Fastening Technology Manual

Connections for Concrete Overlays

B 2.3

B 2.3 Connections for Concrete Overlays

Foreword

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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 with the aid of specific shear tests for a variety of surface treatments as carried out by Hilti Corporate Research.

The Institute for Concrete Structures of the University of Innsbruck, Austria, provided scientific support during the development of this 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 known from 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 makes use of a single equation for calculating the resistance of the bond interface from the three components for different surface treatments.

With increasing surface roughness, shear resistance and shear stiffness are significantly improved. 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 and is particularly notable for its transparency. Through the use of design diagrams, the method can be made straightforward for designers. This makes it suitable for wide-scale use.

Wicke

M. Wicke

Connections for Concrete Overlays B 2.3

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1. Concrete overlay connection

1.1 Application range

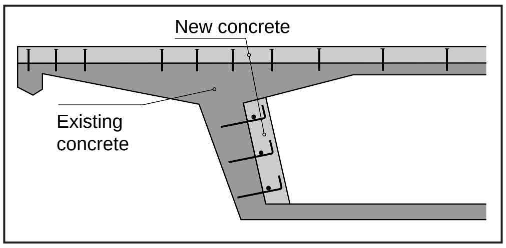


Figure 1: Strengthening a bridge deck

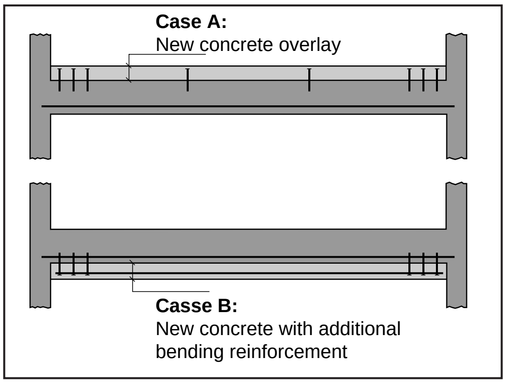


Figure 2: Strengthening a building floor

If a new layer of concrete is applied to existing concrete with the aim of strengthening or repairing a structure, reference is made to a composite concrete structure. This overlay is usually cast directly or placed as shotcrete. It functions to augment the flexural compression or flexural tension zones, depending on the 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. Forces of constraint caused by differential shrinkage and, possibly, by differential temperature gradients cannot be avoided, however. Initially, stresses in the bond interface result from a combination of external loads and internal forces of constraint. 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 external 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 are dependent on time, and bond failure can take place years after overlay placement. When this happens, the tensile forces set up must be taken up by reinforcement or connectors positioned across the interface. Typical examples are shown schematically in Figures 1 and 2.

1.2 Reference to other Hilti manuals

This manual describes a particular application from the Hilti Manual B 2.2 “Rebar Fastening Guide” [5]. For the following, it is assumed that the reader is familiar with this Manual as well as the information in Manual B 3.2 “Product Information” [6] about the use of adhesive anchors for special cases.

1.3 Advantages of the method

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

Repairing a bridge pavement

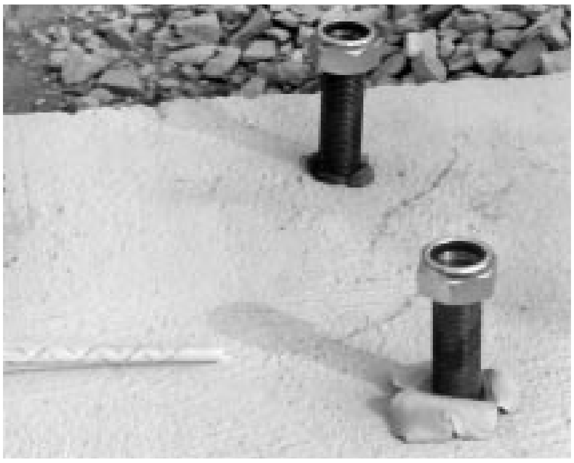
- Removal of damaged concrete layer using high-pressure water jetting
- Anchoring of additional reinforcement using HIT-HY 150
- Installation of shear connectors using HIT-HY 150
- Placement of new concrete overlay

✔ Monolithic load-bearing behavior
✔ Reliable transfer of shear
✔ Stiff connection
✔ Reduced anchor 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-HY 150 according to the engineer's instructions
- Inspection, if necessary, of concrete surface for roughness and pull-away strength, and of connectors for pull-out strength
- Placement of reinforcement and overlay concrete

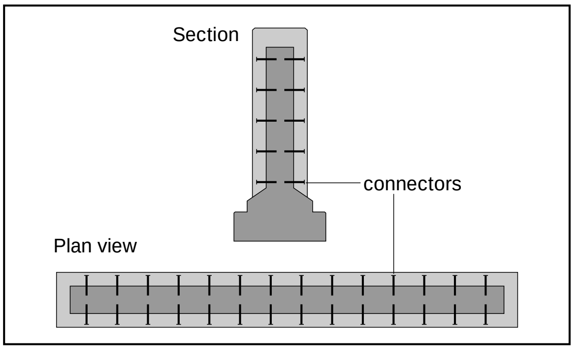
✔ Monolithic load-bearing behavior
✔ Reliable shear transfer; verifiable
✔ Adequate connection stiffness
✔ Small anchorage depth



Strengthening an industrial building foundation

- Exposure of foundation
- Installation of connectors using HIT-HY 150 per design specifications (smooth surface)
- Placement of reinforcement and overlay concrete

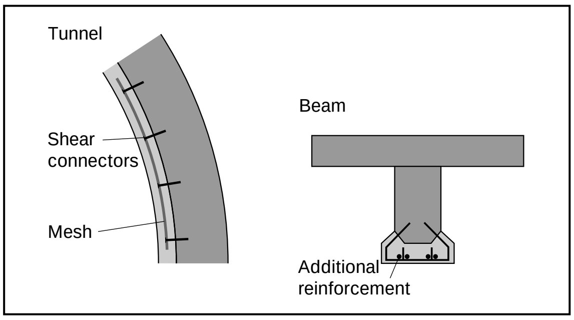
✔ Reduced labor
✔ Monolithic load-bearing behavior
✔ Reduced anchor embedment (6 diameters)
✔ Reliable shear transfer
✔ Ductile connection



Repairing and strengthening a pier

- Roughening of concrete surface
- Installation of shear connectors using HIT-HY 150 per design specifications
- Placement of reinforcement and overlay concrete

✔ Monolithic load-bearing behavior
✔ Reliable shear transfer
✔ A stiff connection
✔ Reduced anchor embedment



Repair and strengthening with shotcrete

- Roughening of concrete surface
- Installation of shear connectors using HIT-HY 150
- Placement of reinforcement and overlay concrete

✔ Monolithic load-bearing behavior
✔ Reliable shear transfer
✔ A stiff connection
✔ Reduced anchor embedment

2. Product information Hilti HIT-HY150

2.1 The injection system

The Hilti HIT-HY 150 injection system is designed to be safe and simple in application resulting in high-quality reinforcement anchorages.

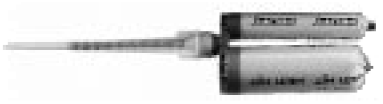
Components:

Dispenser MD 2000:

Manual dispenser
Ergonomic design
Consistent performance

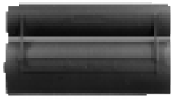
Dual foil pack:

330-ml of two-component adhesive
Opens automatically
Reliable mixing



Holder as “refillable cartridge”:

Stability in use
Storage function
Reduction of waste



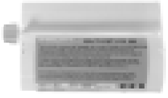
System 2:

Dispenser P5000HY:

Pneumatic dispenser
Ergonomic design
Designed for large applications

Dispenser P5000HY:

1100-ml of two-component adhesive



2.2 Adhesive bond

Hilti HIT-HY 150 adhesive is a hybrid system consisting of organic and inorganic binding agents.

The resin components provide for excellent bond after polymerization resulting in a rapid-curing injection system with favorable handling characteristics.

The cementitious reaction improves the stiffness and bonding, especially at higher temperatures.

Interaction of the two components reduces shrinkage to a negligible amount.

The result is excellent bond stress development between connector and concrete, equatable to that of cast-in rebar.

HY-150 adhesive contains no styrene and is virtually odorless.

Organic agents

+

Cementitious agents

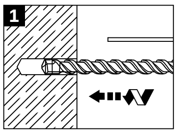
↓

Strong hybrid bond

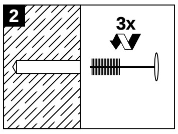
2.3 Installation

Prepare hole

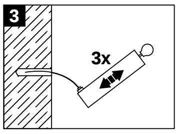
Drill the hole for the connector using a rotary impact hammer; drill and carefully clean the hole.



Drill hole



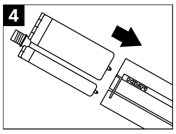
Brush out hole



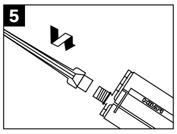
Blow out hole
Hole must be dry

Prepare HIT system

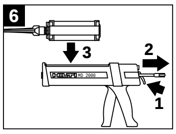
Partly-used dual foil packs can be stored in the holder for up to four weeks. To restart, just change the mixer nozzle. Reject material from the first trigger pull.



Insert foil pack into holder



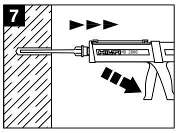
Screw mixer onto foil pack



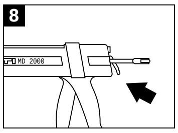
Put this assembly into MD 2000 dispenser

Inject adhesive and insert connector

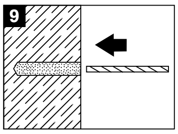
Fill the hole from the bottom up to avoid air bubbles. Insert the connector. Some mortar should be displaced from the hole as an indication of complete coverage.



Fill hole



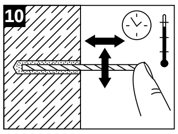
Unlock dispenser



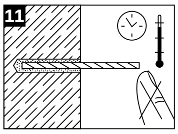
Insert connector

Allow to cure

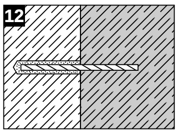
Allow the adhesive to cure completely before applying any load.



