

# Hilti HCC-B for concrete overlays

**B 2.5**

EC-2 : 1992



**Strengthening and rehabilitation with concrete overlays  
for bridges, tunnels and civil structures**

**Structural principles and design  
for redundant systems**

**B 2.5****Hilti HCC-B for concrete overlays**

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**Foreword**

Placing fresh concrete against existing, hardened concrete is a routine task in building construction. In fact, it is a condition which occurs at every joint in concrete construction work. For some time now, the placement of concrete overlays has been gaining in importance as a result of the increasing need for rehabilitation and strengthening of existing structures. For the design of these composite concrete structures, the transfer of internal stresses across the bond interface between new and old concrete is a critical aspect. A design method has been developed based on shear tests specially carried out for this purpose by Hilti Corporate Research for a variety of surface treatments.

The Institute for Concrete Structures of the University of Innsbruck, Austria, provided scientific support during the development of the HCC-B connector and the associated design method. At the same time, test results given in the literature were incorporated. Among other things it was found that, contrary to the usual design approach, the full tensile yield strength of the connectors cannot be equated to the tension clamping force across the interface.

In contrast to design methods described in the literature, this new design approach considers all three mechanisms: cohesion, friction, and shear resistance (dowel action) of the shear reinforcement positioned across the interface, in determining the effective shear transfer. The compressive stress required at the interface for shear transfer by friction is set up by activating tensile forces in the connectors. The design method is based on a single equation to calculate the resistance of the bond interface for each different surface treatment from the three above components.

With increasing surface roughness, shear resistance and shear stiffness are significantly increased. Furthermore, the distribution of total resistance shared by the three components changes considerably. At the extremes, if the surfaces are very rough, the connectors across the bond interface are primarily stressed in tension, whereas, if the surfaces are smooth, the shear resistance of the connectors themselves (dowel action) predominates. For roughened surfaces, the interlocking effect is sufficient to transfer small shear forces without connectors. It is often adequate for concrete overlays to be anchored only at their perimeter.

The very user-friendly Hilti design method is based on the Eurocode safety concept (prEN 1992-2) and is particularly notable for its transparency. The use of design diagrams makes the method straightforward for designers to apply. The method was recently incorporated in the Exbar Overlay design software, making it suitable for widespread use.

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# Hilti HCC-B for concrete overlays

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### 1 Hilti HCC-B for overlays

#### 1.1 Range of application

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 a composite concrete structure. The overlay is usually cast directly or applied as shotcrete. Its function is to augment the flexural compression or flexural tension zones, depending on the position of placement. 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 borne 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. Typical examples are shown schematically in Fig. 1 and Fig. 2. Where Hilti HCC-B applications are concerned, their use is restricted to redundant load-carrying systems.

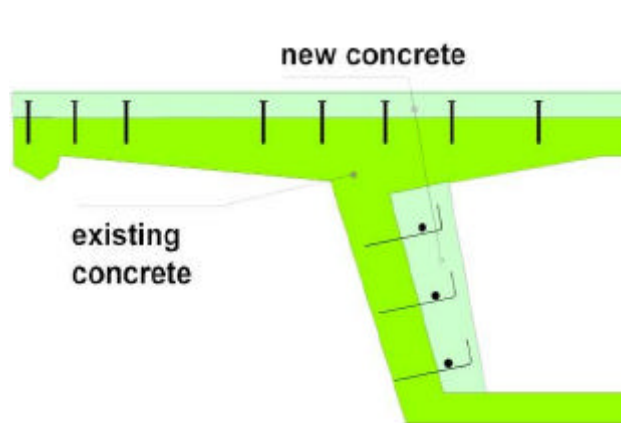


Fig. 1. Strengthening of bridges by means of concrete overlays

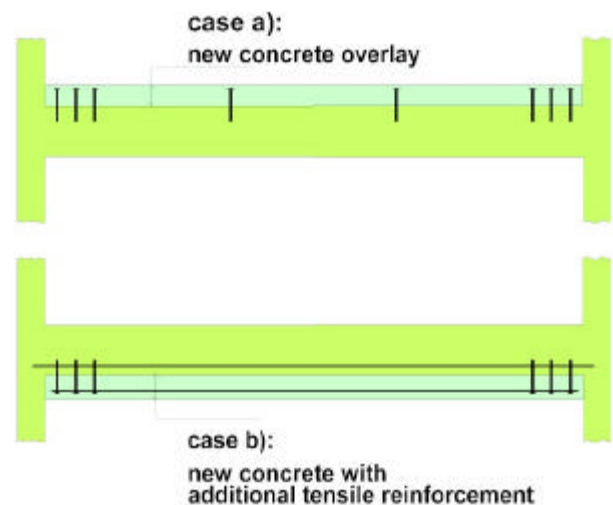


Fig. 2. Strengthening of buildings, decks and slabs

#### 1.2 Advantages of the method

- ↗ Simple and reliable application to a variety of cases
- ↗ Monolithic structural component behaviour assured
- ↗ Shear forces are reliably transferred even if the interface is cracked
- ↗ Wide range of applications
- ↗ Suitable for use with the most common methods of surface roughening
- ↗ Reduced requirements for anchor embedment



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#### Rehabilitation of a bridge deck

- Removal of damaged concrete layer using high-pressure water jetting
  - Anchoring of additional reinforcement using HIT RE-500
  - Installation of HCC-B shear connectors using HIT RE-500
  - Placement of new concrete overlay
- ✓ Monolithic load-bearing behaviour
  - ✓ Reliable shear transfer
  - ✓ Stiff connection
  - ✓ Reduced connector embedment



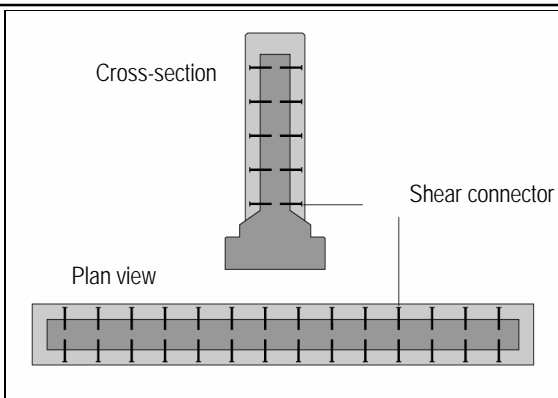
#### Strengthening the floor of an industrial building

- Removal of covering and any loose overlay
  - Roughening of surface by shot-blasting
  - Installation of connectors using HIT RE-500 injection mortar according to engineer's instructions
  - Inspections, if necessary, of concrete surface for roughness and pull-away strength, and of connectors for pull-out strength.
  - Placement of reinforcement and overlay concrete
- ✓ Monolithic load-bearing behaviour
  - ✓ Reliable and verifiable shear transfer
  - ✓ Adequate connection stiffness
  - ✓ Small anchorage depth



#### Strengthening an industrial building foundation

- Exposure of foundation
  - Installation of connectors using HIT RE-500 as per design specifications (smooth surface)
  - Placement of reinforcement and overlay concrete
- ✓ Reduced labour
  - ✓ Monolithic load-bearing behaviour
  - ✓ Reduced anchor embedment
  - ✓ Reliable shear transfer
  - ✓ Ductile connection



#### Repairing and strengthening a pier

- Roughening of concrete surface
  - Installation of shear connectors using HIT RE-500 as per design specifications
  - Placement of reinforcement and overlay concrete
- ✓ Monolithic load-bearing behaviour
  - ✓ Reliable shear transfer
  - ✓ Stiff connection
  - ✓ Reduced anchor embedment

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### 2 Hilti HCC-B with Hilti HIT-RE 500

#### 2.1 Notes on application and material

<b>Features:</b>	<ul style="list-style-type: none"> <li>• For concrete-to-concrete bonding for redundant systems</li> <li>• Base material (existing concrete) <math>\geq</math> C 20/25, overlay <math>\geq</math> C 20/25</li> <li>• Immediately temporarily loadable (100 kg)</li> <li>• Variable setting depth</li> <li>• Usable as reinforcement support</li> <li>• Anchoring in base material with very small splitting forces</li> </ul>
<b>Material:</b>	Shear connector HCC-B: Malleable cast iron EN-GJMB-550-4 Adhesive mortar: Hilti HIT-RE 500: Foil pack 330 ml, 500 ml and 1400 ml Dispensers: HIT-MD 2000, HIT-BD 2000, HIT-P3500 F, HIT-P 8000 D
<b>Recommended drill system:</b>	Rotary impact hammer TE 35 C with drills TE-TX 16/23 Rotary impact hammer TE 56, TE 56-ATC, TE 76 P, TE 76 P-ATC with drills TE-YX 16/23
<b>Setting tool:</b>	Setting tool (machine) TE-Y: HCC M14 TE-C HSD-M M12

Setting details:			
$l$	Length of HCC-B element	[mm]	180
$d_0$	Drill bit diameter	[mm]	16
$h$	Hole depth	[mm]	$90 \leq h \leq 125$
$h_0$	Nominal embedment depth in existing concrete	[mm]	$90 \leq h_0 \leq 125$
$h_n$	Nominal anchorage in overlay	[mm]	$90 \geq h_n \geq 55$



HIT-RE 500 foil pack, mixer

Anchor mechanical properties:			
$A_s$	Characteristic stressed cross-section	[mm <sup>2</sup> ]	83
$f_{uk}$	Nominal tensile strength	[N/mm <sup>2</sup> ]	550
$f_{yk}$	Yield strength	[N/mm <sup>2</sup> ]	400



Concrete



Limited spacing and edge distance



Dynamic

# Hilti HCC-B for concrete overlays

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### Basic loading data for Hilti HCC-B

#### $N_{Rd,s}$ : Steel design tensile resistance

$N_{Rd,s}$	[kN]	27.7	$N_{Rd,s} = A_s \times f_{yk} / g_{ms}$ with $g_{ms} = 1.2$
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#### $N_{Rd,c}$ : Concrete cone/pull-out resistance

Chemical anchor installed according to setting instructions in holes drilled by rotary impact hammer and cleaned

$N_{Rd,c} = N_{Rd,c}^0 \times f_{B,N}$  for  $s = s_{crit}$  and  $c = c_{crit}$

For  $s < s_{crit}$  or  $c < c_{crit}$ , the design value must be reduced according to the CC method

Note:

The required anchoring force in the HCC-B chemical anchor is:  $N_d = k \times A_s \times f_{yk} / g_{ms} = 0.4 \times 27.7 = 11.1$  kN

**Base material: concrete C 20/25**  $N_{Rd,c}^0 = N_{Rk,c}^0 / g_{mc}$  where  $g_{mc} = 1.5$

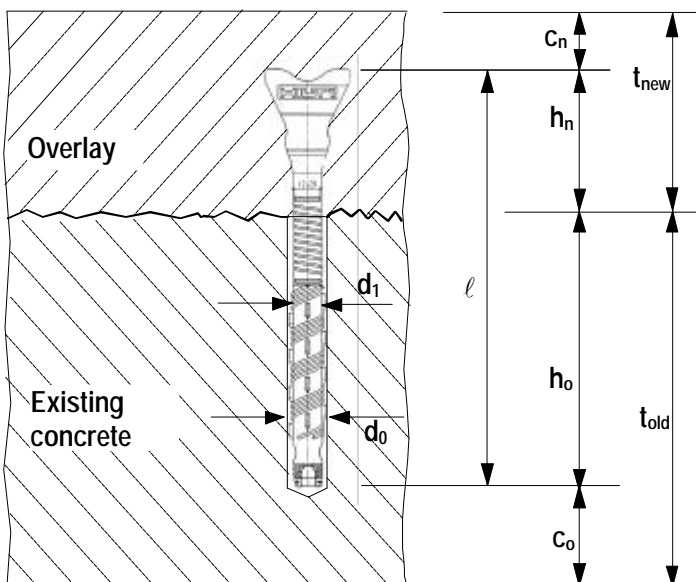
Nominal embedment depth $h_0$	[mm]	90	100	110	120	125
$N_{Rd,c}^0$ HIT-RE 500	[kN]	22.9	25.5	28.0	30.6	31.8
$s_{crit}$	[mm]	180	200	220	240	250
$c_{crit}$	[mm]	90	100	110	120	125

$f_{B,N}$ : Influence of concrete strength		
Concrete strength	Base material	Overlay
C 20/25	1.00	1.00
C 25/30	1.03	1.10
C 30/37	1.06	1.22
C 35/45	1.10	1.34
C 40/50	1.13	1.41
C 45/55	1.15	1.48
C 50/60	1.18	1.55

**Overlay: concrete C 20/25**  $N_{Rd,c}^0 = N_{Rk,c}^0 / g_{mc}$  where  $g_{mc} = 1.5$

Nominal anchorage in overlay $h_n$		90	80	70	60	55
$N_{Rd,c}^0$	[kN]	20.9	17.3	14.0	10.9	9.4
$s_{crit}$	[mm]	270	240	210	180	165
$c_{crit}$	[mm]	135	120	105	90	83

The shear connectors are to be anchored sufficiently in the existing concrete and in the overlay.



