CONCRETE OVERLAY

Design and Installation following Technical Report TR066

CONCRETE OVERLAYS

What are they

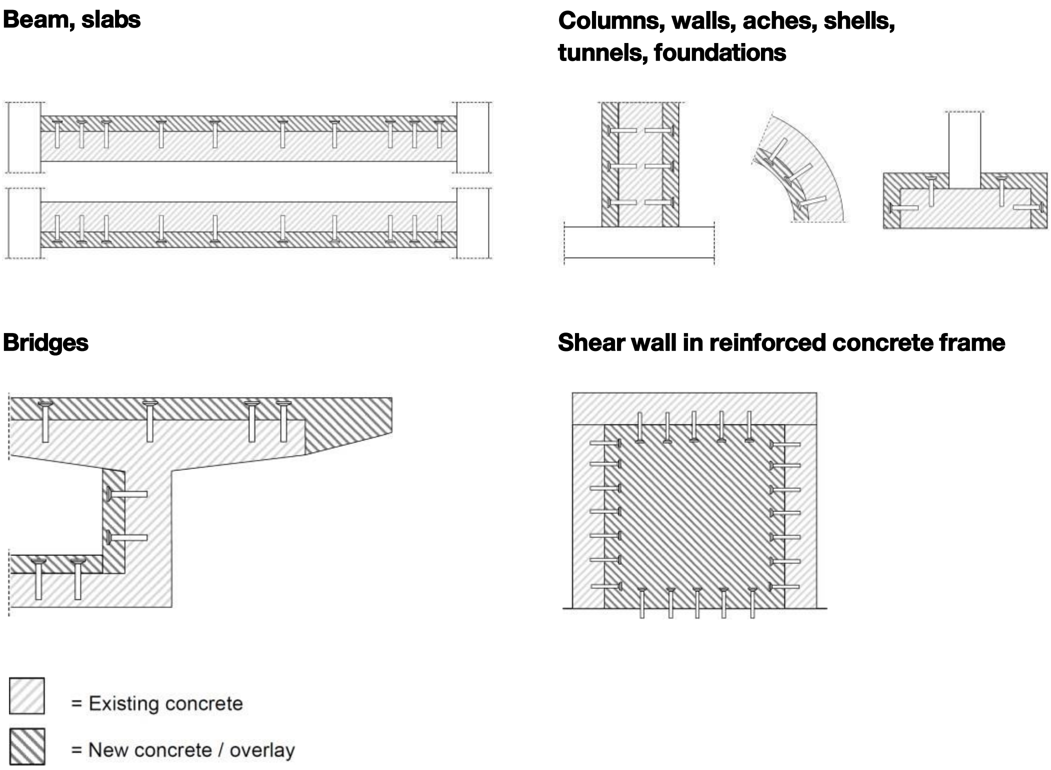
When a new layer of concrete is applied to existing concrete with the aim of strengthening or repairing a structure, the result is referred to as an overlay. The overlay (here the term overlay is used even for concrete jacketing applications) is usually cast directly or applied as shotcrete. Its function is to augment the flexural compression, flexural tension, shear strength and ductility, depending on the position of placement. Some typical applications involve the strengthening of structural elements such as vaults, pillars, beams and foundations (Figure 1).

Prior to placement of the overlay, the surface of the old concrete member is prepared by suitable means and pre-wetted.

Shrinkage of the new concrete overlay can be reduced by careful selection of the concrete mix. However, the constraint forces caused by differential shrinkage and, in certain cases, by differential temperature gradients, cannot be avoided. Initially, stresses in the bond interface result from a combination of peripheral loads and internal constraint forces. It must be kept in mind that stresses due to shrinkage and temperature gradients in the new concrete typically reach their maximum at the perimeter (peeling forces). The combination of peripheral and internal stresses often exceeds the capacity of the initial bond, thus requiring the designer to allow for a de-bonded interface. This is particularly true in the case of bridge overlays, which are subject to fatigue stresses resulting from traffic loads.

Furthermore, these stresses vary with time, and bond failure can take place years after installing the overlay. When this happens, the tensile forces set up must be taken up by connectors positioned across the interface.

Figure 1 Concrete overlay common scheme object of this paragraph



Design principles

Forces at the interface between the new and existing concrete are determined from the external and internal forces acting on the building component. When designing the interface, it must normally be assumed that the interface is de-bonded. The shear connectors crossing the interface must be placed in such a way that shear forces ("shear flow") at the interface are transmitted at design level (Figure 2).