Align connector



Allow to cure



Place overlay

3. Design of interface

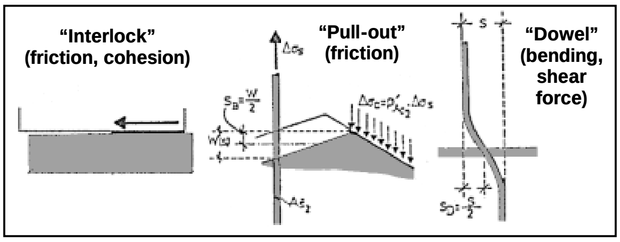
3.1. Basic considerations

Structures made of reinforced concrete or prestressed concrete which have a concrete overlay at least 40 mm thick ([2], Section 2.5.3.5.8 (109)), or at least 60 mm thick on bridge structures, may be designed as monolithic building components if shear forces at the interface between the new and the old concrete are resisted in accordance with the following rules:

3.2. Ultimate limit state for shear transfer at the interface

3.2.1 Principle and set-up of the model

Actions at the interface between new and old concrete are determined from the overall forces acting on the entire building component.
As a rule for the design, it must be assumed that the interface is de-bonded.
Reinforcement or connectors crossing the interface surface must be placed in such a way that shear forces at the interface are transferred in the ultimate limit state.



As a result of the separation of the interface surfaces, connectors are subjected to a tensile force and simultaneously to a bending moment depending 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.

3.2.2 Design shear resistance at interface, V_{Rd}

$$\boxed{V_{Rd} \geq V_{Sd}} \tag{1}$$

Where:

$$\boxed{V_{Rd} = \tau_{Rdj} \cdot b_j \cdot l_j} \tag{2}$$

V_{Rd}	design shear resistance at interface
V_{Sd}	design shear force acting at interface as per section 3.3
τ_{Rdj}	design shear strength at interface under consideration as per Formula (3) and Diagrams 1 to 3
b_j	effective width of interface under consideration
l_j	effective length of interface under consideration

3.2.3 Design shear strength at interface, τ_{Rdj}

Formula (3) is used to calculate the design shear strength at the interface, τ_{Rdj} [8]. When doing so, an upper limit is given by the design strength in the concrete struts:

$$\boxed{\tau_{Rdj} = \underset{\text{cohesion}}{k_T \cdot \tau_{Rd}} + \underset{\text{friction}}{\mu \cdot (\rho \cdot \kappa \cdot f_{yd} + \sigma_n)} + \underset{\text{dowel action}}{\alpha \cdot \rho \cdot \sqrt{f_{yd} \cdot f_{cd}}} \leq \underset{\text{concrete struts}}{\beta \cdot \nu \cdot f_{cd}}} \tag{3}$$

Where:

τ_{Rd}	basic design shear strength of concrete as per [1], Section 4.3.2.3 (the smaller value of new or old concrete), refer also to Table 2.
k_T	cohesion factor as per Table 1
μ	coefficient of friction as per Table 1
κ	coefficient for effective tensile force in the connector as per Table 1
α	coefficient for effective dowel action as per Table 1
β	coefficient for effective concrete strength as per Table 1
ν	efficiency factor as per [1], Formula (4.20); also refer to Table 2.
$\rho = A_s / b_j l_j$	reinforcing ratio corresponding to connectors of interface under consideration
$\sigma_n \leq 0,6 f_{cd}$	normal stress certainly acting on interface (positive compression)
f_{yd}	design value of yield strength of connector
f_{cd}	design value of cylinder compressive strength of concrete (smaller value of new or old concrete)
R_t	mean depth of interface roughness, measured according to the sand-patch method [9]

Concrete surface treatment	Mean depth of roughness R_t [mm]	Coefficients				μ	
		k_T	κ	α	β	$f_{ck} \geq 20$	$f_{ck} \geq 35$
High-pressure water jets / Scoring	> 3.0	2.3	0.5	0.9	0.4	0.8*)	1.0*)
Sandblasting / Chipping hammer	> 0.5	0	0.5	1.1	0.3	0.7	
Smooth: wood or steel forms or no forms	–	0	0	1.5	0.2	0.5	

Table 1: Parameters for Formula (3)

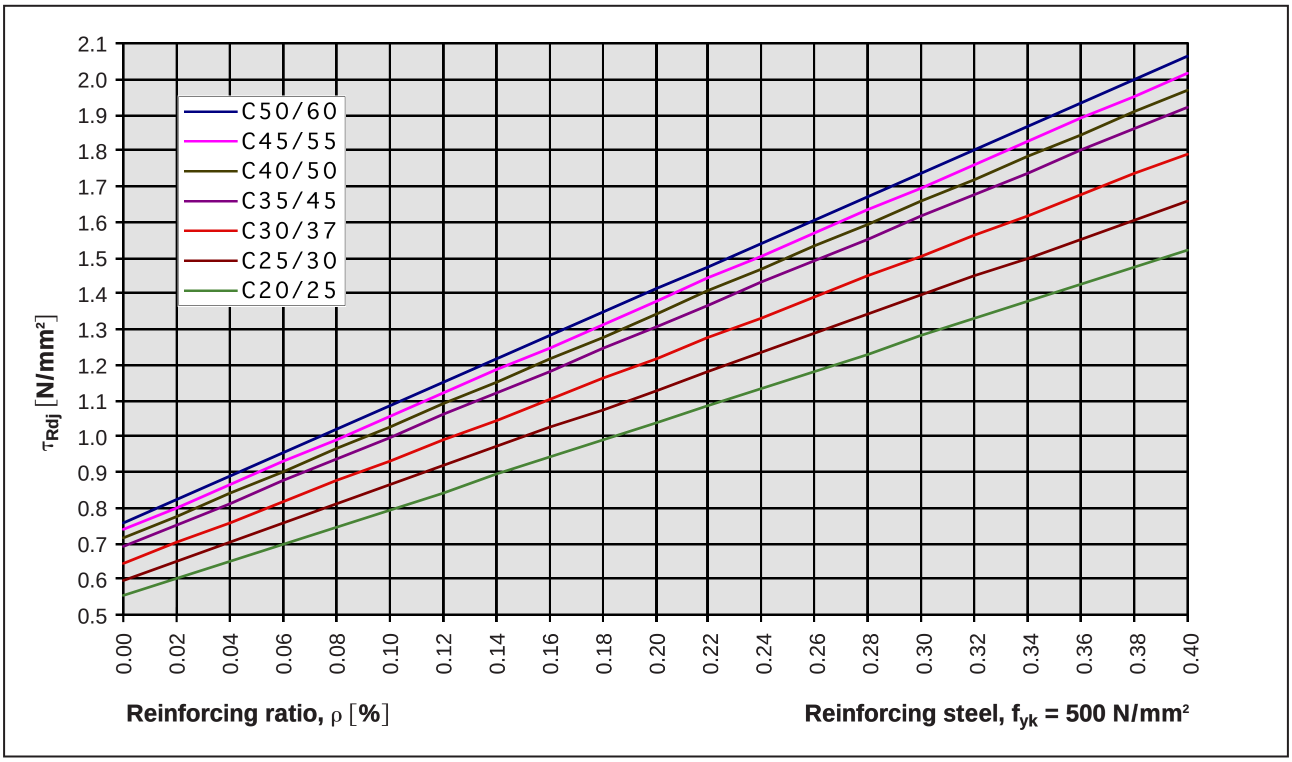
*) Intermediate values may be linearly interpolated.

Concrete strength class		C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60
f_{ck}	[N/mm²]	20	25	30	35	40	45	50
f_{cd}	[N/mm²]	13.3	16.7	20.0	23.3	26.7	30.0	33.3
ν		0.60	0.58	0.55	0.53	0.50	0.50	0.50
τ_{Rd}	[N/mm²]	0.24	0.26	0.28	0.30	0.31	0.32	0.33

Table 2: τ_{Rd} and υ (as per [1]; Table 4.8).

Diagram 1: for surfaces roughened with high-pressure water jets or scored

(mean roughness R_t > 3 mm, i.e. peaks > approx. 6 mm high)