- $d_0$  Drill bit diameter
- $d_1$  Nominal diameter of the shear connector
- $h_n$  Nominal anchorage in overlay
- $C_n$  Concrete cover above head of shear connector
- $t_{new}$  Thickness of overlay
- $t_{old}$  Thickness of existing concrete
- $h_0$  Nominal embedment depth in existing concrete
- $C_0$  Concrete cover of drilled hole in existing concrete  $C_0 = 2 d_0$  and/or  $= 30$  mm
- $l$  Length of shear connector  $l = h_n + h_0 = 180$  mm

Fig. 3. Setting details for shear connector HCC-B



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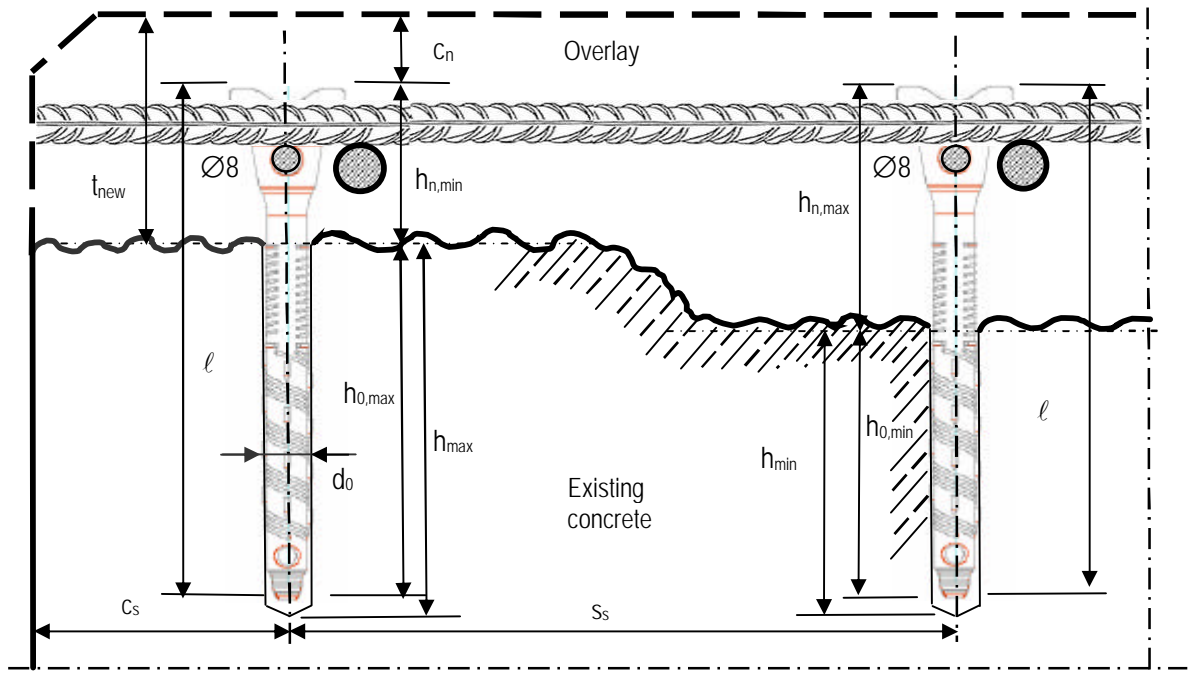
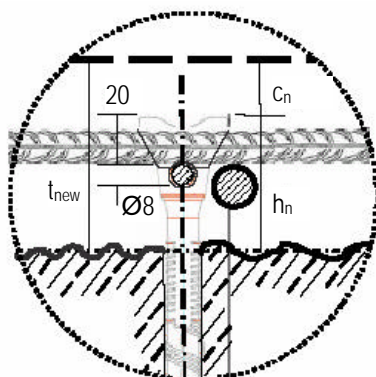


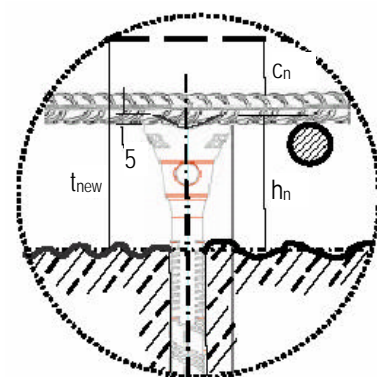
Fig. 4. Structural details

Setting details:			Minimum	Maximum
$l$	Length of shear connector	[mm]	180	
$d_0$	Drill bit diameter	[mm]	16	
$d_s$	Allowable drill side-to-side dimension	[mm]	16.2	16.5
$h$	Hole depth	[mm]	90	130
$h_0$	Nominal embedment depth in existing concrete	[mm]	90	125
$h_n$	Nominal anchoring in overlay	[mm]	55	90
$t_{new}$	Thickness of overlay			
$C_n$	Concrete cover above head of shear connector		in accordance with EC-2	
$C_o$	Concrete cover of drilled hole in existing concrete		$\geq 2 d_0$ and/or $\geq 30$ mm	
$C_s$	Edge distance of shear connector		in accordance with Table 9	
$S_s$	Spacing of shear connector		in accordance with Table 9	

Table 1: Designation and setting details



Reinforcement at supporting rebar  $\varnothing$  8 mm



Reinforcement supported by HCC-B

Fig. 5. Structural details

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### 2.2 Injection volume $V_m$

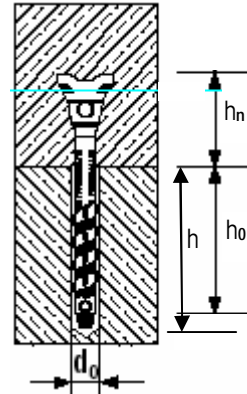
The approximate required injection volume  $V_m$  is listed in Table 2.

However, unexpectedly deep boreholes, hollow areas in the concrete and wastage must also be considered. For this purpose, the formula for the computation of the approximate required injection volume  $V_m$  [ml] contains an additional 20% over and above the nominal injection volume ( $V_{m,n}$ ).

**Recommendation: for cost estimate, add 15% to this**

Design values:

- $\varnothing = 14$  mm      Nominal diameter of HCC-B element
- $A = 115$  mm<sup>2</sup>      Average cross-section of HCC-B element
- $d_0 = 16$  mm      Drill bit diameter
- $h$                       Hole depth in accordance with execution drawings
- $h_0$                     Nominal embedment depth in accordance with execution drawings
- $h_n$                     Nominal Anchoring in overlay



The nominal injection volume is calculated as followed:

$$V_{m,n} = \left( \left( \frac{1}{4} \pi d_0^2 - A \right) h_0 + \frac{1}{4} \pi d_0^2 (h - h_0) \right) / 1000 \text{ [ml]}$$

Equation 1

Nominal embedment depth $h_0$ [mm]	90	95	100	105	110	115	120	125
Nominal anchorage $h_n$ [mm]	90	85	80	75	70	65	60	55
Hole depth $h$ [mm]	$V_m$ [ml]	$V_m$ [ml]	$V_m$ [ml]	$V_m$ [ml]	$V_m$ [ml]	$V_m$ [ml]	$V_m$ [ml]	$V_m$ [ml]
90	9							
95	11	10						
100	12	11	10					
105	13	12	12	11				
110	14	13	13	12	11			
115	15	15	14	13	13	12		
120	17	16	15	14	14	13	12	
125	18	17	16	16	15	14	14	13
130	19	18	18	17	16	15	15	14

Table 2: Approximate injection volume of Hilti HIT-RE 500

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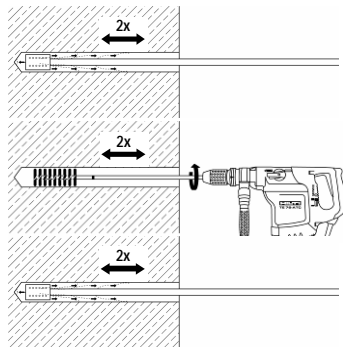
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### 2.3 Cleaning of drilled holes and injection of adhesive

#### 2.3.1 Cleaning of the drilled hole (steps 2 – 4)

Poor cleaning of the boreholes may have a negative influence of the load-bearing capacity of the shear connectors. The borehole must be cleaned by blowing out with air nozzle HIT-D 12 (at least twice), by brushing thoroughly with round brush HIT-RB12/16 (at least twice) and by blowing out with air nozzle HIT-D 12 (again at least twice). Before cleaning the borehole, any water present must be eliminated completely from of the borehole.



Blow out the borehole (twice) starting from borehole bottom with the air nozzle (oil-free compressed air = 6 bar).

**Safety instruction:** do not expose unprotected parts of the body to the dust cloud

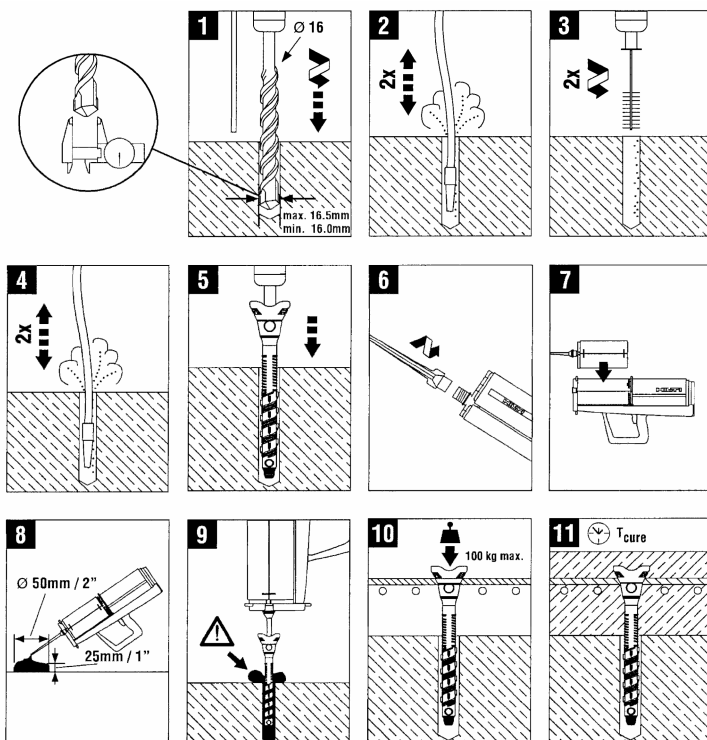
Brush (twice) with round brush HIT-RB 12/16 and brush extension HIT-RBS. Use slow (clockwise) rotating hammer drill, standard drill or screw tool. If round brush may be inserted without resistance, replace with a new brush.

Blow out the borehole (twice) with the air nozzle, starting from the bottom (oil-free compressed air = 6 bar).

Shear connector	Hilti HCC-B
Drill bit diameter $d_0$	16 mm
Air nozzle HIT-D	HIT-D 12
Extension tube HIT-VL	HIT-VL 10/1.15
Round brush HIT-RB	HIT-RB 12/16
Brush extension HIT-RBS	HIT-RBS 10/0.35 or HIT-RBS 10/0.7 (combination possible)

Table 3: Accessories for borehole cleaning

#### 2.3.2 Element setting / adhesive injection (step 5 – 9)



The shear connector HCC-B is set at the desired height in the previously cleaned borehole using the setting tool and a drill hammer. The minimum embedment depth defined in the design calculation must be complied with.

The shear connector can now be loaded temporarily with a maximum of 100 kg, for example to support the upper reinforcement.

After setting and aligning the shear connector, the borehole is filled via the injection channel in the shank of the shear connector with Hilti HIT-RE 500 injection mortar. The injection procedure is terminated when injection mortar overflows at the borehole mouth.

As soon as the curing time  $T_{cure}$  has elapsed, the HCC-B shear connector can be fully loaded.

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### 2.3.3 Working and curing time of Hilti HIT-RE 500

Base material temperature		Gelling time $t_{work} / t_{gel}$	Curing time $t_{cure}$
5°C	41°F	150 min	35 h
10°C	50°F	120 min	24 h
15°C	60°F	70 min	16 h
20°C	70°F	30 min	12 h
30°C	85°F	20 min	8 h
40°C	104°F	12 min	4 h

#### Notes:

- All specified times measured from the time of adhesive passing through mixer
- After  $t_{cure}$  shear connector can be loaded as designed
- If the surface temperature is lower than +5°C, please contact your Hilti consulting engineer
- Storage temperature of the foil packs (between +5°C und +25°C) and expiry date have to be considered

Table 4: Gelling time ( $t_{work} / t_{gel}$ ) and curing time ( $t_{cure}$ ) for Hilti HIT-RE 500

### 2.3.4 Safety notes for Hilti HIT-RE 500

#### Safety instructions



Contains epoxy constituents.  
See information supplied by the manufacturer

contains: m-xylenediamine  
Alkyglycidylether



C corrosive Hazardous to the environment

Gloves and protective goggles must be worn.



#### Risk nomenclature:

- R34 Causes burns.  
 R41 Risk of serious damage to eyes.  
 R20/21 Harmful by inhalation and if swallowed.  
 R43 May cause sensitization by skin contact  
 R51/53 Toxic to aquatic organisms; may cause long-term adverse effects on the aquatic environment.

#### Safety nomenclature:

- S1/2 Keep locked away and out of reach of children.  
 S23 Do not breathe fumes.  
 S24/25 Avoid contact with skin and eyes.  
 S26 In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.  
 S28 After contact with skin, wash immediately with plenty of soap and water.  
 S36/37/39 Wear suitable protective clothing, gloves and eye/face protection.  
 S61 Avoid release to the environment. Refer to special instructions/safety data sheets.

**Expiry date:** Month / year

Foil pack: See notes printed on converter part

#### Instructions for transport and storage:

- Keep in a cool, dry and dark place at temperatures between +5°C and +25°C.

#### Disposal considerations:

Disposal must be in accordance with federal, state and local environmental protection regulations.

- Dispensed / empty foil packs:
- Partly dispensed used and unusable foils packs / cartridges: special waste EAK-No. 200112

**Manufacturer:** Hilti GmbH, Hiltistrasse 6; D-86916 Kaufering; Made in Germany

### 3 Design of interface

#### 3.1 Basic considerations

Structures made of reinforced concrete or prestressed concrete which have a concrete overlay at least 40 mm in thickness (EC 2 [2], Section 2.5.3.5.8 (109)), or at least 60 mm on bridge structures, may be designed as monolithic building components if the shear forces at the interface between the new and the existing concrete are restrained in accordance with the following rules. The minimum embedment depth of the HCC-B in the concrete overlay is 55 mm. The minimum thickness of the concrete overlay is given by adding to this the required thickness of the concrete cover. Usually, layer thicknesses of 80 - 120 mm are used for bridges and 60 - 80 mm in building construction.

#### 3.2 Ultimate limit state for shear transfer at the interface

##### 3.2.1 Principle and set-up of the analytical model

Forces at the interface between the new and existing concrete are determined from the external forces acting on the building component. In 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.

