Design and requirements for construction works of post-installed shear connection for two concrete layers

TR 066
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Contents

1 SCOPE ........................................................................................................................................3

2 DESIGN OF SHEAR INTERFACE ...............................................................................................5
  2.1 Principle..................................................................................................................................5
  2.2 Derivation of the forces acting...............................................................................................7
    2.2.1 Determination of external forces .......................................................................................7
    2.2.2 Determination of restraint forces at the perimeter ..............................................................8
  2.3 Required verifications ...........................................................................................................8
    2.3.1 Design of the interface for static and quasi-static conditions ...........................................9
    2.3.2 Design of the interface for fatigue relevant loading ..........................................................11
    2.3.3 Design of fastening in existing concrete and concrete overlay .........................................12
    2.3.4 Minimum interface reinforcement ...................................................................................12
    2.3.5 Constructive interface reinforcement ................................................................................12

3 REQUIREMENTS FOR CONSTRUCTION WORKS ......................................................................13
  3.1 Surface preparation ...............................................................................................................13
    3.1.1 Sand patch method according Kaufmann to determine roughness $R_t$ .................................13
    3.1.2 Mean profile depth $\text{MPD}$ .............................................................................................13
  3.2 New concrete – mixture, casting, post-treatment ...................................................................14

4 REFERENCE DOCUMENTS .........................................................................................................15
1 SCOPE

This Technical Report contains a method for design of connections made with products with an ETA based on EAD 332347-00-0601 to strengthen existing concrete structures by an additional new concrete layer. The connector is used to ensure monolithic behaviour of concrete cast at different times, by doweling the shear interface and transmitting the tensile forces generated by friction in the shear interface. The interface complies with the requirements given in Table 2.2.

This Technical Report applies for all interfaces according to Table 1.1 subjected to static and quasi-static actions. Furthermore this Technical Report applies for very rough interfaces subject to fatigue cyclic loading.

NOTE: completion of semi-finished concrete parts by casting additional concrete is not intended by this document.

Table 1.1: Categories of surface roughness [11]

<table>
<thead>
<tr>
<th>Category</th>
<th>Methods / Situation (Examples)</th>
<th>Application</th>
<th>Peak to mean roughness $R_t$ [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very rough</td>
<td>High pressure water jetting, shot blasting, indented, shear keys</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Rough</td>
<td>Sand-blasted</td>
<td>yes</td>
<td>not applicable</td>
</tr>
<tr>
<td>Smooth</td>
<td>Untreated, slightly roughened</td>
<td>yes</td>
<td>not applicable</td>
</tr>
<tr>
<td>Very smooth</td>
<td>Existing concrete cast against steel formwork</td>
<td>yes</td>
<td>not applicable</td>
</tr>
</tbody>
</table>

Specific terms used in this TR

$A_s$ = Relevant cross section of the connector in the area of the interface

$A_c$ = Area of concrete related to $A_s$

$b_i$ = Width of the interface of the composed section

$b_j$ = Width the restraint area of the interface at the perimeter

$\beta_i$ = Ratio of the longitudinal force in the new concrete and the total longitudinal force either in the compression or tension zone, both calculated for the section considered

$c_a$ = Coefficient for adhesive bond resistance in an unreinforced interface

$c_r$ = Coefficient for adhesive bond resistance in a reinforced interface

$d_k$ = Height of a shear key

$d_{m}$ = Medium diameter of the circle for sand patch method

ETD = Estimated texture depth

$f_{cd}$ = Minimum value of design concrete compressive strength of the two concrete layers, measured on cylinders