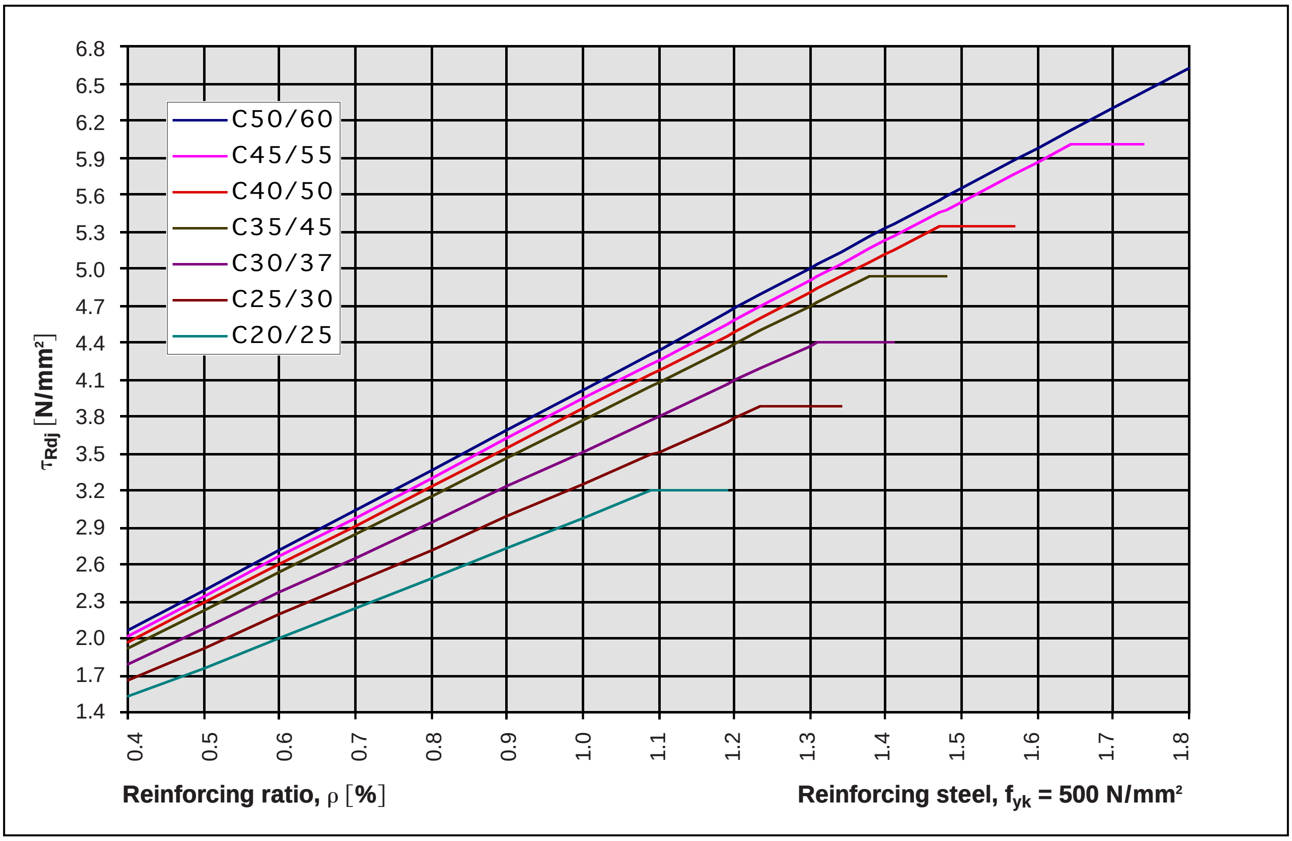
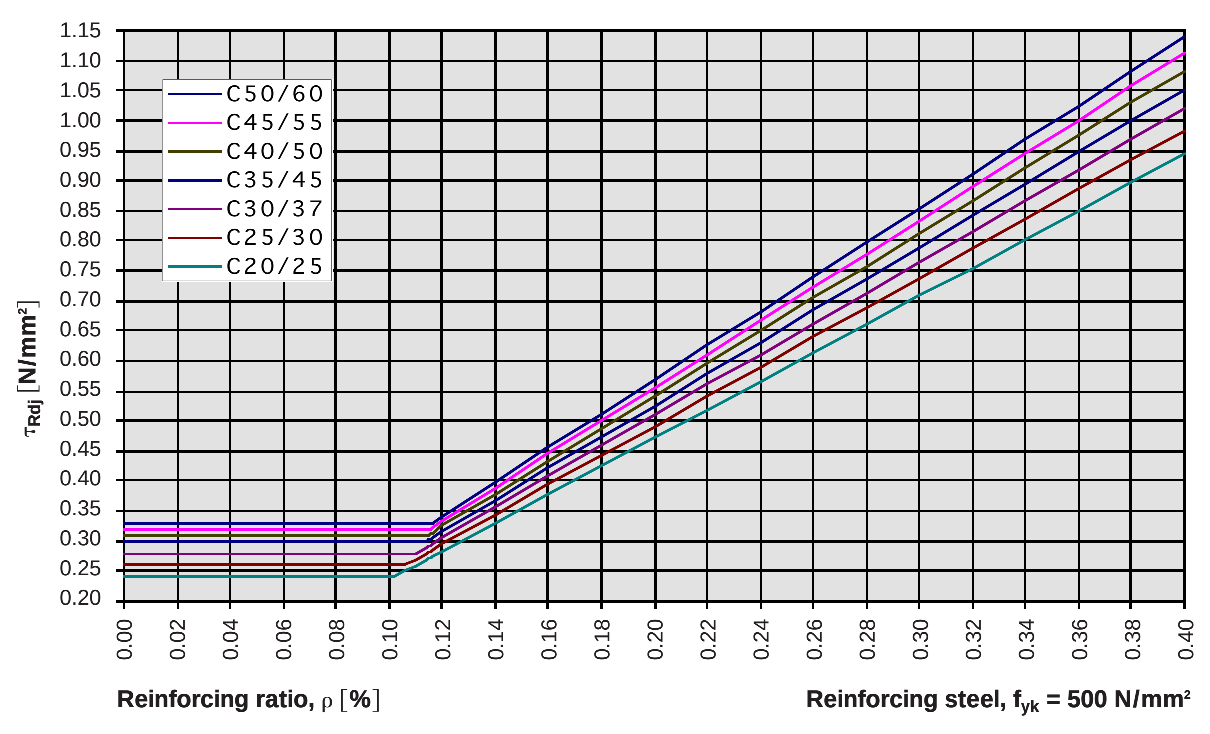


Diagram 2: for sand-blasted surfaces

(mean roughness R_t > 0.5 mm, i.e. peaks > approx. 1.0 mm high)



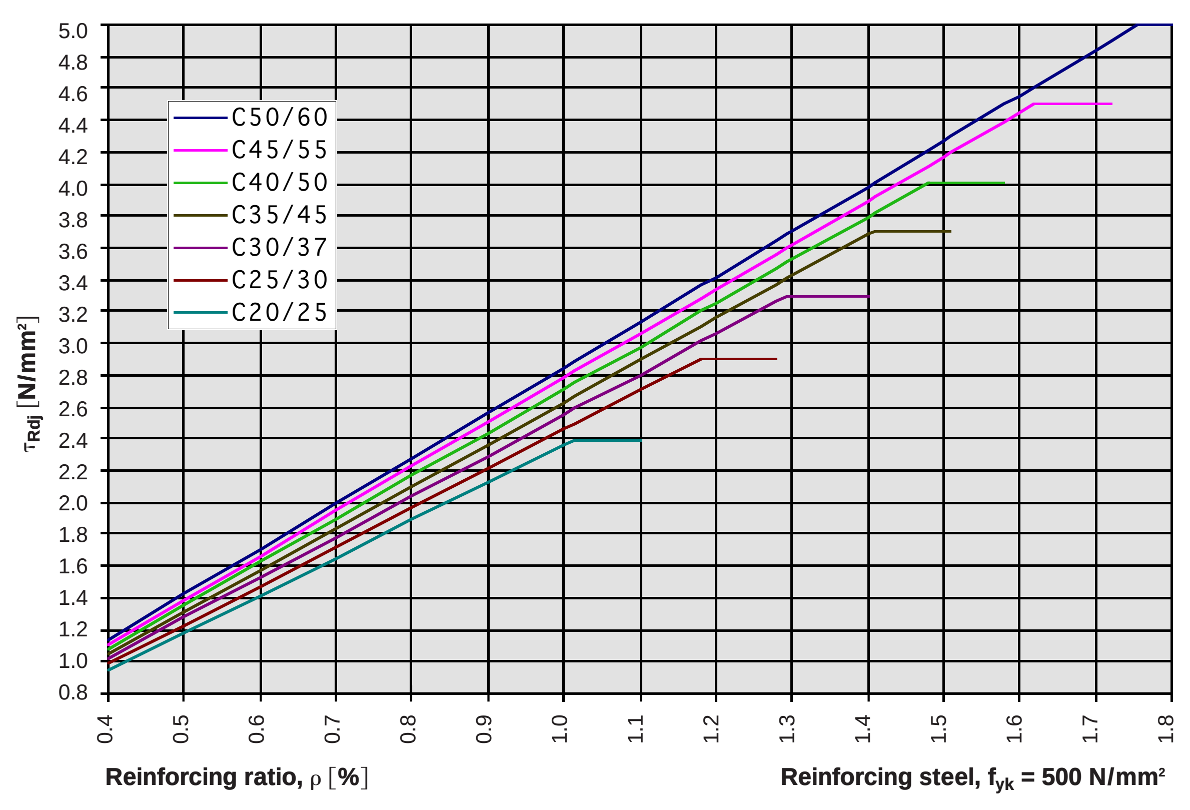
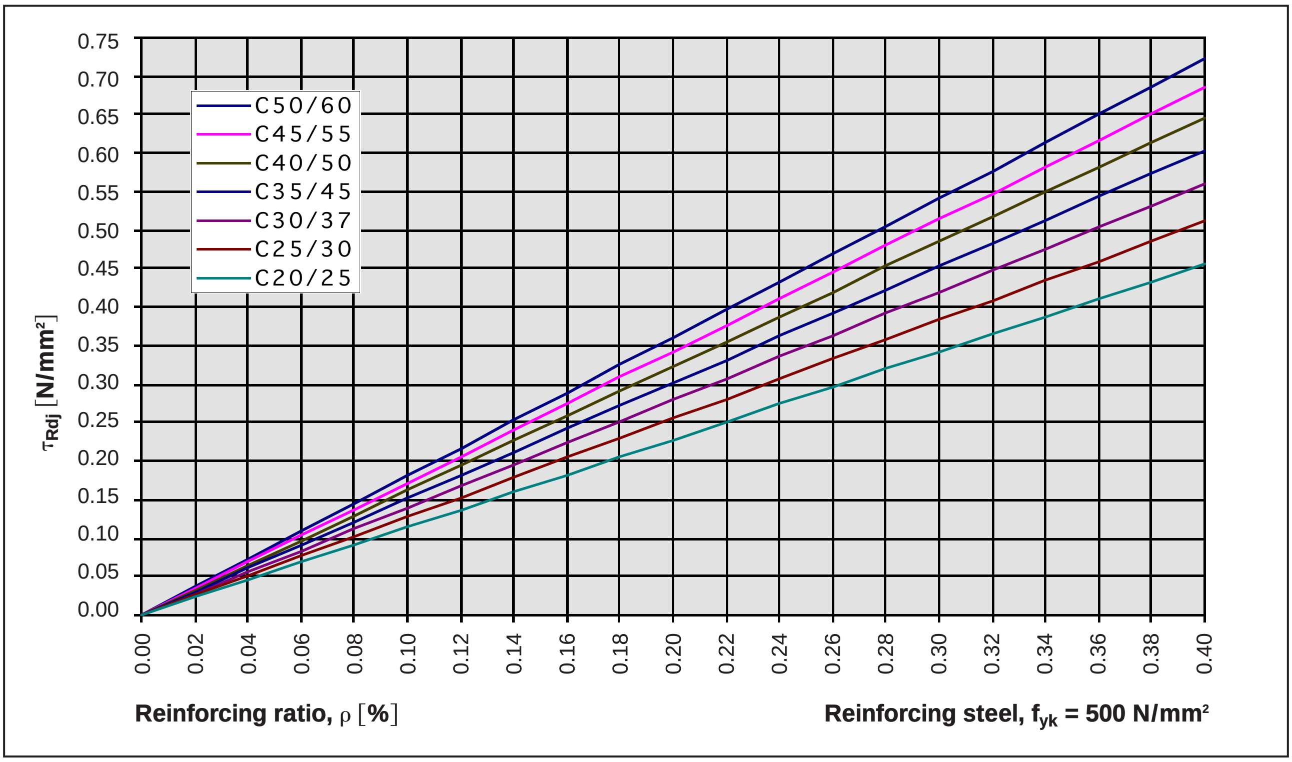
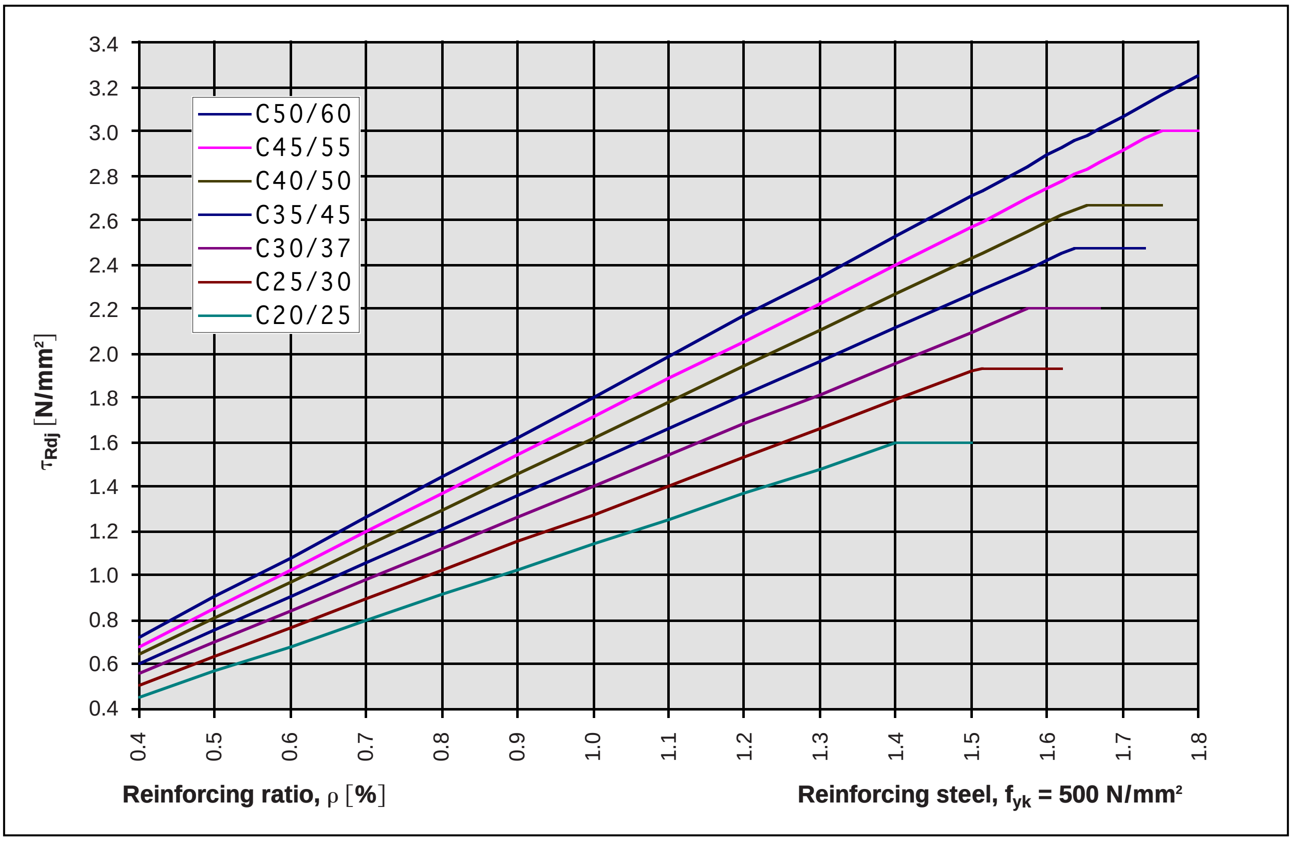