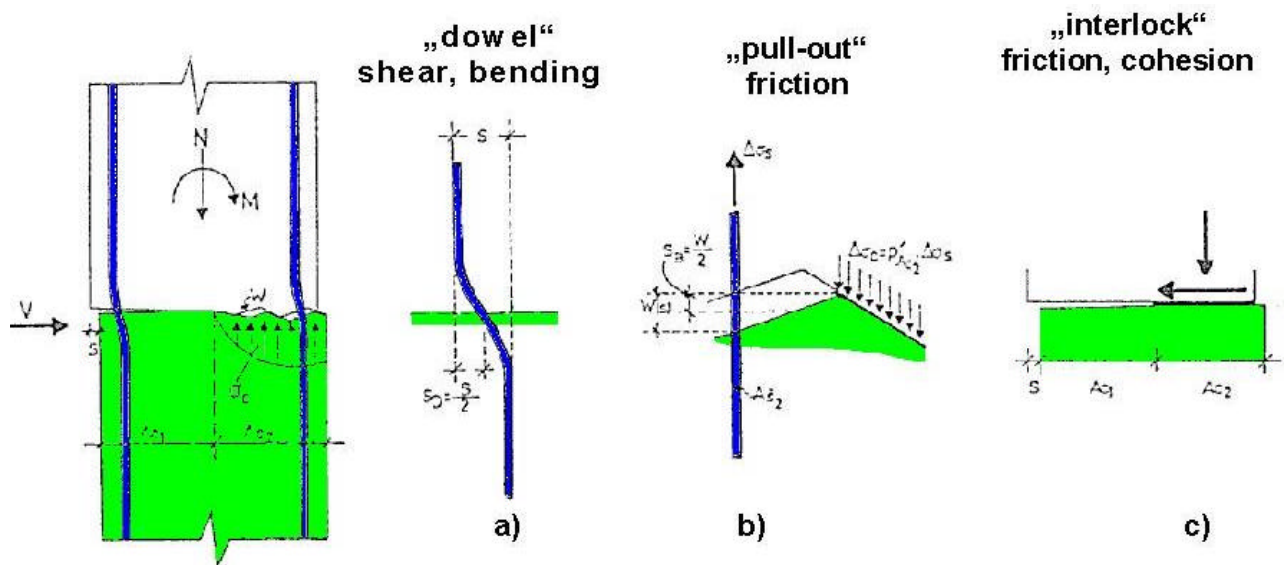


Fig. 6: Load contribution of the different components

As a result 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.



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### 3.2.2 Design shear resistance at the interface, $v_{Rd}$

The transmission of shear forces at the interface between the new and existing concrete is determined by the roughness and surface finish of the joint as well as of the transverse reinforcement perpendicular to the interface. In general, Equation 2 applies:

$$v_{Rd} \geq v_{Ed}$$

Equation 2

where:

$v_{Rd}$  design resistance of the allowable shear force per meter ("shear flow") in [kN/m] at the interface in accordance with Equation 3 (see Diagram 1 and Diagram 2).

$v_{Ed}$  design value of the shear flow acting at the interface in [kN/m]

### 3.2.3 Design shear strength at interface, $v_{Rd}$

Equation 3 is used to calculate the design shear strength at the interface,  $v_{Rd}$  [8]. When doing so, an upper limit is given by the design strength of the concrete struts:

$$v_{Rd} = \left\{ k_T \cdot \tau_{Rd} + \mu \cdot (\rho \cdot \kappa \cdot f_{yd} + \sigma_n) + \alpha \cdot \rho \cdot \sqrt{f_{yd} \cdot f_{cd}} \right\} \cdot b_j \leq \beta \cdot v \cdot f_{cd} \cdot b_j$$

Equation 3

interlock

pull-out

dowel

concrete strut

where:

$\tau_{Rd}$  basic design shear strength of concrete as per [1], Section 4.3.2.3 (the smaller of the two values for new and old concrete). Also refer to Table 6

$k_T$  cohesion factor as per Table 5

$\mu$  coefficient of friction as per Table 5

$\kappa$  coefficient for effective tensile force in the connector as per Table 5

$\alpha$  coefficient for effective dowel action as per Table 5

$\beta$  coefficient for effective concrete strength as per Table 5

$v$  efficiency factor as per [1], Formula (4.20). Also refer to Table 6

$\rho = A_s / b_j l_j$  reinforcing ratio corresponding to connectors at interface under consideration

$\sigma_n \leq 0.6 f_{cd}$  normal stress resulting from an external load normal to the interface (positive compression)

$f_{yd}$  design value of yield strength of shear connector HCC-B

$f_{cd}$  design value of cylinder compressive strength of concrete (smaller of the two values for existing concrete and overlay)

Concrete surface treatment	Mean depth of roughness $R_i$ [mm]	Coefficients					
		$k_T$	$k$	$a$	$b$	$f_{ck}^{>20}$	$f_{ck}^{>35}$
High-pressure water jets / scoring	> 3	2.3	0.4	1.1	0.4	0.8*)	1.0*)
Sand-blasting / chipping hammer	> 0.5	0	0.4	1.3	0.3	0.7	

Table 5: Parameters for Equation 3

\*) Intermediate values may be linearly interpolated

Concrete strength class	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
$f_{ck}$ [N/mm <sup>2</sup> ]	20	25	30	35	40	45	50
$f_{cd}$ [N/mm <sup>2</sup> ]	13.3	16.7	20.0	23.3	26.7	30.0	33.3
$n$	0.60	0.58	0.55	0.53	0.50	0.50	0.50
$\tau_{Rd}$ [N/mm <sup>2</sup> ]	0.24	0.26	0.28	0.30	0.31	0.32	0.33

Table 6:  $\tau_{Rd}$  and  $v$  (as per [1]; Table 4.8)

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Diagram 1: for surfaces roughened with high-pressure water jets or scored  
(mean roughness  $R_t > 3$  mm, i.e. peaks  $>$  approx. 6 mm)

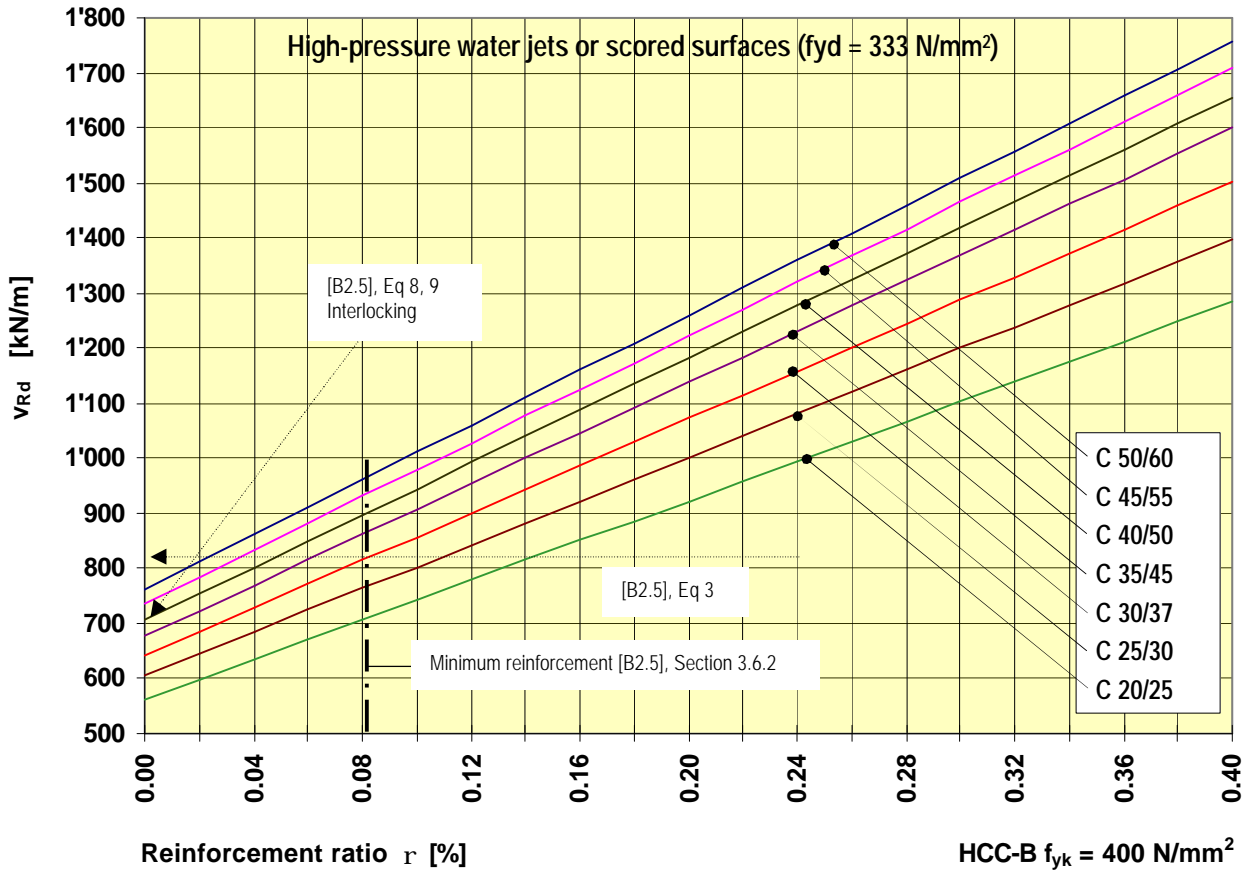
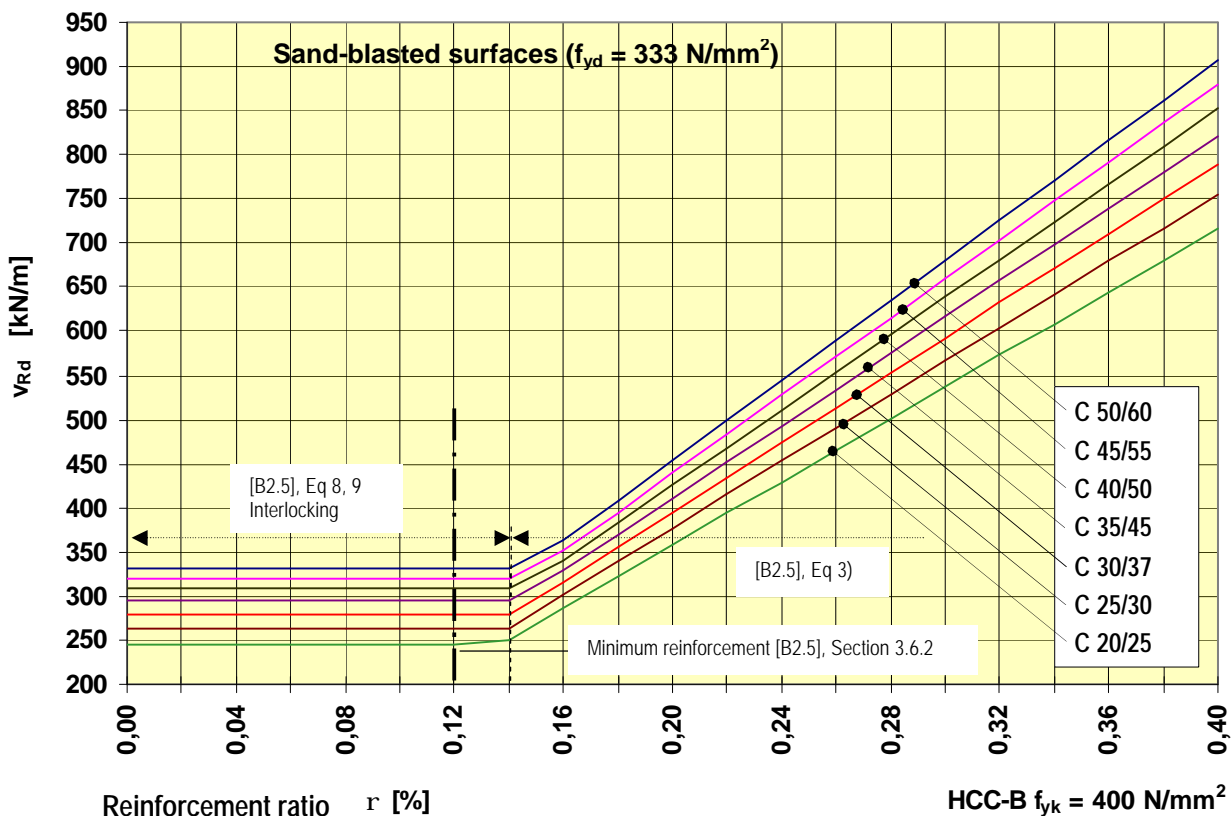


Diagram 2: for sand-blasted surfaces  
(mean roughness  $R_t > 0.5$  mm, i.e. peaks  $>$  approx 1.0 mm high)



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#### 3.3 Design shear force acting longitudinally at interface, $v_{Ed}$

Normally, the design shear force  $v_{Ed}$  is calculated from the bending resistance of the cross-section (shear failure of the member should not be the governing factor). The design shear force  $v_{Ed}$  can also be calculated from the change of the compression and/or tension (shear load  $v_{Ed}$ ) force in the concrete overlay.

##### 3.3.1 Shear force to be transferred at overlay perimeter

At the perimeter of a new concrete overlay, the minimum tensile force  $F_{cr}$  must be taken into account in the design. Here, particular attention must be paid to constraining the moment arising from  $F_{cr}$ :

$$F_{cr} = t_{new} \cdot b \cdot k \cdot f_{ct,eff}$$

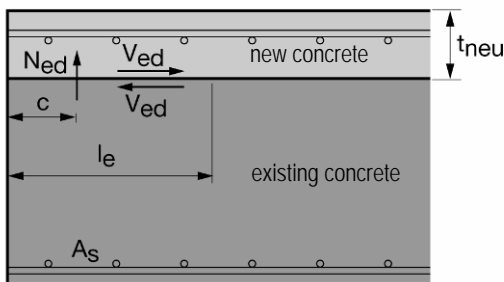
Equation 4

$F_{cr}$  tensile force effective in the overlay at the time when cracks may first be expected to occur, as per [1], Section 4.4.2.2

$k$  coefficient to allow for non-uniform self-equilibrating stresses = 0.8 for  $t_{new} \leq 30$  cm

$f_{ct,eff}$  tensile strength of overlay effective at the time when the cracks may first be expected to occur as per [1], Section 4.4.2.2 (for general cases:  $f_{ct,eff} = 3$  N/mm<sup>2</sup>)

The following values may be applied without further verification:



$$V_{ed} = F_{cr}$$

Equation 5

$$N_{ed} = \frac{V_{ed}}{6}; \quad c \leq 1.5 \cdot t_{new}$$

Equation 6

$V_{ed}$  shear force at interface derived from  $F_{cr}$

$N_{ed}$  tensile force resulting from moment  $F_{cr}$

$V_{ed}$  may be distributed uniformly over the length  $l_e$ :

a)  $l_e = 3 t_{new}$  for rough surfaces

b)  $l_e = 6 t_{new}$  for sand-blasted surfaces

$$v_{ed} = \frac{V_{ed}}{l_e}$$

Equation 7

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### 3.3.2 Center regions without shear connectors

Where the shear stresses are low, shear connectors need not be used in the center region (area) of the overlay if the load is predominantly static and if connectors are positioned around the perimeter in accordance with Section 3.3.1.

a) With surfaces blasted with a high-pressure water jet and scored surfaces:

$$v_{Rd,ct} \leq (k_T \tau_{Rd} + \mu \cdot \sigma_n) \cdot b_j = (0.09 \cdot k_c \cdot f_{ck}^{1/3} + \mu \cdot \sigma_n) \cdot b_j \quad \text{Equation 8}$$

For predominantly non-static loads in bridge construction, it is recommended that in regions where shear connectors are not required for static reasons, a sufficient number of connectors be designed in to prevent local separation.

b) With clean, sand-blasted surfaces, provided that no tensile stresses set up by external forces perpendicular to the interface are acting (assuming a non-cracked interface) for:

$$v_{Rd,ct} \leq (\tau_{Rd} + \mu \cdot \sigma_n) \cdot b_j = (0.09 \cdot k_c \cdot f_{ck}^{1/3} + \mu \cdot \sigma_n) \cdot b_j \quad \text{Equation 9}$$

where:

$k_T$  cohesion factor as per Table 5

$k_c$  coefficients for aggregate interlocking as per Table 7

Concrete surface treatment	Mean height of roughness $R_t$ [mm]	Coefficients		
		$k_c$	m	
			$f_{ck} \geq 20 \text{ N/mm}^2$	$f_{ck} \geq 35 \text{ N/mm}^2$
High-pressure water jets / scoring	> 3.0	2.3	0.8 <sup>1)</sup>	1.0 <sup>1)</sup>
Sand-blasting / chipping hammer	> 0.5	1.0 <sup>2)</sup>	0.7	

<sup>1)</sup> Intermediate values may be linearly interpolated

<sup>2)</sup> In cases where the joint is under tension due to tensile loads perpendicular to it,  $k_c = 0$  for sand-blasted surfaces.

