EOTA®

TECHNICAL REPORT

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

TR 066

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EUROPEAN ORGANISATION FOR TECHNICAL ASSESSMENT

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Contents

1 SCOPE OF THE TECHNICAL REPORT

This Technical Report contains a method for the design of post-installed connections made with products with an ETA based on EAD 332347-00-0601 [1] or EAD 332347-00-0601-v01 [2] and with the aim to strengthen existing concrete structures either by adding a new concrete layer to existing members or by adding new concrete members transferring interface shear without significant transverse bending. Some examples of typical applications covered by this TR are given in Figure 1.1. This design method ensures monolithic or composite behaviour of concrete cast at different times (if a strong or weak adhesive bond is assumed, respectively), 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 1.1.

This Technical Report is applicable for the design of all interfaces according to Table 1.1 and subjected to static, quasi-static, fatigue, and seismic actions. For fatigue cyclic loading, this Technical Report applies only in the case of very rough interfaces. For seismic cyclic loading, only two roughness categories are applicable.

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

Table 1.1: Categories of surface roughness [12]

<table>
<tr><th rowspan="2">Category</th><th rowspan="2">Methods / Situation
(Examples)</th><th colspan="3">Application</th><th rowspan="2">Peak to mean roughness R_t [mm]</th></tr>
<tr><th>Static and quasi-static</th><th>Fatigue cyclic loading</th><th>Seismic cyclic loading</th></tr>
<tr><td rowspan="2">Very rough</td><td>shear key</td><td>yes</td><td>yes</td><td>-</td><td>See Figure 2.5</td></tr>
<tr><td>High pressure water jetting, shot blasting, indented</td><td>yes</td><td>yes</td><td rowspan="2">Yes
(both categories to be handled as “Rough”)</td><td>≥ 3,0</td></tr>
<tr><td>Rough</td><td>Sand-blasted</td><td>yes</td><td>not applicable</td><td>≥ 1,5</td></tr>
<tr><td>Smooth</td><td>Untreated, slightly roughened (e.g., as cast after removal of laitance and loose material)</td><td>yes</td><td>not applicable</td><td>yes</td><td>< 1,5</td></tr>
<tr><td>Very smooth</td><td>Existing concrete cast against steel formwork</td><td>yes</td><td>not applicable</td><td>not applicable</td><td>not measurable</td></tr>
</table>

NOTE: For interfaces subjected to seismic loading the following should be taken into account:

(1) For the case of very rough interfaces (R_t ≥ 3,00 mm), the interface shear resistance is calculated conservatively as for rough interfaces.

(2) Relevant information on interfaces with shear keys subjected to cycling loading is limited. Thus, this TR does not provide guidance for this type of interfaces.

(3) Very smooth interfaces are not covered by this TR in the case of seismic loading, as their resistance under cyclic loads is very limited.

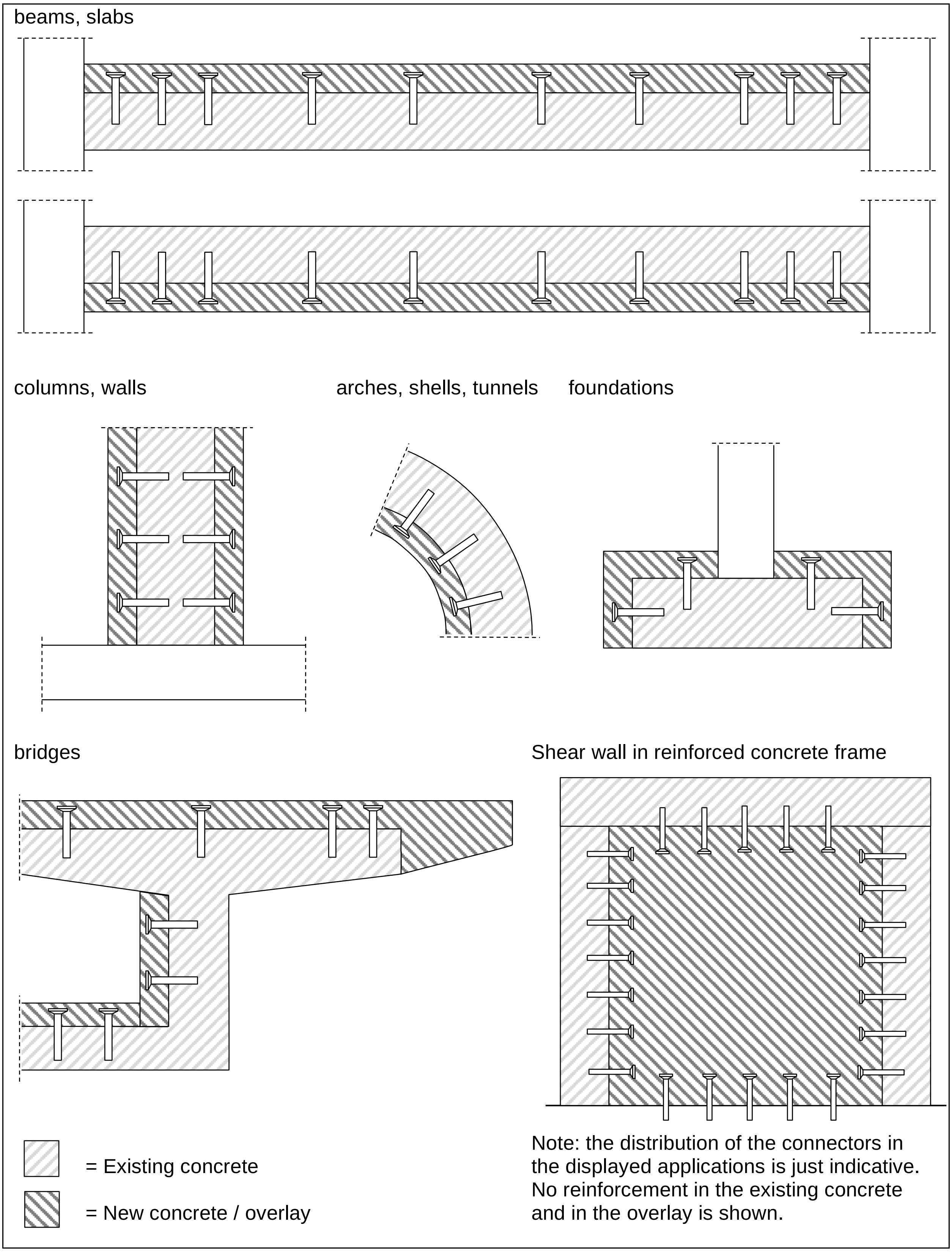


Figure 1.1: Examples of typical applications cover by this TR

Specific terms used in this TR

A_s	=	Relevant cross section of the connectors 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 (e.g., usually taken as 1 m in bi-dimensional elements or as the full geometric width in linear elements)
b_j	=	Depth of the respective area of a composed section considered for the calculation of the restraint forces along the perimeter
c_a	=	Coefficient for adhesive bond resistance in an unreinforced interface
c_r	=	Coefficient for mechanical interlock in a reinforced interface
d	=	Diameter of the connector
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 (usually the existing concrete, see also section 4.2)
f_{ck}	=	Minimum value of concrete compressive strength of the two concrete layers, measured on cylinders (usually the existing concrete, see also section 4.2)
f_{ctd}	=	Design tensile strength of the concrete
$f_{ctk,0,05}$	=	Characteristic tensile strength of the concrete
f_{ctm}	=	Mean tensile strength of the concrete
f_h	=	Bond strength perpendicular to the interface surface
f_{yk}	=	Characteristic yield strength of the shear connector
F_c	=	Force of concrete compression (Table 3.1 - Beam/one-way slab strengthening application)
F_{hor}	=	Horizontal force (Table 3.1 - Infill of frame application)
F_s	=	Force of reinforcement tension (Table 3.1 - Beam/one-way slab strengthening application)
F_s	=	Lateral seismic action (Table 3.1 - Infill of frame application)
$F_{s1,new}$	=	Tensile force developed in the added longitudinal reinforcement (Table 3.1 - Beam/one-way slab strengthening application)
F_{ver}	=	Vertical force (Table 3.1 - Infill of frame application)
h	=	Wall height (Table 3.1 - Infill of frame application)
h_{ef}	=	Effective embedment depth
h_{new}	=	Thickness of the concrete overlay
h_1	=	Base length of a shear key
h_2	=	Distance between shear keys
l	=	Wall length (Table 3.1 - Infill of frame application)
l_e	=	Width of the restraint area of the interface at the perimeter
l_i	=	Length of the respective area of a composed section
L	=	Wall's diagonal length (Table 3.1 - Infill of frame application)
MPII	=	Manufacturer's Product Installation Instruction
MPD	=	Mean Profile Depth
MTD	=	Mean Texture Depth
N_{Ed}	=	Tensile force acting
N^*_{Ed}	=	Tensile force acting at the perimeter due to restraint
N_r	=	Resistance of the diagonal strut (Table 3.1 - Infill of frame application)
$N_{Rd,c}$	=	Resistance of the connector under tension loading for concrete cone failure