Diagram 3: for smooth cast surfaces

(wood forms, steel forms, no forms)

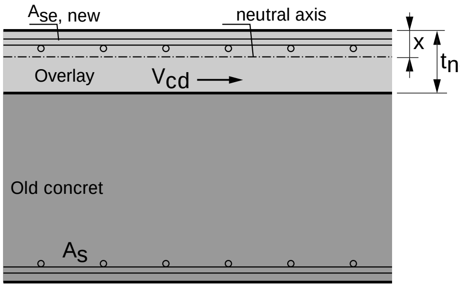




3.3. Design shear force acting longitudinally at interface, V_{Sd}

Normally, V_{Sd} is calculated from the bending resistance of the cross-section. (Shear failure of the member should not govern.)

3.3.1 Augmentation of compression zone



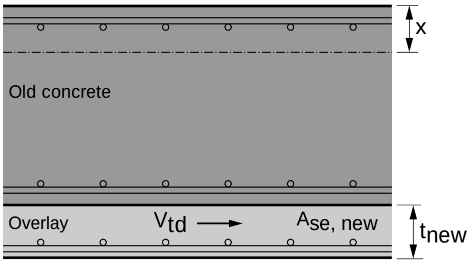
$$\boxed{V_{cd} = 0{,}8 \cdot x \cdot b_{new} \cdot \alpha \cdot f_{cd} + A_{se,new} \cdot f_{yd}} \qquad (4)$$

0,8	Reduction factor for non-rectangular stress distribution
$\alpha = 0{,}85$	Reduction factor for sustained compression

for: $x > t_{new}$ as an approximation:

$$\boxed{V_{cd} = t_{new} \cdot b_{new} \cdot \alpha \cdot f_{cd} + A_{se,new} \cdot f_{yd}} \qquad (5)$$

3.3.2 Augmentation of tension zone



$$\boxed{V_{td} = A_{se,\,new} \cdot f_{yd}} \qquad (6)$$

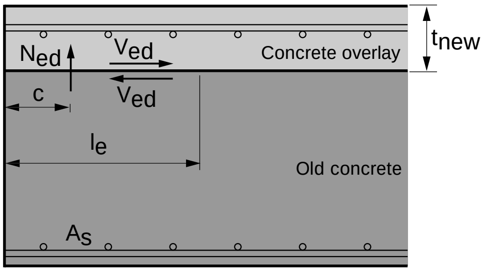
If the reinforcement is staggered: allow for gradation

3.3.3 Shear force to be transferred at overlay perimeter

At the edges of a new concrete overlay, the design must consider a minimum tensile force F_{cr}. Here, particular attention must be paid to transferring the moment arising from F_{cr}:

$$\boxed{F_{cr} = t_{new} \cdot b \cdot k \cdot f_{ctk,eff}} \qquad (7)$$

F_{cr}	tensile force effective in the overlay at the time when the cracks may first be expected to occur, as per [1], Section 4.4.2.2
$k = 0{,}8$ for $t_{new} \leq 30$ cm	coefficient to allow for non-uniform self-equilibrating stresses
$f_{ct,eff}$	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^2)



The following values may be used without further verification:

$$\boxed{V_{ed} = F_{cr}} \qquad (8)$$

$$\boxed{N_{ed} = \frac{V_{ed}}{6}\ ;\ c \leq 1.5 \cdot t_{new}} \qquad (9)$$

V_{ed}	shear force at interface derived from F_{cr}
N_{ed}	tensile force resulting from moment of 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
c) $l_e = 9\ t_{new}$ for smooth surfaces

3.3.4 Regions without connectors

For low shear stresses, connectors need not be used in the field of the overlay if the load is predominantly static and if connectors are positioned around the perimeter in accordance with Section 3.3.3.

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

$$\boxed{\tau_{Sd} \leq k_T \cdot \tau_{Rd} + \mu \cdot \sigma_n} \tag{10}$$

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:

$$\boxed{\tau_{Sd} \leq \tau_{Rd} + \mu \cdot \sigma_n} \tag{11}$$

3.4 Serviceability limit state

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

$$\boxed{w_{eff} = \gamma \cdot w_{calc}} \tag{12}$$

w_{eff}	additional deformation calculated for the reinforced section considering the flexibility of the connectors
w_{calc}	additional deformation calculated for the reinforced section assuming perfect bond
γ	factor per Table 3
s_d	displacement of connectors under the mean permanent load ($F_P \approx 0.5\ F_{uk}$)

The displacement, s_d, per Table 3, can be used for more accurate calculations.

Surface treatment	Mean roughness R_t [mm]	γ	s_d [mm]
High-pressure water jets / Scoring	> 3.0	1.0	≈ 0.005 dia.
Sand-blasting / Chipping hammer	> 0.5	1.1	≈ 0.015 dia.
Smooth: wood forms /steel forms/ no forms	–	1.2	≈ 0.030 dia.

Table 3: Coefficients for calculation of deformation

dia. = diameter of connectors

3.5 Additional rules and detailing provisions

3.5.1 Mixed surface treatments

Variable surface treatments may only be used on the same building component if the different stiffnesses of the connections are taken into account. (See also Table 3, displacement s_d.) Note that a non-cracked interface, i.e., rigid bond, is assumed for interfaces with small shear stresses not requiring field connectors, as per Section 3.3.4.

3.5.2 Minimum amount of reinforcement at the interface

The following minimum amount of reinforcement passing through the interface must be provided if connectors cannot be omitted as described in Section 3.3.4:

1) Slabs and other structures in which no shear reinforcement is necessary:
   a) For rough interface surfaces (high-pressure water jet and scored): $\rho \geq 0.08\%$
   b) For sand-blasted interface surfaces $\rho \geq 0.12\%$
   c) For smooth interface surfaces: $\rho \geq 0.12\%$
2) Beams and other structures with shear reinforcement as per [1], Section 5.4.2.2

3.5.3 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 acting shear force in such a way that both the shear force at the interface can be taken up and de-bonding of the new concrete overlay is prevented.

(2) In sand-blasted and smooth surfaces, the connectors may be equidistantly positioned over the corresponding length, l_j, between neighboring critical sections when the load is predominantly static. According to [3], Section 4.1.2 (4), critical sections are points subject to maximum bending moments, support points, points where concentrated loads are acting and points with sudden changes in cross-section.

(3) If the new concrete overlay is on the tension side of the load-bearing component, the connectors must be distributed according to the graduation of the longitudinal reinforcement without making any allowance for anchorage lengths.

(4) 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.

3.5.4 Anchorage of connectors in the old and the new concrete

(1) The connectors must be adequately embedded in the old concrete and the new overlay. The actually anchored tensile force, N_d, may be assumed to be:

$$\boxed{N_d \geq \kappa \cdot A_S \cdot f_{yd}} \qquad (13)$$

κ = coefficient as per Table 1.