Table 7: Coefficients for aggregate interlocking

### 3.3.3 Redundant load transfer

The design applies to redundant load transfer; which means that a local load must be transferred by at least 3 shear connectors.

## 3.4 Proof for fatigue

### 3.4.1 General

- (1) Bond interfaces subject to substantial changes in stress, i.e. not to predominantly static forces, must be designed to withstand fatigue.
- (2) Bonds subject to fatigue must always be roughened.

### 3.4.2 Proof

- (1) For predominantly non-static loading ( $\geq 2 \cdot 10^6$  load cycles), the strength is set to 50% of the static strength. On the basis of EC2, Part 1 [1] and Part 2 [3], Diagram 3 is used to interpolate between this value and the static fatigue strength.
- (2) For bond interfaces, sufficient fatigue strength may be assumed to exist when the conditions according to Equation 10 and Equation 11, and as shown graphically in Diagram 3, apply.

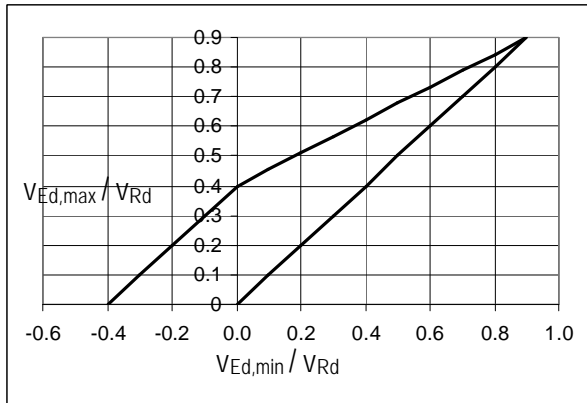
$$\text{- Here: } \frac{v_{Ed, \min}}{v_{Ed, \max}} \geq 0 : \quad \frac{|v_{Ed, \max}|}{|v_{Rd}|} \leq 0.5 + 0.45 \cdot \frac{|v_{Ed, \min}|}{|v_{Rd}|} \leq 0.9 \quad \text{Equation 10}$$

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- and 
$$\frac{V_{Ed,min}}{V_{Ed,max}} \leq 0 : \frac{|V_{Ed,max}|}{|V_{Rd}|} \leq 0.5 - \frac{|V_{Ed,min}|}{|V_{Rd}|}$$
 Equation 11



Here,  
 $V_{Ed,max}$  the design value of the maximum shear flow under frequently changing load combinations  
 $V_{Ed,min}$  the design value of the minimum shear flow under frequently changing load combinations in the region where  $V_{Ed,max}$  occurs  
 $V_{Rd}$  the design resistance of the allowable shear flow according to Equation 3, Equation 8, and Equation 9

Diagram 3: Weyrauch diagram for dynamic loading of the bond interface for high-pressure water jetting or scored surfaces.

### 3.5 Serviceability limit state

As an approximation in normal cases, the additional deformation of a strengthened bending element may be determined using the monolithic cross-section, and then increased as follows:

$$W_{eff} = \gamma \cdot W_{calc}$$
 Equation 12

- $W_{eff}$  additional deformation calculated for the reinforced section considering the elasticity of the shear connectors
- $W_{calc}$  additional deformation calculated for the reinforced section assuming a perfect bond
- $\gamma$  factor as per Table 8
- $s$  displacement of connectors under the mean permanently acting load,  $F_p \approx 0.5 F_{uk}$

The displacement  $s$  as per Table 8 can be used for more precise calculations.

Surface treatment	Mean roughness $R_t$ [mm]	$g$	$s$ [mm]
High-pressure water jets / scoring	> 3.0	1.0	» 0.005 $\varnothing$
Sand-blasting / chipping hammer	> 0.5	1.1	» 0.015 $\varnothing$

Table 8: Coefficients for calculation of deformation  $\varnothing$  = diameter of shear connectors

### 3.6 Additional rules and design details

#### 3.6.1 Mixed surface treatment

The surface treatments used for a building component may differ only if the non-uniform stiffness arising in the bond is taken into account (also see Table 8, displacement  $s$ ). Note that a non-cracked interface, i.e., rigid bond, is assumed for interfaces with low shear stress that do not require connectors in the center region, as per Section 3.3.2.



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### 3.6.2 Minimum amount of reinforcement at the interface

If shear connectors cannot be omitted as described in Section 3.3.2, the following minimum reinforcement must be provided in the interface:

- (1) Slabs and other structural elements in which no shear reinforcement is necessary:
  - a) for rough interface surfaces (high-pressure water jet and scored):  $\rho \geq 0.08\%$  (10 shear connectors per m<sup>2</sup>)
  - b) for sand-blasted interface surfaces:  $\rho \geq 0.12\%$  (15 shear connectors per m<sup>2</sup>)
- (2) Beams and other structural elements with shear reinforcement as per [1], Section 5.4.2.2.

### 3.6.3 Layout of connectors

- (1) 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.
- (2) If the new concrete overlay is on the tension side of the load-bearing component, the connectors must be distributed to accord with the grid spacing of the longitudinal reinforcement without any allowance being made for anchorage length
- (3) The connector spacing in the load-bearing direction may not be larger than 6 times the thickness of the new concrete overlay, or 800 mm.

### 3.6.4 Anchorage of the shear connectors in the existing and new concrete

- (1) The connectors must be adequately embedded in the existing concrete and new concrete overlay. The tensile force actually required to be anchored,  $N_{Ed}$ , may be assumed to be:

$$N_{Ed} \geq \kappa \cdot A_s \cdot f_{yd}$$

Equation 13

$\kappa$  coefficient as per Table 5.

- (2) Where the setting data given in Chapter 2 is complied with, adequate anchoring is assured.
- (3) Cracks in the concrete reduce the tensile strength of the embedded connectors. In these cases, the anchoring length must be increased (e.g. with pure tension reinforcement, or bending reinforcement, with high transverse loading in the region of beam supports or point loads).

### 3.6.5 Geometrical boundary conditions for existing concrete and concrete overlays

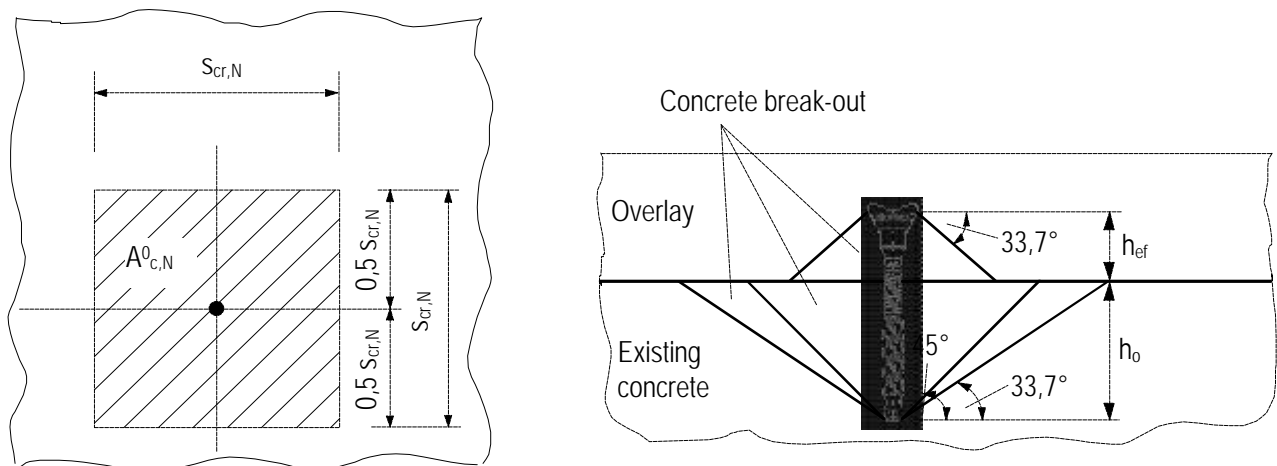


Fig. 7: Area of the concrete break out

	Connector spacing $S_{cr,N}$	Edge distance $C_{cr,N}$
Overlay	$3.0 \cdot h_n$	$1.5 \cdot h_n$
Existing concrete	$3.0 \cdot h_o$	$1.5 \cdot h_o$
	$2.0 \cdot h_o$	$1.0 \cdot h_o$

Table 9: Geometrical boundary conditions for existing concrete and concrete overlay.

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**3.6.6 Minimum reinforcement in overlay**

The procedure in [1] must be adapted to determine the minimum amount of reinforcement in the concrete overlay.

Beams: [1] Section 5.4.2.1.1 and 5.4.2.4,

Slabs: [1] Section 5.4.3.2.1

**3.6.7 Recommendation for overlay placement**

Pre-treatment:

A primer consisting of thick cement mortar is recommended.

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.

Overlay:

The concrete mix for the overlay should normally be such as to ensure low-shrinkage ( $W/C \leq 0.40$ ). The overlay must be placed on the still fresh primer, i.e. wet on wet.

Curing:

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.

**3.6.8 Recommendation for surface treatment**

The roughness of the interface has a decisive influence on the shear force that can be transferred. For design purposes, the characteristic dimension is the mean depth of roughness,  $R_i$ , measured according to the sand-patch method [9]. It must be borne in mind that  $R_i$  is a mean value, and thus the difference between the peaks and valleys is about  $2 R_i$ .

It is recommended that a mean roughness,  $R_i$ , be stipulated when specifying the surface treatment. Prior to approving the treatment, a sample surface must be made up and this checked using the sand-patch method.

## 4 Exbar Overlay dimensioning program

### 4.1 Introduction

Exbar Overlay is a program for the dimensioning of bond interfaces between an existing concrete layer and a concrete overlay. Dimensioning is performed in accordance with the present Fastening Technology Manual B 2.5. For practical purposes, dimensioning is performed in two main steps. In the first step, the bond reinforcement is calculated for the existing shear flow or applied loads. For this, Equation 3 is solved for  $\rho$  as a function of the maximum shear flow as given in Equation 14:

$$r(v_{\max}) = \frac{\frac{\max(v_{ed}; v_{Ed})}{b_j} - 0.09 \cdot k_c \cdot f_{ck}^{1/3} + m \cdot s_{Nd}}{m \cdot k \cdot \frac{f_{yk}}{g_s} + a_s \cdot \sqrt{\frac{f_{yk} \cdot a_1 \cdot f_{ck}}{g_s \cdot g_c}}} \quad [-] \quad \text{Equation 14}$$

In the second step, proof is made that the tension forces in the shear connectors can be satisfactorily taken up both in the existing concrete and in the concrete overlay by virtue of the roughness of the interface. The tension forces to be anchored are calculated by the program as follows:

$$N_{Ed} = b_j \cdot l_e \cdot \rho(v_{Ed}) \cdot \kappa \cdot \frac{f_{yk}}{\gamma_s} \quad \text{Equation 15}$$

The cases handled by the program to ensure satisfactory absorption of the tension forces are clearly set out in Table 10.