$f_{ctd}$ = Design tensile strength of the concrete

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

$f_{yk}$ = Characteristic yield strength of the shear connector

$f_{ctm}$ = Mean tensile strength of the concrete

$f_{yk}$ = Yield strength of the shear connector

$h$ = Bond strength perpendicular to the interface surface

$f_{ctk,0.05}$ = Characteristic tensile strength of the concrete

$F_{cr}$ = Cracking force

$h_{ef}$ = Effective embedment depth

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\( h_{\text{new}} \) = Thickness of the concrete overlay
\( h_1 \) = Base length of a shear key
\( h_2 \) = Distance between shear keys
\( l_i \) or \( l_j \) = Depth of the respective area of a composed section
MPIII = Manufacturer’s product installation instruction
MPD = Mean profile depth
MTD = Mean texture depth
\( N_{\text{Ed}} \) = Tensile force acting
\( N_{\text{Ed},i} \) = Tensile force acting in a composed section
\( N^*_{\text{Ed}} \) = Tensile force acting at the perimeter due to restraint
\( n_{\text{sc}} \) = Number of shear connectors in the respective area of the interface
\( R_c \) = Peak to mean roughness according to sand patch method
\( S_{\text{min}} \) = Minimum spacing between connectors
\( V \) = Volume of sand for sand patch method
\( V_{\text{Ed}} \) = Shear force acting
\( V_{\text{Ed},i} \) = Shear force acting in a composed section
\( V^*_{\text{Ed}} \) = Shear force acting at the perimeter due to restraint
\( z \) = Inner lever arm of the composed section
\( \alpha_{k1} \) = Product specific factor for ductility
\( \alpha_{k2} \) = Product specific factor for geometry
\( \beta_c \) = Coefficient for the strength of the compression strut
\( \gamma_c \) = Safety factor for concrete; 1.50 as given in EN 1992-4 for strengthening of existing structures
\( \gamma_s \) = Safety factor for steel; 1.15 as given in EN 1992-4 for supplementary reinforcement
\( \kappa_1 \) = Interaction coefficient for tensile force activated in the shear connector
\( \kappa_2 \) = Interaction coefficient for flexural resistance in the shear connector
\( \rho \) = Reinforcement ratio of the steel of the shear connector crossing the interface
\( \rho_{\text{min}} \) = Minimum reinforcement ratio
\( \nu \) = Coefficient for reduction of concrete strength
\( \sigma_n \) = Lowest expected compressive stress resulting from an eventual normal force acting on the interface (compression has a positive sign)
\( \sigma_s \) = Steel stress associated to the relevant failure mode; \( \sigma_s \leq f_{yk} / \gamma_s \)
\( \eta_{\text{sc}} \) = Factor for fatigue loading
\( \tau_{\text{Ed}} \) = Shear stress acting
\( \tau_{\text{Ed},i} \) = Shear stress acting in a composed section
\( \tau^*_{\text{Ed}} \) = Shear stress acting at the perimeter due to restraint
\( \Delta \tau_{\text{Ed}} \) = Shear stress acting as fatigue relevant loading
\( \tau_{\text{Ed},\text{max}} \) = Upper shear stress acting as fatigue relevant loading under the frequent action combination
\( \tau_{\text{Ed},\text{min}} \) = Lower shear stress acting as fatigue relevant loading under the frequent action combination related to the upper shear stress of the respective area of a composed section
\( \mu \) = Friction coefficient

Indices:
E = Action effects
R = Resistance, restraint
2 DESIGN OF SHEAR INTERFACE

2.1 Principle

The design given in this Technical Report covers the ultimate limit state. No provisions for serviceability limit state are given in this document.

A principle design workflow is given in Figure 2.1. The loading input is determined by the design engineer responsible for the construction.

The design method is based on [11].

The loading is originating from:

- External action
- Restraint forces along the perimeter (corner or construction joint)

The restraint forces only need to be considered in an area along the perimeter with following distance $b_1$ to the perimeter [12]:

- $b_1 = 3 \cdot h_{new}$ for very rough surfaces
- $b_1 = 6 \cdot h_{new}$ for rough surfaces
- $b_1 = 9 \cdot h_{new}$ for smooth surfaces
Figure 2.1: Design flow chart
2.2 Derivation of the forces acting

There are two types of forces acting on the system:
- External forces
- Forces resulting from constraint at the perimeter

These forces activate tensile forces perpendicular to the interface, which are carried by the connector and transferred in the two concrete layers.

It is allowed to subdivide the interface into zones to contribute to different shear stress (see Figure 2.2).