(2) The type of application is decisive when determining the anchorage depth in the base material:

(2a) Zones with shear reinforcement or other connecting reinforcement (Figure 7):
The basic value of anchorage depth, l_b, must be determined according to [5] (Rebar Fastening Guide, Table 3.4.1). The minimum anchorage depth is 10 times the diameter.
It must be borne in mind that this generally concerns an overlap of the connector and existing reinforcement ($l_s = \alpha_1 \cdot l_b$, see [1], Section 5.2.4).
Furthermore, the tensile force from the trussed-frame analogy as per [1], Section 4.3.2.4 must be verified for building components with required shear reinforcement.

(2b) Zones without shear reinforcement ($V_{Sd} \leq V_{Rd1}$) or any other connecting reinforcement (Figure 8):
The anchorage depth must be determined as per [5] (Rebar Fastening Guide, Table 3.4.1). The edge distances and spacing (c_1, s) of adhesive anchors must be ascertained according to anchor design [6].

Cracks in concrete generally reduce the tensile loading capacity of adhesive anchors. If cracking is anticipated, the anchorage depth must be increased, e.g., in the case of pure tensile reinforcement or strengthening for bending with high shear force near beam supports or for concentrated loads.

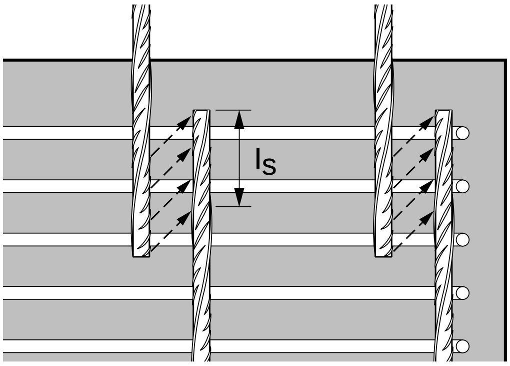


Figure 7: Rebar fastening design

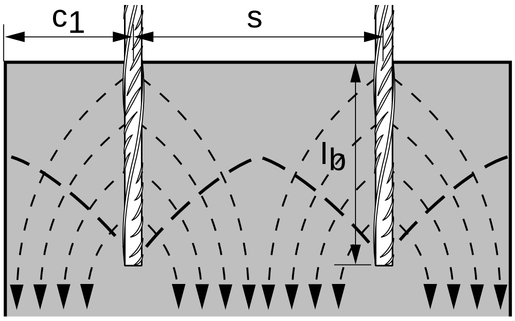


Figure 8: Anchor design

(3) Plates, nuts or forged-on heads can be used to reduce the anchorage depth of connectors in a new concrete overlay. If such a connector is used, the following checks must be made:

a) Concrete cone failure must be checked in accordance with [7], Section 15.1.2.4.

Sufficient reinforcement against splitting must be provided to take up splitting forces set up locally at the top of the connectors. Calculation of the splitting forces may be based on a truss framework model which has a line of compressive action at an angle of 45º.

Normally, the connectors should extend into the upper reinforcement of the concrete overlay and form a truss framework node there.

b) The concrete bearing pressure under the head is limited as per [7] Section 15.1.2.3, or [1], Section 5.4.8.1.

(4) If interface surfaces are smooth, connectors must be provided with an embedment of at least 6 diameters (9 diameters recommended).

3.5.5 Minimum reinforcement in overlay

The procedure in [1] must be adopted 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

3.5.6 Recommendation for overlay placement

Pre-treatment:
A primer consisting of thick cement mortar is recommended.
The old concrete should be adequately pre-wetted (24 hours earlier the first time) before applying the cement mortar primer. At the time of placing the primer, the concrete surface should have dried to such an extent that it has only a dull moist appearance.
The mortar used as primer should consist of water and equal parts by weight of Portland cement and sand of particle size 0/2 mm. This mortar is then applied to the prepared concrete surface and brushed in.
Overlay:
The concrete mix for the overlay should normally be such that a low-shrinkage concrete results ($W/C \leq 0.40$). The overlay must be placed on the still fresh primer i.e. wet on wet.
Curing:
Careful follow-up is necessary to ensure good durability of the overlay. Starting immediately after placement, the concrete overlay must be protected for a sufficiently long period, but at least five days, against drying out and excessive cooling.

3.5.7 Recommendation for surface treatment specification

The roughness of the interface surface has a decisive influence on the shear force that can be transferred. In the case of this design process, the dimension to be measured is the mean depth of roughness, R_t, measured according to the sand-patch method [9]. It must be borne in mind that R_t is a mean value and thus the difference between the peaks and valleys is about $2R_t$.
It is recommended that a mean depth of roughness, R_t, be stipulated when specifying the interface surface treatment. Prior to approving the treatment, a sample surface must be made and this then checked on the basis of the sand-patch method.

4. Examples

4.1 Example: Double-span slab

Given:

Concrete: Overlay: 70 mm: C 30/37
Old concrete 150 mm: C 25/30

Reinforcement: S500, $f_{yk} = 500\ \text{N/mm}^2$
Span: $A_{se}^{+} = 1'030\ \text{mm}^2/\text{m}$
Support: $A_{se}^{-} = 1'420\ \text{mm}^2/\text{m}$

Cracking tensile force at edge (3.3.3):

$V_{ed} = 70 \cdot 1 \cdot 0.8 \cdot 3 = 168\ \text{kN/m}$

Span:

Neutral axis: $x_d = \dfrac{1030 \cdot 0.5 \cdot 1.5}{1.15 \cdot 30 \cdot 0.85 \cdot 0.80} = 33\text{mm}$

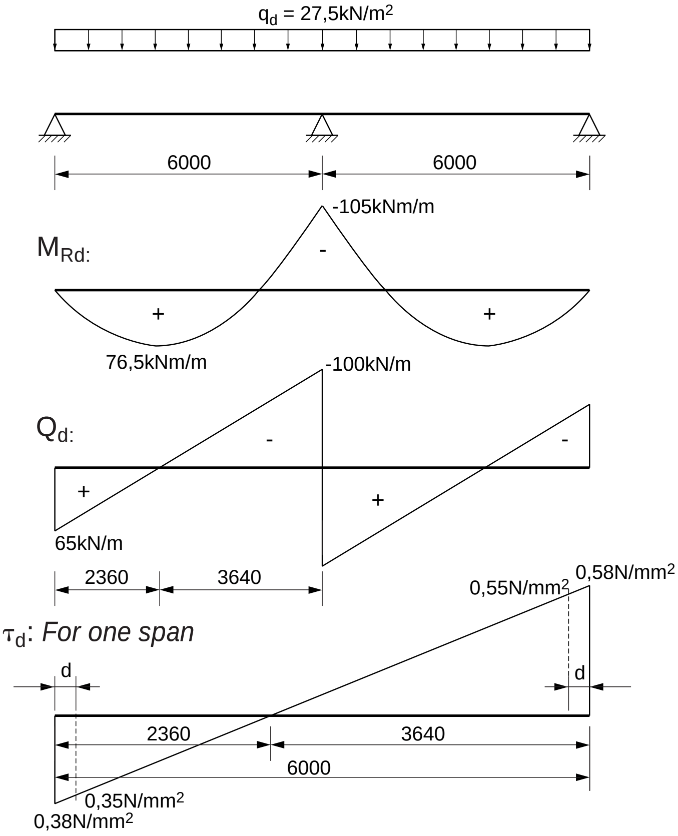
➥ $V_{cd} = 0.85 \cdot 0.80 \cdot 33 \cdot 30/1.5 = 449\ \text{kN/m}$

Support: $A_{se} = 1420\ \text{mm}^2/\text{m}$
$V_{td} = 1420 \cdot 0{,}5/1.15 = 617\ \text{kN/m}$

Max. values of shear stress at interface:

$$\tau_{cd\ max} = \frac{449 \cdot 2}{2360} = 0.38\ \text{N/mm}^2$$

$$\tau_{td\ max} = \frac{(617 + 449) \cdot 2}{3640} = 0.58\ \text{N/mm}^2$$



a) Surface treatment: high-pressure water jet

Cohesion $\tau_{Rdj} = 2.3 \cdot 0.26 = 0.60 > 0.55\ \text{N/mm}^2$ ➡ no reinforcement required

Cracking tensile force at edge: $V_{ed} = 168\ \text{kN/m}$ (Section 3.3.3); Strip width, $l_e = 3 \cdot 70 = 210\ \text{mm}$

➥ $\tau_{td} = \dfrac{168'000}{1000 \cdot 210} = 0.8\ \text{N/mm}^2$ ➡ From diagram $\rho_{req} = 0.08\%$

➥ $A_s = 0.0008 \cdot 210 \cdot 1000 = 168\ \text{mm}^2/\text{m}$ ➡ selected dia. 8 s = 250 mm

Tensile force to be transferred by anchor: $N_d = 0.5 \cdot \dfrac{0.5}{1.15} \cdot 50.3 = 10.9\ \text{kN}$ (Formula 13)

➥ Anchored in old concrete: $h_{eff} = 100\ \text{mm}$ ➡ $N_{Rd} = 14.6\ \text{kN}$ ([5], Table Section 3.4.1)

selected: edge distance $c_1 = 100\ \text{mm}$ ➡ $N_{Rd,red} = 14.6 \cdot \dfrac{100}{130} = 11.2\ \text{kN}$ ([6] page 15)

➥ Anchored in overlay: head dia. = 14 mm

Transferable bearing force under head ([7], Section 2.1.2.3):

$N_{Rd,p} = \dfrac{7.5}{1.5} \cdot \dfrac{\pi}{4} \cdot (14^2 - 8^2) \cdot 30 = 15\ \text{kN} > N_{Rd} = 11.2\ \text{kN}$ ➡ OK

Concrete cone capacity: ([7], Section 2.1.2.4)

$N_{Rd,c} = \dfrac{9}{1.8} \cdot 30^{0.5} \cdot 55^{1.5} = 11.2\ \text{kN} = N_{Rd} = 11.2\ \text{kN}$ ➡ OK

Tensile force from resisted moment: $N_{ed} = \frac{168}{6} = 28.0$ kN/m (Formula 9)