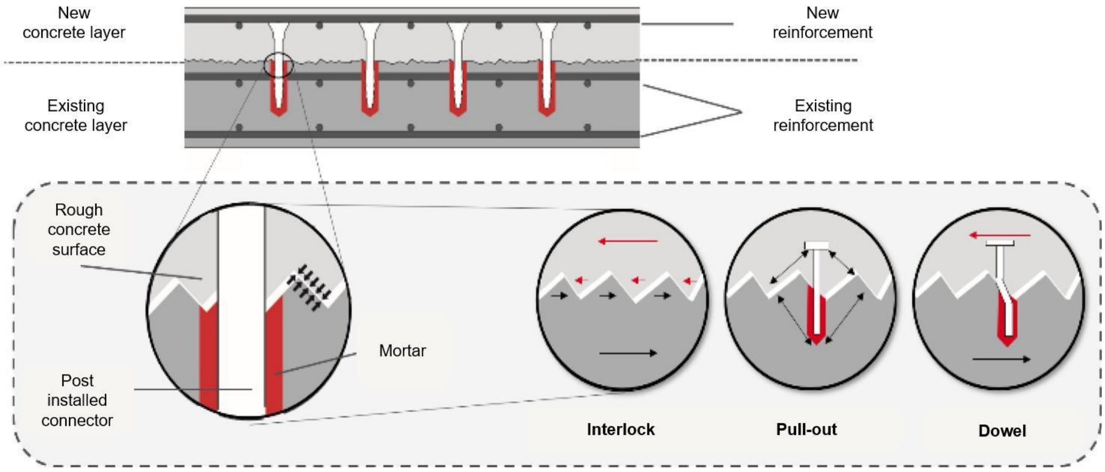


Figure 2
Load contribution of the different components

Because of separation at the interface, the shear connectors are subject to a tensile force and simultaneously to a bending moment, both of which depend on the roughness of the interface surfaces. If the surfaces are roughened, additional interlocking effects and cohesion can take up part of the shear force at the interface.

Together with external forces, the structure will be subject even to other forces resulting from constraint at the perimeter.

Though subdividing the interface into zones to contribute to different shear stress is allowed, re-distributing the stress for rough and very rough surfaces is not, so the maximum value of each zone is decisive. When designing concrete overlay applications, three verifications have to be taken into account:

1. Verification of the shear interface
2. Verification of fastening in existing concrete
3. Verification of fastening in the new concrete overlay

The EAD that identify the qualification process for connectors that connect two layers of concrete cast at different times is the EAD 332347-00-0601 [14].

The following paragraph will concern point 1 considering both the European design report TR 066 and the method based on Hilti expertise. Points 2 and 3 will be addressed in the baseplate fastening section as referring to the same verifications required for post-installed anchor as per Eurocode 2 part 4 for baseplate applications.

Design shear interface resistance following TR 066

The transmission of shear forces at the interface between the new and existing concrete is determined by aggregate interlock, shear friction and dowel action. In general, the following equation applies:

$\tau_{Rd} \geq \tau_{Ed}$

where:

τ_{Rd} Design resistance of the shear force per meter ("shear flow") at the interface

τ_{Ed} Design value of the shear flow acting at the interface

Static design resistance following TR 066

To evaluate design resistance TR 066 recommends the following equation:

$$\tau_{Rd} = \underbrace{c_r \cdot f_{ck}^{1/3}}_{\text{Interlock}} + \underbrace{\mu \cdot \sigma_n + \mu \cdot \kappa_1 \cdot \alpha_{k1} \cdot \rho \cdot \sigma_S}_{\text{pull-out}} + \underbrace{\kappa_2 \cdot \alpha_{k2} \cdot \rho \cdot \sqrt{\frac{f_{yk}}{\gamma_s} \cdot \frac{0{,}85 \cdot f_{ck}}{\gamma_c}}}_{\text{dowel}} \leq \underbrace{\beta_c \cdot \nu_e \cdot \frac{0{,}85 \cdot f_{ck}}{\gamma_c}}_{\text{concrete strut}} \quad \text{(TR066 2.9, 2.11)}$$

where:

c_r Coefficient for adhesive bond resistance in a reinforced interface (Table 1)

c_a Coefficient for adhesive bond resistance in an unreinforced interface (Table 1)

f_{ck} minimum value of concrete compressive strength of the two concrete layers, measured on cylinders

f_{yk} Characteristic yield strength of the shear connector

μ Friction coefficient (Table 1)

σ_n Lowest expected compressive stress resulting from an eventual normal force acting on the interface (compression has a positive sign)

κ_1 Interaction coefficient for tensile force activated in the shear connector (Table 1)

κ_2 Interaction coefficient for flexural resistance in the shear connector (Table 1)

k_1 Modification factor for material properties of the connector from product ETA

α_{k2} Modification factor for geometry of the connector from product ETA

ρ Reinforcement ratio of the steel of the shear connector crossing the interface

σ_S Steel stress associated to the relevant failure mode

γ_c Safety factor for concrete; 1.50 as given in EN 1992-4 for strengthening of existing structures

γ_s Safety factor for steel; 1.15 as given in EN 1992-4 for supplementary reinforcement

b_i Width of the interface of the composed section

ν_e Coefficient for reduction of concrete strength - $\nu_e = (0{,}55 \cdot (\frac{30}{f_{ck}})^{1/3} < 0{,}55$

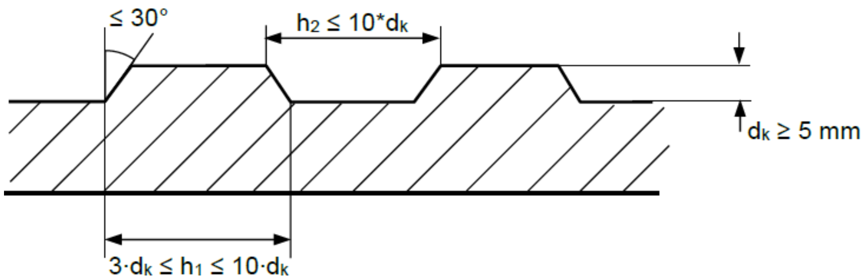
β_c Coefficient for the strength of the compression strut (Table 1)

Table 1
Coefficients and parameters for different surface roughness

Surface characteristics of interface	c_a	c_r	κ_1	κ_2	β_c	μ
Very rough, (including shear keys[1]) **$R_t \geq 3{,}0$ mm**	0,5	0,2	0,5	0,9	0,5	0,8 ($f_{ck} \geq 20$) 1,0 ($f_{ck} \geq 35$)
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 Figure 3

Figure 3
Geometry of shear keys



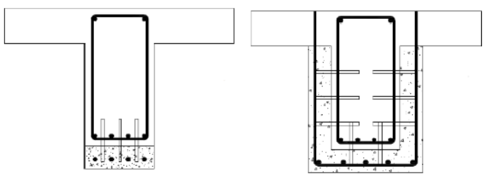
where: d_k is the height of a shear key, h_1 is the base length of a shear key.

Design under seismic

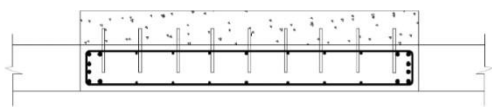
Design of shear interface under seismic cyclic loading is covered by TR 066. Seismic force acting on the structural element activate tensile forces perpendicular to the interface, which are carried by connector and transferred to the two concrete layers.

Typical seismic repair/ strengthening applications involving shear interfaces

Layer over/ under/ lateral/ closed jacket



Closed or partial jacketing thickening of sides/ thickening of the confined boundary elements



Under seismic conditions, resistance of the connectors and the decisive failure mode shall be calculated assuming performance category C1 or C2, depending on the application and the design assumption (see Table 4 as reference). As for static, guidance in this regard is provided by EN 1992-4 [18]. Seismic design resistance at the interface is calculated as follows:

$$\tau_{Rd} = \alpha_{seis}\left[c_r \cdot f_{ck}^{\frac{1}{3}} + \mu \cdot \sigma_n + \mu \cdot \kappa_1 \cdot \alpha_{k1} \cdot \rho \cdot \sigma_{S,eq} + \kappa_2 \cdot \alpha_{k2} \cdot \rho \cdot \sqrt{\frac{f_{yk}}{\gamma_s} \cdot \frac{f_{ck}}{\gamma_c}}\right] \leq \beta_c \cdot \nu_e \cdot \frac{0.85 \cdot f_{ck}}{\gamma_c} \qquad \text{(TR066, 3.2)}$$

where:

$\sigma_{A,eq}$ Steel stress associated with the relevant failure mode under seismic conditions

α_{seis} given in the relevant product ETA in accordance to EAD 332347

Other parameter as per the table 5.

Table 2
Coefficients and parameters for different surface roughness for seismic cycling loading

Surface characteristics of interface	c_r	κ_1	κ_2	β_c	μ_e ($f_{ck} \geq 20$)	μ_e ($f_{ck} \geq 35$)
Rough, $R_t \geq 1{,}5$ mm	0	0,5	0,9	0,5	$0{,}4\sqrt[3]{\left(\frac{f_{cd}}{\sigma_c+\sigma_n}\right)^2}$	$0{,}27\sqrt[3]{\left(\frac{f_{cd}}{\sigma_c+\sigma_n}\right)^2}$
Smooth (concrete surface without treatment after vibration or slightly roughened when cast against formwork)	0	0,5	1,1	0,4	$0{,}27\sqrt[3]{\left(\frac{f_{cd}}{\sigma_c+\sigma_n}\right)^2}$	$0{,}135\sqrt[3]{\left(\frac{f_{cd}}{\sigma_c+\sigma_n}\right)^2}$

Design under fatigue

When an interface is subject to substantial changes in stress, i.e. not predominantly static forces, it must be designed to withstand fatigue. In these circumstances the interface between the two concrete layers must always be very roughened.

According to EOTA TR066, fatigue is taken into account by means of a reduction coefficient η_{sc}:

$\Delta v_{Ed} \leq \eta_{sc} \cdot v_{Rd}$ (TR066 2.13)

Without the effect of static loadings:

$\Delta v_{Ed} = v_{Ed,\max}$ (TR066 2.14)

η_{sc} = 0,4 or otherwise given inthe relevant connector's ETA

where:

Δv_{Ed} Shear stress acting as fatigue relevant loading

η_{sc} Factor for fatigue loading

$v_{Ed,max}$ Upper shear stress acting as fatigue relevant loading

Δv_{Ed} Shear stress acting as fatigue relevant loading

Design shear interface resistance following Hilti Method

As an alternative to TR 066 when an ETA is not available, Hilti supports structural engineers by providing a design method based on Hilti expertise both for static and seismic design. Design resistance follows the equation:

$$v_{Rd} = \underbrace{\mu_h \cdot (\sigma_n + \kappa_{1h} \cdot \rho \cdot \sigma_s)}_{\text{Pull-out}} + \underbrace{\kappa_{2h} \cdot \rho \cdot \sqrt{\frac{f_{yk}}{\gamma_s} \cdot \frac{\alpha_{cc} \cdot f_{ck}}{\gamma_c}}}_{\text{dowel}} \leq \underbrace{\beta_c \cdot \nu \cdot \frac{\alpha_{cc} \cdot f_{ck}}{\gamma_c}}_{\text{concrete strut}}$$

where:

μ_h coefficient of friction

σ_n lowest expected compressive stress resulting from an eventual normal force acting on the interface (perpendicular to the joint surface)

ρ reinforcement ratio of the steel of the shear connector crossing the interface (total cross-section area of connectors / joint surface area)

σ_s steel stress in the shear connector associated to the relevant failure mode

κ_{1h} contribution factor for the friction mechanism according to table below

κ_{2h} contribution factor for the dowel mechanism according to table below

f_{yk} characteristic steel yield strength of the shear connector

γ_s Partial factor for steel

γ_c Partial factor for concrete

α_{cc} is the coefficient taking account of long-term effects on the compressive strength and of unfavorable effects resulting from the way the load is applied

f_{ck} Characteristic compressive cylinder strength of concrete at 28 days

β_c coefficient for the strength of the compression strut depending on the surface roughness category acc. to TR 066 table 2.2

ν $0{,}55 \cdot (\frac{30}{f_{ck}})^{\frac{1}{3}} < 0{,}55$ coefficient for reduction of concrete strength according to Fib MC2010 7.3-51

In the Hilti Method, only mechanically roughened and smooth Interface are taken in account.

Table 3 gives the parameters needed for the application of the Hilti method.

Table 3 Parameters needed for the application of the Hilti method

Parameter K_{1h} (Static Loading)	**Interface characteristics**	**K_{1h} (6d < h_{eff} < 20d)**
	Mechanically roughened (≥ 1.5mm)	0.60
	Smooth Interface (< 1,5mm)	0.40
Parameter K_{1h} (Seismic Loading)	**Interface characteristics**	**K_{1h} (10d < h_{eff} < 20d)**
	Mechanically roughened (≥ 1.5mm)	$0.02\frac{h_{eff}}{d}+0.2$
	Smooth Interface (< 1,5mm)	0.20
Parameter K_{2h}	**Normalized embedment depth**	**K_{2h}**
	$\frac{h_{ef}}{d} > 8$	0.70
	$6 \leq \frac{h_{ef}}{d} \leq 8$	$0.1\frac{h_{eff}}{d} - 0.1$
	$\frac{h_{ef}}{d} = 6$	0.5

Installation

Proper surface preparation and connector installation is key to fulfill design requirements. Main phases are the following:

1. Removal of damaged concrete/concrete covering
2. Surface preparation through roughening
3. Installation of post-installed connectors as per manufacturer instructions
4. Inspection and on-site pull-out testing if required from the structural engineer
5. Placement of new reinforcement, pre-treatment and pouring of new concrete layer

Surface roughness has a decisive influence on the shear forces that can be transmitted. For design purposes, the characteristic dimension is the mean depth of roughness, R_t, measured according to the sand-patch method. Three commonly used technology to roughen surface are water jetting, sand blasting and grating (Figure 4).

Figure 4 Methodology to roughen concrete surface

Water jetting | **Sand blasting** | **Grating**

It is recommended that a mean roughness, R_t, is stipulated when specifying the surface treatment. Prior to approving the treatment, a sample surface must be created and checked using the sand-patch method. An indication of surface roughness is reported in Table 4.

Table 4 Indication of surface roughness

Category	Methods/ Situation	Application: Static & quasi-static	Application: Fatigue cyclic loading	Application: Seismic cyclic loading	Peak to mean roughness R_t* [mm]
Very rough	Water jetting, indented	Yes	Yes	Yes (to handle as Rough)	≥ 3,0
Rough	Sand-blasted	Yes	No	Yes (to handle as Rough)	≥ 1,5
Smooth	Untreated, slightly roughened	Yes	No	Yes	< 3,0
Very smooth	Existing concrete cast against steel formwork	Yes	No	No	Not measurable

***Parameter for surface roughness based on volumetric measurement according sand patch method.**
Rt is the mean height based on this measurement. Other methods for determination of the surface roughness maybe used.
Equivalence with the given values of R_t need to be provided.

The connectors must be positioned in the load-bearing direction of the building component with respect to the distribution of the applied shear force in such a way that the shear force at the interface can be constrained and de-bonding of the new concrete overlay prevented.

Pre-treatment is usually done with primer consisting of thick cement mortar.

Before the cement mortar primer is applied, the old concrete should be adequately wetted 24 hours in advance, and thereafter at suitable intervals. Before applying the primer, the concrete surface should be allowed to dry to such an extent that it has only a dull moist appearance.

The mortar used as a primer should consist of water and equal parts by weight of Portland cement and sand of 0/2 mm particle size. This is applied to the prepared concrete surface and brushed in.

The concrete mix for the overlay should be formulated to ensure low-shrinkage (Water-Cement Ratio 0.40). The overlay must be placed on the still fresh primer, i.e., wet on wet.

Careful follow-up is necessary to ensure an overlay of adequate durability. Immediately after placement, the concrete overlay must be protected for a sufficiently long period (at least five days) against drying out and excessive cooling.

Hilti recommended solutions

Table 5
Recommended solutions for concrete overlays

Hilti System	**Threaded rod HAS-U + RE 500 V4 or HY 200 R V3**	**Bended rebar + RE 500 V4 or HY 200 R V3**	**HUS4-H**
			
Applications recommended	Deck strengthening, pillar, foundation strengthening		Deck, vault, wall, and beam strengthening and refurbishment
Advantages	High flexibility in embedment depth both in existing and new concrete		Solution for jobsite productivity and easiness to install
Certification and available designs	ETA Static	Hilti Method Static Seismic	ETA Static Seismic
Range of diameters	Static M10 – M12 – M16	Static from ϕ8 to ϕ20 Seismic From ϕ10 to ϕ20	Static [mm] 8 – 10 – 14 Seismic [mm] 10 – 14
Design software	PROFIS Engineering concrete overlay module		
Installation phases	1. Surface roughening 2. Hole drilling 3. Drill hole cleaning 4. Connector installation 5. Mortar injection 6. Mortar curing time 7. Pour new concrete		1. Surface roughening 2. Hole drilling 3. Drill hole cleaning 4. HUS4-H installation 5. Pour new concrete
Comment for installation	Hilti SafeSet system with hollow drill bit helps to increase installation productivity		No mortar needed and no hole cleaning requirement if concrete hole is ventilated 3 times. HUS4-H installed with impact screwdriver

Simplified overview, detail can be found in the relevant product ETA

Hilti Aktiengesellschaft
9494 Schaan, Liechtenstein
P +423-234 2965

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