It is not allowed to re-distribute (smudge) the stress for rough and very rough surfaces, the maximum value of each zone is decisive.

![Static model](image1)

![Subdivision to zones with different maximum stress](image2)

![Resulting in different required number of connectors](image3)

Figure 2.2: stepped distribution of the shear stress

2.2.1 Determination of external forces

External forces are resulting from the loading of the concrete structure and are determined following the common design rules for concrete structures. In particular, it's a shear force $V_{Ed,i}$, which is converted into a shear stress $\tau_{Ed,i}$ acting parallel to the interface in a defined area.

$$\tau_{Ed,i} = \beta \cdot \frac{V_{Ed,i}}{z \cdot b_i} \quad (2.1)$$

Tensile load $N_{ed}$ is the resulting loading from shear friction in the interface.

$$N_{ed,i} = (\sigma_n + \kappa_1 \cdot \alpha_{k_1} \cdot \rho \cdot \sigma_s) \cdot \left(\frac{b_1 \cdot l_i}{n_{sc}}\right) \quad (2.2)$$

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2.2.2 Determination of restraint forces at the perimeter

To determine the restraint forces at the perimeter the cracking force is the upper limit.

\[ V_{Ed} = h_{\text{new}} \cdot b_j \cdot f_{ctd} \]  \hspace{1cm} (2.3)

*NOTE: the value of the overlay concrete shall be taken for \( f_{ctd} \) (reductions due to early age effects might be considered) [11].

\( \tau_{ed}^* \) is the resulting shear stress from constraint along the perimeter.

\[ \tau_{Ed}^* = \frac{V_{Ed}^*}{b_j} \]  \hspace{1cm} (2.4)

\( N_{ed}^* \) is the resulting loading from constraint along the perimeter.

\[ N_{Ed}^* = \frac{V_{Ed}^*}{6} = \frac{h_{\text{new}} \cdot b_j \cdot f_{ctd}}{6} \]  \hspace{1cm} (2.5)

2.3 Required verifications

External forces and forces from constraint are not superpositioned.

\[ \tau_{Ed} = \max(\tau_{Ed,i}; \tau_{Ed}^*) \]  \hspace{1cm} (2.6)

\[ N_{Ed} = \max(N_{Ed,i}; N_{Ed}^*) \]  \hspace{1cm} (2.7)

The required verifications for tension load are summarised in Table 2.1.

**Table 2.1: Required verifications for interface and connectors**

<table>
<thead>
<tr>
<th>Verification</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verification of the shear interface (static, quasi-static and fatigue loading)</td>
<td></td>
</tr>
<tr>
<td>1 Shear interface</td>
<td>( \tau_{Ed} \leq \tau_{Rd} ) \hspace{1cm} ( \Delta \tau_{Ed} \leq \eta_{sc} \cdot \tau_{Rd} )</td>
</tr>
<tr>
<td>Verification of the steel failure (static, quasi-static loading)</td>
<td></td>
</tr>
<tr>
<td>2 Steel failure of connector</td>
<td>( N_{Ed} \leq N_{Rd,s} )</td>
</tr>
<tr>
<td>Verification of fastening in existing concrete (static, quasi-static loading)</td>
<td></td>
</tr>
<tr>
<td>3 Concrete cone failure in existing concrete</td>
<td>( N_{Ed} \leq N_{Rd,c} )</td>
</tr>
<tr>
<td>4 Pull-out failure of connector in existing concrete</td>
<td>( N_{Ed} \leq N_{Rd,p} )</td>
</tr>
<tr>
<td>5 Combined pull-out and concrete failure in existing concrete</td>
<td>( N_{Ed} \leq N_{Rd,p} )</td>
</tr>
<tr>
<td>6 Concrete splitting failure in existing concrete</td>
<td>( N_{Ed} \leq N_{Rd,sp} )</td>
</tr>
<tr>
<td>Verification of fastening in concrete overlay (static, quasi-static loading)</td>
<td></td>
</tr>
<tr>
<td>7 Concrete cone failure in concrete overlay</td>
<td>( N_{Ed} \leq N_{Rd,c} )</td>
</tr>
<tr>
<td>8 Pull-out failure of connector in concrete overlay</td>
<td>( N_{Ed} \leq N_{Rd,p} )</td>
</tr>
<tr>
<td>9 Concrete splitting failure in concrete overlay</td>
<td>( N_{Ed} \leq N_{Rd,sp} )</td>
</tr>
</tbody>
</table>
2.3.1 Design of the interface for static and quasi-static conditions

The shear interface resistance is created by three different working principles (aggregate interlock, shear friction and dowel action) and limited by the concrete strut resistance. Shear friction and dowel action are depending on the connector and thus require product specific factors:

- Shear friction: The product specific factor for ductility $\alpha_{k1}$ is a reduction factor to consider ductility of the steel element. This is in line with other factors considering ductility in EN 1992-1-1 [5].
- Dowel action: In addition to material strength and cross section the resistance of the shear interface is determined by the geometry of the cross section. Based on resistance moment of hollow cross sections a product specific factor for geometry $\alpha_{k2}$ is applied.

The shear stress at the interface between concrete cast at different times should satisfy following condition:

$$\tau_{Ed} \leq \tau_{Rd} \quad (2.8)$$

with $\tau_{Rd}$ being the design values of the shear resistance in the interface

a) for interfaces without use of shear connectors

$$\tau_{Rd} = c_e \cdot f_{ctd} + \mu \cdot \sigma_n \leq 0.5 \cdot \gamma \cdot f_{cd} \quad (2.9)$$

$$c_e = \text{given in Table 2.2}$$

$$\mu = \text{given in Table 2.2; values for very rough surface may be interpolated}$$

$$\gamma = 0.55 \cdot \left( \frac{f_{ck}}{f_{ck}} \right)^{1/3} < 0.55 \quad (2.10)$$

$$f_{ctd}, \sigma_n, f_{cd} \quad \text{see 1}$$

b) for interfaces with use of shear connectors

$$\tau_{Rd} = c_r \cdot \frac{1}{3} \cdot f_{ck} + \mu \cdot \sigma_n + \mu \cdot \kappa_1 \cdot \alpha_{k1} \cdot \rho \cdot \sigma_s + \kappa_2 \cdot \alpha_{k2} \cdot \rho \cdot \sqrt{\frac{f_{yk} \cdot 0.85 \cdot f_{ck}}{\gamma_s}} \leq \beta_c \cdot \gamma \cdot \frac{0.85 \cdot f_{ck}}{\gamma_c} \quad (2.11)$$

Comprising terms of different working principles:

- term for aggregate interlock, may only be applied if no tension due to external loading is present
- term for shear friction
  This term must not be used if the connector is placed with a distance < 10 d and the shear load is acting in the direction to the edge.
- term for dowel action
- term for concrete strut resistance
with
\[ c_r = \text{given in Table 2.2} \]
\[ \mu = \text{given in Table 2.2; values for very rough surface may be interpolated} \]
\[ k_1 = \text{given in Table 2.2} \]
\[ \alpha_{k1} = \text{given in the European Technical Assessment of the connector} \]
\[ \sigma_s = \text{Steel stress associated to the relevant failure mode; } \sigma_s = N_{Rd,2}/A_s \leq f_{yk}/\gamma_s \]
\[ f_{yk} = \text{given in the European Technical Assessment of the connector} \]
\[ \gamma_s = 1.15 \text{ as given in EN 1992-4 for supplementary reinforcement} \]
\[ k_2 = \text{given in Table 2.2} \]
\[ \omega_{k2} = \text{given in the European Technical Assessment of the connector} \]
\[ \gamma_c = 1.50 \text{ as given in EN 1992-4 for strengthening of existing structures} \]
\[ \beta_c = \text{given in Table 2.2} \]
\[ \nu = 0.55 \cdot \left( \frac{30}{f_{ck}} \right)^{1/3} < 0.55 \]  \hspace{1cm} (2.12)
\[ f_{ck}, f_{yk}, \sigma_s, \sigma_n, \rho \text{ see 1} \]

**Table 2.2: Coefficients and parameters for different surface roughness [11]**

<table>
<thead>
<tr>
<th>Surface characteristics of interface</th>
<th>( c_a )</th>
<th>( c_r )</th>
<th>( k_1 )</th>
<th>( k_2 )</th>
<th>( \beta_c )</th>
<th>( \mu )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very rough,</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(including shear keys(^1))</td>
<td>0.5</td>
<td>0.2</td>
<td>0.5</td>
<td>0.9</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>( R_t \geq 3.0 \text{ mm} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rough,</strong></td>
<td>0.4</td>
<td>0.1</td>
<td>0.5</td>
<td>0.9</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>( R_t \geq 1.5 \text{ mm} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Smooth</strong></td>
<td>0.2</td>
<td>0</td>
<td>0.5</td>
<td>1.1</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>(concrete surface without treatment after vibration or slightly roughened when cast against formwork)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Very smooth</strong></td>
<td>0.025</td>
<td>0</td>
<td>0</td>
<td>1.5</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>(steel, plastic, timber formwork)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) shear keys should satisfy the geometrical requirements given in Figure 2.3.

**Figure 2.3: Geometry of shear keys**
2.3.2 Design of the interface for fatigue relevant loading

Design for fatigue relevant loading is limited to very rough surface of the interface. Following condition shall be satisfied:

\[
\Delta \tau_{Ed} \leq \eta_{sc} \cdot \tau_{Rd}
\]  

(2.13)

\[\eta_{sc} = \text{Factor for fatigue loading:}\]

= given in the European Technical Assessment of the shear connector for interfaces with use of shear connectors.

For situations where there is a cyclic stress superimposed to a static stress, the factor \(\eta_{sc}\) depends on the combination of the applied stresses (static and cyclic).

The value of \(\eta_{sc}\) is the cornerstone for the constant life diagram given in Figure 2.4.

![Figure 2.4: Constant life diagram (Goodman diagram)](image)

For verification three different situations may occur:

Situation 1: No static loading, with \(\tau_{Ed,\text{min}} = 0\)

\[\Delta \tau_{Ed} = \tau_{Ed,\text{max}}\]

(2.14)

\[\eta_{sc} = 0,4\] \text{Or otherwise given in the European Technical Assessment of the shear connector for interfaces with use of shear connectors}

(2.15)

Situation 2: Pulsating cyclic shear stress (same direction) with \(\tau_{Ed,\text{min}} > 0\)

\[\Delta \tau_{Ed} = \tau_{Ed,\text{max}} - \tau_{Ed,\text{min}}\]

(2.16)

\[\left|\frac{\tau_{Ed,\text{max}}}{\tau_{Rd}}\right| - \left|\frac{\tau_{Ed,\text{min}}}{\tau_{Rd}}\right| \leq \eta_{sc} - 0,45 \cdot \left|\frac{\tau_{Ed,\text{min}}}{\tau_{Rd}}\right|\]

(2.17)
Situation 3: Alternating cyclic shear stress (different directions) with $\tau_{Ed,min} \leq 0$

$$\Delta \tau_{Ed} = \tau_{Ed,max} - |\tau_{Ed,min}|$$  \hspace{1cm} (2.18)

$$\frac{\tau_{Ed,max}}{\tau_{Ed}} \leq \eta_{sc} - \frac{|\tau_{Ed,min}|}{\tau_{Ed}}$$  \hspace{1cm} (2.19)

### 2.3.3 Design of fastening in existing concrete and concrete overlay

For design of the fastenings in existing concrete as well as in concrete overlay the rules of EN 1992-4 apply.

In addition, following requirement needs to be ensured:
The minimum spacing between the connectors is the minimum value of the values required in existing concrete and concrete overlay.

$$s_{min} = \max (s_{min}(\text{existing concrete}); s_{min}(\text{concrete overlay}))$$  \hspace{1cm} (2.20)

### 2.3.4 Minimum interface reinforcement

A minimum amount of reinforcement $\rho_{min}$ should be foreseen to prevent brittle failure at loss of aggregate interlock. This is according [11]:

$$\rho_{min} = 0,20 \cdot \frac{f_{ctm}}{f_{yk}} \geq 0,001 \text{ for beams} \quad \text{or} \quad \rho_{min} = 0,12 \cdot \frac{f_{ctm}}{f_{yk}} \geq 0,0005 \text{ for slabs}$$  \hspace{1cm} (2.21)

With

$$\rho_{min} = \frac{A_s}{A_c}$$  \hspace{1cm} (2.22)

**Note:**

In case of strengthening concrete bridges by means of a concrete overlay the minimum reinforcement crossing the interface according to eq. (2.21) and (2.22) may be omitted if the values for maximum and minimum shear forces in each section are based on the most unfavourable arrangement of the model for traffic loads (TS and UDL) according EN 1991-2, section 4.3.2 [4], corresponding to influence lines or influence surfaces.

### 2.3.5 Constructive interface reinforcement

In case that shear transfer is proven without use of shear connectors, see Equation (2.8), no minimum reinforcement is needed. In this case a constructive reinforcement is recommended [8].

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3 REQUIREMENTS FOR CONSTRUCTION WORKS

3.1 Surface preparation

Following conditions shall be satisfied for the surface preparation [13]:

- Roughening of the surface until required roughness according to Table 1.1 is achieved and the grain texture is visible.
- Roughness $R_t$ measured according sand patch method according to Kaufmann. Alternative methods, e.g. optical measurement, may be used.
- Bond strength perpendicular to the interface surface $f_h \geq \min (1.5 \text{ N/mm}^2; f_{ctm})$; Measurement of $f_h$ according [9].
- For the interval of measurements of roughness and bond strength one test per 100 m$^2$ of surface, but a minimum of five tests, shall be done.
- Recognition of post-hardening of the existing concrete only with statistical evaluation and a limit $f_{ct0.05} \leq 3.0 \text{ N/mm}^2$
- Cleanliness of the surface: no dirtying, drilling with use of vacuums, cleaning of drill holes with oil free compressed air, cleaning according MPII of the shear connector.
- Keep existing concrete moist, without free water standing on the surface. At time of casting new concrete the surface needs to have a moist satin finish.

3.1.1 Sand patch method according Kaufmann to determine roughness $R_t$

A volume of sand (dry quartz sand, grain size 0.1 to 0.5 mm) is spread on the surface with a wooden plate (diameter 50 mm, thickness 10 mm) in a circular way. The (mean) diameter of the circle should be measured. For calculation of roughness $R_t$, see (2.23).

$$R_t = \frac{4 \cdot V}{d_m^2 \cdot \pi}$$  \hspace{1cm} (2.23)

![Figure 2.5: Sand patch method according Kaufmann](image)

3.1.2 Mean profile depth MPD

With the mean profile depth MPD gathered by optical measurement a more advanced and flexible procedure is available. The mean profile depth is determined according [7] and correlates with the peak to mean roughness with a transformation factor of 1.1, see equation (2.24). The equation is valid in the range of $0.3 \text{ mm} < \text{MPD} < 3.0 \text{ mm}$.

$$R_t = \text{MTD} = \text{ETD} = 1.1 \cdot \text{MPD}$$  \hspace{1cm} (2.24)

![Figure 2.6: Mean profile depth MPD](image)
3.2 New concrete – mixture, casting, post-treatment

Following conditions shall be satisfied for the new concrete [13]:

- Concrete compressive strength of the new concrete shall be higher than the concrete compressive strength of the existing concrete.
- Use of concrete with low shrinkage is recommended.
- Slump of fresh concrete $f \geq 380$ mm $F_{38}$, a slump value $f \geq 450$ mm $F_{45}$ is recommended, if applicable. Determination of slump according to [15]
- Concrete consolidation with vibratory screed. With thickness of the overlay concrete $> 10$ cm internal vibrators are recommended to be used prior to the vibratory screed. Alternatively, the specific vibratory screed must be checked for its maximum working depth.
- Very good posttreatment
4 REFERENCE DOCUMENTS

[1] EAD 332347-00-0601: Connector for strengthening of existing concrete structures by concrete overlay