$N_{Rd} = \frac{11.2}{0.25} = 44.8 > 28.0$ kN/m; $c_1 = 100 \leq 1.5 \cdot 70 = 105$ mm ➡ OK

Shear force to be anchored: $V_{ed} = 168$ kN/m: Sirrup-type reinforcement: $A_s = \frac{168 \cdot 1.15}{0.5} = 386\ \mathrm{mm}^2/\mathrm{m}$

Selected: Pins 8 dia. per connector (lap splice with mesh reinforcement 6.5 dia. s = 100 mm)

b) Surface treatment: sand-blasted

Cohesion: $\tau_{Rdj} = 0.26\ \mathrm{N/mm}^2$

At edge support: mean shear stress at interface $\bar{\tau}_d = \frac{0.35 + 0.26}{2} = 0.305\ \mathrm{N/mm}^2$

➥ From diagram: $\rho_{req} = 0.12$ % Strip width 745 mm

➥ $A_s = 0.0012 \cdot 1000 \cdot 745 = 894\ \mathrm{mm}^2/\mathrm{m}$
➡ selected: dia. 8 s = 200/200 mm

At intermediate support: mean shear stress at interface $\bar{\tau}_d = \frac{0.55 + 0.26}{2} = 0.405\ \mathrm{N/mm}^2$

➥ From diagram: $\rho_{req} = 0.16$ % Strip width 2015 mm

➥ $A_s = 0.0016 \cdot 1000^2 = 1600\ \mathrm{mm}^2/\mathrm{m}^2$
➡ selected: dia. 8 s = 200/150 mm

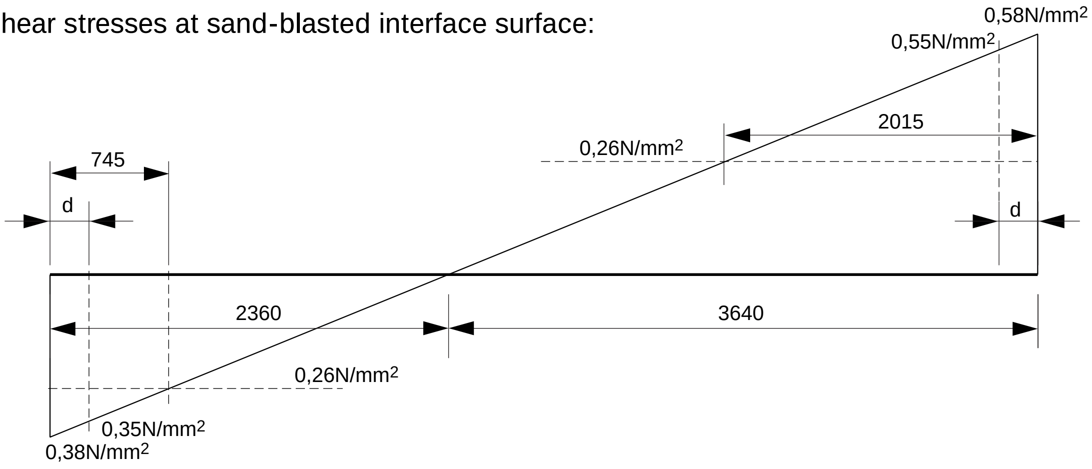
Cracking tensile force at edge: $V_{ed} = 168\ \mathrm{kN/mm}^2$ Strip width $l_e = 6 \cdot 70 = 420$ mm

➥ $\tau_d = \frac{168'000}{1000 \cdot 420} = 0.4\ \mathrm{N/mm}^2$ ➡ From diagram: $\rho_{req} = 0.16$ %

➥ $A_s = 0.0016 \cdot 420 \cdot 1000 = 672\ \mathrm{mm}^2/\mathrm{m}$
➡ selected: dia. 8 s = 200/150 mm

Forces to be anchored: same as a)

Bond shear stresses at sand-blasted interface surface:



c) Surface without treatment (smooth)

Edge support/span:

Mean shear stress at interface $\bar{\tau}_d = \frac{0.35}{2} = 0.175$ N/mm^2

➥ From diagram: $\rho_{req} = 0.15$ % Strip width 2360 mm

➥ $A_s = 0.0015 \cdot 1000^2 = 1500$ mm^2/m^2
➡ selected dia. 10 s = 200/250 mm

At intermediate support:

Mean shear stress at interface $\bar{\tau}_d = \frac{0.55}{2} = 0.275$ N/mm^2

➥ From diagram: $\rho_{req} = 0.23$ % half-strip width 3640 mm

➥ $A_s = 0.0023 \cdot 1000^2 = 2300$ mm^2/m^2
➡ selected dia.10 s = 200/170 mm

Cracking tensile force at edge:

$V_{ed} = 168$ kN/mm^2 Strip width $l_e = 9 \cdot 70 = 630$ mm

➥ $\tau_d = \frac{168'000}{1000 \cdot 630} = 0.27$ N/mm^2
➡ From diagram: $\rho_{req} = 0.23$ %

➥ $A_s = 0.0023 \cdot 630 \cdot 1000 = 1449$ mm^2/m
➡ selected dia. 10 s = 200/170 mm

Anchorage of dowel:
Forces to be anchored:

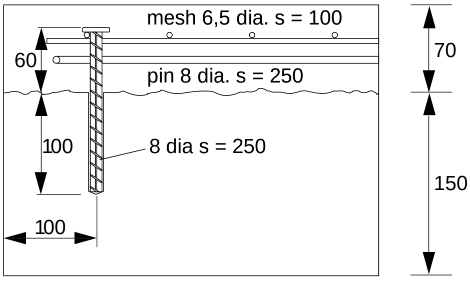
l_b = 6 times dia., = 60 mm in new and old concrete
Every second connector in an edge row should be a headed connector designed as in a)

$N_{Rd} = \frac{11.2}{0.34} = 32.9 > N_{ed} = 28.0$ kN

Anchoring against de-bonding:

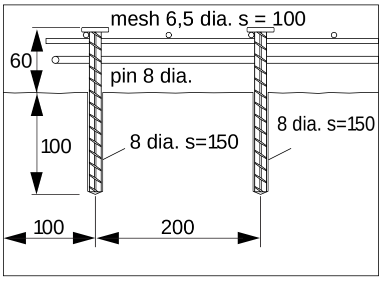
It is recommended, that a suitable number of headed connectors also be installed in appropriate locations to prevent the concrete overlay from de-bonding locally.

High-pressure water jet



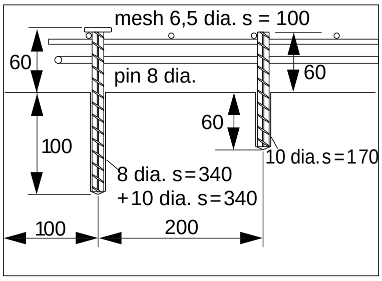
Connectors only at edge
8 dia. s = 250 mm headed connector

Sand-blasted



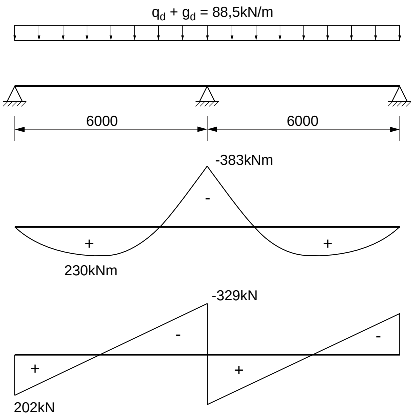
Connectors at edge:
8 dia. s = 200 / 150 mm headed connector
Edge support:
8 dia. s = 200 / 200 mm headed connector
Strip width: b_{tot} = 745 mm
Intermediate support:
8 dia. s = 200 / 150 mm headed connector
Strip width: b ≥ 2 x 2015 mm

Smooth

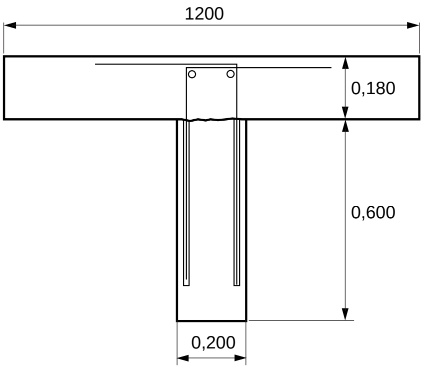


Connectors at edge
1st row 10 dia. s = 340 mm shear dowel
+ 8 dia. s = 340 headed connector
10 dia. s = 200 / 170 mm shear dowel
Edge strip width: b = 630 mm
10 dia. s = 200/250 mm shear dowel
Strip width: b_{tot} = 2360 mm
Intermediate support:
10 dia. s = 200 / 170 mm shear dowel
Strip width: b ≥ 2 x 3640 mm

4.2 Example: Double-span beam with new slab



Cross-section:



Given:

Concrete: New slab: C 30/37, Beam C 25/30

Reinforcement: Rebar S500; $A_{se}^{+} = 804\ \text{mm}^2$; $A_{se}^{-} = 1340\ \text{mm}^2$ $f_{yk} = 500\ \text{N/mm}^2$

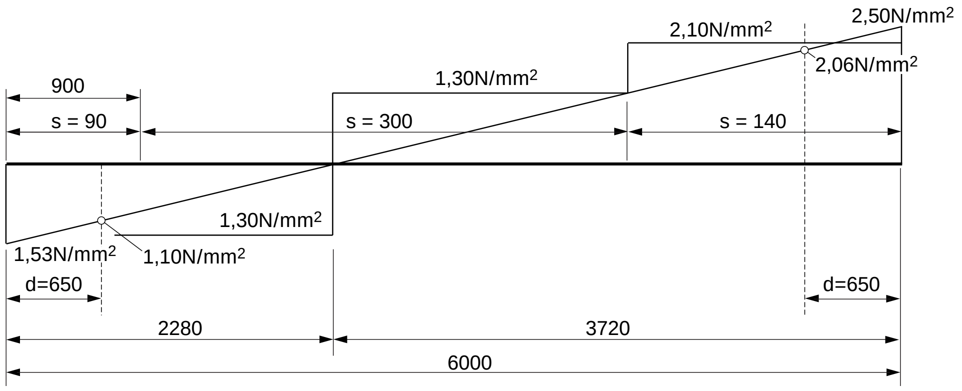
Span: Neutral axis $x_d = \dfrac{804 \cdot 0.5 \cdot 1.5}{1.15 \cdot 0.8 \cdot 0.85 \cdot 1.2 \cdot 30} = 21.4\ \text{mm}$

