TECHNICAL REPORT

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

TR 066

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Contents

1 SCOPE OF THE TECHNICAL REPORT

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]

Category	Methods / Situation (Examples)	Application		Peak to mean roughness R_t [mm]
		Static and quasi-static	Fatigue cyclic loading	
Very rough	High pressure water jetting, shot blasting, indented, shear keys	yes	yes	≥ 3,0
Rough	Sand-blasted	yes	not applicable	≥ 1,5
Smooth	Untreated, slightly roughened	yes	not applicable	< 1,5
Very smooth	Existing concrete cast against steel formwork	yes	not applicable	not measurable

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
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
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
f_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

h_{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
MPII	=	Manufacturer's product installation instruction
MPD	=	Mean profile depth
MTD	=	Mean texture depth
N_{Ed}	=	Tensile force acting
$N_{Ed,i}$	=	Tensile force acting in a composed section
N^*_{Ed}	=	Tensile force acting at the perimeter due to restraint
n_{sc}	=	Number of shear connectors in the respective area of the interface
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_{k1}	=	Product specific factor for ductility
α_{k2}	=	Product specific factor for geometry
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
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 steel of the shear connector crossing the interface
ρ_{min}	=	Minimum reinforcement ratio
ν	=	Coefficient for reduction of concrete strength
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; $\sigma_s \leq f_{yk} / \gamma_s$
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
μ	=	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_j to the perimeter [12]:

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

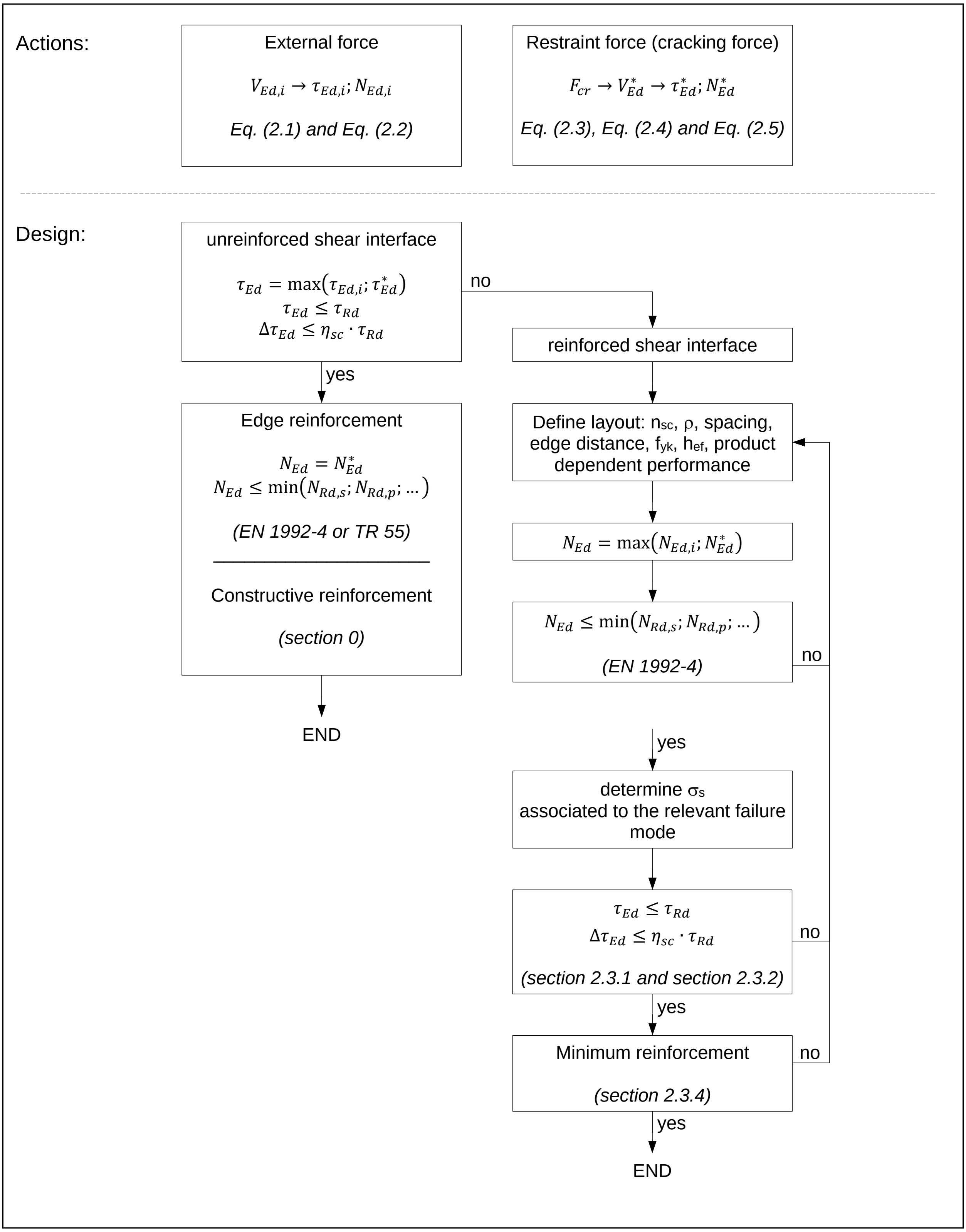

Figure 2.1: Design flow chart

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.

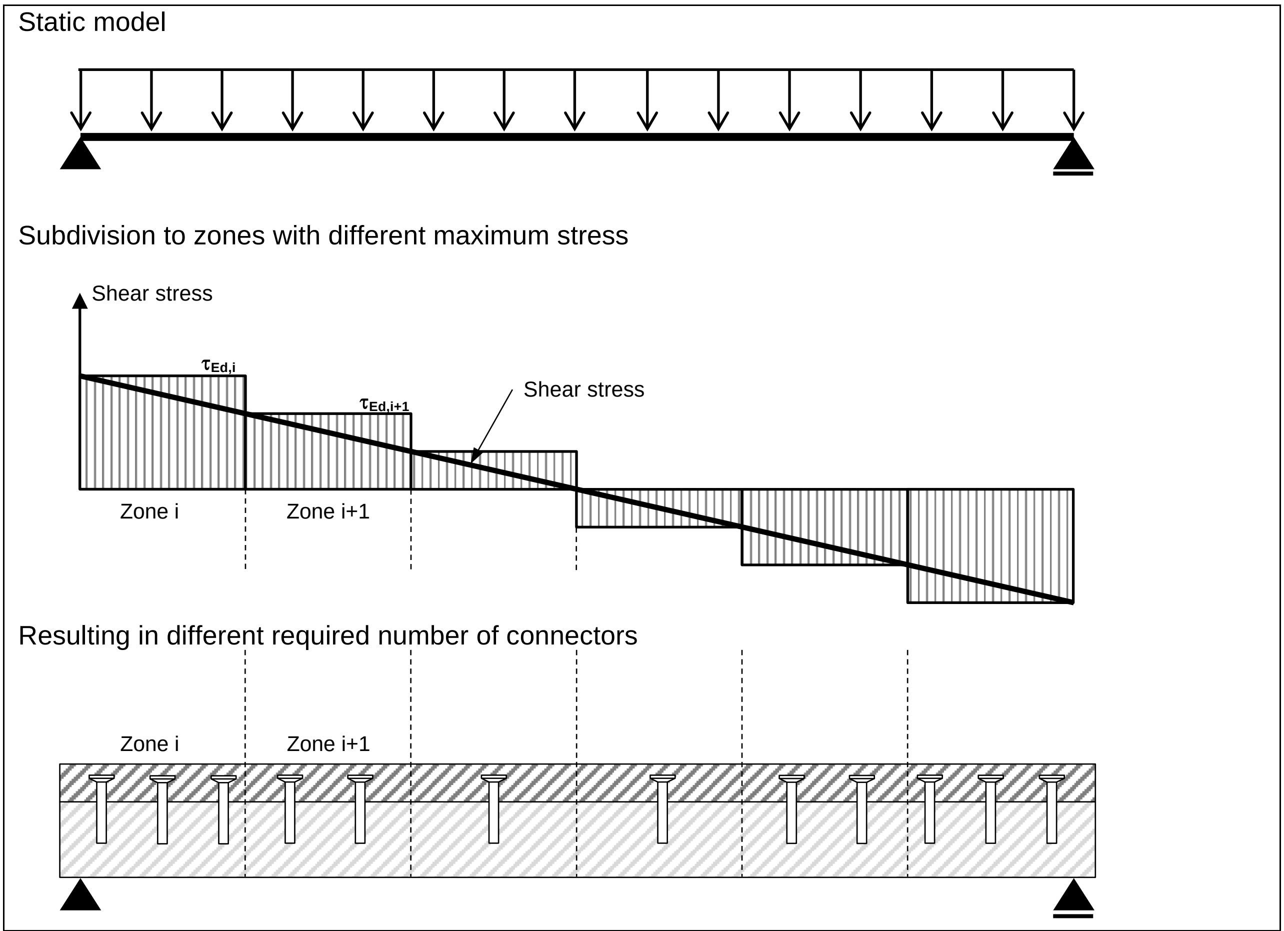

Figure 2.2: stepped distribution of the shear stress

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.

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

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

$$N_{ed,i} = (\sigma_n + \kappa_1 \cdot \alpha_{k1} \cdot \rho \cdot \sigma_s) \cdot \left(\frac{b_i \cdot l_i}{n_{sc}}\right) \tag{2.2}$$

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.

$$V_{Ed}^{*} = h_{new} \cdot b_j \cdot f_{ctd} \tag{2.3}$$

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

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

$$\tau_{Ed}^{*} = \frac{V_{Ed}^{*}}{b_j} \tag{2.4}$$

N^{*}_{ed} is the resulting loading from constraint along the perimeter.

$$N_{ed}^{*} = \frac{V_{ed}^{*}}{6} = \frac{h_{new} \cdot b_i \cdot f_{ctd}}{6} \tag{2.5}$$

2.3 Required verifications

External forces and forces from constraint are not superpositioned.

$$\tau_{Ed} = \max(\tau_{Ed,i}; \tau^*_{Ed}) \quad (2.6)$$

$$N_{Ed} = \max(N_{Ed,i}; N^*_{Ed}) \quad (2.7)$$

The required verifications for tension load 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	$\tau_{Ed} \le \tau_{Rd}$ $\Delta\tau_{Ed} \le \eta_{sc} \cdot \tau_{Rd}$	Section 2.3.1 Section 2.3.2
Verification of the steel failure (static, quasi-static loading)			
2	Steel failure of connector	$N_{Ed} \le N_{Rd,s}$	EN 1992-4 [6]
Verification of fastening in existing concrete (static, quasi-static loading)			
3	Concrete cone failure in existing concrete	$N_{Ed} \le N_{Rd,c}$	EN 1992-4 [6]
4	Pull-out failure of connector in existing concrete	$N_{Ed} \le N_{Rd,p}$	EN 1992-4 [6]
5	Combined pull-out and concrete failure in existing concrete	$N_{Ed} \le N_{Rd,p}$	EN 1992-4 [6]
6	Concrete splitting failure in existing concrete	$N_{Ed} \le N_{Rd,sp}$	EN 1992-4 [6]
Verification of fastening in concrete overlay (static, quasi-static loading)			
7	Concrete cone failure in concrete overlay	$N_{Ed} \le N_{Rd,c}$	EN 1992-4 [6]
8	Pull-out failure of connector in concrete overlay	$N_{Ed} \le N_{Rd,p}$	EN 1992-4 [6]
9	Concrete splitting failure in concrete overlay	$N_{Ed} \le N_{Rd,sp}$	EN 1992-4 [6]

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

a) for <u>interfaces without use of shear connectors</u>

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

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)
$f_{ctd}, \sigma_n, f_{cd}$	see 1

b) for <u>interfaces with use of shear connectors</u>

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

Comprising terms of different working principles:

- term for aggregate interlock, may only be applied if no tension due to external loading is present — $c_r \cdot f_{ck}^{\frac{1}{3}}$
- term for shear friction — $\mu \cdot \sigma_n + \mu \cdot \kappa_1 \cdot \alpha_{k1} \cdot \rho \cdot \sigma_s$
  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 — $\kappa_2 \cdot \alpha_{k2} \cdot \rho \cdot \sqrt{\frac{f_{yk}}{\gamma_s} \cdot \frac{0{,}85 \cdot f_{ck}}{\gamma_c}}$
- 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; $\sigma_s = N_{Rd,s}/A_s \leq f_{yk} / \gamma_s$
f_{yk} =	given in the European Technical Assessment of the connector
γ_s =	1,15 as given in EN 1992-4 for supplementary reinforcement
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 1992-4 for strengthening of existing structures
β_c =	given in Table 2.2
ν =	$0{,}55 \cdot \left(\frac{30}{f_{ck}}\right)^{1/3} < 0{,}55$ (2.12)
$f_{ck}, f_{yk}, \sigma_n, \sigma_s, \rho$	see 1

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

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 2.3.

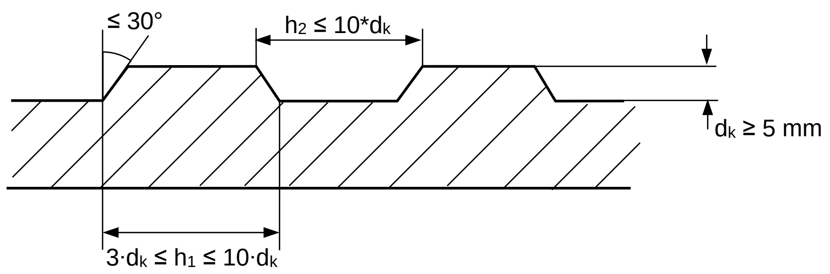

Figure 2.3: Geometry of shear keys

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:

$$\Delta\tau_{Ed} \leq \eta_{sc} \cdot \tau_{Rd} \quad (2.13)$$

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 2.4.

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):

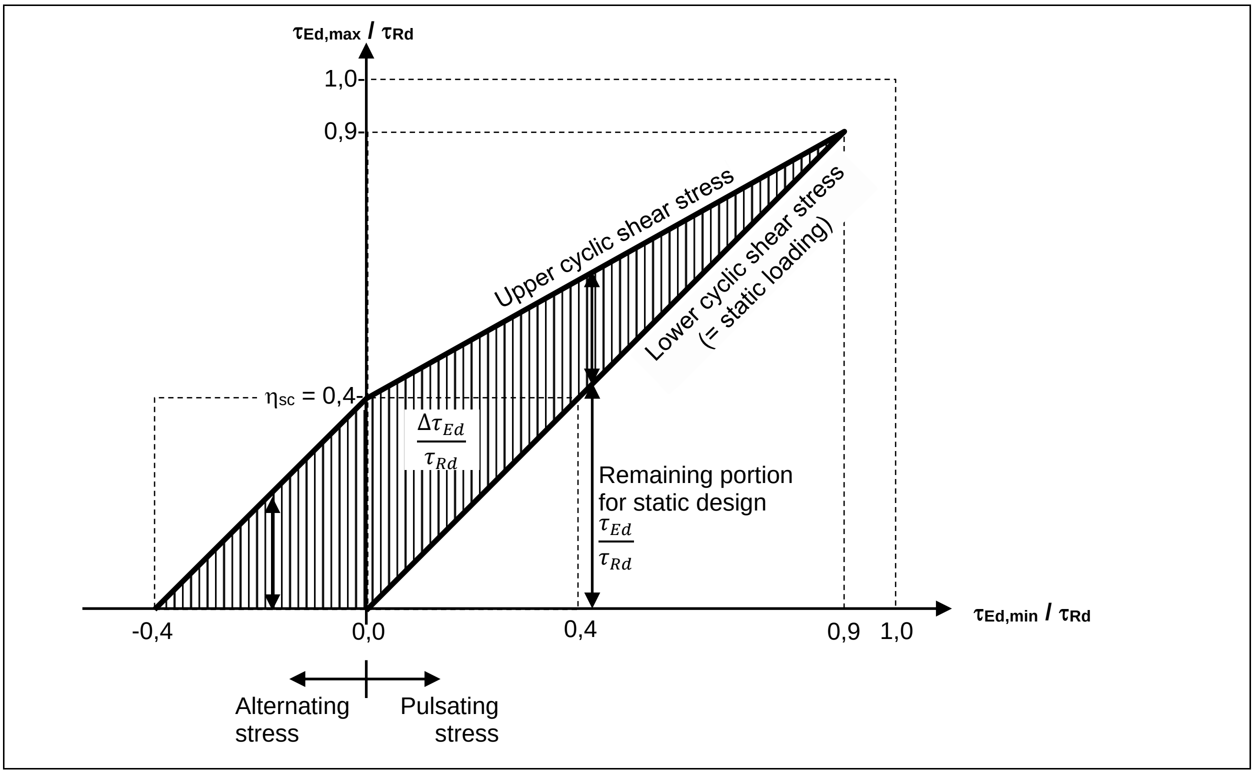

Figure 2.4: Constant life diagram (Goodman diagram)

For verification three different situations may occur:

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

$$\Delta\tau_{Ed} = \tau_{Ed,max} \qquad (2.14)$$

$$\frac{\tau_{Ed,max}}{\tau_{Rd}} \leq \eta_{sc} \qquad (2.15)$$

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

Cyclic shear stress as given in Figure 2.4:

$$\Delta\tau_{Ed} = \tau_{Ed,max} - \tau_{Ed,min} \qquad (2.16)$$

Upper cyclic shear stress as given in Figure 2.4:

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

Lower cyclic shear stress = Maximum static shear stress as given in Figure 2.4.

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

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

Cyclic shear stress as given in Figure 2.4:

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

Upper cyclic shear stress as given in Figure 2.4:

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

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.

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

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. This is according [11]:

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

With

$$\rho_{min} = \frac{A_s}{A_c} \qquad (2.22)$$

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].

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 $f_h \geq \min(1{,}5\ N/mm^2;\ f_{ctm})$; 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 $f_{ctk,0,05} \leq 3{,}0\ N/mm^2$
- 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).

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

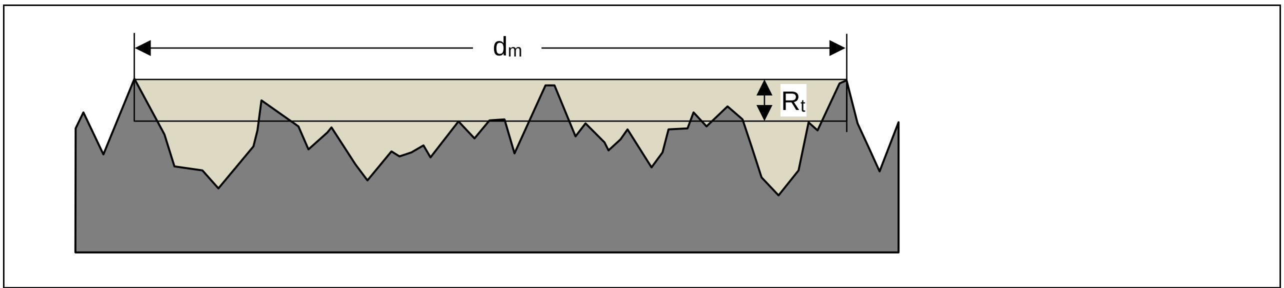

Figure 2.5: Sand patch method according Kaufmann

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 mm < MPD < 3,0 mm.

$$R_t = MTD = ETD = 1{,}1 \cdot MPD \qquad (2.24)$$

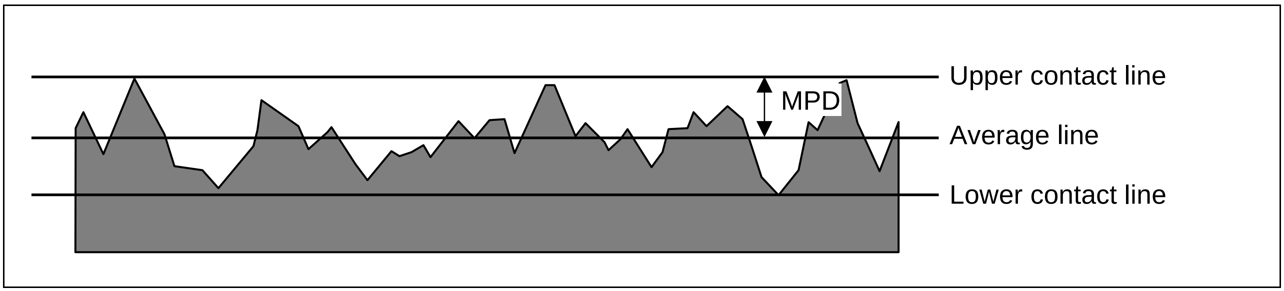

Figure 2.6: Mean profile depth MPD

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 ≥ 380 mm ~~≥F38~~, a slump value f ≥ 450 mm ~~≥ F45~~ 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

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