$N_{Rd,cb}$	=	Resistance of the connector under tension loading for concrete blow-out failure
$N_{Rd,p}$	=	Resistance of the connector under tension loading for pull-out failure
$N_{Rd,sp}$	=	Resistance of the connector under tension loading for concrete splitting failure
N_s	=	Compressive force acting along the diagonal of the frame (Table 3.1 - Infill of frame application)
n_{sc}	=	Number of shear connectors in the respective area of the interface
P	=	Vertical force (Table 3.1 - Infill of frame application)
R_t	=	Peak to mean roughness according to sand patch method
s_{min}	=	Minimum spacing between connectors
V	=	Volume of sand for sand patch method
V_{Ed}	=	Shear force acting
$V_{Ed,i}$	=	Shear force acting in a composed section
V^*_{Ed}	=	Shear force acting at the perimeter due to restraint
z	=	Inner lever arm of the composed section
α_{cc}	=	Coefficient to account for the effect of long-term actions
α_{k1}	=	Product specific factor for ductility
α_{k2}	=	Product specific factor for geometry
α_{seis}	=	Seismic reduction factor of the shear resistance of the interface using specific connectors as given in the European Technical Assessment of the connector
β	=	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
β_c	=	Coefficient for the strength of the compression strut
γ_c	=	Safety factor for concrete; 1,50 as given in EN 1992-4 for strengthening of existing structures
γ_s	=	Safety factor for steel; 1,15 as given in EN 1992-4 for supplementary reinforcement
ε_c	=	Strain related to compression of concrete (Table 3.1 - Beam/one-way slab strengthening application)
ε_s	=	Strain related to tension of reinforcement (Table 3.1 - Beam/one-way slab strengthening application)
κ_1	=	Interaction coefficient for tensile force activated in the shear connector
κ_2	=	Interaction coefficient for flexural resistance in the shear connector
ρ	=	Reinforcement ratio of the shear connector crossing the interface
ρ_{min}	=	Minimum reinforcement ratio of the shear connector crossing the interface
ν	=	Coefficient for reduction of concrete strength
σ_c	=	Normal stress imposed to the concrete, $\sigma_c=\rho\ \sigma_s$
σ_n	=	Lowest expected compressive stress resulting from an eventual normal force acting on the interface (compression has a positive sign)
σ_s	=	Steel stress associated to the relevant failure mode; $\sigma_s = \min(N_{Rd,s}\ ;\ N_{Rd,c}\ ;\ N_{Rd,p}\ ;\ \ldots) / A_s \leq f_{yk} / \gamma_s$
η_{sc}	=	Factor for fatigue loading
τ_{Ed}	=	Shear stress acting
$\tau_{Ed,i}$	=	Shear stress acting in a composed section
τ^*_{Ed}	=	Shear stress acting at the perimeter due to restraint
$\Delta\tau_{Ed}$	=	Shear stress acting as fatigue relevant loading
$\tau_{Ed,max}$	=	Upper shear stress acting as fatigue relevant loading under the frequent action combination
$\tau_{Ed,min}$	=	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

τ_{Rd}	=	Design value of the shear resistance in the interface
μ	=	Friction coefficient

Indices:

E	Action effects
R	Resistance, restraint
seis	Shear seismic action/resistance on the interface
eq	Tension seismic action/resistance on the connector
ex	Existing concrete
ov	Concrete overlay
C1	Seismic category C1 in accordance with EN 1992-4 [5]
C2	Seismic category C2 in accordance with EN 1992-4 [5]
i	subscript for the interface zone that is intended to withstand external forces
j	subscript for the interface zone that is intended to withstand forces originated along the perimeter
*	refers to forces coming from the perimeter

2 DESIGN OF SHEAR INTERFACE UNDER STATIC, QUASI STATIC AND FATIGUE CYCLIC LOADING

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 and Figure 2.2. The loading input is determined by the design engineer responsible for the construction.

The design method is based on [12].

The loading is originating from:

- External action (see Figure 2.1)
- Restraint forces along the perimeter (~~corner~~ edge or construction joint) (see Figure 2.2)

The restraint forces only need to be considered in an area along the perimeter with following distance l_e to the perimeter [13]:

  - $l_e = 3 \cdot h_{new}$ for very rough surfaces
  - $l_e = 6 \cdot h_{new}$ for rough surfaces
  - $l_e = 9 \cdot h_{new}$ for smooth and very smooth surfaces

b_j is the depth of the considered section.

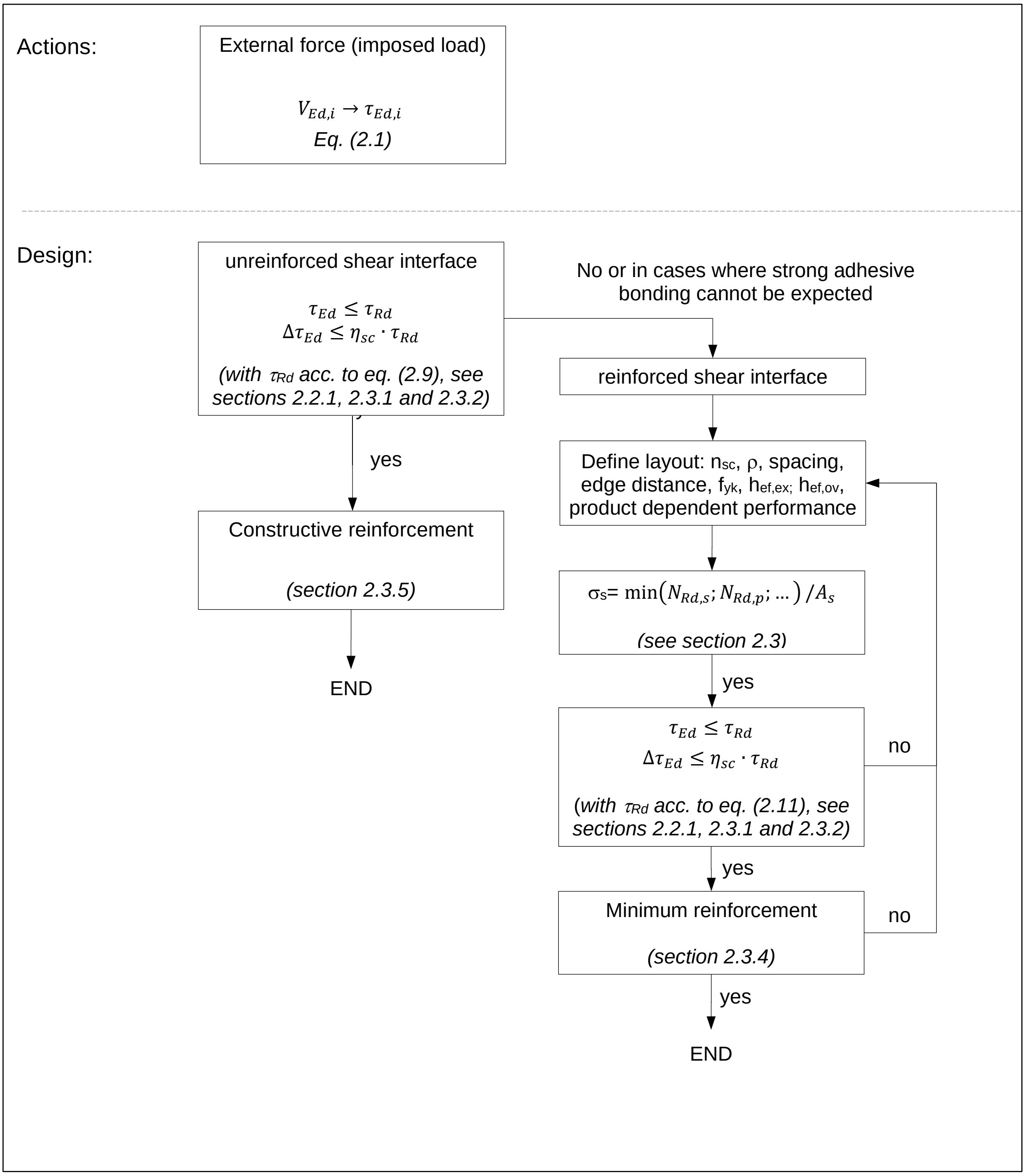


Figure 2.1: Design flow chart for static, quasi-static, and fatigue cyclic actions for design against external forces

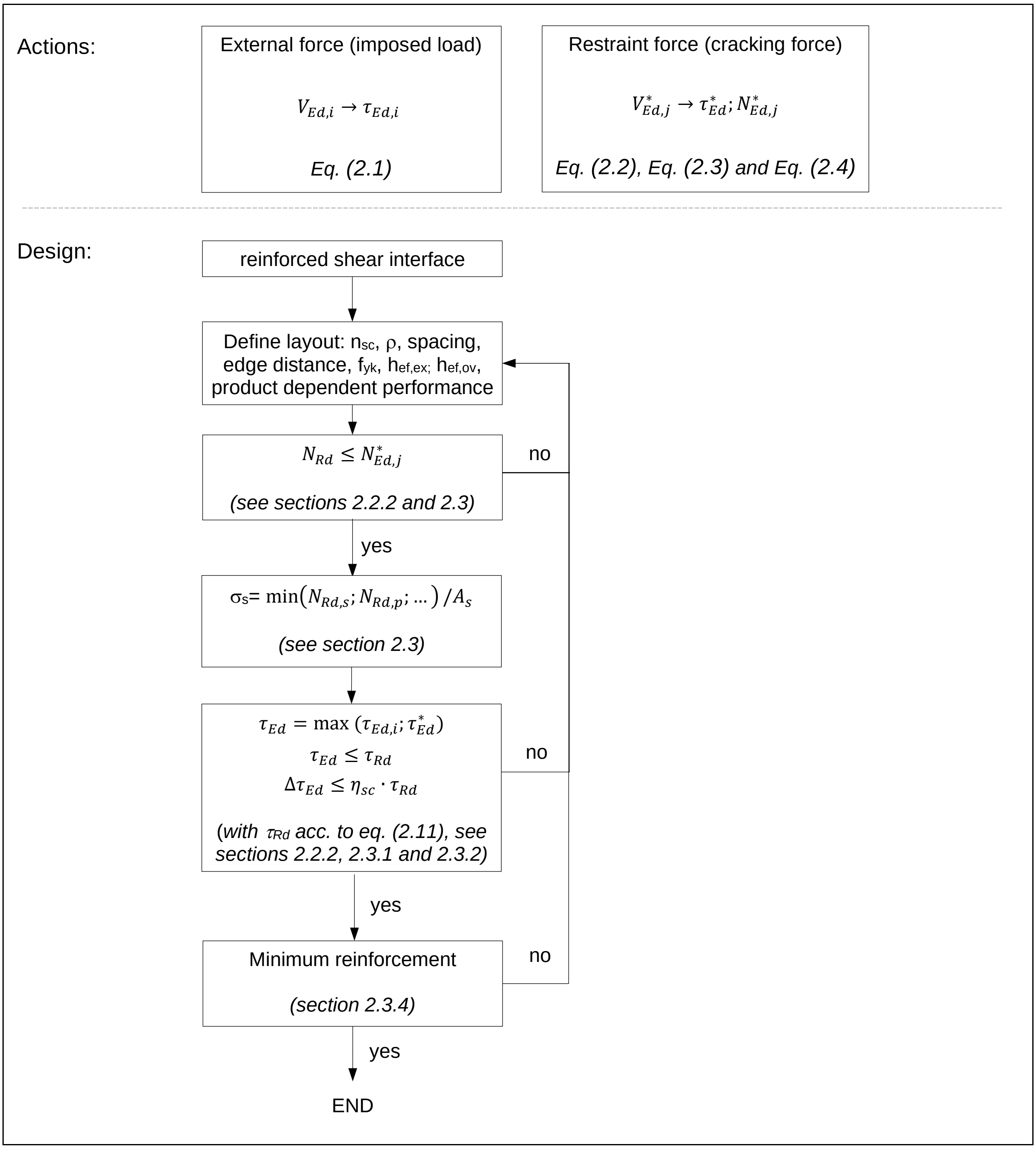


Figure 2.2: Design flow chart for static, quasi-static, and fatigue cyclic actions for design against external actions and restraint force along the perimeter

Note: The design flow charts require iterative loops to achieve an optimized design solution.

2.2 Derivation of the acting forces

There are two types of forces acting on the system:

- External forces
- Forces resulting from restraint at the perimeter due to concrete shrinkage

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 2.3).

It is not allowed to re-distribute (smudge) the stress for rough and very rough surfaces, the maximum value of each zone is decisive. The re-distribution of stresses is allowed only for smooth interfaces, if the design is conducted considering a reinforced interface (see Figure 2.1 and section 2.3.1).

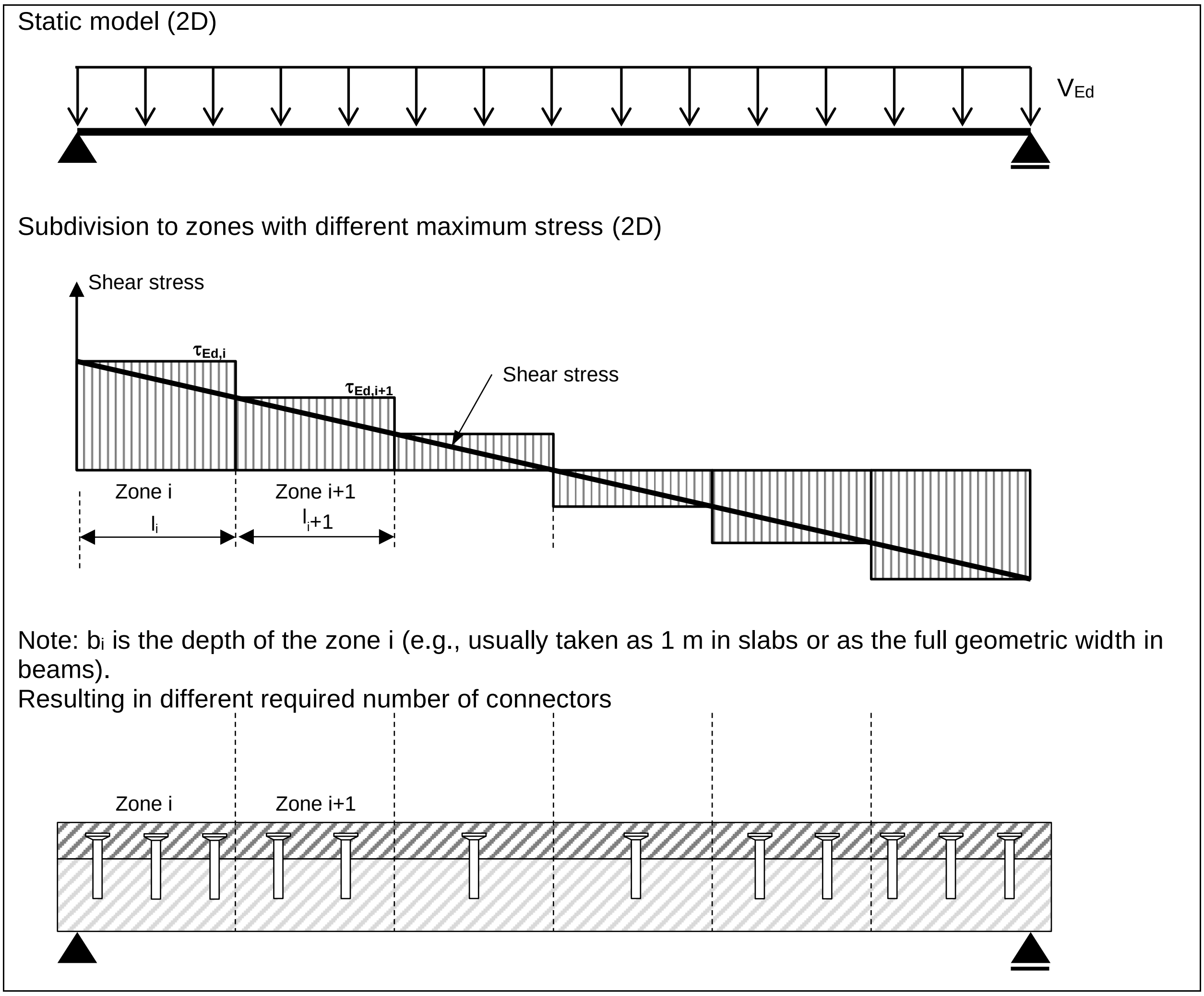


Figure 2.3: Stepped distribution of the shear stress

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, the shear force $V_{Ed,i}$ is converted into a shear stress $\tau_{Ed,i}$ acting parallel to the interface in a defined area. Equation (2.1) is valid for the determination of interface shear due to imposed loads perpendicular to the interface. More discussion on the determination of the shear stress at the interface is given in Section 3.2.

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

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 (see Figure 2.4).

$$V^*_{Ed,j} = h_{new} \cdot b_j \cdot f_{ctd} \tag{2.2}$$

NOTE: the value of the overlay concrete shall be taken for f_{ctd} (reductions due to early age effects might be considered) [12].

τ^*_{ed} is the resulting shear stress from restraint along the perimeter.

$$\tau^*_{Ed} = \frac{V^*_{Ed,j}}{l_e \cdot b_j} = h_{new} \cdot \frac{f_{ctd}}{l_e} \tag{2.3}$$

N^*_{ed} is the resulting uplift force from restraint along the perimeter.

$$N^*_{ed,j} = \frac{V^*_{ed,j}}{6} = \frac{h_{new} \cdot b_j \cdot f_{ctd}}{6} \tag{2.4}$$

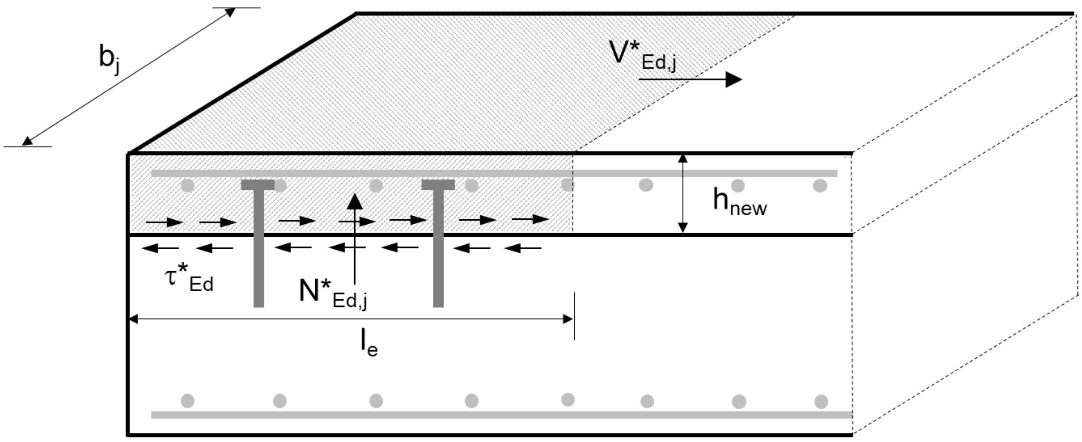


Figure 2.4: Schematic representation of connectors to resist restraint forces along the perimeters

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

2.3 Required verifications

External forces and forces from restraint are not superimposed. Therefore, the following conditions can be considered:

Verification against external actions:

$$\tau_{Ed} = \tau_{Ed,i} \leq \tau_{Rd,i} \tag{2.5}$$

Verification against forces from restraint at the perimeter:

$$\tau_{Ed} = \max\left(\tau_{Ed,i}; \tau^*_{Ed}\right) \leq \tau_{Rd} \tag{2.6}$$

$$N_{Ed} = N^*_{Ed,j} \leq N_{Rd} \tag{2.7}$$

The required verifications are summarised in Table 2.1.

Table 2.1: Required verifications for interface and connectors

	Verification		Reference
Verification of the shear interface (static, quasi-static and fatigue loading)			
1	Shear interface	$\tau_{Ed} \leq \tau_{Rd}$ $\Delta\tau_{Ed} \leq \eta_{sc} \cdot \tau_{Rd}$	Section 2.3.1 Section 2.3.2
Verification of the steel failure (static, quasi-static loading)			
2	Steel failure of connector	$N_{Ed} \leq N_{Rd,s}$	EN 1992-4 [5]
Verification of fastening in existing concrete (static, quasi-static loading)			
3	Concrete cone failure in existing concrete	$N_{Ed} \leq N_{Rd,c}$	EN 1992-4 [5]
4	Pull-out failure of connector in existing concrete	$N_{Ed} \leq N_{Rd,p}$	EN 1992-4 [5]
5	Combined pull-out and concrete failure in existing concrete	$N_{Ed} \leq N_{Rd,p}$	EN 1992-4 [5]
6	Concrete splitting failure in existing concrete	$N_{Ed} \leq N_{Rd,sp}$	EN 1992-4 [5]
Verification of fastening in concrete overlay (static, quasi-static loading)			
7	Concrete cone failure in concrete overlay	$N_{Ed} \leq N_{Rd,c}$	EN 1992-4 [5]
8	Pull-out failure of connector in concrete overlay	$N_{Ed} \leq N_{Rd,p}$	EN 1992-4 [5]
9	Concrete splitting failure in concrete overlay	$N_{Ed} \leq N_{Rd,sp}$	EN 1992-4 [5]
10	Concrete blow-out in concrete overlay	$N_{Ed} \leq N_{Rd,cb}$	EN 1992-4 [5]

NOTE: The resistances of the connectors under tension loading $N_{Rd,c}$, $N_{Rd,p}$, $N_{Rd,sp}$ and $N_{Rd,cb}$ shall be calculated assuming cracked or uncracked concrete conditions depending on the application and the design assumptions. Guidance in this regard is provided by EN 1992-4 [5].

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 α_{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 [4].
- 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 $\alpha_{\kappa 2}$ is applied.

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

$$\tau_{Ed} \leq \tau_{Rd} \tag{2.8}$$

with τ_{Rd} being the design values of the shear resistance in the interface

a) for interfaces without use of shear connectors (strong adhesive bond)

$$\tau_{Rd} = c_a \cdot f_{ctd} + \mu \cdot \sigma_n \leq 0{,}5 \cdot \nu \cdot f_{cd} \tag{2.9}$$

c_a =	given in Table 2.2
μ =	given in Table 2.2; values for very rough surface may be interpolated
ν =	$0{,}55 \cdot \left(\frac{30}{f_{ck}}\right)^{1/3} < 0{,}55$ (2.10)
$\sigma_n \geq$	0 (no tension is allowed)
$f_{ctd}, \sigma_n, f_{cd}$	see Section 1

b) for interfaces with use of shear connectors (weak adhesive bond)

$$\tau_{Rd} = c_r \cdot f_{ck}^{\frac{1}{3}} + \mu \cdot \sigma_n + \mu \cdot \kappa_1 \cdot \alpha_{k1} \cdot \rho \cdot \sigma_s + \kappa_2 \cdot \alpha_{k2} \cdot \rho \cdot \sqrt{\frac{f_{yk}}{\gamma_s} \cdot \frac{0{,}85 \cdot f_{ck}}{\gamma_c}} \leq \beta_c \cdot \nu \cdot \frac{0{,}85 \cdot f_{ck}}{\gamma_c} \tag{2.11}$$

Comprising terms of different working principles:

- term for aggregate interlock, may only be applied if no tension due to external loading is present: $c_r \cdot f_{ck}^{\frac{1}{3}}$
- term for shear friction: $\mu \cdot \sigma_n + \mu \cdot \kappa_1 \cdot \alpha_{k1} \cdot \rho \cdot \sigma_s$
- term for dowel action: $\kappa_2 \cdot \alpha_{k2} \cdot \rho \cdot \sqrt{\frac{f_{yk}}{\gamma_s} \cdot \frac{0{,}85 \cdot f_{ck}}{\gamma_c}}$
- term for concrete strut resistance: $\beta_c \cdot \nu \cdot \frac{0{,}85 \cdot f_{ck}}{\gamma_c}$

With

c_r =	given in Table 2.2
μ =	given in Table 2.2; values for very rough surface may be interpolated
κ_1 =	given in Table 2.2
α_{k1} =	given in the European Technical Assessment of the connector
σ_s =	steel stress associated to the relevant failure mode; $\sigma_s = \min(N_{Rd,s}; N_{Rd,p}; \ldots) / A_s \leq f_{yk} / \gamma_s$ (2.12)
f_{yk} =	given in the European Technical Assessment of the connector
γ_s =	1,15 as given in EN 1992-1-1

κ_2 =	given in Table 2.2
α_{k2} =	given in the European Technical Assessment of the connector
γ_c =	1,50 as given in EN 1992-1-1
β_c =	given in Table 2.2
ν =	calculated as per equation (2.10)
$f_{ck}, f_{yk}, \sigma_n, \sigma_s, \rho$	see Section 1

Table 2.2: Coefficients and parameters for different surface roughness [12], [15]

Surface characteristics of interface	c_a	c_r	κ_1	κ_2	β_c	μ	
						$f_{ck} \geq 20$	$f_{ck} \geq 35$
Very rough, (including shear keys [1)]) $R_t \geq 3{,}0$ mm	0,5	0,2	0,5	0,9	0,5	0,8	1,0
Rough, $R_t \geq 1{,}5$ mm	0,4	0,1	0,5	0,9	0,5	0,7	
Smooth (concrete surface without treatment after vibration or slightly roughened when cast against formwork)	0,2	0	0,5	1,1	0,4	0,6	
Very smooth (steel, plastic, timber formwork)	0,025	0	0	1,5	0,3	0,5	
[1)] shear keys should satisfy the geometrical requirements given in Figure 2.5.							

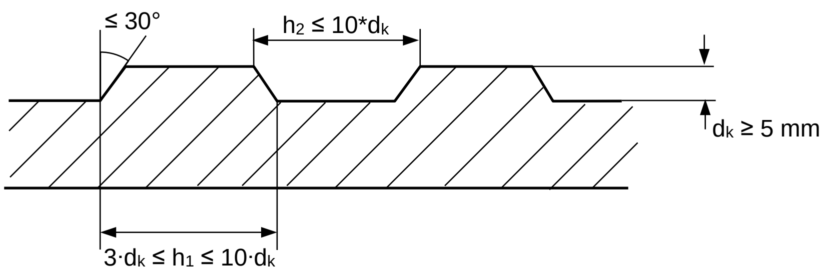


Figure 2.5: Geometry of shear keys

Note: a design using equation (2.9) *assumes that a "monolithic" connection between the old and the new concretes is ensured by strong adhesive bond (i.e., very clean interface). The use of equation (2.11) implies that the interface is cracked and the presence of dowels ensures a "composite" behaviour of the old and new concretes. See [12] for more details.*

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. The minimum allowed strength classes of existing and new concrete are given in the relevant European Technical Assessment. The following condition shall be satisfied:

$$\Delta\tau_{Ed} \leq \eta_{sc} \cdot \tau_{Rd} \tag{2.13}$$

η_{sc} = 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 or where there is alternating cyclic stress, the factor η_{sc} depends on the combination of the applied stresses (static and cyclic).

The value of η_{sc} is the cornerstone for the constant life diagram given in Figure 2.6.

The value for η_{sc} = 0,4 (or otherwise given in the European Technical Assessment of the shear connector for interfaces with use of shear connectors) shall be used.

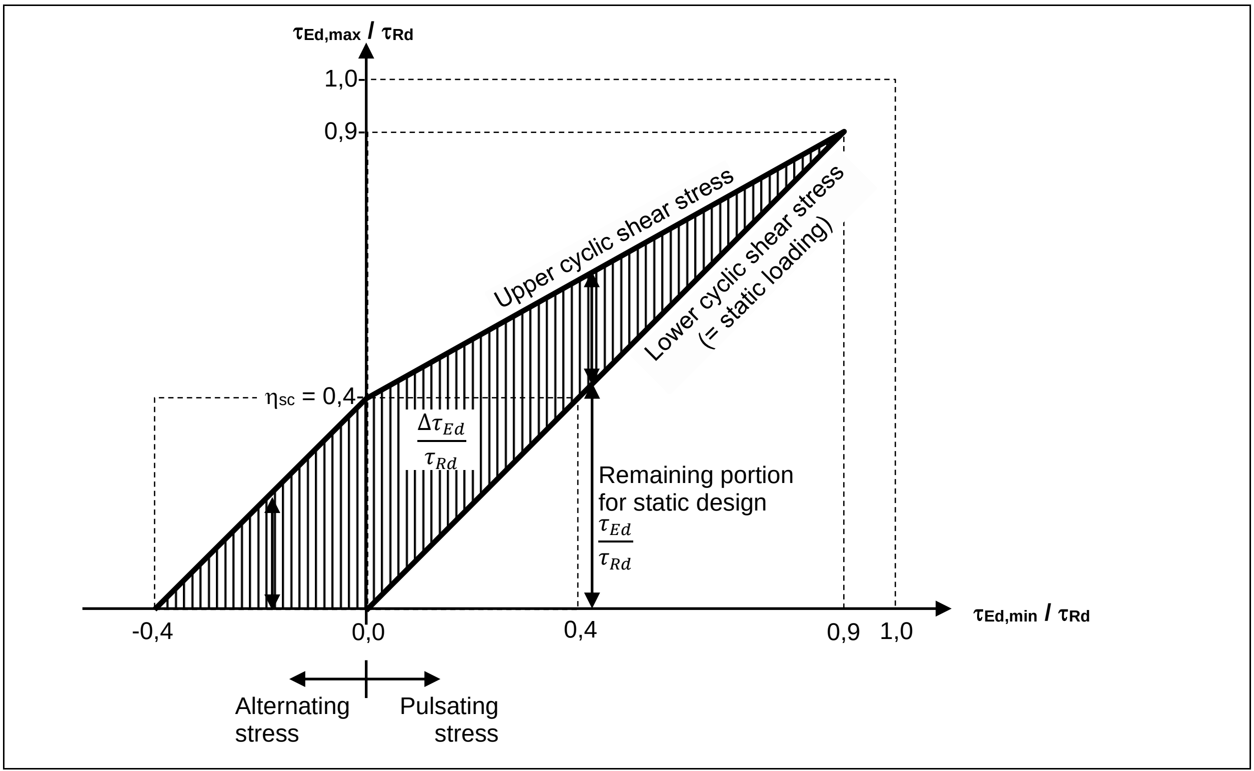


Figure 2.6: Constant life diagram (Goodman diagram)

For verification, three different situations may occur:

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

$$\Delta\tau_{Ed} = \tau_{Ed,max} \tag{2.14}$$

$$\frac{\tau_{Ed,max}}{\tau_{Rd}} \leq \eta_{sc} \tag{2.15}$$

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

Cyclic shear stress as given in Figure 2.6:

$$\Delta\tau_{Ed} = \tau_{Ed,max} - \tau_{Ed,min} \tag{2.16}$$

Upper cyclic shear stress as given in Figure 2.6:

$$\frac{\tau_{Ed,max}}{\tau_{Rd}} \leq \eta_{sc} + 0{,}55 \cdot \frac{\tau_{Ed,min}}{\tau_{Rd}} \leq 0{,}9 \tag{2.17a}$$

Lower cyclic shear stress = Maximum static shear stress as given in Figure 2.6.

$$0 < \frac{\tau_{Ed,min}}{\tau_{Rd}} = \frac{\tau_{Ed}}{\tau_{Rd}} \leq 0{,}9 \tag{2.17b}$$

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

Cyclic shear stress as given in Figure 2.6:

$$\Delta\tau_{Ed} = \tau_{Ed,max} - |\tau_{Ed,min}| \tag{2.18}$$

Upper cyclic shear stress as given in Figure 2.6:

$$\frac{\tau_{Ed,max}}{\tau_{Rd}} \leq \eta_{sc} - \frac{|\tau_{Ed,min}|}{\tau_{Rd}} \tag{2.19}$$

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, the following requirement needs to be ensured:

The minimum spacing between the connectors is the maximum value of the values required in existing concrete and concrete overlay.

$$s_{min} = max\ (s_{min}(existing\ concrete);\ s_{min}(concrete\ overlay)) \tag{2.20}$$

2.3.4 Minimum interface reinforcement

A minimum amount of reinforcement ρ_{min} should be foreseen to prevent brittle failure at loss of aggregate interlock and ensure the composite behaviour of the new section, when weak adhesive bond conditions are assumed (see section 2.3.1) allowing re-distribution of stresses. This is according [12]:

$$\rho_{min} = 0{,}20 \cdot \frac{f_{ctm}}{f_{yk}} \geq 0{,}001\ \ in\ general \tag{2.21a}$$

$$\rho_{min} = 0{,}12 \cdot \frac{f_{ctm}}{f_{yk}} \geq 0{,}0005\ for\ slabs\ or\ walls \tag{2.21b}$$

With

$$\rho_{min} = \frac{A_{s,min}}{A_c} \tag{2.22}$$

NOTE:

- *In the case of bidimensional elements like slabs or walls, extensive debonding is unlikely. Therefore, the minimum interface shear reinforcement ratio can be reduced by approximately 50% in comparison to linear element like beams and columns.*
- *In case of strengthening of 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 [3], corresponding to influence lines or influence surfaces.*

In cases where shear transfer requires the use of shear connectors, to prevent premature splitting of the concrete section parallel or perpendicular to the loading direction,

(a) The reinforcement of the interface should be located at sufficient distance from the edges of the concrete section and

(b) The distance between consecutive reinforcing elements (either bars or anchors) parallel to the loading direction should be sufficiently large.

NOTE: it is known that the presence of the reinforcement on either side of the interface (e.g. hoops in a beam or a column) is beneficial, as it may reduce the risk of splitting and/or improve the bonding conditions of the reinforcement crossing the interface. However, in most applications, it cannot be reliably ensured that there will be adequate reinforcement at close distance from the interface reinforcement, especially in the existing structural member. Thus, it is a safe assumption to neglect any edge reinforcement.

The design equations in this TR cover interfaces in which minimum distances, as shown in Figure 2.7, are ensured between consecutive connectors and between connectors and edges of the concrete section. These minimum values shall be accordingly increased, if the minimum spacing and edge distances (s_{min} and c_{min}) for the considered connector are larger.

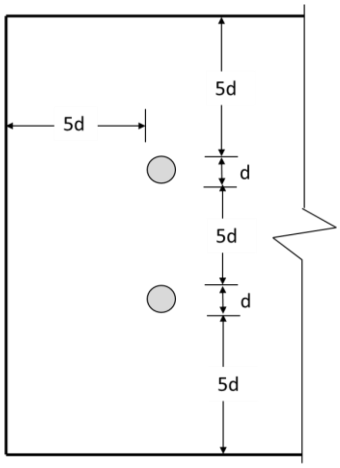


Figure 2.7: Minimum requirements for the applicability of Equations (2.11) and (3.2).

NOTE: The minimum distances shown in Figure 2.7 are based on experimental evidence [17], [18] and they allow for the mobilization of both dowel and friction mechanisms

2.3.5 Constructive interface reinforcement

In case where shear transfer is verified without use of shear connectors, see Equation (2.9), no minimum reinforcement is required. In this case a constructive reinforcement is recommended [9] to support the surface reinforcement in the new concrete element following the relevant local code provisions (see e.g., [19]).

3 DESIGN OF SHEAR INTERFACE UNDER SEISMIC CYCLIC LOADING

3.1 Principle

The design provisions given in this section cover the ultimate limit state under seismic cyclic loading. A schematic design workflow is given in Figure 3.1. The input load is determined by the design engineer responsible for the construction.

NOTE: unreinforced shear interfaces are not recommended for seismic cyclic loading applications and are outside the scope of this TR.

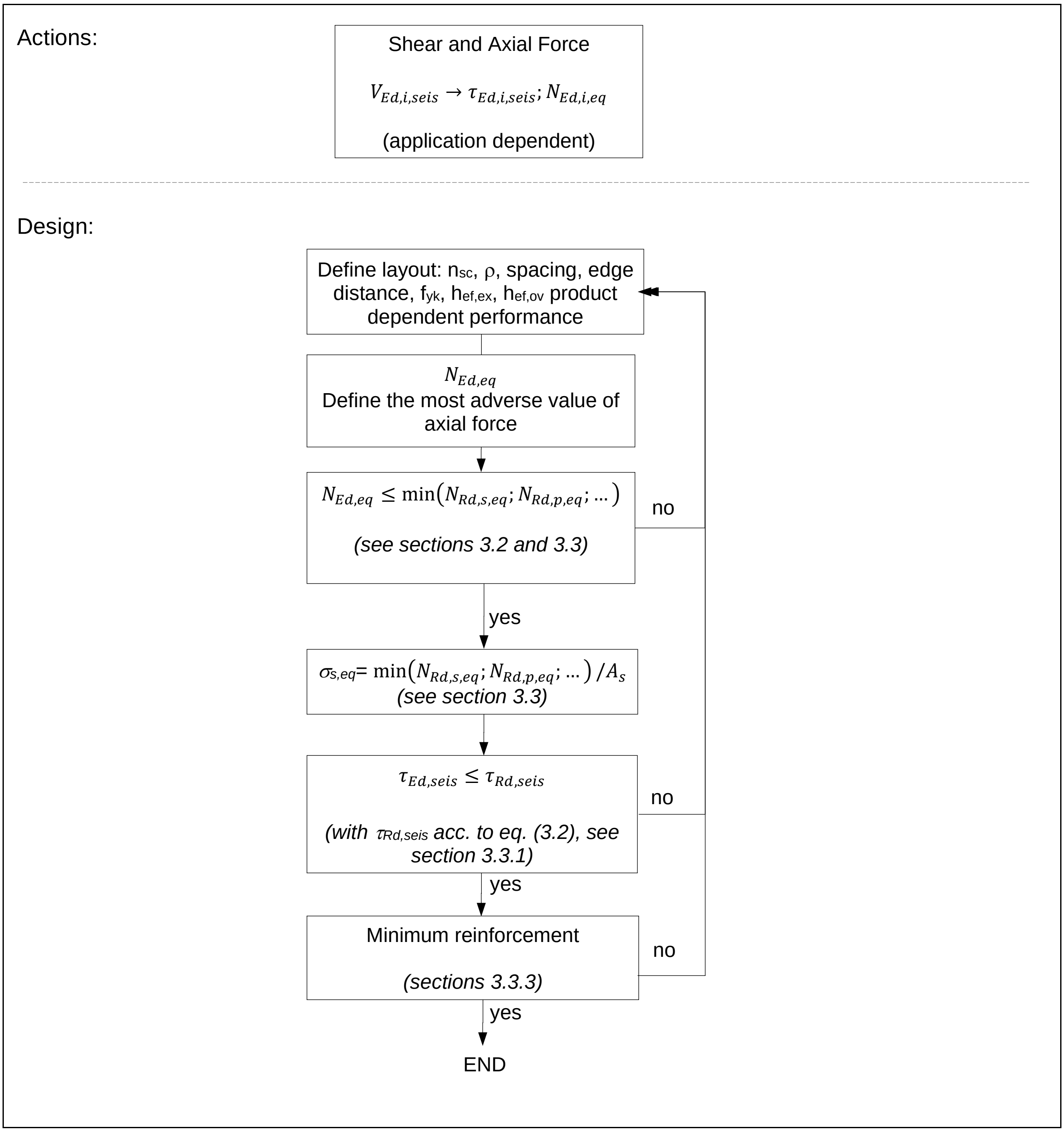


Figure 3.1: Design flow chart for seismic loading

3.2 Derivation of the acting forces

The seismic forces acting on the structural element activate tensile forces perpendicular to the interface, which are carried by the connector and transferred to the two concrete layers.

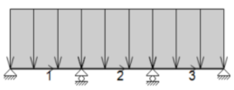
The provisions included in Section 2.2 apply. However, seismic actions and resistances shall be considered. The forces required to be transferred through an interface depend on the repair/strengthening application selected for each type of element.

NOTE: For this purpose, based on the combinations of actions required by the Seismic Code in use, the most adverse combination shall be used for the design of the interface.

For some typical intervention techniques, Table 3.1 includes qualitative guidance for the calculation of loads at the level of interfaces.

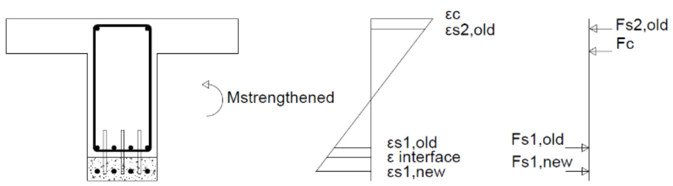
The calculation of seismic resistances shall be carried out following the provisions of Section 3.3.

Table 3.1: Typical repair/strengthening applications involving shear interfaces

<table>
<tr><th>Application with indicative static system and loading input</th><th>Description of interface design</th></tr>
<tr><td>Beam/one-way slab strengthening

</td><td>

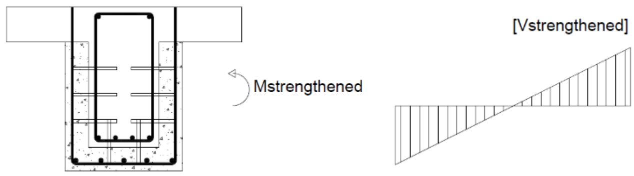
- <u>Type of intervention:</u> layer over/under/lateral/closed jacket
- <u>Determination of forces acting along the interface:</u>

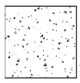
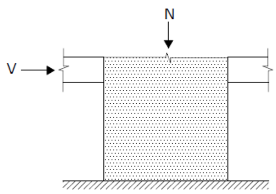
Horizontal interfaces: The acting force is equal to the tensile force developed in the added longitudinal reinforcement ($F_{s1,new}$), deriving from the maximum bending moment acting on the cross-section.



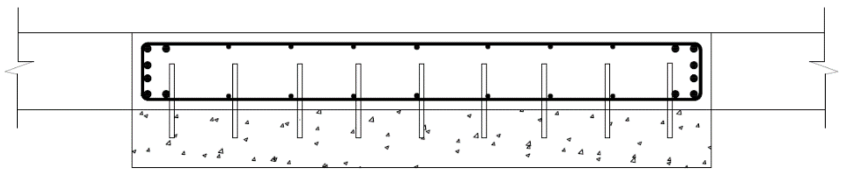
Where ε_c and ε_s (F_c and F_s) are strain (forces) of concrete compression and reinforcement tension, respectively

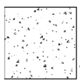
Vertical interfaces: Conservatively, it can be assumed that the two vertical interfaces transfer the maximum shear force derived from sectional analysis and reduced by the shear resistance of the existing beam.



The added layers are represented with hatch.
</td></tr>
<tr><td>Wall strengthening

</td><td>

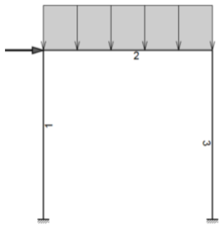
- <u>Type of intervention:</u> closed or partial jacketing/thickening of sides/thickening of the confined boundary elements
- <u>Determination of forces acting along the vertical interface:</u>
The acting force is equal to the vectorial difference between the resultant of all forces (axial force, shear force, additional axial force induced by bending moment) that are resisted by the entire strengthened shear wall and the forces that were resisted by the existing shear wall.



The added part (new wall) is represented with hatch. The new wall shall be reinforced according to the Seismic Code in use.
</td></tr>
</table>

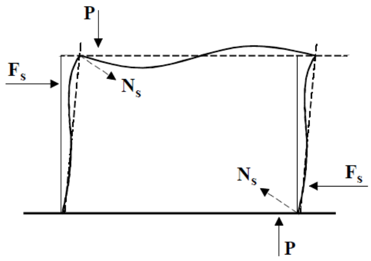
<table>
<tr>
<td>

Infill of frame



</td>
<td>

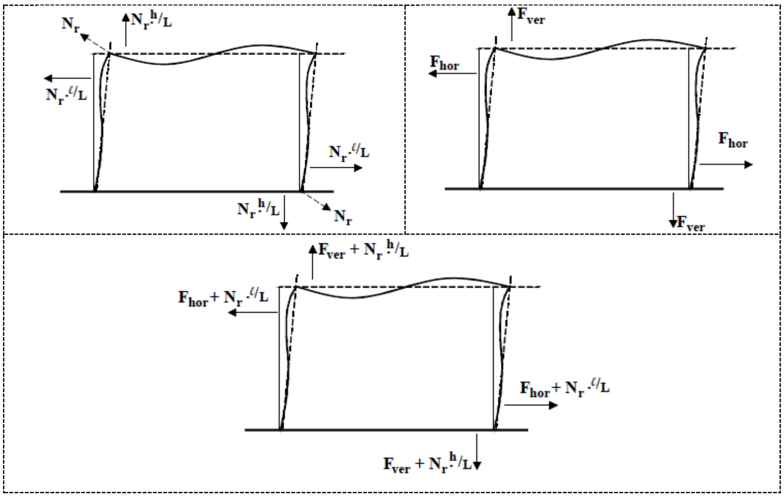
- <u>Type of intervention:</u> infill of a frame with a wall of thickness smaller than/equal to/greater than the beam thickness
- <u>Determination of forces acting along the interface:</u>
  The lateral seismic action F_s is applied on the infilled frame and the vertical force P is developed for its equilibrium. The resultant, N_s, is the compressive force acting along the diagonal of the frame.



$$P = F_s \cdot h/l$$
$$N_s = F_s \cdot L/l$$

with:
h the wall height, *l* the wall length and *L* the wall's diagonal length
The mobilized resistance of the infilled frame derives from:

a) The diagonal concrete strut, which takes a percentage of the shear force acting on the frame. The force N_r, which is resisted by the diagonal strut, shall be calculated as per applicable reinforced concrete standard.
b) The horizontal and vertical interfaces between the added wall and the existing frame, which undertake the remaining part of the force acting. The resistance of the horizontal interfaces is denoted with F_{hor}, whereas the resistance of the vertical interfaces is indicated with F_{ver}.



$$F_s = N_r \cdot l/L + F_{hor}$$
$$P = N_r \cdot h/L + F_{ver}$$

</td>
</tr>
</table>

3.2.1 Determination of external forces

The provisions of Section 2.2.1 and Section 3.2 shall be taken into account.

3.3 Required verifications

The forces are usually not superimposed with static and quasi static actions as well as forces resulting from constraint at the perimeter.

The required verifications for tension load on the connectors listed in Table 2.1, lines 2 to 10 are still valid. However, the seismic actions and resistances shall be taken into account. For the verifications of the interface the provisions of Section 3.3.1 supersede Table 2.1, line 1.

The resistance of the connectors and the decisive failure mode (steel yielding $N_{Rd,s,eq}$ or concrete-related failure modes under tension loading $N_{Rd,c,eq}$, $N_{Rd,p,eq}$, $N_{Rd,sp,eq}$ and $N_{Rd,cb,eq}$) shall be calculated assuming seismic performance category C1 or C2 depending on the application and the design assumption. Guidance in this regard is provided by EN 1992-4 [5]. Depending on the type of application, the impact of the decisive failure modes of the connectors (e.g., concrete cone, pull-out, combined pull-out and concrete cone, splitting, blow-out, or steel yielding) on the desired behaviour of the interface shall be considered by the designer.

NOTE:

- *Steel yielding of the connectors might be required as decisive failure mode to ensure a ductile behaviour of primary structural members (e.g., connection of shear walls to an existing frame).*

- *Concrete related failure modes might be acceptable in interfaces between members that are not supposed to undergo significant deformation during the seismic event and/or where a high redundancy is provided and the failure of single connector is not expected to endanger the integrity of the structure (e.g., floor thickening).*

- *Different requirements might be needed for the anchorage of the connectors in the existing concrete and the overlay (i.e., under extreme seismic conditions the overlays might be damaged, but the existing element should not be significantly damaged to ensure its capability in continuing carrying gravity loads).*

3.3.1 Design of the interface for seismic cyclic conditions

The shear stress at the interface between concretes cast at different times shall satisfy the following condition:

$$\tau_{Ed,seis} \leq \tau_{Rd,seis} \tag{3.1}$$

where $\tau_{Rd,seis}$ is the design value of the shear resistance of the interface calculated as follows

$$\tau_{Rd,seis} = \alpha_{seis}\left[c_r \cdot f_{ck}^{1/3} + \mu \cdot \sigma_n + \mu \cdot k_1 \cdot \alpha_{\kappa 1} \cdot \rho \cdot \sigma_{s,eq} + k_2 \cdot \alpha_{\kappa 2} \cdot \rho \cdot \sqrt{f_{yd} \cdot f_{cd}}\right] \leq \beta_c \cdot v \cdot f_{cd} \tag{3.2}$$

It is noted that for the case of cyclic loading $f_{cd} = \frac{f_{ck}}{\gamma_c}$

The upper limit for the interface resistance, $\tau_{Rd,seis}$, is the interface resistance calculated for static loading as follows

$$\tau_{Rd,seis} \leq \tau_{Rd} \tag{3.3}$$

The design coefficients of Eq. (3.2) are described in Section 2.3.1 and require the following modifications to account for seismic cyclic actions:

c_r =	given in Table 3.2
μ =	given in Table 3.2 as a function of f_{cd}, σ_n and σ_c, being σ_c the normal stress imposed to the concrete ($\sigma_c = \rho\ \sigma_{s,eq}$).
κ_1 =	given in Table 3.2
κ_2 =	given in Table 3.2
β_c =	given in Table 3.2
$\sigma_{s,eq}$ =	Steel stress associated with the relevant failure mode under seismic conditions; $\sigma_{s,eq} = \min(N_{Rd,s,eq}; N_{Rd,p,eq}; \ldots) \leq f_{yk} / \gamma_s$

α_{seis}= given in the European Technical Assessment of the connector in accordance with EAD 332347-00-0601-v01 [2]

Table 3.2: Coefficients and parameters for different surface roughness for seismic cyclic loading

Surface characteristics of interface	c_r	κ_1	κ_2	β_c	μ	
					$f_{ck} \geq 20$ MPa	$f_{ck} \geq 50$ MPa
Rough $R_t \geq 1{,}5$ mm	0	0,5	0,9	0,5	$\mu = 0{,}40 \cdot \sqrt[3]{\left(\frac{f_{cd}}{(\sigma_c + \sigma_n)}\right)^2}$	$\mu = 0{,}27 \cdot \sqrt[3]{\left(\frac{f_{cd}}{(\sigma_c + \sigma_n)}\right)^2}$
Smooth (concrete surface without treatment after vibration or slightly roughened when cast against formwork) $R_t < 1{,}5$ mm	0	0,5	1,1	0,4	$\mu = 0{,}27 \cdot \sqrt[3]{\left(\frac{f_{cd}}{(\sigma_c + \sigma_n)}\right)^2}$	$\mu = 0{,}135 \cdot \sqrt[3]{\left(\frac{f_{cd}}{(\sigma_c + \sigma_n)}\right)^2}$

NOTE:

- *The term of adhesive bond resistance/aggregate interlock, added to the resistance due to friction and to dowel action in the static equation (2.11) is neglected in the equation for the calculation of the interface resistance under cyclic loading (Table 3.2).*
- *The value of friction coefficient, μ, shown Table 3.2 is determined as a function of the compressive stress (σ_c+σ_n) acting on the interface. This is in accordance with experimental evidence, as shown in the international literature (e.g., [17]).*

3.3.2 Design of fastening in existing concrete and concrete overlay

The provisions of Section 2.3.3 and Section 3.3 apply.

3.3.3 Minimum interface reinforcement

The provision of Section 2.3.4 apply.

3.3.4 Constructive interface reinforcement

The provisions of Section 2.3.5 apply.

4 REQUIREMENTS FOR CONSTRUCTION WORKS

4.1 Surface preparation

The following conditions shall be satisfied for the surface preparation [14]:

- 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 [11]. Alternative methods, e.g. optical measurement, may be used.
- Bond strength perpendicular to the interface surface $f_h \geq$ min (1,5 N/mm²; f_{ctm}); measurement of f_h according [10].
- For the interval of measurements of roughness and bond strength one test per 100 m² 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 $f_{ctk,0,05} \leq 3{,}0$ N/mm²
- 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.

4.1.1 Sand patch method according Kaufmann to determine roughness R_t

A volume, V 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, d_m of the circle should be measured. For calculation of roughness R_t, see (4.1):

$$R_t = \frac{4 \cdot V}{d_m^2 \cdot \pi} \tag{4.1}$$

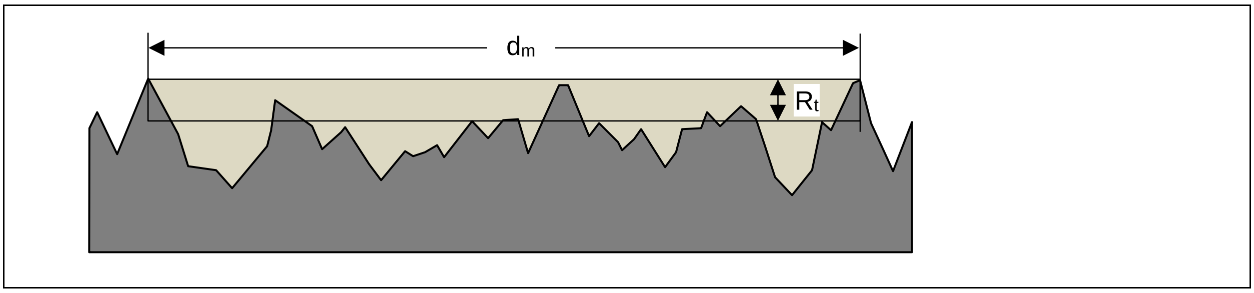


Figure 4.1: Sand patch method according Kaufmann

Alternatively, the provisions of EN 13036-1 [7] can be followed.

4.1.2 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 in accordance with EN ISO 13473-1 [8] and correlates with the peak to mean roughness with a transformation factor of 1,1, see equation (4.2). The equation is valid in the range of 0,3 mm < MPD < 3,0 mm.

$$R_t = MTD = ETD = 1{,}1 \cdot MPD \tag{4.2}$$

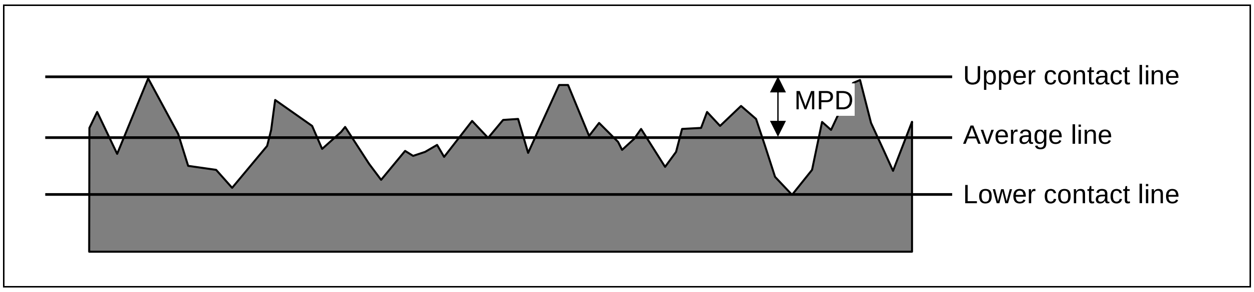


Figure 4.2: Mean profile depth MPD

4.2 New concrete – mixture, casting, post-treatment

The following conditions shall be satisfied for the new concrete [14]:

- 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 ≥ 380 mm, a slump value f ≥ 450 mm is recommended, if applicable. Determination of slump according to [16].
- 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 post-treatment (see [14]).

5 REFERENCE DOCUMENTS

[1] EAD 332347-00-0601:12-2018: Connector for strengthening of existing concrete structures by concrete overlay

[2] EAD 332347-00-0601-v01:03-2021: Connector for strengthening of existing concrete structures by concrete overlay: behaviour under seismic action

[3] EN 1991:2002 + AC 2009: Actions on structures

[4] EN 1992-1-1:2004+AC:2010: Design of concrete structures. Part 1-1: General rules and rules for buildings

[5] EN 1992-4:2018: Design of concrete structures; Part 4: Design of fastenings for use in concrete

[6] EN 1998-1: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings

[7] EN 13036-1:2010: Road and airfield surface characteristic – Test methods: Part 1: Measurement of pavement surface macrotexture depth using a volumetric patch technique

[8] EN ISO 13473-1:2019: Characterization of pavement texture by use of surface profiles - Part 1: Determination of mean profile depth

[9] Randl, N., Münger, F., Wicke, M.: Verstärkung von Brückentragwerken durch Aufbeton (Strengthening of structural behavior of bridges with overlays). In: Bauingenieur, Band 80, April/2005 (in German)

[10] EN 1542:1999: Products and systems for the protection and repair of concrete structures. Test methods. Measurement of bond strength by pull-off

[11] Kaufmann, N.: Das Sandflächenverfahren (The sand-patch method). In: Straßenbautechnik, 24 (1971), No. 3 (in German)

[12] fib Model Code for Concrete Structures 2010 (10/2013)

[13] Randl, N., Wicke, M.: Schubübertragung zwischen Alt- und Neubeton (Shear transfer between old and new concrete). In: Beton- und Stahlbetonbau, vol. 95/8, 2000 (in German)

[14] RVS 15.02.34: Design and detailing of concrete overlays (07/2011)

[15] Randl, N: Design recommendations for interface shear transfer in fib Model Code 2010. In: Structural concrete 03/2013

[16] EN 12350-5:2009: Testing fresh concrete – Part 5: Flow table test

[17] Vintzileou, E., Palieraki, V., Genesio, G., Piccinin, R.: Shear behaviour of interfaces within repaired/strengthened RC elements subjected to cyclic actions. In: International Workshop on Advanced Materials and Innovative Systems in Structural Engineering: Seismic Practices, 16 November 2018, Istanbul, Turkey.

[18] Vintzileou E., Tassios T.P.: Eccentric dowels against core of concrete sections. In: Journal of Structural Engineering, 116 (10), October 1990, 2621-2633

[19] Bewehren von Stahlbetontragwerken nach DIN EN 1992-1-1:2011-01 in Verbindung mit DIN EN 1992-1-1/NA:2011-01, Arbeitsblätter, Arbeitsblatt 11: Unterstützungen für die obere Bewehrung (Reincing of reinforced concrete structures in accordacen with DIN EN 1992-1-1 in connections with DIN EN 1992-1-1/NA:2011-01, Working sheets, Working sheet 11: support of upper layer of reinforcement, in German).