$V_{cd} = 1.20 \cdot 0.8 \cdot 0.85 \cdot 21.4 \cdot \dfrac{30}{1.5} = 349\ \text{kN}$ ➡ $\tau_{cd} = \dfrac{349 \cdot 10^3 \cdot 2}{2280 \cdot 200} = 1.53\ \text{N/mm}^2$

Intermediate support: $V_{td} = 1340 \cdot \dfrac{0.5}{1.15} = 583\ \text{kN}$ ➡ $\tau_{td} = \dfrac{(349 + 583) \cdot 10^3 \cdot 2}{3720 \cdot 200} = 2.50\ \text{N/mm}^2$

Edge: Cracking tensile force: $V_{ed} = 1.2 \cdot 180 \cdot 0.8 \cdot 3 = 518\ \text{kN}$; $l_e \approx 0.75\ b = 900\ \text{mm}$ ➡ $\tau_{ed} = \dfrac{518 \cdot 10^3}{900 \cdot 200} = 2.9\ \text{N/mm}^2$

Minimum reinforcement [1], Table 5.5: $\rho_{min} = 0.26\ \%$, $s_{max} = 300\ \text{mm}$



2 dia. 10	s = 300 mm	$A_s = 523\ \text{mm}^2/\text{m}$	$\rho = 0.26\ \%$	$\tau_{Rd} = 1.3\ \text{N/mm}^2$
2 dia. 10	s = 140 mm	$A_s = 1121\ \text{mm}^2/\text{m}$	$\rho = 0.56\ \%$	$\tau_{Rd} = 2.1\ \text{N/mm}^2$
2 dia. 10	s = 90 mm	$A_s = 1743\ \text{mm}^2/\text{m}$	$\rho = 0.87\ \%$	$\tau_{Rd} = 2.9\ \text{N/mm}^2$

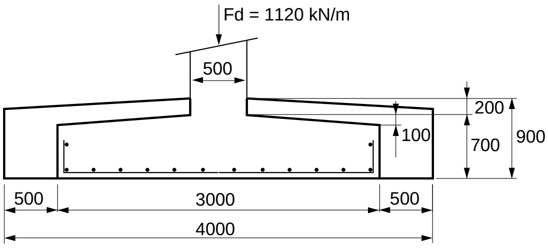
Notes:

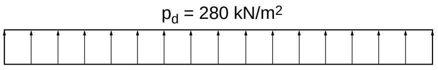
- The anchorage length is determined by the existing stirrup-type reinforcement (lap splice).
- The shear stresses at the interface are too high for smooth or sand-blasted surfaces.

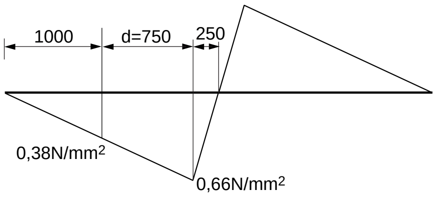
4.3 Example: Foundation reinforcement

Given:

Concrete: Old C 20/25; New: C 25/30
Rebar steel: S500; $f_{yk} = 500$ N/mm²
Reinforcement existing in foundation:
16 dia. s = 150 $A_{se} = 1340$ mm²







Neutral axis: $x_d = \frac{1340 \cdot 500 \cdot 1.5}{25 \cdot 0.8 \cdot 0.85 \cdot 1000 \cdot 1.15} = 51$ mm

➥ $V_{cd} = 0.8 \cdot 51 \cdot 0.85 \cdot \frac{25}{1.5} = 579$ kN/m

➥ $\tau_{cd,max} = \frac{579'000 \cdot 2}{1750 \cdot 1000} = 0.66$ N/mm²

1. End-face: Shear force on end-face

$V_d = 280 \cdot 0.5 = 140$ kN/m

➥ $\tau_d = \frac{V_d}{d \cdot b} = \frac{140'000}{750 \cdot 1000} = 0.19$ N/mm²

a) High-pressure water jet or scored
$\tau_{Rdj} = 2.3 \cdot 0.24 = 0.55 > \tau_d = 0.19$ N/mm² ➡ no connectors required

b) Sand-blasted (special case: the interface has cracked due to the bending moment)
$\tau_d = 0.19$ N/mm² ➡ $A_{s,req} = 486$ mm²/m (Formula 3) superimposed tensile force from bending
The minimum reinforcement for flexure governs: $A_{se,min} > A_{s,req} + A_{se,req}$

2. Bending

$M_d = 280 \cdot 0.5^2 \cdot {}^1/_2 = 35$ kNm/m $A_{se,req} = 163$ mm²/m

Min. reinforcement ([1], Section 4.4.2.2 (3) and Table 4.11) $A_{se,min} = 0.4 \cdot 0.8 \cdot 3 \cdot \frac{1000 \cdot 600}{2 \cdot 280} = 1285$ mm²/m

selected: dia. 16 s = 150 mm (A_s = 1340 mm²/m) anchorage length, $F_d = 201 \cdot 280 = 56.3$ kN : $l_b = 1.4 \cdot 285 = 400$ mm

3. Topside

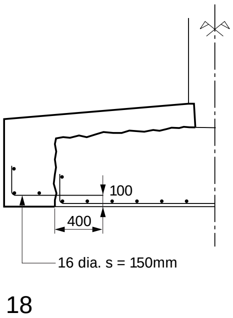
a) High-pressure water jet or scored

Cohesion: $\tau_{Rdj} = 2.3 \cdot 0.24 = 0.55 > \tau_d = 0.38$ N/mm² ➡ no connectors required

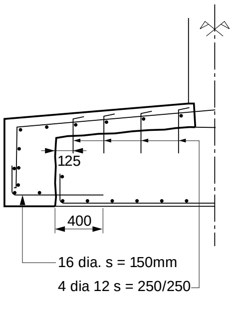
b) Sand-blasted
$\tau_{d,max} = 0.38$ N/mm² ➡ $\rho_{req} = 0.16$ % ➡ $A_{s,req} = 0.0016 \cdot 1000^2 = 1600$ mm²/m² selected 12 dia. s = 250 mm

Tensile force per connector $N_d = 0.5 \cdot 113 \cdot \frac{0.5}{1.15} = 24.6$ kN ➡ anchorage length, l_b = 150 mm ([5], Section 3.4.1)

High-pressure water jet:



Sand-blasted:



Smooth:

In this case, un-roughened interface surfaces cannot be used. The concrete edge at the end face would hinder the necessary displacement of the connectors.

5. Test results

5.1 Transfer of shear across a concrete crack

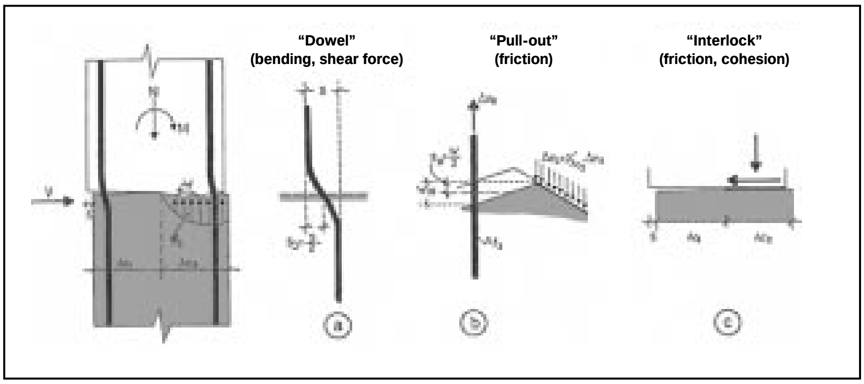


Figure 9: Transfer of shear across a concrete crack (shear-friction model)

Review of the literature reveals little research into the specific behavior of reinforced bond interfaces between new and old 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 the surface of the old concrete was first investigated in 1960 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. They, in turn, create clamping forces across the interface and thus also frictional forces.

In 1987, Tsoukantas and Tassios [4] presented analytical investigations into the shear resistance of connections between precast concrete components. They cover the different contributing mechanisms of friction and dowel action (Figure 9).

5.2 Laboratory tests by Hilti Corporate Research

Figure 10: Shear tests

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 interrelationships of various degrees of roughness and transferable shear stresses with various degrees of reinforcement.

Using a unique test frame design, it was possible to avoid secondary eccentric moments in the specimen and to achieve nearly parallel separation of the interface surfaces (Figure 10). 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.

When 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 by Randl [8].

