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European Assessment Document for

Connector for strengthening of existing concrete structures by concrete overlay

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This European Assessment Document (EAD) has been developed taking into account up-to-date technical and scientific knowledge at the time of issue and is published in accordance with the relevant provisions of Regulation (EU) 305/2011 as a basis for the preparation and issuing of European Technical Assessments (ETA).

Contents

1 SCOPE OF THE EAD

1.1 Description of the construction product

This EAD covers connectors for strengthening of existing concrete structures by concrete overlay (in the following referred to as connectors) consisting of metal or consisting of a bonding material and an embedded metal part. The metal part consists of carbon steel, stainless steel or malleable cast iron. Connectors are connecting two layers of concrete cast at different times. A general sketch of the principle is given in Figure 1.1.1.

To prevent the separation of the layers the shear stress is carried by the roughness of the shear interface. Both layers are clamped to each other by means of the connectors.

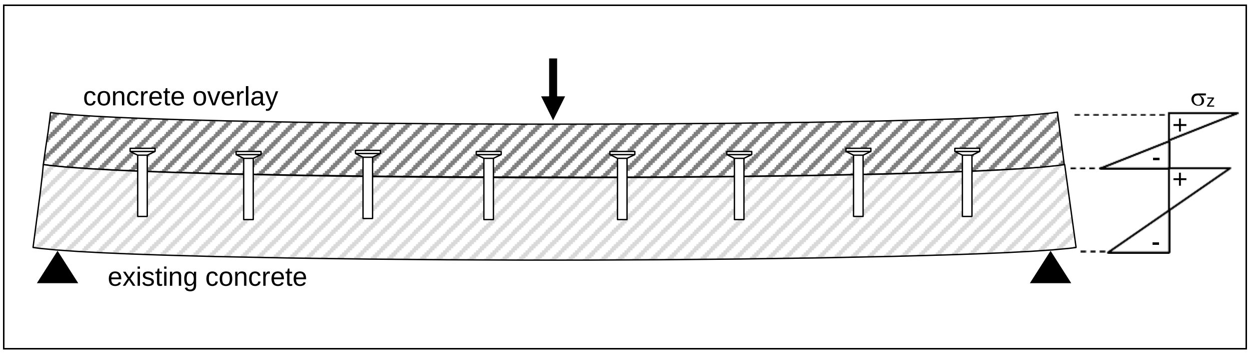

Figure 1.1.1 Deformation and normal stress with cracked bonding between the two concrete layers

The transfer of the shear stress is given by adhesion, friction and doweling.

The connectors are fastened into a pre-drilled hole in the existing concrete and cast into a new layer of concrete (concrete overlay), see Figure 1.1.2. They transfer the resulting tension load to the existing concrete and the concrete overlay.

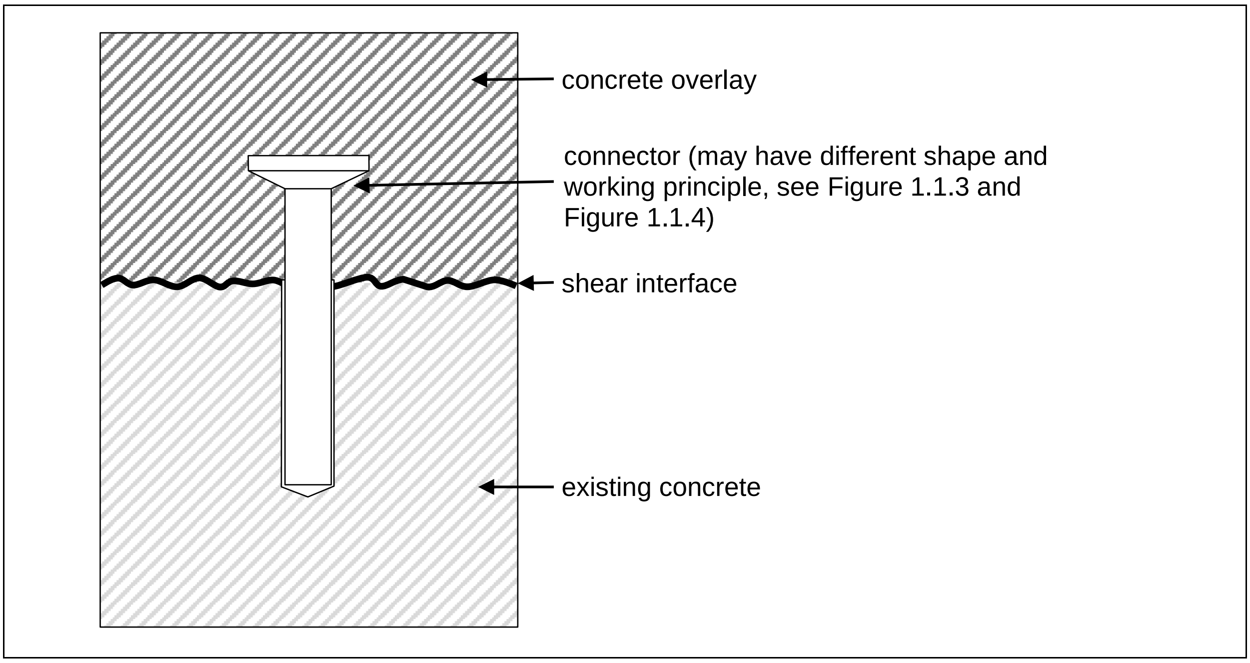

Figure 1.1.2 Connector; definitions and use

The part of the connector, which is anchored in the existing concrete, complies with bonded fasteners (BF) according to EAD 330499-01-0601 [4][1] or concrete screws (CS) according to EAD 330232-01-0601 [2] (see Figure 1.1.3).

The part of the connector in the concrete overlay is anchored by mechanical interlock with an anchor head or a shaped head (see Figure 1.1.4).

Existing concrete:

Bond
- Bonded fastener (BF)

Mechanical interlock
- Concrete screw (CS)

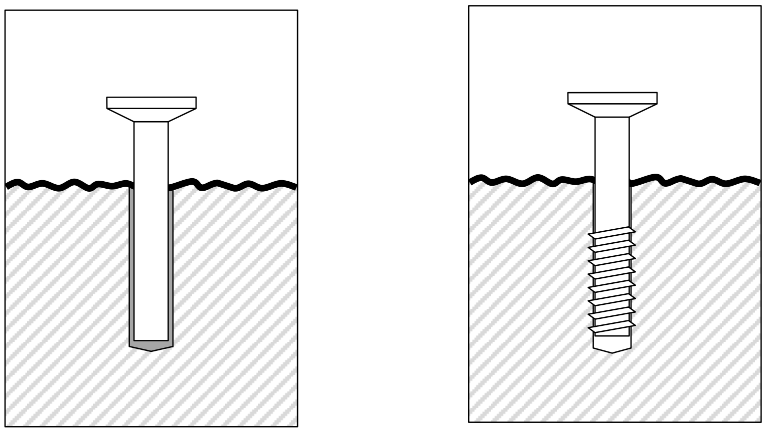

Figure 1.1.3 Fastening principles in existing concrete (post-installed fastener part)

Concrete overlay:

Mechanical interlock
- Anchor head

Mechanical interlock
- Shaped head

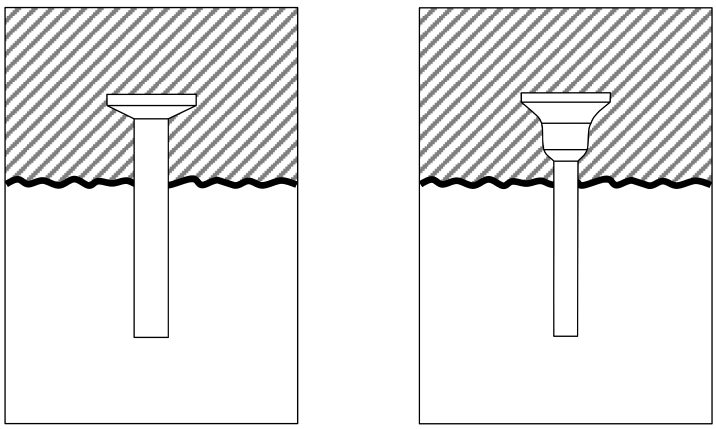

Figure 1.1.4 Fastening principles in concrete overlay (cast-in fastener part)

The connectors consist of a longitudinal shaft with constant or varying shape along its length. The shaft ends in an anchor head or a shaped head for load transmission. Dimension and examples of connectors are given in Figure 1.1.5.

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1 All undated references to standards or to EADs in this EAD are to be understood as references to the dated versions listed in chapter 4.