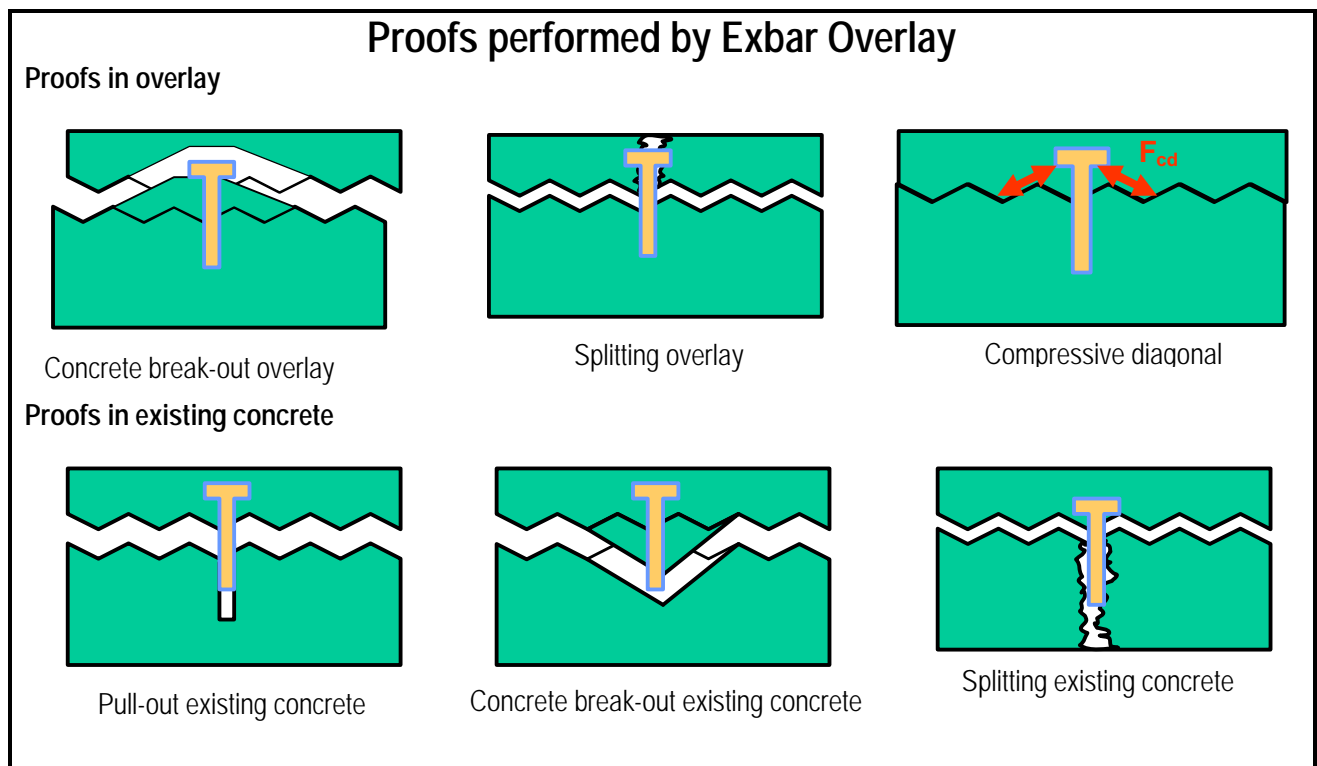


Table 10: Proofs for absorption of tensile forces

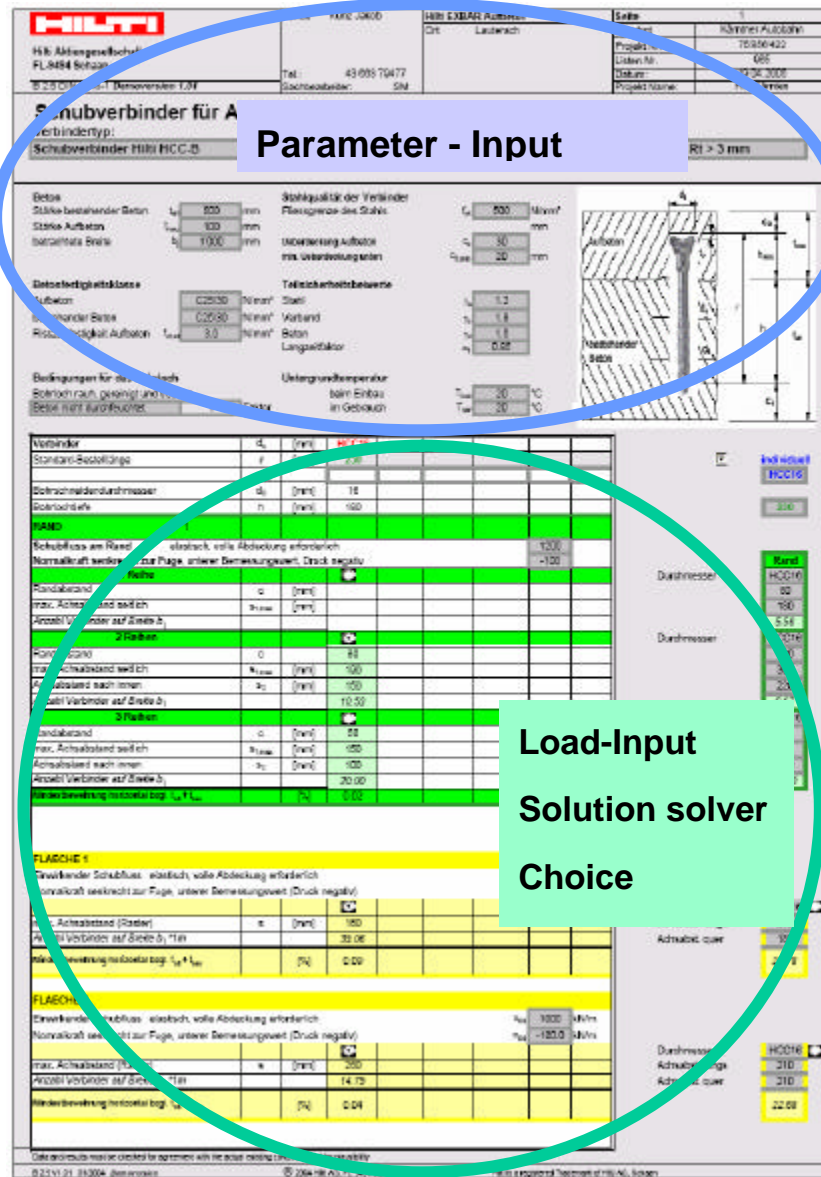
For a full explanation of the proofs, reference is made to the Exbar Overlay dimensioning program, in which the proofs are presented in detail.

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### 4.2 Dimensioning procedure



When the dimensioning program is opened, the start page (Fig. 8) appears as shown at left. The parameters required for the calculation must first be entered in the upper part.

In a further step, the shear flow can be entered for the perimeter region (green) and for up to 4 areas (yellow). The program then immediately displays suggested solutions, which can, if necessary, be adjusted via the "Individual" option. From these, *one* solution in the perimeter region and *one* for each area can be selected. From these solutions, the proofs are prepared.

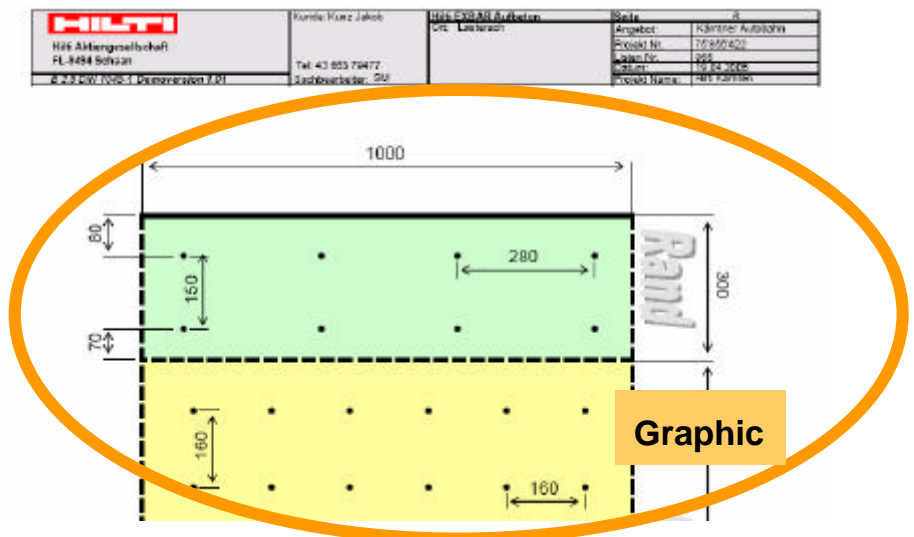
The proof for the perimeter region may be seen by scrolling down. Below that are shown the proofs for the areas.

Fig. 8: Exbar Overlay start page

On clicking "Graphic", a graphical presentation of the solution is given.

The example given in Chapter 5 for a two-span slab is used to illustrate how Exbar Overlay can be used for simple and rapid dimensioning.

Fig. 9: Exbar Overlay graphical display.



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### 5 Examples

#### 5.1 Two-span slab

The following example is used to illustrate how bond interfaces can be dimensioned with the help of Exbar Overlay. The program permits the parameters to be modified, enabling their influence to be rapidly determined. Exbar Overlay enables projects to be optimized much quicker than before. The example illustrates the case where the surface of the concrete is modified. This shows how important the roughness of the bond interface is. The two-span slab is first assumed to be high-pressure water jetted, and then sand-blasted. The result of the calculation is shown graphically at the bottom of the example.

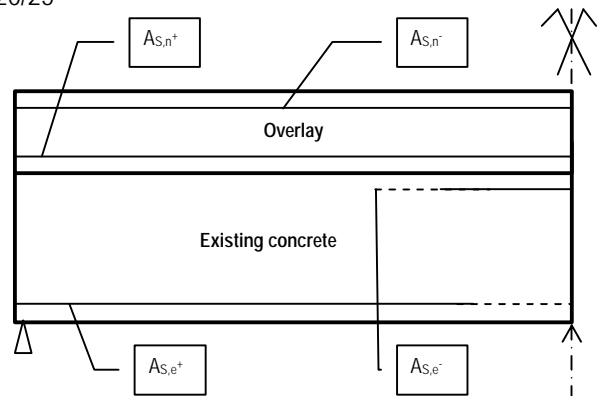
##### 5.1.1 Set values

Concrete: Overlay 100 mm C 25/30  
Existing concrete 200 mm C 20/25

Reinforcement: Area:  $A_{S,e^+} = 1005 \text{ mm}^2 / \text{m}$   
 $d = 255 \text{ mm}$   
 $A_{S,n^+}$  structural only  
Strut:  $A_{S,e^-} = 1435 \text{ mm}^2 / \text{m}$   
 $d = 255 \text{ mm}$   
 $A_{S,n^-}$  = unknown

Loading:  $q_d = 35.5 \text{ kN / m}$

Setting details:  $c_n = 45 \text{ mm}$   
(HCC-B)  $h_n = 55 \text{ mm}$   
 $h_0 = 125 \text{ mm}$   
 $\ell = 180 \text{ mm}$



Note: The notations of the setting details are shown in Fig. 3.

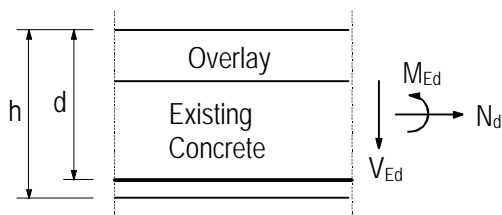


Fig. 10: Cross-section of slab

#### Static system

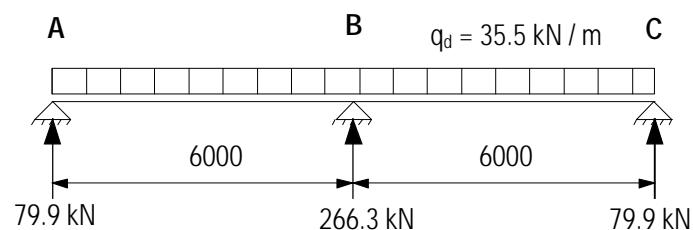


Fig. 11: Static system



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### Load distribution

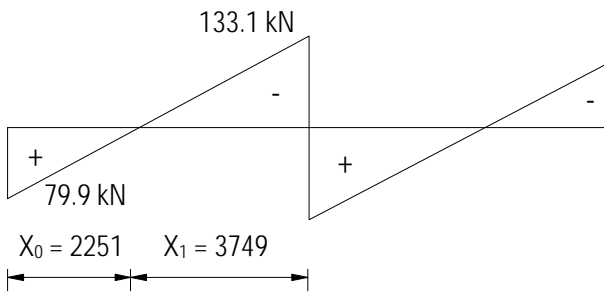


Fig. 12: Distribution of shear load,  $V_{Ed}$

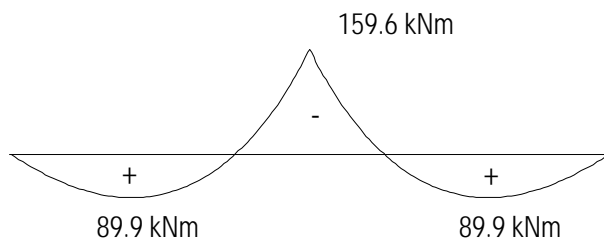


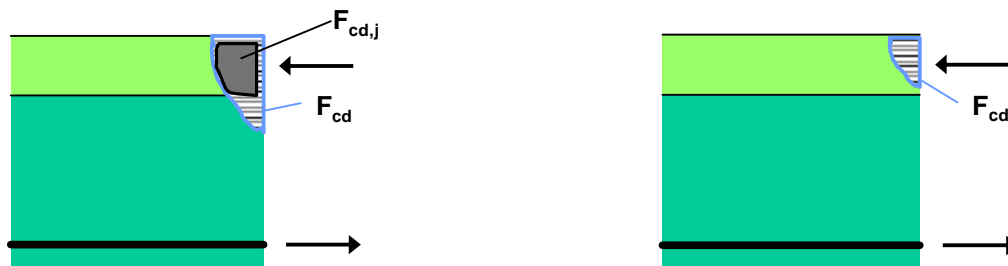
Fig. 13: Distribution of bending moment,  $M_{Ed}$

### 5.1.2 Shear flow $v_{Ed}$ resulting from external loads ( $V_{Ed}$ ) in the bond interface for span 1 (A – B)

#### Support A

- $$v_{Ed} = \frac{F_{cd,j}}{F_{cd}} \cdot \frac{V_{Ed}}{z}$$

In determining  $v_{Ed}$ , a distributed shear load  $V_{Ed} / z$  is applied which is constant over the height of the inner levelling arm. This is reduced by the factor  $F_{cd,j} / F_{cd}$ . Here,  $F_{cd} = M_{Ed} / z$  is the total longitudinal force resulting from bending. The applied longitudinal force in the overlay  $F_{cd,j}$  is that part of  $F_{cd}$  lying above the bond interface. This can attain a maximum value of  $F_{cd}$ . Basically, two cases must be considered. The first is where the neutral axes lies above the bond interface, and the second below it. This decides whether the pressure zone lies completely within the overlay or not. The two cases are shown in Fig. 14.



$$v_{Ed} = \frac{F_{cd,j}}{F_{cd}} \cdot \frac{V_{Ed}}{z} \left[ \frac{kN}{m} \right]$$

$$v_{Ed} = \frac{V_{Ed}}{z} \left[ \frac{kN}{m} \right]$$

Fig. 14: Position of the neutral axes for the overlay in the pressure zone.

Where:

$z$	inner levelling arm between the bending compression and tensile force [m]
$V_{Ed}$	design value of the applied shear force in section [kN]
$F_{cd,j}$	Design value of the part of the longitudinal force to be transmitted through the joint resulting from bending [kN]
$F_{cd}$	design value of the total longitudinal force resulting from bending [kN]

$$F_{cd} = \frac{M_{Ed}}{z} \quad [kN]$$

#### Assumption

At support A, the compressive zone lies above the bond interface, so that the simplified assumption is made that the

quotient  $\frac{F_{cd,j}}{F_{cd}} = 1.0$ , thereby lying on the safe side.

$$V_{Ed,A} = 1.0 \cdot \frac{79,9}{0,23} = 347.4 \text{ kN/m}$$

$$z = 0.9 \cdot d$$

$$d = 0.255 \text{ m (see value specified above)}$$

- Effect of the static height (d):

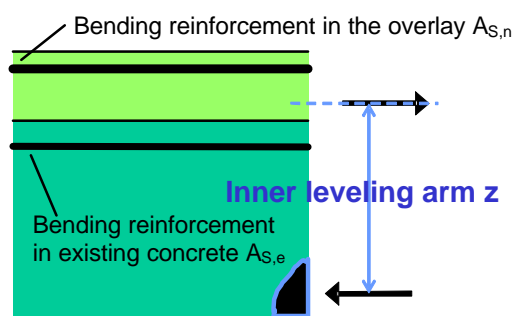
shear flow at a distance of  $d = 0.255 \text{ m}$  from the support:

$$?v_{Ed,A} = \frac{v_{Ed} \cdot d}{x_0} = \frac{347.4 \cdot 0.255}{2.251} = 39.4 \text{ kN/m}$$

$$v_{Ed,A} = 347.4 - 39.4 = 308.0 \text{ kN/m}$$

#### Support B<sub>left</sub>:

$$\bullet \quad v_{Ed} = \frac{A_{S,n}}{A_{S,n} + A_{S,e}} \cdot \frac{V_{Ed}}{z}$$



where:

$A_{S,n}$  cross-section of the bending reinforcement in the overlay [ $\text{mm}^2 / \text{m}$ ]

$A_{S,e}$  cross-section of the bending reinforcement in the existing concrete [ $\text{mm}^2 / \text{m}$ ]

$$v_{Ed} = \frac{A_{S,n}}{A_{S,n} + A_{S,e}} \cdot \frac{V_{Ed}}{z} \quad \left[ \frac{kN}{m} \right]$$

Fig. 15: Position of the reinforcement with overlay in the tension zone.

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The simplified assumption is made that the quotient  $\frac{A_{S,n}}{A_{S,n} + A_{S,n}} = 1.0$ , thereby lying on the safe side.

$$V_{Ed,B} = 1.0 \cdot \frac{133.1}{0.23} = 578.7 \text{ kN/m}$$

$$z = 0.9 \cdot d$$

$$d = 0.255 \text{ m (see value specified above)}$$

- Effect of the static height (d):

shear flow at a distance of  $d = 0.255 \text{ m}$  from the support:

$$?V_{Ed,B} = \frac{v_{Ed} \cdot d}{x_1} = \frac{578.7 \cdot 0.255}{3.749} = 39.4 \text{ kN/m}$$

$$v_{Ed,B} = 578.7 - 39.4 = 539.3 \text{ kN/m}$$

### Distribution of the shear flow $v_{Ed}$ in span 1 (A – B)

The figure shows the shear flow resulting solely from the external loads. The shear flow at the perimeter ( $v_{ed}$ ) resulting from constraints is not shown.

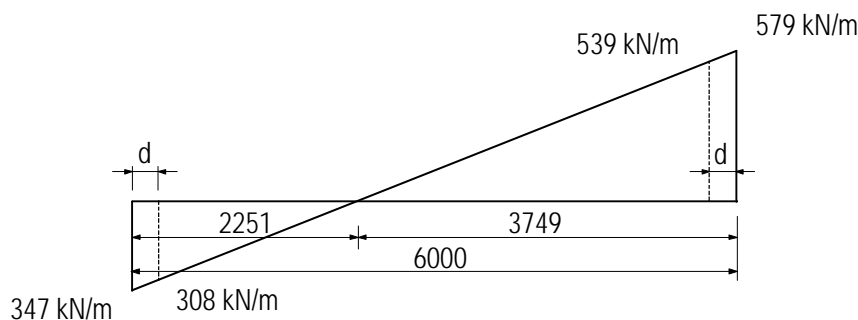


Fig. 16: Distribution of shear flow,  $v_{Ed}$

## 5.2 High-pressure water jetted bond interface

### 5.2.1 Area

Design value of the sustainable shear flow  $v_{Rd,ct}$  in the interface for aggregate interlocking without use of an interface reinforcement.

- Manual calculation

$$v_{Rd,ct} = \left( 0.09 \cdot k_c \cdot f_{ck}^{1/3} - \mu \cdot \sigma_{Nd} \right) \cdot b_j$$

where:

- $k_c$  cohesion factor from Table 5 > 2.3
- $f_{ck}$  characteristic cylinder compressive strength of the concrete after 28 days from Table 6 > 20 N/mm<sup>2</sup>
- $\sigma_{Nd}$  normal stress resulting from an external load normal to the interface = 0 N/mm<sup>2</sup>
- $b_j$  effective width of interface in the contact area in the region considered = 1000 mm

⇒

$$v_{Rd,ct} = \left( 0.09 \cdot 2.3 \cdot 20^{1/3} - 0 \right) \cdot 1000 = 562 \text{ kN/m}$$

$$V_{Rd,ct} = 562 \text{ kN/m} > 308 \text{ kN/m} = V_{Ed} \text{ at support A}$$

$$V_{Rd,ct} = 562 \text{ kN/m} > 539 \text{ kN/m} = V_{Ed} \text{ at support B}_{\text{left}}$$

⇒ For external loads, no shear connectors are necessary in this area from considerations of statics.

- Exbar Overlay

The information given in this example is entered in the Exbar Overlay input field, and the values  $V_{Ed} = 308 \text{ kN/m}$  and  $539 \text{ kN/m}$  entered for areas 1 and 2 respectively. In both cases,  $n_{Ed} = 0 \text{ kN/m}$ . First click on the suggested solutions and then scroll downwards to view the resulting proofs under "Proof connectors area 1" and "Proof connectors area 2".

For both areas, the design value of the sustainable shear flow without reinforcement,  $V_{Rd,ct} = 562 \text{ kN/m}$ , i.e.  $\Rightarrow V_{Rd,ct} > V_{Ed}$ . **No interface reinforcement required.**

**Theoretically, no interface reinforcement is required for predominantly static loads. To ensure that any delamination cracks can be stopped and the connectors can be used as support points for the reinforcement, for structural purposes an interface reinforcement of 2 connectors per  $\text{m}^2$  is recommended.**

Thus for the entire area (A – B) an interface reinforcement is only required for structural purposes. The following center distances give an interface reinforcement of 2 connectors per  $\text{m}^2$ :

Transverse spacing  $s_1 = 700 \text{ mm}$

Longitudinal spacing  $s_2 = 700 \text{ mm}$

### 5.2.2 Perimeter

The minimum perimeter doweling is determined from the shear flow resulting from constraints ( $v_{ed}$ ) at the perimeter. The calculation is performed as follows:

(1) Tension force due to cracking

- Manual calculation

Loads at the perimeter resulting from constraints (shrinkage and temperature gradients):

$$F_{cr} = t_{\text{new}} \cdot b_j \cdot k \cdot f_{ct,eff}$$

$$F_{cr} = 100 \cdot 1000 \cdot 0.8 \cdot 3.0 = 240\,000 \text{ N} = 240 \text{ kN}$$

$$V_{ed} = F_{cr} = 240 \text{ kN}$$

Length of load introduction:  $\ell_e = 3 \cdot t_{\text{new}} = 3 \cdot 100 = 300 \text{ mm}$

⇒ shear flow,  $v_{ed}$ :

$$v_{ed} = \frac{V_{ed}}{\ell_e} = \frac{240}{0.30} = 800 \text{ kN/m}$$

From Diagram 1 (high-pressure jetted bond interface)  $v_{ed} = 800 \text{ kN/m}$ :

$p_{\text{erf}} = \pm 0.13 \%$  for concrete C 20/25 (the smaller of the two values for the overlay and the existing concrete is applied)

$$A_{s,erf} = \ell_e \cdot b_j \cdot p_{\text{erf}} = 300 \cdot 1000 \cdot 0.0013 = 390 \text{ mm}^2/\text{m}$$

Perimeter doweling:

Connector type: Hilti HCC-B  $A_s = 83 \text{ mm}^2$

$$n_{\text{erf}} = A_{s,erf} / A_s = 390 / 83 = 4.7 \text{ HCC-B/m}$$

**B 2.5****Hilti HCC-B for concrete overlays**

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- Exbar Overlay

Enter the following values for the perimeter in Exbar Overlay:  $v_{Ed} = 308$  kN/m and  $n_{Ed} = 0$  kN/m. The shear flow ( $v_{Ed}$ ) resulting from constraints is calculated automatically by the program. The subsequent calculation is carried out using the maximum value of the shear flow,  $\max(v_{Ed}, v_{Ed})$ . Exbar Overlay shows the solutions for each of the possible numbers of rows (1, 2 or 3). Click the suggested solution for 1 row and scroll down to view the proof under "Proof connectors perimeter". The minimum reinforcement for shear flow  $\rho(v)$  of 0.132 % is given under the heading "Anchorage". Exbar Overlay also suggests an edge distance of  $c = 150$  mm and a maximum transverse spacing of  $s_{1,max} = 190$  mm. This results in 5.3 HCC-B connectors per m, corresponding to an existing interface reinforcement  $\rho_{vorh}$  of 0.146 %.

It will be assumed that for some reason the design engineer is not satisfied with the solution suggested by the program and wishes to change this to provide a better fit to the HCC-B connector grid. By activating "Individual" in the program, the user can change certain values. The changes made by the engineer are assumed to be  $c = 90$  mm and  $s_1 = 180$  mm for 1 row of connectors. Click to obtain the solution as follows:  $n = 5.6$  HCC-B connectors per m at a strip width of 300 mm. By scrolling downwards, the recalculated values may be viewed.

$$\rho_{vorh} = 0.154 \%$$

$$V_{Rd} = 839 \text{ kN/m} \Rightarrow V_{Rd} = V_{Ed}$$

$$\text{Edge distance } c = 90 \text{ mm} < 1.5 t_{neu} = 1.5 \times 100 = 150 \text{ mm}$$

**(2) Edge tension force**

- Manual calculation

Tension force normal to interface:

$$N_{Ed} = F_{cr} / 6 = V_{Ed} / 6 = 240 / 6 = 40 \text{ kN}$$

This load must be applied over the anchoring in the first row in the overlay and the existing concrete. All proofs are based on current technology (CC method) and comply with the European Technical Accreditation procedure (ETAs). The individual proofs are explained in the next section.

- Exbar Overlay

As explained above, Exbar Overlay calculates the minimum reinforcement required for an applied shear flow ( $v_{Ed}$ ,  $v_{Ed}$ ). Over and above this, the resulting loads in the connectors, both in the overlay and in the existing concrete, must be properly transferred. It is also necessary to avoid cracking of the concrete.

The loads to be anchored are:

(a) The tension force resulting from shear flow ( $v_{Ed}$ )

$$N_{Ed} \geq \kappa \cdot A_s \cdot f_{yd} = \kappa \cdot \rho(v) \cdot l_j \cdot b_j \cdot f_{yd}$$

(b) The tension force resulting from constraints ( $v_{Ed}$ )

$$N_{Ed} = V_{Ed} / 6$$

(This load must be taken up at the perimeter by the first row).

## Hilti HCC-B for concrete overlays

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The proofs performed by Exbar Overlay are shown in Table 11.

Position	Proof	Reference to ETA
Overlay	Anchorage in overlay	ETA 02/006
	Splitting in overlay	ETA 02/006
Existing concrete	Pull-out in existing concrete	ETA 04/027
	Concrete pull-out in existing concrete	ETA 04/027
	Splitting of existing concrete	ETA 04/027
Concrete compression strut	As specified in standard	

Table 11: Exbar Overlay proofs for  $N_{Ed}$ ,  $N_{ed}$

The above proofs are shown and explained in detail in Exbar Overlay and are not repeated here.

### (3) Minimum longitudinal reinforcement

The minimum longitudinal reinforcement in the overlay is determined as given in [1], paragraph 5.4.3.2.1

The crack tension force at the perimeter must be sustained by a retention reinforcement in the longitudinal reinforcement:

$$V_{ed} = 240 \text{ kN}: A_s = \frac{V_{ed} \cdot \gamma_s}{f_{yk}} = \frac{240 \cdot 1.15}{0.5} = 552 \text{ mm}^2/\text{m}$$

Selected: U-shaped rebar  $\varnothing 10$  per connector (buted to reinforcement grid  $\varnothing 6.5$ ,  $e = 100$ )

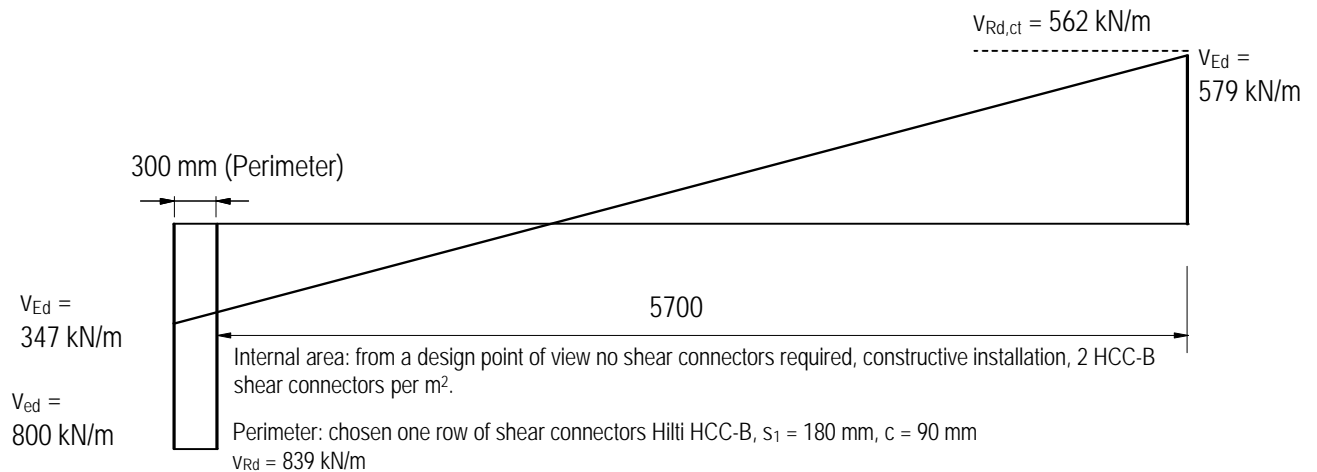


Fig. 17: Distribution of shear flow,  $v_{Ed}$  and  $v_{ed}$



# Hilti HCC-B for concrete overlays

## B 2.5

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### 5.3 Sand-blasted bond interface

#### 5.3.1 Area

Design value of the shear flow sustainable in the interface for aggregate interlocking without use of an interface reinforcement.

- Manual calculation

$$v_{Rd,ct} = \left( 0.09 \cdot k_c \cdot f_{ck}^{1/3} - \mu \cdot \sigma_{Nd} \right) \cdot b_j$$

where:

$k_c$	coefficients for aggregate interlocking as per Table 7 > 1
$f_{ck}$	characteristic cylinder compressive strength of the concrete after 28 days from Table 6 > 20 N/mm <sup>2</sup>
$\sigma_{Nd}$	normal stress resulting from an external load normal to the interface = 0 N/mm <sup>2</sup>
$b_j$	effective width of interface in the contact area in the region considered = 1000 mm

$$v_{Rd,ct} = \left( 0.09 \cdot 1.0 \cdot 20^{1/3} - 0 \right) \cdot 1000 = 244 \text{ kN/m}$$

$v_{Rd,ct} = 244 \text{ kN/m} < 308 \text{ kN/m} = v_{Ed}$  at support A

$v_{Rd,ct} = 244 \text{ kN/m} < 539 \text{ kN/m} = v_{Ed}$  at support B<sub>left</sub>

⇒ For external loads, shear connectors are required for the edge and intermediate supports!

#### Width of strip in which connectors are required

Support A:

$$b_A = \frac{(v_{Ed,A} - v_{Rd,ct}) \cdot x_0}{v_{Ed,A}} = \frac{(347 - 244) \cdot 2251}{347} = 668 \text{ mm}$$

Support B<sub>left</sub>:

$$b_B = \frac{(v_{Ed,B} - v_{Rd,ct}) \cdot x_1}{v_{Ed,B}} = \frac{(579 - 244) \cdot 3749}{579} = 2169 \text{ mm}$$

#### Determination of the number of shear connectors at support A

Average shear flow:  $v_{Ed,m} = (308 + 244)/2 = 276 \text{ kN/m}$ ; strip width 668 mm

From diagram 2 (sand-blasted bond interface) with  $v_{Ed} = 276 \text{ kN/m}$ :

$\rho_{erf} = \pm 0.15 \%$  for concrete C20/25 (the smaller of the two values for the overlay and the existing concrete is applied).

$$A_{s,erf} = \ell_j \cdot b_j \cdot \rho_{erf} = 1000 \cdot 1000 \cdot 0.0015 = 1500 \text{ mm}^2/\text{m}^2$$

Doweling:

Connector type: Hilti HCC-B  $A_s = 83 \text{ mm}^2$

$$n_{erf} = A_{s,erf} / A_s = 1500 / 83 = 18.1 \text{ HCC-B/m}^2$$

# Hilti HCC-B for concrete overlays

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- Exbar Overlay

Enter the following values for area 1 in Exbar Overlay:  $v_{Ed} = 276$  kN/m and  $n_{Ed} = 0$  kN/m. Alter the concrete surface to "Sand-blasted, Chipping hammer". Exbar Overlay now shows the solution for area 1. Click the suggested solution and view the resulting proof under "Proof connectors area 1".

Results:

Minimum reinforcement for shear flow  $\rho(v) = 0.153$  %

Transverse spacing  $s_1 = 220$  mm, longitudinal spacing  $s_2 = 220$  mm

$n = 20.7$  HCC-B shear connectors per  $m^2$  corresponding to an existing interface reinforcement of  $\rho_{vorh} = 0.171$  %.

It is again assumed here that for some reason the design engineer is not satisfied with the solution suggested by the program and wishes to change this to provide a better fit to the HCC-B connector grid. By activating "Individual" in the program, the user can change certain values. The changes made by the engineer are assumed to be  $s_1 = 240$  mm und  $s_2 = 200$  mm. The result is:

$n = 20.8$  HCC-B connectors per  $m^2$ .

$\rho_{vorh} = 0.173$  %

$V_{Rd} = 311$  kN/m  $\Rightarrow V_{Rd} = V_{ed}$

### Determination of the number of shear connectors at support $B_{left}$

Average shear flow:  $v_{Ed,m} = (539 + 244)/2 = 392$  kN/m ; strip width 2169 mm

From diagram 2 (sand-blasted bond interface) with  $v_{Ed} = 392$  kN/m:

$\rho_{eff} = \pm 0.22$  % for concrete C20/25 (the smaller of the two values for the overlay and the existing concrete is applied).

$$A_{s,eff} = \ell_j \cdot b_j \cdot \rho_{eff} = 1000 \cdot 1000 \cdot 0.0022 = 2200 \text{ mm}^2/\text{m}^2$$

Doweling:

Connector type: Hilti HCC-B  $A_s = 83$   $\text{mm}^2$

$n_{eff} = A_{s,eff} / A_s = 2200 / 83 = 26.5$  HCC-B/ $m^2$

- Exbar Overlay

The following values for area 2 are entered in Exbar Overlay:  $v_{Ed} = 392$  kN/m and  $n_{Ed} = 0$  kN/m. Exbar Overlay now shows the solution for area 2. Click the suggested solution and view the resulting proofs under "Proof connectors area 2". The results:

Minimum reinforcement for shear flow  $\rho(v) = 0.218$  %

Transverse spacing  $s_1 = 180$  mm, longitudinal spacing  $s_2 = 180$  mm

$n = 30.9$  HCC-B shear connectors per  $m^2$ , corresponding to an existing bond interface of  $\rho_{vorh} = 0.256$  %.

$V_{Rd} = 461$  kN/m  $\Rightarrow V_{Rd} = V_{ed}$

### 5.3.2 Perimeter

The minimum perimeter doweling is determined from the shear flow resulting from constraints ( $v_{ed}$ ) at the perimeter. The calculation is performed as follows:

(1) Tension force due to cracking

- Manual calculation

Loads at the perimeter resulting from constraints (shrinkage and temperature gradients):

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$$F_{cr} = t_{new} \cdot b_j \cdot k \cdot f_{ct,eff}$$

$$F_{cr} = 100 \cdot 1000 \cdot 0.8 \cdot 3.0 = 240\,000 \text{ N} = 240 \text{ kN}$$

$$V_{ed} = F_{cr} = 240 \text{ kN}$$

Length of load introduction:  $\ell_e = 6 \cdot t_{new} = 6 \cdot 100 = 600 \text{ mm}$

⇒ shear flow,  $v_{ed}$ :

$$v_{ed} = \frac{V_{ed}}{\ell_e} = \frac{240}{0.60} = 400 \text{ kN/m}$$

From Diagram 2 (sand-blasted bond interface)  $v_{ed} = 400 \text{ kN/m}$ :

$\rho_{erf} = \pm 0.23 \%$  for concrete C 20/25 (the smaller of the two values for overlay and the existing concrete is applied)

$$A_{s,erf} = \ell_e \cdot b_j \cdot \rho_{erf} = 600 \cdot 1000 \cdot 0.0023 = 1380 \text{ mm}^2/\text{m}$$

Perimeter doweling:

Connector type: Hilti HCC-B  $A_s = 83 \text{ mm}^2$

$$n_{erf} = A_{s,erf} / A_s = 1380 / 83 = 16.6 \text{ HCC-B/m}$$

- Exbar Overlay

Enter the following values for the perimeter in Exbar Overlay:  $v_{Ed} = 308 \text{ kN/m}$  and  $n_{Ed} = 0 \text{ kN/m}$ . Exbar Overlay now shows a solution for the perimeter, for which 3 rows are required. The solution for the suggested 3 rows is shown under "Proof connectors perimeter":

Minimum reinforcement for shear flow  $\rho(v) = 0.222 \%$

Edge distance  $c_1 = 100 \text{ mm}$

Max. transverse spacing  $s_{1,max} = 170 \text{ mm}$ , inner spacing  $s_2 = 200 \text{ mm}$  ( $s_2 = 600 \text{ mm} / 3 \text{ rows} = 200 \text{ mm}$ )

$n = 17.6 \text{ HCC-B}$  shear connectors per  $\text{m}^2$  corresponding to an existing interface reinforcement of  $\rho_{vorh} = 0.244 \%$ .

$$V_{Rd} = 439 \text{ kN/m} \Rightarrow V_{Rd} = V_{ed}$$

Edge distance  $c_1 = 100 \text{ mm} < 1.5 t_{new} = 1.5 \times 100 = 150 \text{ mm}$

For the strip having a width equal to the load introduction length  $\ell_e$ , 3 rows of connectors are provided at a center distance of 200 mm. This arrangement is shown in Fig. 18.

(2) Edge tension force

- Manual calculation

Tension force normal to the interface:

$$N_{ed} = F_{cr} / 6 = V_{ed} / 6 = 240 / 6 = 40 \text{ kN}$$

This load must be applied over the anchoring in the first row in the overlay and the existing concrete. All proofs are based on current technology (CC method) and comply with the European Technical Accreditation procedure (ETAs). The proofs are explained in the section on the high-pressure water jetted bond interface.

- Exbar Overlay

The procedure for this is given on page 27.

(3) Minimum longitudinal reinforcement

Retention reinforcement in the overlay: see page 28, high-pressure water jetted surface

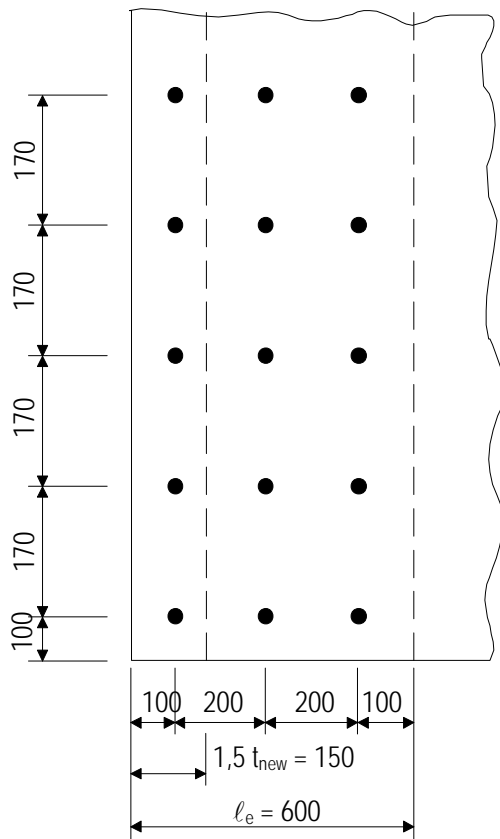


Fig. 18: Perimeter doweling at support A

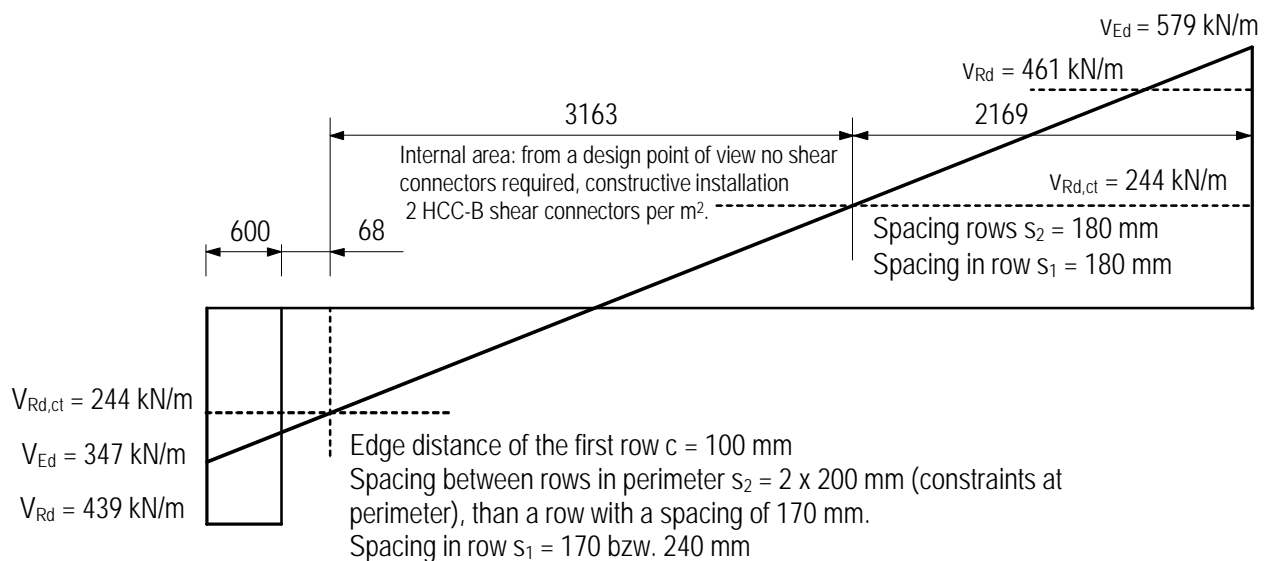


Fig. 19: Distribution of shear flow

# Hilti HCC-B for concrete overlays

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## 5.4 Summary

Arrangement of the shear connectors for different surface roughnesses in area 1 (A – B). In order to show clearly the influence of the chosen surface roughnesses, only the theoretically required shear connectors are shown.

### (a) High-pressure water jetted surface of the existing concrete

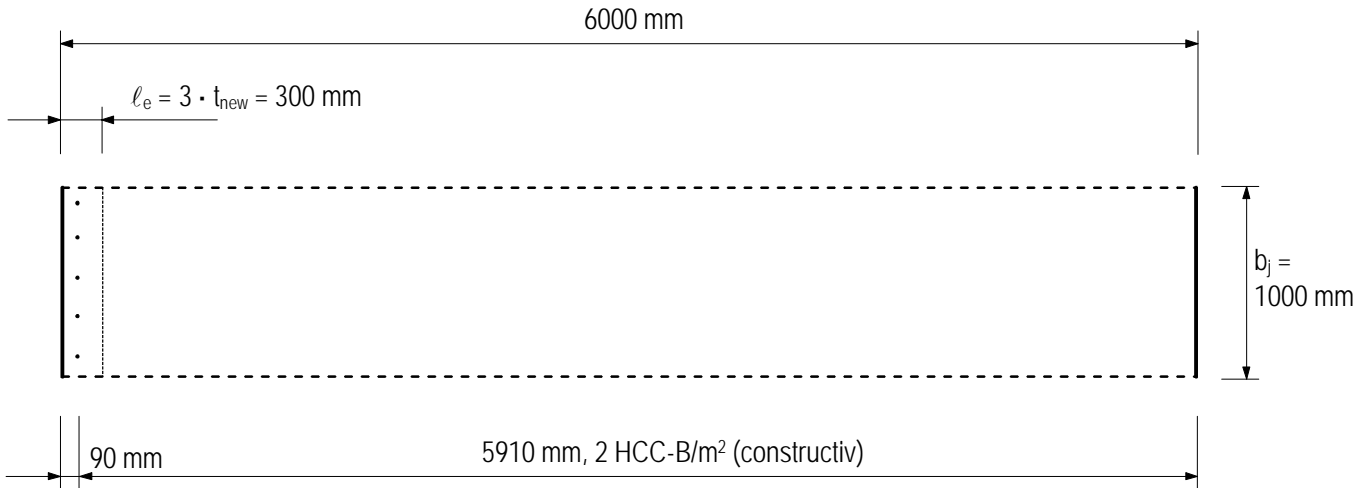


Fig. 20: Arrangement of the shear connectors for high-pressure water jetted bond interface

**Perimeter doweling only:**  
 1 row Hilti HCC-B  
 $c = 90 \text{ mm}$   
 Spacing in row:  $s_1 = 180 \text{ mm}$

### (b) Sand-blasted surface of existing concrete

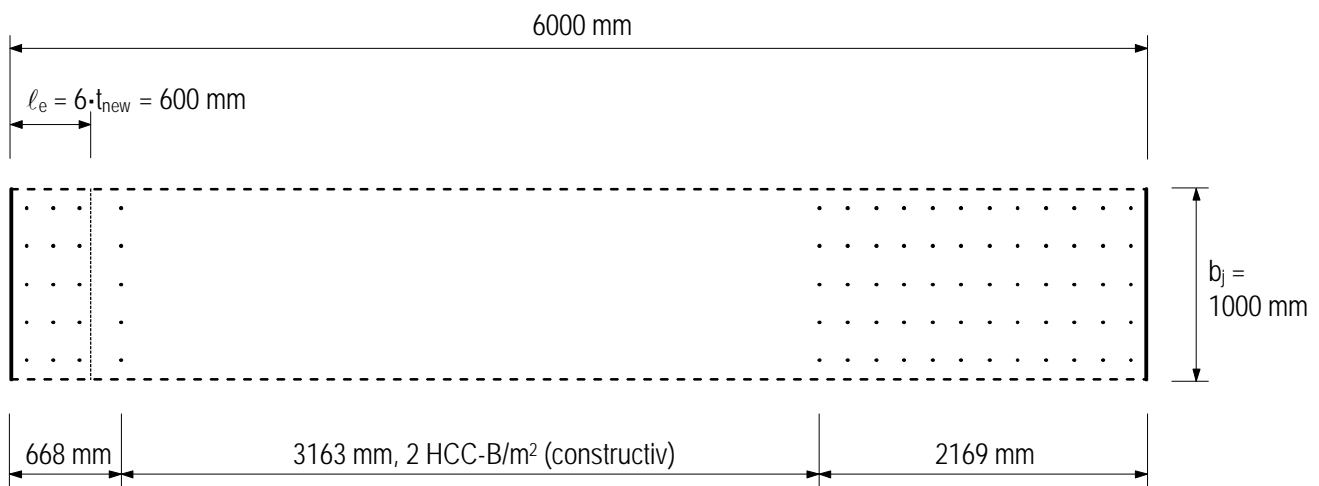


Fig. 21: Arrangement of shear connectors for sand-blasted bond interface

**Perimeter doweling:**  
 3 rows Hilti HCC-B  
 $c = 100 \text{ mm}$   
 Spacing in row:  $s_1 = 170 \text{ mm}$ ; spacing between rows:  $s_2 = 200 \text{ mm}$

**Edge support (support A):**  
 Perimeter doweling plus 1 row Hilti HCC-B  
 Spacing in row:  $s_1 = 240 \text{ mm}$

**Intermediate support (support B):**  
 12 rows Hilti HCC-B  
 Spacing in row:  $s_1 = 180 \text{ mm}$ ; spacing between rows:  $s_2 = 180 \text{ mm}$

# Hilti HCC-B for concrete overlays

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### 6 Test results

#### 6.1 Transfer of shear across a concrete crack

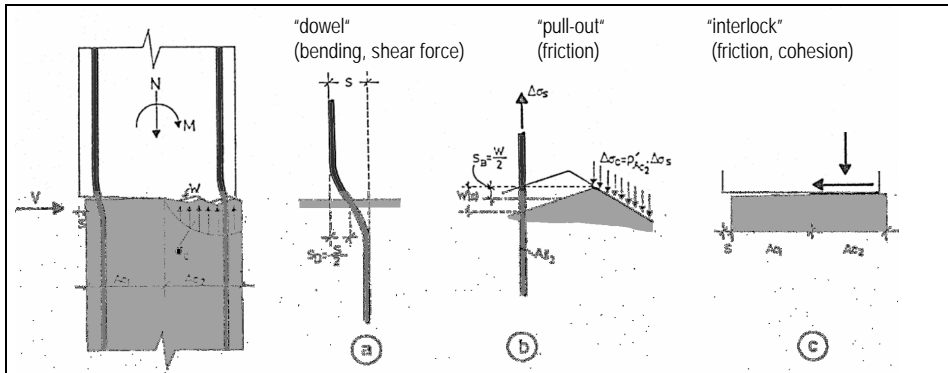


Fig. 22: Transfer of shear across a concrete crack (shear-friction-model)

A review of the literature revealed little research into the specific behaviour of reinforced bond interfaces between existing and new concrete. The majority of the existing studies concentrate on the transfer of shear forces across cracks. The effect on the shear loading capacity of subsequent roughening of the surface of the existing concrete was first investigated in the United States. A few years later, the so-called shear-friction theory was developed. This theory attempts to explain the phenomena with the aid of a simple saw-tooth model. According to this, the roughness of surfaces in the case of relative displacement always leads to a widening of the interface which sets up stresses in steel connectors passing across the interface. These create clamping forces across the interface, leading in their turn to frictional forces.

In 1987, Tsoukantas and Tassios [4] presented analytical investigations into the shear strength of connections between precast concrete components. They cover the different contributing mechanisms of friction and dowel action (Fig. 22).

#### 6.2 Laboratory tests by Hilti Corporate Research



Fig. 23: Shear tests

When the interface surfaces are rough and the amount of reinforcement at the interface is small (low shear stress), cohesion makes a major contribution to transferring the shear force. The general design concept is presented in the thesis of Randl [8].

Specific shear tests were carried out in the laboratories of Hilti Corporate Research in cooperation with the University of Innsbruck (Supervision: Professor Dr. techn. M. Wicke), to investigate the effects of various degrees of roughness and transferable shear stresses with different degrees of reinforcement.

Using a unique design for the test frame, it was possible to avoid secondary eccentric moments in the specimen and to achieve nearly parallel separation of the interfaces (Fig. 23). The roughened surfaces were treated with a debonding agent before the new concrete was placed.

The results clearly demonstrate that a significant increase in load-bearing capacity can be achieved by proper roughening of the surfaces. If the surfaces are very rough, the steel connectors across the bond interface are primarily stressed in tension, whereas if the surfaces are smooth the shear resistance of the connectors (dowel action) predominates.



## 7 Notations

### Lengths:

$b_A$	Width of strip at support A in which connectors are required
$b_B$	Width of strip at support B in which connectors are required
$b_j$	effective width of interface in the contact area in the region considered
$c_n$	Concrete cover above head of shear connector
$c_0$	Concrete cover of drilled hole in existing concrete $c_0 = 2 d_0$ and/or $= 30$ mm
$c$	Edge distance
$c_1$	Edge distance
$c_2$	Inner edge distance
$c_{crit}$	Critical edge distance of shear connector
$c_s$	Edge distance of shear connector
$s_s$	Spacing of shear connector
$s_{crit}$	Critical spacing of shear connector
$s_{cr,N}$	Critical spacing for normal force
$d$	Static height
$d_0$	Drill bit diameter
$d_1$	Nominal diameter of the shear connector
$s$	Spacing
$s_{crit}$	Critical spacing of shear connectors
$s_1$	Transverse spacing / spacing in row
$s_2$	Longitudinal spacing / spacing between rows
$h$	Hole depth
$h_0$	Nominal embedment depth in existing concrete
$h_n$	Nominal anchorage in overlay
$h_{n,eff}$	Effective anchorage in overlay
$l_e$	Length over which tensile cracking force is introduced
$l$	Length of shear connector (HCC-B)
$l_j$	Effective length of interface under consideration
$R_t$	Mean depth of interface roughness, measured according to the sand-patch method [9]
$s$	Displacement of connectors under the mean permanently acting load, $F_p \approx 0.5 F_{uk}$
$t_{old}$	Thickness of existing concrete
$t_{new}$	Thickness of overlay
$w_{calc}$	Additional deformation calculated for the reinforced section assuming a perfect bond
$w_{eff}$	Additional deformation calculated for the reinforced section considering the elasticity of the shear connectors
$x$	Distance of neutral axis from compressed edge (bending)
$x_0$	Distance between support A and zero crossing of shear load distribution
$x_1$	Distance between zero crossing of shear load distribution and support B
$z$	Inner levelling arm between bending compression and tensile forces [m]

### Areas:

$A$	Average cross-section of HCC-B element
$A_{c,N}^0$	Basic load bearing area
$A_s$	Characteristic stressed cross-section
$A_{s,eff}$	Required cross-section of the shear connectors
$A_{s,e}^+$	Cross-section of the positive bending reinforcement in the existing concrete [ $mm^2 / m$ ]
$A_{s,e}^-$	Cross-section of the negative bending reinforcement in the existing concrete [ $mm^2 / m$ ]
$A_{s,n}^+$	Cross-section of the positive bending reinforcement in the overlay [ $mm^2 / m$ ]
$A_{s,n}^-$	Cross-section of the negative bending reinforcement in the overlay [ $mm^2 / m$ ]

# Hilti HCC-B for concrete overlays

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### Forces:

$F_{cr}$	Tensile force effective in the overlay at the time when cracks may first be expected to occur, as per [1], Section 4.4.2.2
$F_{cd}$	Design value of the total longitudinal force resulting from [kN]
$F_{cd,j}$	Design value of the part of the longitudinal force to be transmitted through the joint resulting from bending [kN]
$M_{Ed}$	Design value of bending moment
$N_d$	Design value of normal force
$N_{Ed}$	Design value of the tensile force actually required to be anchored
$N_{ed}$	Tensile force resulting from moment $F_{cr}$
$N_{Rd,s}$	Steel design tensile resistance
$N_{Rd,c}$	Concrete cone/pull-out resistance
$N_{Rd,c}^0$	Basic value of design resistance for concrete failure
$N_{Rk,c}^0$	Characteristic resistance for concrete failure
$V_{Ed,max}$	Design value of the maximum shear flow under frequently changing load combinations
$V_{Ed,min}$	Design value of the minimum shear flow under frequently changing load combinations in the region where $V_{Ed,max}$ OCCURS
$V_{Ed,A}$	Design value of the shear flow at support A
$V_{Ed,B}$	Design value of the shear flow at support B
$V_{Ed,m}$	Design value of the average shear flow
$V_{Rd}$	Design resistance of the allowable shear force per meter ("shear flow") in [kN/m] at interface
$V_{Rd,ct}$	Design resistance of the allowable shear force per meter ("shear flow") in [kN/m] at interface without shear connectors in [kN/m], aggregate interlocking
$V_{Ed}$	Design value of the applied shear force in section [kN]
$V_{ed}$	Shear force at interface derived from $F_{cr}$
$v_{ed}$	Design value (constraints) of the shear flow acting at the interface in [kN/m]
$V_{Ed}$	Design value of the shear flow acting at the interface in [kN/m]

### Volume:

$V_m$	Injection volume
$V_{m,n}$	Nominal injection volume

### Stresses:

$f_{uk}$	Nominal tensile strength
$f_{yk}$	Yield strength
$f_{yd}$	Design value of yield of shear connector HCC-B
$f_{ck}$	Characteristic cylinder compressive strength of the concrete after 28 days from Table 6 > 20 N/mm <sup>2</sup>
$f_{cd}$	Design value of cylinder compressive strength of concrete (smaller of the two values for existing concrete and overlay)
$f_{ct,eff}$	Tensile strength of overlay effective at the time when the cracks may first be expected to occur as per [1], Section 4.4.2.2 (for general cases: $f_{ct,eff} = 3$ N/mm <sup>2</sup> )
$\sigma_{Nd}$	Normal stress resulting from an external load normal to the interface (positive compression)
$\tau_{Rd}$	Basic design shear strength of concrete as per [1], Section 4.3.2.3

### Factors and coefficients:

$g_{ms}$	Partial safety factor for steel
$g_s$	Partial safety factor for steel
$g_{mc}$	Partial safety factor for concrete
$g_c$	Partial safety factor for concrete
$f_{B,N}$	Concrete strength influencing factor
$k$	Coefficient to allow for non-uniform self-equilibrating stresses = 0.8 for $t_{new} \leq 30$ cm
$k_1$	Factor for anchoring in overlay
$k_c$	Coefficients for aggregate interlocking as per Table 7
$k_T$	Cohesion factor as per Table 5
$\alpha$	Coefficient for effective dowel action as per Table 5
$\alpha_1$	Long-term factor for concrete

**B 2.5****Hilti HCC-B for concrete overlays**

EC-2 ; 1992

$\beta$	Coefficient for effective concrete strength as per Table 5
$\gamma$	Factor as per Table 8
$\mu$	Coefficient of friction as per Table 5
$\nu$	Efficiency factor as per [1] Formula (4.20), also refer to Table 6
$\kappa$	Coefficient for effective tensile force in the connector as per Table 5
$\rho$	Reinforcing ratio corresponding to connectors at interface under consideration = $A_s/b_j l_j$
$\rho(V_{max})$	Minimum reinforcement ratio for shear flow
$\rho(v)$	Minimum reinforcement ratio for shear flow
$\rho_{perf}$	Required reinforcement ratio
$\rho_{vorh}$	Existing interface reinforcement ratio
$n_{erf.}$	Number of required shear connectors = $\frac{\rho \cdot b_j \cdot l_j}{A_s}$
$n$	Number of shear connectors

## 8 Literature

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