5.3 Working principle of connectors

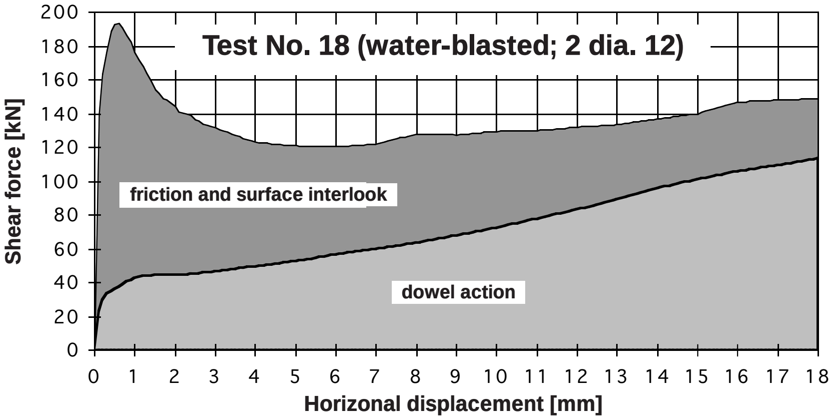


Figure 11: Test example for water-blasted surface

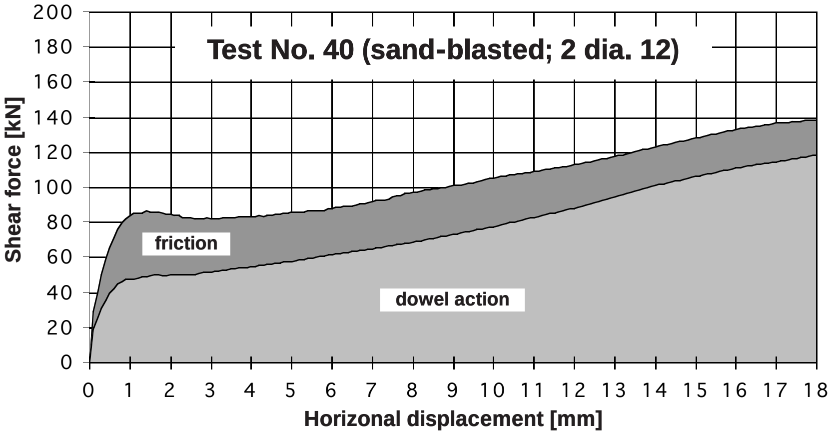


Figure 12: Test example for sand-blasted surface

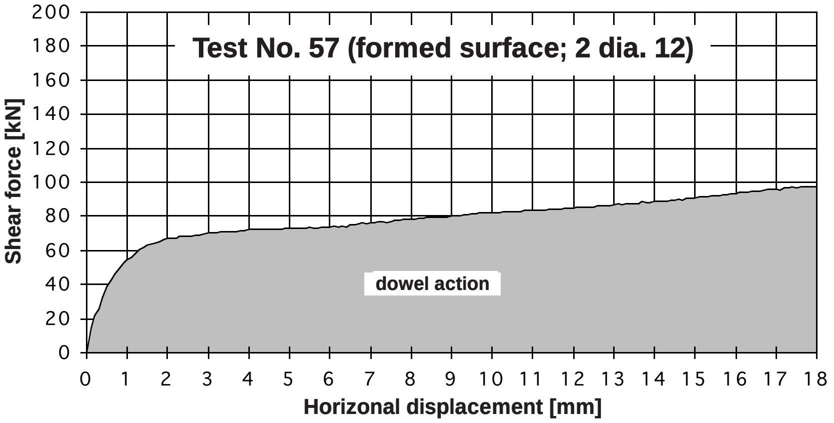


Figure 13: Test example for smooth surface

The test results confirm the strong influence of roughness on shear resistance and shear stiffness. If the load-displacement curves are regarded in conjunction with the measured displacement, the three components of cohesion, friction and dowel action can be isolated and determined quantitatively. They make different contributions to the overall resistance (Figures 11, 12 and 13), depending on surface roughness and amount of reinforcement.

Hence, the frictional component predominates when the surface is blasted with a high-pressure water jet and larger amounts of reinforcement are provided. But small shear stresses can also be transferred even when no reinforcement is present, due to the good interlocking effect of the interface surfaces. In the case of sand-blasted surfaces, however, shear stresses are transferred by a combination of friction and dowel action, but the forces that can be resisted are generally far smaller than in the case of high-pressure water blasting.

Investigations were also conducted as to whether the post-installed rebar connectors are stressed to yield at ultimate shear transfer. For this purpose, the strain in the connectors at the level of the interface was measured. To avoid any disturbance of the bond, and in order to obtain the strain due to tensile loading only, the strain gauges were fitted in a central bore along the longitudinal axis of the connectors.

These test results clearly show that, when surfaces have the above-mentioned degrees of roughness, the tensile force in the connectors has not reached the full connector tensile yield strength, contrary to assumpti-

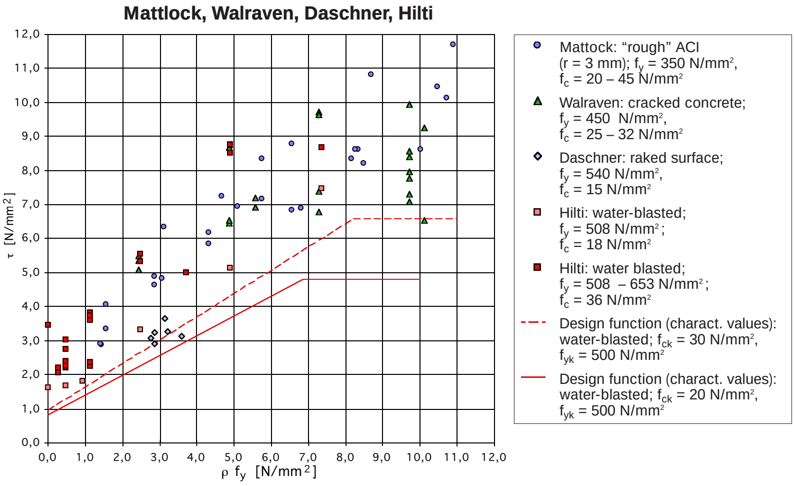


Figure 14: Shear tests, „rough“ interface

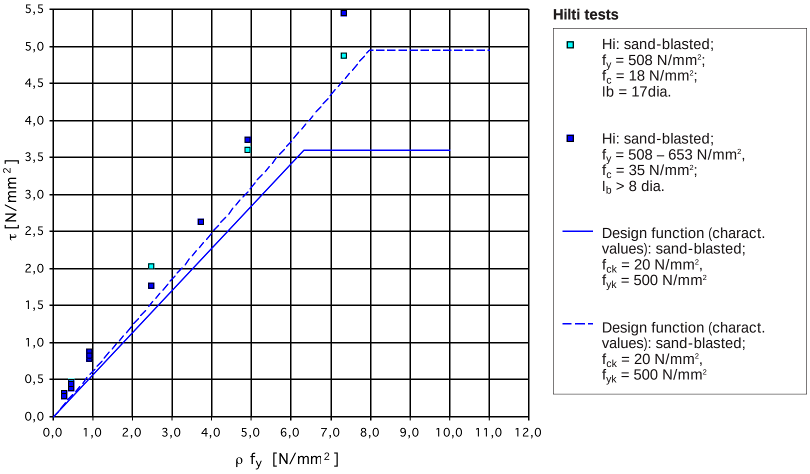


Figure 15: Shear tests, sand-blasted interface

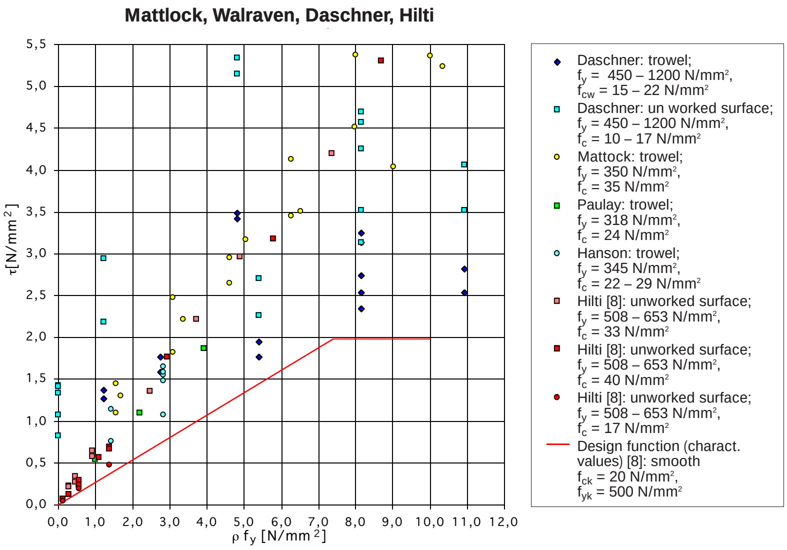


Figure 16: Shear tests, „smooth“ interface

ons for other design models. Tests carried out with connectors of various lengths confirm this result, as they showed that reduced anchorage lengths are sufficient to carry the effective connector tensile force at maximum shear transfer capacity. Additional connector embedment (e. g., as required for theoretical connector tensile yield) did not result in increased shear transfer.

The load-bearing behavior of smooth interface surfaces with connectors was also investigated. As displacement readings for the horizontal and vertical directions showed, there is in this case also a separation of the interface under shear loading and, thus, owing to the lack of roughness, a loss of contact between the shear surfaces. In this case, the entire resistance is provided by dowel action.

On the basis of these findings, design approaches are developed which permit separate and realistic analyses of the various components of shear resistance. As a result, a standardized level of safety is ensured with respect to resistance, regardless of whether the normal stresses at the interface are induced by an externally applied normal force or by internal connectors.

5.4 Comparison with international test results

In his thesis [8], Randl has proven through a study of literature and with reference to world-wide research results that the determined design equations are conservative. The results are shown in Figures 14, 15 and 16.

6. Notations

Lengths

b_j	effective width of interface in the area under consideration
c_1	anchor edge distance [6]
l_b	anchorage depth of connector in base material as per [5], Section 3.4.1
l_e	length over which tensile cracking force is introduced
l_j	effective length of interface under consideration
R_t	mean depth of interface roughness, measured according to the sand-patch method
s	spacing of connectors or rebar
s_d	displacement of connectors under the mean of permanent load ($F_P \approx 0.5 F_{uk}$)
t_{new}	thickness of concrete overlay
w_{eff}	additional deformation calculated for the reinforced section considering the flexibility of the connectors
w_{calc}	additional deformation calculated for the reinforced section assuming perfect bond
x	distance of neutral axis from compressed edge (bending)

Areas:

A_s	cross-sectional area of interface reinforcement (connectors)
A_{se}	cross-sectional area of bending reinforcement

Forces:

F_{cr}	tensile force, effective in the overlay at the time when the cracks may first be expected to occur, as per [1], Section 4.4.2.2
N_d	design value of tensile force in connector
N_{ed}	tensile force resulting from moment of F_{cr}
V_{Rd}	design shear resistance at interface
V_{Sd}	design shear force acting at interface
V_{ed}	shear force at interface derived from F_{cr}
V_{cd}	design shear force acting at interface in compression zone
V_{td}	design shear force acting at interface in tension zone

Stresses:

f_{cd}	design value of cylinder compressive strength of concrete
f_{yd}	design value of yield strength of connector
$f_{ct,eff}$	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
σ_n	normal stress (positive compression) certainly acting at interface
τ_{Rd}	basic design shear strength of concrete as per [1], Section 4.3.2.3
τ_{Rdj}	design shear strength at interface under consideration

Factors and coefficients:

k	coefficient to allow for non-uniform self-equilibrating stresses
k_T	cohesion factor as per Table 1
α	coefficient for effective dowel action as per Table 1
β	coefficient for effective concrete strength as per Table 1
γ	increasing factor for deformation as per Table 3
μ	coefficient of friction as per Table 1
ν	efficiency factor as per [1], Formula (4.20); also refer to Table 2
κ	coefficient for effective tensile force in the connector as per Table 1

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

7. Reference literature

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Personal notes: