS (SHEAR CONNECTORS + ADHESIVE ANCHORS)

Hilti's product solutions qualified according to the EAD 332347 [5] with published ETAs are presented in the table 5 below. The concrete screw systems (mechanical type) such as HUS4-H are driven in with a special impact screwdriver. The post-installed shear connectors of the "adhesive mortar" type are special elements or standard elements equipped with additional accessories, e.g., HCC-B (special element, optimized for positioning the reinforcement and installation), HCC-K (reinforcement bar with headed end (special element) and HCC HAS-U (threaded rod with washer and nut) (standard element).

Table 5: Hilti's qualified solutions for shear-friction applications (concrete overlays)

Hilti System	HUS4-H	HAS-U (HCC-U) + RE 500 V4 or HY 200 R V3	HCC-K + RE 500 V4 or HY 200 R V3	HCC-B + RE 500 V4	Hooked Rebar * + RE 500 V4 or HY 200 R V3
					
Portfolio size (Dia in mm)	8,10,12,14,16	M8 to M30	10,12,14,16	14	8 to 25
Certification **loading type**	ETA Static & Seismic	ETA Static	ETA Static	ETA Static & Fatigue	HILTI **Method** Static & Seismic
Advantages	Faster and easier installation. Jobsite Productivity	Flexible and cheaper solution	Rebar is used and hence flexibility in embedment diameters	Faster and easier installation. Jobsite Productivity	Rebar is used and flexibility in embedment diameters
Immediate loading	Yes	No	No	Yes (1 kN)	No
Adjustability	During setting	Cutting before setting	Cutting before setting	During setting	Cutting before setting

11. SUMMARY

Traditional design methods following conventional shear-friction theory for shear-friction applications (concrete overlays) as per provision of EC2-1-1 [1] have limitations in terms of covered loading types and thicker sections required due to larger embedment. **EOTA TR 066 [2] is an improved design method** utilizing all three components of shear-transfer at the interface (adhesion/interlock, friction, and dowel action) allowing thin concrete overlay solutions for static, fatigue, and seismic load cases. This design method involves the use of qualified shear connectors qualified following EAD 332347 [5]. In situations requiring the use of post-installed rebars as shear connectors with bent-ends in the cast-in side of strengthening applications, the **Hilti method** can be used to arrive at a workable solution for static and seismic load cases.

The surface roughness parameters of the existing concrete layer are crucial for the design capacity of the shear-interface in overlay applications. Achieving the design-intended surface roughness paves the way for efficient construction and performance of the application. Hilti's **PROFIS Engineering** software's concrete overlay module includes a range of features that allow engineers to create quick and efficient code-compliant designs of shear-friction applications using different design methods for static, seismic, and fatigue actions.

12. REFERENCES

[1] EN 1992-1-1:2004-12: Eurocode 2 - Design of concrete structures - Part 1-1: General rules and rules for buildings, Brussels: CEN, 2004.

[2] EOTA TR 066: Design and requirements for construction works of post-installed shear connection for two concrete layers, Brussels: EOTA, 2022.

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

[4] DIN EN 1992-1-1/NA: National Annex – Nationally determined parameters – Eurocode 2: Design of concrete structures – Part 11: General rules and rules for buildings, Berlin: DIN, 2013.

[5] EOTA EAD 332347: Connector for strengthening of existing concrete structures by concrete overlay, Brussels: EOTA, 2021.

[6] V. Palieraki, E. Vintzileou and J. F. Silva, "Behavior of RC interfaces subjected to shear: State-of-the art review," *Construction and Building Materials,* 2021.

[7] V. Palieraki, E. Vintzileou and J. F. Silva, "Interface Shear Strength under Monotonic and Cyclic Loading," *ACI Structural journal,* vol. 119, no. 3, pp. 17-28, 2022.

[8] EOTA EAD 332347-00-0601-v01: Variant: Connector for strengthening of existing concrete structures by concrete overlay: behavior under seismic action, Brussels: EOTA, Pending for citation in OJEU.

[9] J. Heinrich, T. Zenk and R. Mauerer, "bewehrte Beton-Beton-Verbundfugen bei nachträglicher Verstärkung: Ermüdungsbeansprchung (Reinforced concrete-to-concrete interfaces in case of post-installed strengthening: Fatigue Action, in German)," *Bauingenieur,* vol. 95, no. 4, pp. 115-125, 2020.

[10] EN 10080:2005: Steel for the reinforcement of concrete - Weldable reinforcing steel - General, Brussels: CEN, 2005.

[11] EN 13036-2:2010: Road and airfild surface characteristic - Test methods: part 1: Measurement of pavement surface macrotexture depth using volumetric patch technique, Brussels: CEN, 2010.

[12] EN 1992-2:2018: Eurocode 2 - Design of concrete structures - Part 2: Concrete bridges - Design and detailing rules, Brussels: CEN, 2018.

[13] EN 206:2013+A1:2016: Concrete - Specification, performance, production and conformity, Brussels: CEN, 2013.

[14] RVS 15.02.34: Bemessgun und Ausführung von Aufebton auf Fahrbahnplatten (Dimensioning and calculation aid design and detailing of concrete overlays), in German, Vienna: Österreichische Forschungsgesellschaft Strasse - Schiene - Verkehr (Austrian research association Roads - Railways - Traffic), 2011.

[15] ETA-18/1022: Connector Hilti HCC-B with injection mortar Hilti HIT-RE 500 V3 and Hilti HIT-RE 500 V4, Berlin: DIBt, 05.05.2023.

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