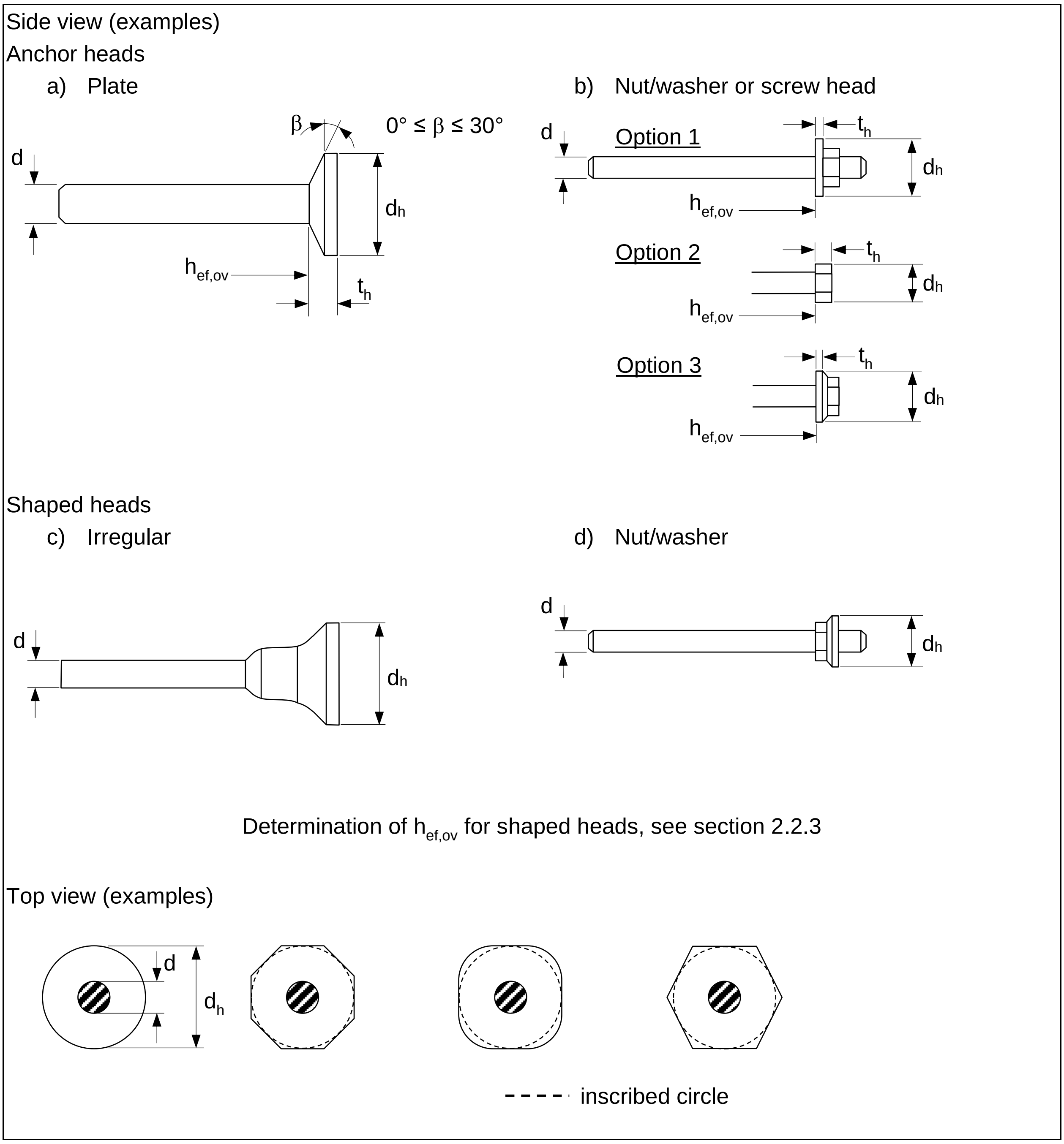


Figure 1.1.5 Connector, types and geometries

The EAD covers connectors with an angle β of the head 0° ≤ β ≤ 30°.

A shaped head is characterized by an increase of the outer diameter of the connector in the area, which is in the concrete overlay. The increased outer diameter has a symmetrical geometry.

The EAD applies to connectors with a circular cross section of the shaft with a minimum outer diameter of the connector of d = 6 mm.

This EAD covers fasteners with a coefficient of variation of the failure loads tests of 30% at maximum.

The minimum embedment depth in the existing concrete complies with EAD 330499-01-0601 [4] respectively EAD 330232-01-0601 [2]. The minimum embedment depth in concrete overlay is 40 mm.

The connector is installed perpendicular to the shear interface.

The product is not covered by a harmonised European standard (hEN).

Concerning product packaging, transport, storage, maintenance, replacement and repair it is the responsibility of the manufacturer to undertake the appropriate measures and to advise his clients on the transport, storage, maintenance, replacement and repair of the product as he considers necessary.

It is assumed that the product will be installed according to the manufacturer's instructions or (in absence of such instructions) according to the usual practice of the building professionals.

Relevant manufacturer's stipulations having influence on the performance of the product covered by this European Assessment Document shall be considered for the determination of the performance and detailed in the ETA.

1.2 Information on the intended use(s) of the construction product

1.2.1 Intended use

The intended use is strengthening of existing concrete structures by an additional concrete overlay. 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 connectors are used as redundant components, which allow redistribution to neighbouring connectors.

The connector is not intended to be used for completion of semi-finished concrete parts by casting additional concrete.

The connectors apply for the use of interfaces with a roughness according to Table 1.2.1.1.

This connector is intended to be used subject to static and quasi-static action as well as under fatigue cyclic loading. For fatigue cyclic loading of the shear interface the current experience is represented by the S/N-curve given in Figure 1.2.1.2. This EAD covers systems following this function, proven by tests and assessment according to A.7.

The connector is intended to be used in compacted reinforced or unreinforced normal weight concrete without fibres with strength classes in the range C20/25 to C50/60 all in accordance with EN 206 [6]. For the concrete overlay following requirements on the mixture apply:

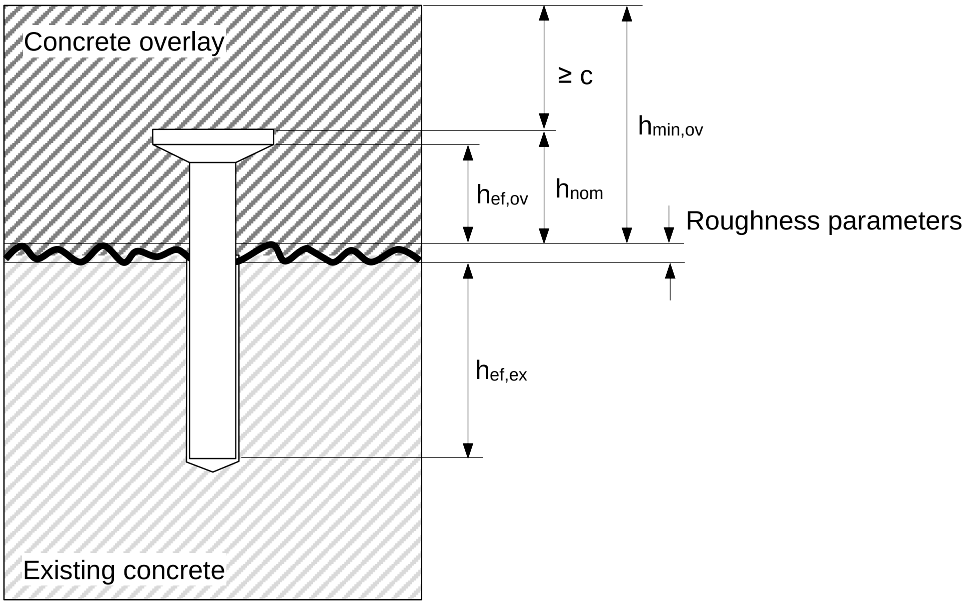
- Concrete compressive strength of the new concrete shall be higher than the concrete compressive strength of the existing concrete.
- Use of concrete with low shrinkage.
- Slump of fresh concrete f ≥ 380 mm, a slump value f ≥ 450 mm, if applicable. Determination of slump according to EN 12350-5 [15].

Anchorage in cracked and uncracked concrete in both layers of concrete are covered. The hardened concrete is at least 21 days old.

The thickness of the concrete overlay $h_{min,ov}$ is depending on the overall anchorage depth h_{nom} and the required minimum concrete cover c according to EN 1992-1-1 [12] (see also Figure 1.2.1.1).

The connector is intended to be used with edge distance in existing concrete $c_{cr,sp,ex} \geq 1,5\ h_{ef,ex}$.

This EAD does not cover fasteners for which this limit cannot be achieved.



For determination of h_{ef} in existing concrete and in concrete overlay the roughness needs to be considered.

Figure 1.2.1.1: Shear connection measures

Table 1.2.1.1: Values of surface roughness

Category	Methods / Situation	Application		Peak to mean roughness R_t [1)] [mm]
		Static and quasi-static	Fatigue cyclic loading	
Very rough	High pressure water jetting, 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

1) Parameter for surface roughness based on a volumetric measurement according to sand patch method (Kaufmann, 1971 [16]). R_t is the mean height based on this measurement.

Other methods for determination of the surface roughness may be used under the condition that equivalence with results of the sand patch method is ensured.
The mean texture depth (MTD) according to EN 13036-1 [10] is equivalent to R_t.
Optical measurement devices deliver a value of mean profile depth (MPD) according to EN ISO 13473-1 [11]. In this standard, an estimated texture depth (ETD) is described, which is equivalent to MTD. The value of ETD is transformed from MPD with the factor of 1,1.

$R_t = MTD = ETD = 1{,}1 * MPD$ (equation is valid in the range of 0,3 mm < MPD < 3,0 mm)

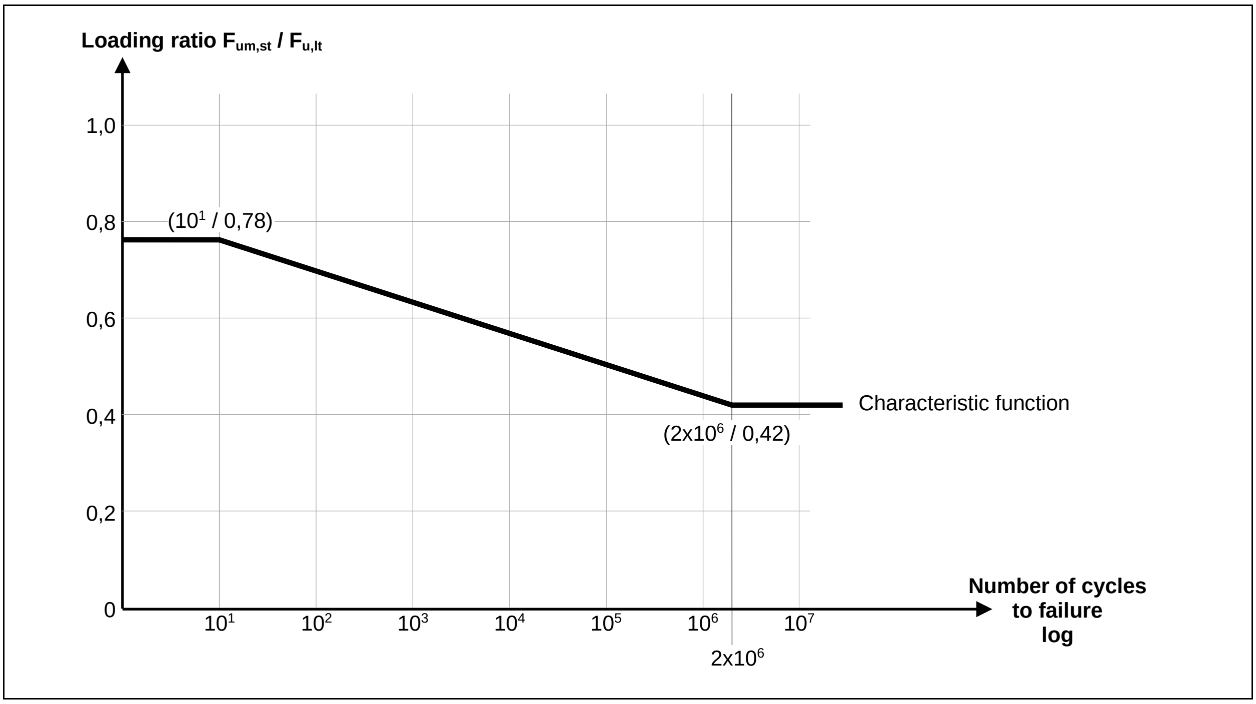


Figure 1.2.1.2: Given function for fatigue behaviour of the shear interface

The connector is intended to be used as follows:

- Connectors installed in building components subject to dry internal conditions according to exposure class X0 and XC1 of EN 1992-1-1 [12],
- Connectors made of stainless steel installed in building components subjected to environmental conditions according to EN 1993-1-4 [7], Table A.1 (corrosion resistance factor – CRF) dependent on the corrosion resistant class (CRC depending on the material number, see EN 1993-1-4 [7], Table A.3),
- Connectors made of carbon steel or malleable cast iron with the appropriate concrete cover according to EN 1992-1-1 [12] and if a bond between the existing concrete and the concrete overlay is ensured,
- Connectors made of carbon steel or malleable cast iron with the appropriate concrete cover according to EN 1992-1-1 [12] and no water can penetrate into the joint between existing concrete and concrete overlay.

The purpose of this EAD is to provide assessment methods for essential characteristics which might be used for design of the connector in existing concrete and concrete overlay under static and quasi-static loading according to EN 1992-4 [14].

Furthermore, the purpose of this EAD is to provide assessment methods for essential characteristics which might be used for design of the shear connection concrete to concrete under static, quasi-static and fatigue cyclic loading according to TR 066 [8].

1.2.2 Working life/Durability

The assessment methods included or referred to in this EAD have been written based on the manufacturer's request to take into account a working life of the connector for the intended use of 50 years when installed in the works (provided that the shear connection is subject to appropriate installation (see 1.1)). These provisions are based upon the current state of the art and the available knowledge and experience.

When assessing the product, the intended use as foreseen by the manufacturer shall be taken into account. The real working life may be, in normal use conditions, considerably longer without major degradation affecting the basic requirements for works[2].

The indications given as to the working life of the construction product cannot be interpreted as a guarantee neither given by the product manufacturer or his representative nor by EOTA when drafting this EAD nor by the Technical Assessment Body issuing an ETA based on this EAD, but are regarded only as a means for expressing the expected economically reasonable working life of the product.

1.3 Specific terms used in this EAD

1.3.1 Abbreviations

BF	=	Bonded fastener
CS	=	Concrete screw
MPII	=	Manufacturer's product installation instructions
ETD	=	Estimated texture depth
MTD	=	Mean texture depth
MPD	=	Mean profile depth

1.3.2 Notation

A_5	=	Rupture elongation
A_h	=	Projected area of the head in the concrete overlay
A_s	=	Relevant cross section of the connector in the area of the interface
c	=	Minimum concrete cover for concrete overlay
$c_{cr,N}$	=	Characteristic edge distance for concrete cone failure in tension
$c_{cr,sp}$	=	Characteristic edge distance for concrete splitting
c_{min}	=	Minimum edge distance
cv_F (cv_δ)	=	Coefficient of variation of failure loads (of displacements)
$cv_{R,i}$ ($cv_{R,m}$)	=	Coefficient of variation of the roughness on single test specimens (on all test specimens in a test series)
d	=	Diameter of the anchor (shaft) of a connector
d_0	=	Diameter of the drill hole
d_c	=	Inner diameter of a hollow core connector in the area of the interface
d_h	=	Diameter of the head of a connector
E_s	=	Modulus of elasticity of the connector
f_c	=	characteristic concrete compressive strength of cylinders
f_{cube}	=	characteristic concrete compressive strength of cubes
f_{uk}	=	Characteristic ultimate strength of the connector
f_{yk}	=	Characteristic yield strength of the connector

2 The real working life of a product incorporated in a specific works depends on the environmental conditions to which that works is subject, as well as on the particular conditions of the design, execution, use and maintenance of that works. Therefore, it cannot be excluded that in certain cases the real working life of the product may also be shorter than referred to above.

$F_{um,st}$	=	Failure load under static loading in the system test
F_{up}	=	Upper load under cycling loading in the system test
F_{lp}	=	Lower load under cycling loading in the system test
h_{ef}	=	Effective embedment depth
$h_{ef,geom}$	=	Effective embedment depth resulting from geometrical assessment (for shaped heads only)
$h_{ef,test}$	=	Effective embedment depth resulting from assessment of tests (for shaped heads only)
h_{min}	=	Minimum thickness of the concrete member in which the connector is installed
h_{nom}	=	Overall embedment depth in the concrete overlay
k	=	Factor for resistance to concrete failure
k_5	=	Factor for concrete blow-out
L_1	=	length at the anchor head, where the area of the head does no longer increase
L_2	=	length at the anchor head, where the area of the head does increase
m	=	Normalization exponent taking into account the effect of concrete strength on the resistance
$N^0_{Rk,cb}$	=	Characteristic tension resistance for concrete blow-out
$N^0_{Rk,c}$	=	Characteristic tension resistance for concrete cone failure
$N_{Rk,s}$	=	Characteristic tension resistance for steel
$N_{Rk,p}$	=	Characteristic tension resistance for pull-out
$N_{sl,t}$	=	load level where uncontrolled slip occurs in the test
$N_{u,m}$ ($N_{u,5\%}$)	=	Mean (5% fractile of) failure loads in tests
n_{min}	=	Minimum required number of tests
R_t	=	Roughness parameter according to volumetric measurement with sand patch method
$R_{t,i}$	=	mean value of the measured roughness of the test member i
$R_{t,m}$	=	mean value of the measured roughness of all test member in a series
$s_{cr,N}$	=	Characteristic spacing for concrete cone failure in tension
$s_{cr,sp}$	=	Characteristic spacing for concrete splitting
s_{min}	=	Minimum spacing
t_h	=	Thickness of the head of an anchor head
α_1	=	Criteria for loss of adhesion (for BF only)
α_{k1}	=	Product specific factor for ductility
α_{k2}	=	Product specific factor for geometry
rqd. α	=	Required value for reduction factor α in the assessment
β	=	Angle between the shaft and the head of an anchor head
δ_u	=	Deflection at failure in the system test
γ_{inst}	=	Factor accounting for the sensitivity of installation
η_{sc}	=	Reduction factor for system performance under fatigue loading
ψ_c	=	Increasing factor accounting for concrete strength

σ_z	=	Normal stress in a cross-section of a concrete structure
τ_{Rk}	=	Characteristic bond resistance (for BF only)

1.3.3 Indices

cr	=	Cracked concrete
ucr	=	Uncracked concrete
test	=	Related to the value in a test
ex	=	Existing concrete
ov	=	Concrete overlay

1.3.4 Definitions

Anchor head	=	Head of a fastener creating mechanical interlock and following common definition for the geometry
Concrete overlay	=	Concrete cast to the existing concrete at a different time. The contact area of the existing concrete and the concrete overlay is the interface.
Connector	=	Device used for connecting the two concrete layers cast at different times. The connector is post-installed in the existing concrete. Also described as fastener in this document.
Existing concrete	=	Concrete structure, were the connector is fastened by the means of post-installed fastening principles
Fastener	=	See: connector
Interface	=	Also shear interface, the interface between the existing concrete and the concrete overlay
Layer	=	Synonymous for the concrete structures cast at different times
Roughness	=	Roughness of the surface of the existing concrete before concreting the concrete overlay.
Run-out	=	Test specimens that did not fail in a cyclic loading test with the given number of cycles and were successfully loaded to failure in a test at a higher load level
Shaped head	=	Head of a fastener creating mechanical interlock and not following common definition for the geometry
Shear stress	=	Stress between the two concrete layers parallel to the interface

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1.1 shows how the performance of connector for strengthening of existing concrete structures by concrete overlay is assessed in relation to the essential characteristics.

Table 2.1.1 Essential characteristics of the product and methods and criteria for assessing the performance of the product in relation to those essential characteristics

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability			
Existing concrete; post-installed **concrete screw**			
1	Resistance to steel failure	EAD 330232-01-0601, 2.2.1	Level $N_{Rk,s,ex}$ [kN]
2	Resistance to pull-out failure	EAD 330232-01-0601, 2.2.2	Level $N_{Rk,p,ex}$ [kN], $\psi_{c,ex}$
3	Resistance to concrete cone failure	EAD 330232-01-0601, 2.2.3	Level $k_{cr,N,ex}$, $k_{ucr,N,ex}$ [-], $h_{ef,ex}$, $c_{cr,N,ex}$ [mm]
4	Robustness	EAD 330232-01-0601, 2.2.4	Level γ_{inst} [-]
5	Minimum edge distance and spacing	EAD 330232-01-0601, 2.2.5	Level $c_{min,ex}$, $s_{min,ex}$ $h_{min,ex}$ [mm]
Existing concrete; post-installed **bonded** fastener			
6	Resistance to steel failure	EAD 330499-01-0601, 2.2.1	Level $N_{Rk,s,ex}$ [kN]
7	Resistance to combined pull-out and concrete failure	EAD 330499-01-0601, 2.2.2 and A.2.3.2	Level τ_{Rk} [N/mm²], $\psi_{c,ex}$, ψ^{0}_{sus} [-]
8	Resistance to concrete cone failure	EAD 330499-01-0601, 2.2.3	Level $c_{cr,N,ex}$ [mm] $k_{cr,N,ex}$, $k_{ucr,N,ex}$ [-]
10	Robustness	EAD 330499-01-0601, 2.2.5	Level γ_{inst} [-]
11	Minimum edge distance and spacing	EAD 330499-01-0601, 2.2.6	Level $c_{min,ex}$, $s_{min,ex}$ $h_{min,ex}$ [mm]

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability			
Concrete overlay; cast-in fastener			
12	Characteristic resistance to steel failure for cast-in fastener in concrete overlay	2.2.1	Level $N_{Rk,s,ov}$ [kN]
13	Characteristic resistance to pull-out failure for cast-in fastener in concrete overlay under static and quasi-static tension loading	2.2.2	For anchor heads: Level A_h [mm²], t_h [mm] For shaped heads: Level $N_{Rk,p,ov}$ [kN], $\psi_{c,ov}$ [-]
14	Characteristic resistance to concrete cone failure for cast-in fastener in concrete overlay under static and quasi-static tension loading	2.2.3	Level $c_{cr,N}$ [mm], $h_{ef,ov}$ [mm] $k_{cr,N,ov}$, $k_{ucr,N,ov}$ [-]
15	Resistance to blow-out failure and edge distances and spacing	2.2.4	Level A_h [mm²] Level $c_{min,ov}$, $s_{min,ov}$ $h_{min,ov}$ [mm] Level $c_{cr,sp,ov}$ [mm]
Shear interface parameters under **static and quasi-static and fatigue cyclic loading**			
16	Shear interface parameters under static and quasi-static and fatigue loading	2.2.5	Level α_{k1} [-], f_{yk} [N/mm²] Level α_{k2} [-], A_s [mm²] Level η_{sc} [-]
Basic Works Requirement 2: Safety in case of fire			
17	Reaction to fire	2.2.6	Class

2.2 Methods and criteria for assessing the performance of the product in relation to essential characteristics of the product

This chapter is intended to provide instructions for TABs. Therefore, the use of wordings such as "shall be stated in the ETA" or "it has to be given in the ETA" shall be understood only as such instructions for TABs on how results of assessments shall be presented in the ETA. Such wordings do not impose any obligations for the manufacturer and the TAB shall not carry out the assessment of the performance in relation to a given essential characteristic when the manufacturer does not wish to declare this performance in the Declaration of Performance.

2.2.1 Characteristic resistance to steel failure for cast-in fastener in concrete overlay

For anchor head and shaped head:

The characteristic resistance to steel failure $N_{Rk,s,ov}$ shall be calculated for steel elements with constant strength over the length of the element as given in equation (2.2.1.1). The smaller cross section in the area of load transfer applies.

$$N_{Rk,s,ov} = A_s \cdot f_{uk} \quad \text{[N]} \qquad (2.2.1.1)$$

If the steel strength differs along the length of the element, calculate the ratio $N_{Rk,s,ov}/\gamma_{Ms}$ for the specified steel strength and the corresponding nominal stressed cross sections according to equation (2.2.1.1). In absence of national regulations recommended partial factor for steel resistance γ_{Ms} are given in EN 1992-4 [14], Table 4.1. The characteristic resistance and the corresponding partial factor γ_{Ms} for the minimum ratio $N_{Rk,s,ov}/\gamma_{Ms}$ is given in the ETA.

Tests are needed only if the calculation of the characteristic resistance to steel failure is not reasonable because the distribution of the steel strength of the finished product along the length of the fastener is not known or cannot be easily determined.

The modulus of elasticity for steel can be taken as E_s = 210 000 N/mm².

Test conditions

Perform at least 5 steel tension tests with the finished product.

Assessment

Determine the 5%-fractile of the failure load according to A.5.4. This value shall be normalized to the specified nominal strength to account for over-strength of tested samples according to equation (A.5.2.6).

2.2.2 Characteristic resistance to pull-out failure for cast-in fastener in concrete overlay under static and quasi-static tension loading

For anchor head:

The characteristic resistance $N_{Rk,p,ov}$ is determined according to EN 1992-4, clause 7.2.1.5 [14].

The value of A_h is calculated with equation (2.2.2.1). The value of t_h is given by the geometry of the product.

$$A_h = \frac{\pi}{4} \cdot (d_h^2 - d^2) \qquad (2.2.2.1)$$

for circular head geometry;
other head geometries shall be calculated different or conservative with an inscribed circle.

For shaped head:

The characteristic resistance for pull-out failure in C20/25 without edge and spacing effects under tension loading based on tests and is calculated as follows. The description of the tests is given in A.4.

$$N_{Rk,p,ov} = N_{Rk,p,0} \cdot min \cdot \left(\min \alpha_1 ; \min \alpha_{line\ 5,6}\right) \cdot \min \beta_{cv} \ \leq \ N_{Rk,c}^0 \qquad (2.2.2.2)$$

where:

$N_{Rk,p,0}$= 5%-fractile (according to A.5.4) of the failure load, converted to C20/25 according to Equation A.5.2.2,

for uncracked concrete evaluated from test results of tests according to Table A.1.1, line A1, for cracked concrete evaluated from test results of tests according to Table A.1.1, line A3.

$\min \alpha_1$= minimum value according to equation (A.6.1.1) or (A.6.1.2) of all test series

$\min \alpha_{line\ 5,6}$= according to A.5.5 for cracked concrete only.

For uncracked concrete this factor is min $\alpha_{line\ 5,6}$ = 1,0.

$\min \beta_{cv}$= minimum value according to equation (A.5.3.1) of all test series

$N^0_{Rk,c}$= characteristic resistance to concrete cone failure according to EN 1992-4, clause 7.2.1.4 [14], by using the values $h_{ef,ov,}$ according to 2.2.3 and $k_{cr,N,ov}$ = 8,9 and $k_{ucr,N,ov}$ = 12,7.

The characteristic resistance is rounded down accounting for increments as given in Table 2.2.2.1.

Table 2.2.2.1: Values of characteristic resistance $N_{Rk,p,ov}$

Range of $N_{Rk,p,ov}$ [kN]	Increment [kN]	example
≤ 10	0,5	3,0 / 3,5 / 4,0 … 9,5 / 10,0
≤ 20	1	11,0 / 12,0 … 19,0/ 20,0
≤ 50	2	22,0 / 24,0 … 48,0/ 50,0
> 50	5	55,0 / 60, 0 / 65,0 / …

The characteristic resistance of a fastener in case of pull-out failure in concrete of strength > C20/25 is determined by multiplying the characteristic value for concrete C20/25 by a factor ψ_c according to A.5.2.

The limitation of the scatter of displacements is assessed according to A.6.2.

2.2.3 Characteristic resistance to concrete cone failure for cast-in fastener in concrete overlay under static and quasi-static tension loading

<u>For anchor head</u>:

The values for $k_{cr,N,ov}$ and $k_{ucr,N,ov}$ to consider the load transfer mechanism are determined according to EN 1992-4, clause 7.2.1.4 [14].

<u>For shaped head</u>:

The value of effective embedment depth $h_{ef,ov}$ is determined by geometrical approach, see equation (2.2.3.1) in conjunction with tests according to Table A.1.1, lines 1 to 4, assessed by equation (2.2.3.2) for each test series.

The effective embedment depth is the distance between concrete surface and that part of the fastener where mechanical interlock arises. In some cases, the effective embedment depth cannot be identified by geometry of the fastener. Therefore, $h_{ef,ov}$ can be approached by equation (2.2.3.1) referring to Figure 2.2.3.1).

$$h_{nom} - L_1 - L_2 \leq h_{ef,geom} \leq h_{nom} - L_1 \qquad (2.2.3.1)$$

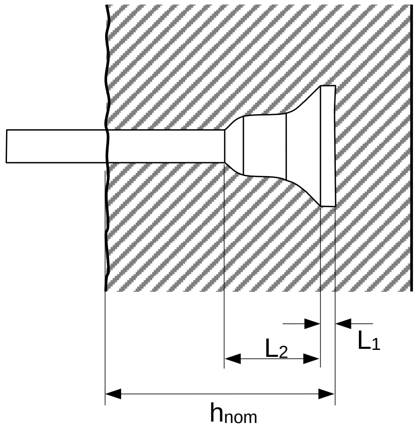


Figure 2.2.3.1: Approximation of effective embedment depth for shaped heads

The effective embedment depth is proven by test according to Table A.1.1, lines A1 to A4. The description of the tests is given in A.4.

The effective embedment depth from the tests $h_{ef,test}$ is determined according to equation (2.2.3.2).

$$h_{ef,test} = \left(\frac{N_{u,5\%,test}}{\sqrt{f_{c,test}} \cdot k_{cr,N,ov/ucr,N,ov}} \right)^{\frac{2}{3}} \qquad (2.2.3.2)$$

where:

$N_{u,5\%,test}$ = 5%-fractile (according to A.5.4) of the failure load, converted to C20/25 according to A.5.2 for uncracked concrete evaluated from test results of tests according to Table A.1.1, line A1
for cracked concrete evaluated from test results of tests according to Table A.1.1, line A3.

$f_{c,test}$ = concrete compressive strength of test members

$k_{cr,N,ov/ucr,N,ov}$ = for cracked concrete $k_{cr,N,ov}$= 8,9
for uncracked concrete $k_{ucr,N,ov}$= 12,7

The effective embedment depth should be determined according to equation (2.2.3.3).

$$h_{ef,ov} = \min\left((h_{nom} - L_1); h_{ef,test}\right) \qquad (2.2.3.3)$$

The value for characteristic edge distance $c_{cr,N,ov}$ is determined according to equation (2.2.3.4).

$$c_{cr,N,ov} = 1{,}5 \cdot h_{ef,ov} \qquad (2.2.3.4)$$

2.2.4 Resistance to blow-out failure and edge distances and spacing

Edge distance to prevent splitting under load

$$c_{cr,sp,ov} = 3 \cdot h_{ef,ov} \quad (2.2.4.1)$$

Characteristic resistance to blow-out failure

For both, anchor heads and shaped heads the value of A_h is calculated with equation (A.2.2.1). In case of a shaped head the area of A_h is associated with the effective embedment depth $h_{ef,ov}$ determined in section 2.2.3.

Minimum edge distance, minimum concrete thickness, minimum spacing

$$c_{min,ov} = 0{,}5 \cdot d_h + c \quad (2.2.4.2)$$

Minimum concrete thickness h_{min} is determined to ensure the minimum concrete cover according to EN 1992-1-1 [12] at any position.

$$h_{min} = h_{nom} + c \quad (2.2.4.3)$$

Minimum spacing $s_{min,ov}$ is determined as follows.

$$s_{min,ov} = max\,(2\,d_h\,;\,d_h + 20\,mm) \quad (2.2.4.4)$$

2.2.5 Shear interface parameters under static and quasi-static and fatigue loading

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 (see EOTA TR 066, Equation (2.11)). 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 [12].
- 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 parameters f_{yk} and A_s of the connector in the area of the interface are determined as follows:

f_{yk} = nominal yield strength of the connector
A_s = relevant cross section of the connector in the area of the shear interface

Product specific factor for ductility α_{k1}

- for ductile steel: $\alpha_{k1} = 1{,}0$
- for non-ductile steel: $\alpha_{k1} = 0{,}8$

Note:
Connectors are rated as ductile, if they fulfil the criteria of EN 1992-1-1, Annex C [12], for reinforcement bars "Class B" with regard to:

- *Characteristic yield strength f_{yk} or $f_{0,2k}$*
- *Minimum value of k = $(f_t/f_y)_k$*
- *characteristic strain at maximum force, ε_{uk}*

Product specific factor for geometry α_{k2}

- for solid cross sections: $\alpha_{k2} = 1{,}0$
- for hollow cross sections: $\alpha_{k2} = \frac{d^3 - d_c^3}{(d^2 - d_c^2)^{1{,}5}}$

  with d and d_c being the diameters of the cross section around the interface +/- 1*d (see Figure 2.2.5.1).

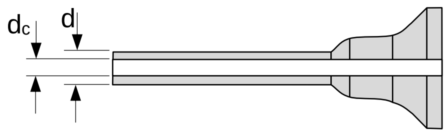


Figure 2.2.5.1: Hollow cross section

If no test is done the factor for fatigue cyclic loading $\eta_{sc} = 0$.

If the shear interface is tested and assessed according to A.7 and if the test results comply with the current experience for fatigue cyclic loading of the shear interface (see Annex A.7) the factor for fatigue cyclic loading $\eta_{sc} = 0,4$.

The factor η_{sc} applies for the tested interface roughness ($R_{t,test}$) and concrete strength combinations in the tests. Clustering of the tested concrete strength into concrete strength classes is possible according to Table A.7.1.1. Higher interface roughness or concrete strength is conservative and, therefore, also applicable. The information of roughness and concrete strength classes is given in the ETA.

Note: Example for definition in the ETA:
"η_{sc} = 0,40 for ≥ C20/25 (existing concrete), ≥ C30/37 (concrete overlay), R_t ≥ 3,0 mm"

The fasteners are tested according to A.8 to determine the Wöhler line of the fasteners. For tests according to A.8 the same material batches are used as for the tests according to A.4.

2.2.6 Reaction to fire

The connectors are considered to satisfy the requirements for performance class A1 of the characteristic reaction to fire in accordance with Commission Decision 96/603/EC, as amended by Commission Decisions 2000/605/EC and 2003/424/EC, without the need for testing on the basis of they fulfilling the conditions set out in that Decision and its intended use being covered by that Decision.

Therefore, the performance of the connectors is class A1.

Due to the intended end-use application of the connectors being completely embedded in concrete, the bonding material have no possibility to ignite and may therefore not contribute to fire. Thus, the bonding material is considered as small component, where its own reaction to fire performance can be seen as negligible and without the need for testing and classification. This shall be stated in the ETA in addition to the reaction to fire class of the metal connectors.

3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

3.1 System(s) of assessment and verification of constancy of performance to be applied

For the products covered by this EAD the applicable European legal act is Commission Decision 96/582/EC.

The system is 1.

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of the product in the procedure of assessment and verification of constancy of performance are laid down in Table 3.2.1.

Table 3.2.1 Control plan for the manufacturer; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC) [including testing of samples taken at the factory in accordance with a prescribed test plan]					
1	Connector, material	According to EAD 330232-01-0601, Table 3.1	Laid down in control plan	5	1 / material batch
2	Connector, geometry of the head	Measuring: Caliper and/or gauge		5	1 / production batch
3	Concrete screw in existing concrete	EAD 330232-01-0601, Table 3.1	EAD 330232-01-0601, Table 3.1	EAD 330232-01-0601, Table 3.1	EAD 330232-01-0601, Table 3.1
4	Bonded fastener in existing concrete	EAD 330499-01-0601, Table 3.1	EAD 330232-01-0601, Table 3.1	EAD 330232-01-0601, Table 3.1	EAD 330232-01-0601, Table 3.1
5	Steel fatigue limit resistance	Tests [1] under different fatigue cyclic loading [2]	[2]	3 (1 per level)	1 / material batch

[1] Test conditions according to Annex 0.

[2] The load levels and the criteria of the chosen method following EAD 330250-00-0601 [3] apply.

3.3 Tasks of the notified body

The cornerstones of the actions to be undertaken by the notified body in the procedure of assessment and verification of constancy of performance for the connector for strengthening of existing concrete structures by concrete overlay are laid down in Table 3.3.1.

Table 3.3.1 Control plan for the notified body; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control					
1	Ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the connector. In particular it shall be checked if all tasks given in Table 3.2.1 were performed. 1)	See control plan	Laid down in control plan	-	1
Continuous surveillance, assessment and evaluation of factory production control					
2	Verifying that the system of factory production control and the specified automated manufacturing process are maintained taking account of the control plan. In particular it shall be checked if all tasks given in Table 3.2.1 were performed. 1)	-	Laid down in control plan	-	1 / year

1) If the product criteria in Table 3.2.1 are observed, it is not necessary to monitor specific stages of production.

4 REFERENCE DOCUMENTS

[1] EN 13791:2019: Assessment of in-situ compressive strength in structures and precast concrete components

[2] EAD 330232-01-0601:2019-12: Mechanical fasteners for use in concrete

[3] EAD 330250-00-0601:2018-01: Post installed fasteners in concrete under fatigue cyclic loading

[4] EAD 330499-01-0601:2018-12: Bonded fasteners for use in concrete

[6] EN 206:2013+A2:2021: Concrete - Specification, performance, production and conformity

[7] EN 1993-1-4:2006+A1:2015, Eurocode 3: Design of steel structures - Part 1-4: General rules - Supplementary rules for stainless steels

[8] EOTA TR 066:2019-04: Technical Report 066, “Design and requirements for construction works of post-installed shear connections for two concrete layers”

[9] EN 197 1:2011, Cement - Part 1: Composition, specifications and conformity criteria for common cements

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

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

[12] EN 1992-1-1:2004+AC:2010: Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings

[13] EN ISO/IEC 17025:2017: General requirements for the competence of testing and calibration laboratories (ISO/IEC 17025:2017)

[14] EN 1992-4:2018: Eurocode 2 - Design of concrete structures - Part 4: Design of fastenings for use in concrete

[15] EN 12350-5:2019: Testing fresh concrete – Part 5: Flow table test

For further information:

[16] Kaufmann: Das Sandflächenverfahren in Straßenbautechnik, 1971, Nr.3

[17] R, Lewandowski, Beurteilung von Bauwerksfestigkeiten an Hand von Betongütewürfeln und -bohrproben, Schriftenreihe der Institute für Konstruktiven Ingenieurbau der Technischen Universität Braunschweig, Heft 3, Werner Verlag, Düsseldorf, 1971

ANNEX A: TEST PROGRAM AND GENERAL ASPECTS OF ASSESSMENT

A.1 Test program

The test program to determine the essential characteristics for connectors in concrete overlay and in the interface is given in Table A.1.1. The test program covers connectors for use in cracked and uncracked concrete overlay and connectors for use in uncracked concrete overlay only. Detailed information concerning the tests is given in the corresponding sections referred to in these tables.

Table A.1.1: Test program for connectors

No	Purpose of test	concrete	Crack width [mm]	size	h_{ef}	n_{min}	rqd. α	Section
Tension test in concrete overlay								
A1	Characteristic resistance for tension loading not influenced by edge and spacing effects	C20/25	0	All	min h_{ef}	5	-	2.2.2 2.2.3
A2		C50/60	0	All	min h_{ef}	5	-	
A3		C20/25	0,3	All	min h_{ef}	5	-	
A4		C50/60	0,3	All	min h_{ef}	5	-	
5	Increased crack width	C20/25	0,5	s/m/l	min h_{ef}	5	0,8	
6	Increased crack width	C50/60	0,5	s/m/l	min h_{ef}	5	0,8	
Resistance to fatigue cyclic loading								
S1	Fatigue tests for steel failure in tension	- [1)]	- [1)]	All [2)]	- [1)]	20	-	A.8
S2	Fatigue tests for shear connection	- [3)]	0	s/m/l	- [4)]	6 [5)]	-	2.2.5

1) This test is performed on the connector element only. The Test shall be performed in that way that the failure occurs on the most unfavourable cross section of the connector.

2) Test connectors of all sizes, steel qualities, steel properties and steel coatings.

3) Concrete strength of existing concrete and concrete overlay specified by the manufacturer.

4) Test the shear connection in the most unfavourable embedment depth in either the existing concrete or the concrete overlay.

5) 2 short term tests (static tests), 2 tests for fatigue failure, 2 run-out tests

For certain test series, according to Table A.1.1 a reduced range of tested sizes, indicated by “s/m/l”, may be used. The number of diameters to be tested in this case depends on the number of requested sizes and is given in Table A.1.2.

Table A.1.2: Reduced range of tested sizes s/m/l

Number of requested sizes	Number of diameters to be tested
≤ 5	3
≤ 8	4
≤ 11	5
> 11	6

A.2 Test samples, test members, installation and test equipment

A.2.1 Provisions for all tests

It is recommended that handling of tests and calibration items are performed in accordance with EN ISO/IEC 17025 [13].

The failure mode "concrete cone failure" is typically characterized by a concrete failure starting from the deepest point of embedment. This failure mode may be observed for single fasteners without an influence of edge distances.

"Steel failure" or "splitting failure" or "blow-out failure" may limit the resistance of connectors compared to the resistance of "pull-out failure" or "concrete cone failure".

To avoid "steel failure" in the tests embedded metal parts of a higher strength than specified by the manufacturer and published in the ETA may be used as long as the functioning of the fastener is not influenced. This condition is fulfilled if the geometry of the embedded part of higher strength steel is identical with the specified embedded part.

In cases where the use of high strength fastener elements (steel strength ≥ 10.9) is insufficient to prevent "steel failure" of the fastener the embedment depth shall be reduced. This principle may overrule the required embedment depth given in Table A.1.1. If higher strength fasteners are used, the functioning of the fasteners shall not be influenced in any way. The use of such test specimens shall be clearly recorded.

A.2.2 Test members

A.2.2.1 General

This EAD is valid for fasteners intended to be used in concrete members using compacted normal weight concrete without fibres with strength classes in the range of C20/25 - C50/60 in accordance with EN 206 [6] and tested accordingly. The fastener performance is only valid for the range of tested concrete.

The test members shall comply with the following:

A.2.2.2 Aggregates

Aggregates shall be of natural occurrence (i.e., non-artificial) and with a grading curve falling within the boundaries given in Figure A.2.2.2.1. The maximum aggregate size shall be 16 mm or 20 mm. The aggregate density shall be between 2.0 and 3.0 t/m³ (see EN 206 [6]).

The boundaries reported in Figure A.2.2.2.1 are valid for aggregate with a maximum size of 16 mm. For different values of maximum aggregate sizes, different boundaries may be adopted, if previously agreed with the responsible Technical Assessment Body.

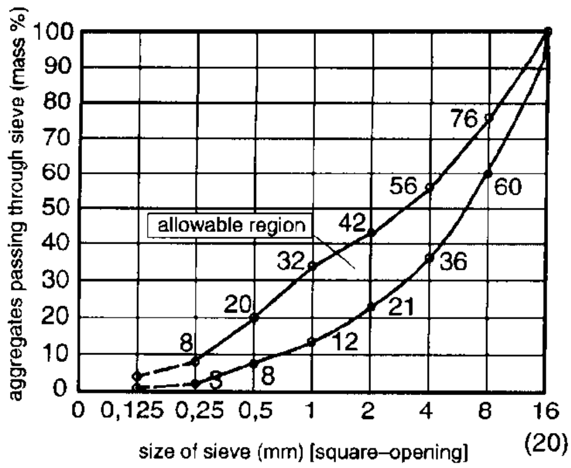


Figure A.2.2.2.1: Admissible region for the grading curve

A.2.2.3 Cement

The concrete shall be produced using Portland cement Type CEM I or Portland-Composite cement Type CEM II/A-LL, CEM II/B-LL (see EN 197-1 [9]).

A.2.2.4 Water/cement ratio and cement content

The water/cement ratio shall not exceed 0,75 and the cement content shall be at least 240 kg/m³.

No additives likely to change the concrete properties (e.g., fly ash, or silica fume or other powders) shall be included in the mixture.

A.2.2.5 Concrete strength

For the tests according to Table A.1.1, lines A1 to A4 and lines 5 to 6 carried out in low strength concrete (strength class C20/25) and high strength concrete (strength class C50/60) the following mean compressive strengths at the time of testing fasteners shall be obtained for the two classes:

C20/25	f_c	=	20-30 MPa (cylinder: diameter 150 mm, height 300 mm)
	f_{cube}	=	25-35 MPa (cube: 150 x 150 x 150 mm)
C50/60	f_c	=	50-60 MPa (cylinder: diameter 150 mm, height 300 mm)
	f_{cube}	=	60-70 MPa (cube: 150 x 150 x 150 mm)

It is recommended to measure the concrete compressive strength either on cylinders with a diameter of 150 mm and height of 300 mm, or on cubes of 150 mm.

The following conversion factors for concrete compressive strength from cube to cylinder may be used:

C20/25

$$f_c = \frac{1}{1,25} \cdot f_{cube} \qquad \text{(A.2.2.5.1)}$$

C50/60

$$f_c = \frac{1}{1,20} \cdot f_{cube} \qquad \text{(A.2.2.5.2)}$$

For other dimensions, the concrete compressive strength may be converted as follows:

$$f_{cube100} = \frac{1}{0,95} \cdot f_{cube} \qquad \text{(A.2.2.5.3)}$$

$$f_{cube} = \frac{1}{0,95} \cdot f_{cube200} \qquad \text{(A.2.2.5.4)}$$

$$f_{cube} = f_{core100}\ (according\ to\ EN\ 13791\ [1], section\ 7.1) \qquad \text{(A.2.2.5.5)}$$

Note 1: Additional literature for conversion is given by R. Lewandowski, [17]

For every concreting operation, specimens (cylinder, cube) shall be prepared having the dimensions conventionally employed in the member country. The specimens shall be made, cured and conditioned in the same way as the test members.

Generally, the concrete control specimens shall be tested on the same day as the fasteners to which they relate. If a test series takes a number of days, the specimens shall be tested at a time giving the best representation of the concrete strength at the time of the fastener tests, e.g., at the beginning and at the end of the tests. In this case the concrete strength at the time of testing can be determined by interpolation.

The concrete strength at a certain age shall be measured on at least 3 specimens. The mean value of the measurements governs.

If, when evaluating the test results, there should be doubts whether the strength of the control specimens represents the concrete strength of the test members, at least three cores of 100 mm diameter shall be taken from the test members outside the zones where the concrete has been damaged in the tests, and tested in compression. The cores shall be cut to a height equal to their diameter, and the surfaces to which the compression loads are applied shall be ground or capped. The compressive strength measured on these cores shall be converted into the strength of cubes by equation (A.2.2.5.5).

A.2.2.6 Test members for tests in cracked concrete

The tests are carried out on test members with unidirectional cracks. The crack width shall be approximately constant throughout the member thickness. The thickness of the test member shall be $h \geq 2\ h_{ef}$ but at least 100 mm. To control cracking, so-called 'crack-formers' shall be built into the member, provided they are not situated near the anchorage zone. An example for a test member is given in Figure A.2.2.6.1.

In the test with variable crack width the reinforcement ratio (top and bottom reinforcement) shall be $\mu = A_s / (b \cdot h) \sim 0{,}01$ and the spacing of the bars ≤ 250 mm.

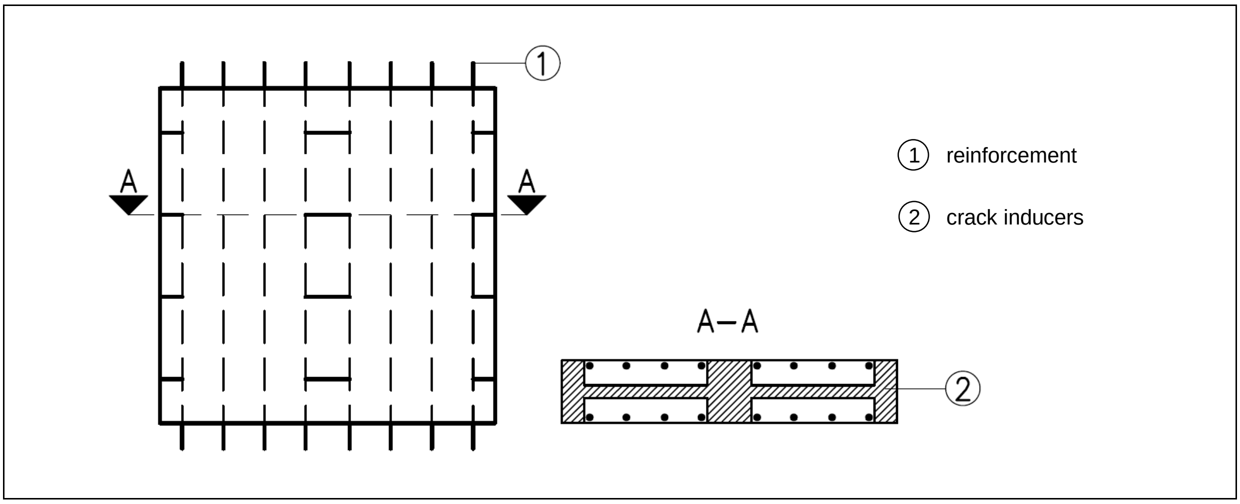


Figure A.2.2.6.1: Example of a test member for fasteners tested in cracked concrete

A.2.2.7 Test members for tests in uncracked concrete

Generally, the tests are carried out on unreinforced test members. In cases where the test member contains reinforcement to allow handling or for the distribution of loads transmitted by the test equipment, the reinforcement shall be positioned such as to ensure that the loading capacity of the tested fasteners is not affected. This requirement will be met if the reinforcement is located outside the zone of concrete cones having a vertex angle of 120°.

A.2.2.8 Casting and curing of test members

The test members shall be cast horizontally. They may also be cast vertically if the maximum height is 1,5 m and complete compaction is ensured.

Test members and concrete specimens (cylinders, cubes) shall be cured and stored indoors for seven days. Thereafter, they may be stored outside provided they are protected such that frost, rain and direct sun does not cause a deterioration of the concrete compression and tension strength. When testing the fasteners, the concrete shall be at least 21 days old.

Test members and concrete specimen shall be stored in the same way.

A.2.3 Installation

For tests according to Table A.1.1, lines A1 to A4 and lines 5 and 6, the fastener is cast in the concrete.

The tested fastener shall be placed in the concrete surface that has been cast against a form of the test member.

When testing in cracked concrete, fasteners are placed in the middle of hairline cracks. It shall be verified that the fastener is placed over the entire anchoring zone in the crack by suitable methods.

For tests according to Table A.1.1, lines S1 and S2, the fastener is installed according to the MPII.

In all cases the fasteners shall be perpendicular (± 5° deviation) to the surface of the concrete member.

A.2.4 Test equipment

Tests shall be carried out using measuring equipment having a documented calibration according to international standards. The load application equipment shall be designed to avoid sudden increase in load especially at the beginning of the test. The measurement bias of the measuring chain of the load shall not exceed 2% of the measured quantity value.

Displacements shall be recorded continuously (e.g., by means of electrical displacement transducers) with a measuring bias not greater than 0,020 mm or 2,0 % for displacements > 1 mm.

For unconfined tests the test rigs shall allow the formation of an unrestricted rupture cone. For this reason, the distance between the support reaction and a fastener shall be at least 2 h_{ef} (tension test) as shown in Figure A.4.2.1.

During all tests, the load shall be applied to the fastener by a fixture representing the conditions found in practice.

In tests on single fasteners without edge and spacing influences the centre-to-centre distance and the distances from free edges shall be large enough to allow the formation of an unrestricted rupture cone of vertex angle 120° in the concrete.

During tension tests the load shall be applied concentrically to the fastener. To achieve this, hinges shall be incorporated between the loading device and the fastener. An example of a tension test rig is illustrated in Figure A.4.2.1.

A.3 Test procedure – general aspects

The fasteners shall be installed in accordance with the MPII, except where special conditions are specified in the EAD for the test series.

The tests in cracked concrete are undertaken in unidirectional cracks. The required crack width Δw is given in Table A.1.1. Δw is the difference between the crack width when loading the fastener and the crack width before loading the fastener. Before loading the fastener, the crack is widened to the required crack width while the fastener is unloaded. The initial crack width shall be set to within +10 % of the specified value. However, the mean value of a series shall reflect the specified value.

Use one-sided tolerance for crack width.

Then the fastener is subjected to load while the crack width is controlled, either

- at a constant width, for example, by means of a servo system, or
- limited to a width close to the initial value by means of appropriate reinforcement and depth of the test member.

In both cases the crack width at the face opposite to that through which the fastener is installed be maintained at a value larger than or equal to the specified value.

The load shall be increased in such a way that the peak load occurs after 1 to 3 minutes from commencement. Load and displacement shall be recorded continuously. The tests may be carried out with load, displacement or hydraulic control. In case of displacement control the test shall be continued beyond the peak of the load/displacement curve to at least 75 % of the maximum load to be measured (to allow the drop of the load/displacement curve). In case of displacement-controlled test setup the speed shall be kept constant.

The data shall be collected with a frequency of 3 Hz – 5 Hz.

A.4 Tension tests in concrete overlay

A.4.1 General

The tests are performed according to A.4.2 as unconfined tests.

The tests are performed in uncracked and cracked concrete with strength classes C20/25 and C50/60 as given in Table A.1.1, lines A1 to A4 and lines 5 and 6.

If the manufacturer applies for intended use in uncracked concrete only, the test series in cracked concrete according to Table A.1.1, lines A3, A4, 5 and 6, may be omitted.

If the manufacturer applies for one tension resistance for all concrete strength classes in uncracked concrete only, the test series in high strength concrete according to Table A.1.1, line A2, may be omitted.

The fastener is connected to the test rig and loaded to failure. The displacements of the fastener relative to the concrete surface shall be measured by use of either one displacement transducer on the head of the fastener or by use of at least two displacement transducers on either side at a distance of ≥ 1,5 h_{ef} from the fastener; the mean value of the transducer readings shall be recorded in the latter case.

When testing in cracked concrete, the crack width shall be regularly measure during the test on both sides of the fastener at a distance of approximately 1,0 h_{ef} and at least on the face of the test member in which the fasteners are installed.

A.4.2 Unconfined test setup

Unconfined tests allow an unrestricted formation of the rupture concrete cone. An example for an unconfined test setup is shown in Figure A.4.2.1.

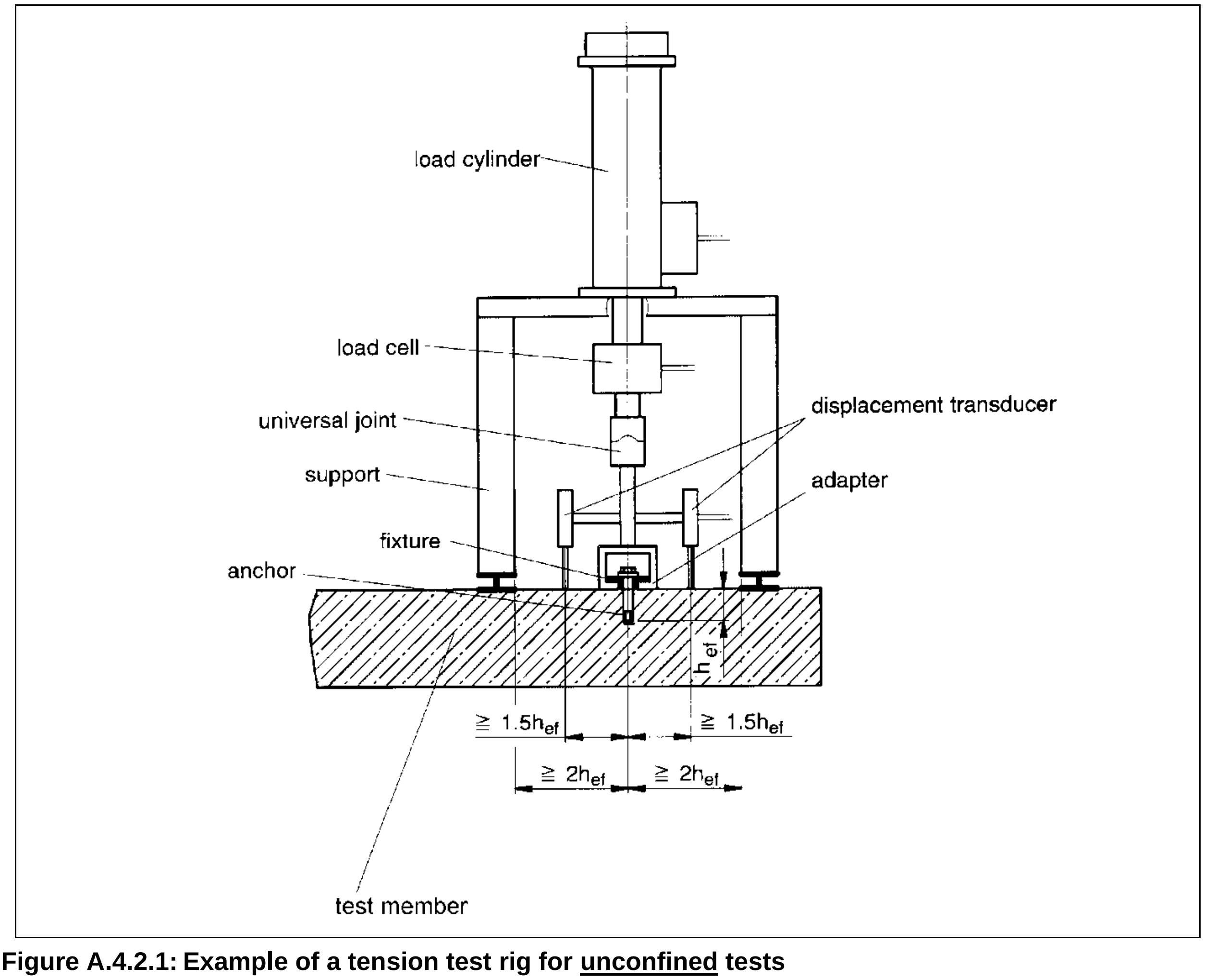
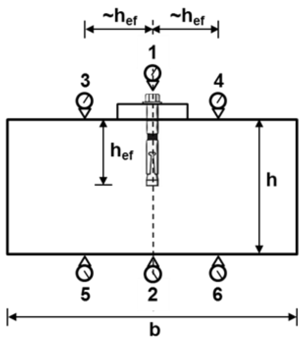


Figure A.4.2.1: Example of a tension test rig for <u>unconfined</u> tests

A.4.3 Information to be recorded

Since only relevant parameter shall be followed for each test series this table is meant as a check list. The appropriate information for the particular test series shall be recorded.

1. Description test specimen	Fastener type	Manufacturer, trade name, dimensions, material
	status of specimen	serial product / prototype
	production lot / batch	
	Mechanical properties (tensile strength, yield limit, fracture elongation), type of coating,	e.g., (f_u = 970 N/mm², R_{p02} = 890 N/mm², A_5 = 18%, galvanized 5 µm, functional coating)
2. Test member	element type / drawing no.	sketch according to "examples cross section" and "example for test member with bond breaking pipes"
	dimensions	(l / w / h)
	concrete mix	e.g., cement, aggregate type and content, w/c-ratio
	curing conditions	
	age of concrete member at time of testing	
	type and grade of reinforcement	
	longitudinal reinforcement quantity.	
	longitudinal reinforcement size	
	pre-debonding length	
	type of bond breaker sheets	e.g., wood/ plastic/ metal/ none
	reinforcement spacing	e.g., 254 mm horizontal, 50 mm from edges
	distribution of reinforcement over depth of member	e.g., two rows, 100 mm from top and bottom
	reinforcement is distributed double symmetrically	
3. Setting/ Installation information	ratio member thickness / h_{nom}	e.g., 2,2
	place of fastener installation	formwork side
	type/ diameter of support	confined / unconfined d = 450 mm
	spacing between rebar and fastener	200 mm
	nominal / effective embedment depth h_{nom}/h_{ef}	
	position of the fastener over load transfer zone in the crack	sketch
	verification method of fastener position in crack	e.g., borescope (sketch of crack formation over load transfer zone)
4. Test parameter	crack opening mechanism	Describe how the crack width in the area of the load transfer zone is ensured
	loading/ unloading rates [sec.]	e.g., 2,5 / 2,5
	no. of replicates tested simultaneously	e.g., one
	measuring of fastener displacement	e.g., continuously / at the fastener

	no. of replicates tested in one specimen/ crack	e.g., 6 per specimen / 2 per crack
	amount / type of crack width measurement	e.g., 4 / capacitive sensor
	position of the crack width sensors	sketch with distances e.g.: 
	determination of crack width at fastener	e.g., (linear interpolation)
	Diagram containing: - crack width at the fastener position for the top and bottom of the load transfer zone - plot the cycles in normal logarithmic scale - plot the upper and the lower crack width	
	measuring uncertainty for crack width transducers	e.g., ±0,005 mm.
	minimal frequency during the test	
	maximal frequency during the test	
5. Test results	Load at failure	
	Displacement at failure	
	Displacement at 50% of failure load	
	Diagram with load displacement curve	
	Failure mode (If initial failure is not clear, a combination of failure modes shall be recorded.)	- (cc) concrete cone failure – give diameter and depth of concrete cone - (sp) splitting– test condition for tests in uncracked concrete in case when a first crack of the concrete is observed - (po) pull-out – pull-out failure may be combined with a shallow concrete breakout - (pt) pull-through– cone being pulled through the expansion sleeve - (s) steel failure– define position of the steel rupture over length of the fastener - (pr) pry-out – concrete breakout opposite to the load direction (may occur for shallow embedment)

A.5 Analysis of ultimate loads for fastening in concrete overlay

A.5.1 Assessment of the failure mode

The test lab shall identify and record the initial failure mode for any tension test:

- concrete cone failure (cc) – give diameter and depth of concrete cone
- splitting (sp) – test condition for tests in uncracked concrete in case when a first crack of the concrete is observed
- pull-out failure between element and concrete material (po)
- Blow-out failure (bo)
- steel failure (s) – define position of the steel rupture over length of the fastener

If initial failure is not clear, a combination of failure modes shall be recorded.

A.5.2 Conversion of failure loads to nominal strength

The conversion of failure loads shall be done according to equations (A.5.2.1) to (A.5.2.6) depending on the failure mode.

The increasing factor $\psi_{c,xx}$ shall be determined separately for cracked and non-cracked concrete.

Concrete failure

$$F_{u,c} = F_{u,t} \cdot \left(\frac{f_c}{f_{c,test}}\right)^{0,5} \; with \; \frac{f_c}{f_{c,test}} \leq 1,0 \qquad \text{(A.5.2.1)}$$

pull-out failure

$$F_{u,p} = F_{u,t} \cdot \left(\frac{f_c}{f_{c,test}}\right)^{m} \; with \; \frac{f_c}{f_{c,test}} \leq 1,0 \qquad \text{(A.5.2.2)}$$

ucr

$$m = \frac{log\left(N_{u,m,A2}/N_{u,m,A1}\right)}{log\left(f_{c,A2}/f_{c,A1}\right)} \leq 0,5 \qquad \text{(A.5.2.3)}$$

cr

$$m = \frac{log\left(N_{u,m,A4}/N_{u,m,A3}\right)}{log\left(f_{c,A4}/f_{c,A3}\right)} \leq 0,5 \qquad \text{(A.5.2.4)}$$

$$\Psi_{c,xx} = \left(\frac{f_{ck,xx}}{f_{ck,20}}\right)^{m} > 1,0 \qquad \text{(A.5.2.5)}$$

steel failure

$$F_{u,s} = F_{u,t} \cdot \frac{f_{uk}}{f_{u,test}} \qquad \text{(A.5.2.6)}$$

A.5.3 Criteria regarding scatter of failure loads

If the coefficient of variation of the failure load in any test series according to Table A.1.1, lines A1 to A4, exceeds 15 % and is not larger than 30 %, the following reduction is taken into account:

$$\beta_{cv} = \frac{1}{1 + 0,03\,(cv - 15)} \leq 1,0 \qquad \text{(A.5.3.1)}$$

If the maximum limit for the coefficient of variation of the failure loads of 30% is exceeded the number of tests shall be increased to meet this limit. This EAD does not cover fasteners for which this limit cannot be achieved (see 1.1). The smallest result min $ß_{cv}$ in any test shall be taken for assessment.

A.5.4 Establishing 5% fractile

The 5 %-fractile value of the ultimate resistance measured in a test series shall be calculated according to statistical procedures for a confidence level of 90 %. A normal distribution and an unknown standard deviation of the population are assumed.

$$F_{u,5\%} = F_{u,m}(1 - k_s \cdot cv_F) \qquad \text{(A.5.4.1)}$$

e.g.: n = 5 tests: k_s = 3,40
n = 10 tests: k_s = 2,57

Note: The confidence level of 90% is defined for characteristic resistance of fasteners in EN 1992-4 and is therefore used for the assessment in this EAD.

A.5.5 Failure loads (reduction factors α)

For test series according to Table A.1.1, lines 5 and 6, the mean failure loads and 5%-fractile of failure loads shall be compared with the corresponding reference test series of tension test series according to Table A.1.1. In this case these are the test series with the 0,3 mm crack width in the respective concrete strength class.

$$\alpha = \min\left\{\frac{F_{u,m,t}}{F_{u,m,r}};\frac{F_{u,5\%,t}}{F_{u,5\%,r}}\right\} \qquad \text{(A.5.5.1)}$$

The comparison of the 5%-fractile may be omitted for any number of tests in a test series when the coefficient of variation of the test series is smaller than or equal to the coefficient of variation of the reference test series or if the coefficient of variation in both test series is smaller than 15 %.

If the criteria for the required value of α given in equation (A.5.5.1) are not met in one test series, the characteristic resistance shall be reduced by following reduction factor:

$$\min \alpha_{line\ 5,6} = min\ \left(\frac{\alpha_{line\ 5}}{rqd.\alpha}\ ;\ \frac{\alpha_{line\ 6}}{rqd.\alpha}\right) \qquad \text{(A.5.5.2)}$$

A.6 Assessment of displacement for fasteners in concrete overlay

A.6.1 Uncontrolled slip

Uncontrolled slip is characterised by a significant change of stiffness, see Figure A.6.1.1. The corresponding load when uncontrolled slip starts is called N_1. The value N_1 shall be evaluated for every tension test from the measured load displacement curve. If the load/displacement curves show a steady increase then $N_1 = N_{Ru}$ (see Figure A.6.1.1, Curve 1).

For tension tests the factor α_1 shall be calculated for each test series according to following equation:

$$\alpha_1 = N_1/0{,}7\ N_{Ru} \leq\ 1{,}0 \quad \text{(in cracked concrete)} \qquad \text{(A.6.1.1)}$$

$$\alpha_1 = N_1/0{,}8\ N_{Ru} \leq\ 1{,}0 \quad \text{(in uncracked concrete)} \qquad \text{(A.6.1.2)}$$

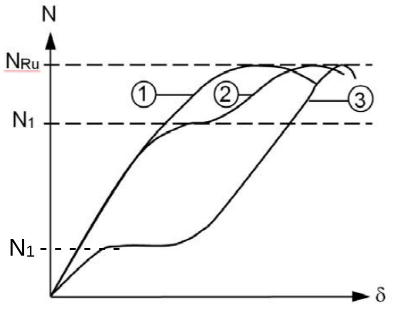
where:

N_1 = load level where uncontrolled slip occurs in the test

N_{Ru} = ultimate load in the test

This reduction may be omitted if, within an individual series of tests, not more than one test shows a load/displacement curve with a short plateau below the value 0,7 N_{Ru} (in cracked concrete) or below the value 0,8 N_{Ru} (in uncracked concrete), provided all of the following conditions are met:

- the deviation is not substantial,
- the deviation can be justified as uncharacteristic of the fastener behaviour and is due to a defect in the fastener tested, test procedure, etc.,
- the fastener behaviour meets the criterion in an additional series of 10 tests.



Curve 1: steady increase of the load displacement curve

Curve 2 and Curve 3: uncontrolled slip at level N_1

Figure A.6.1.1: Load/displacement curve

A.6.2 Limitation of the scatter of displacements

In order to properly activate all fasteners, the displacement behaviour (stiffness) of individual fasteners shall be similar.

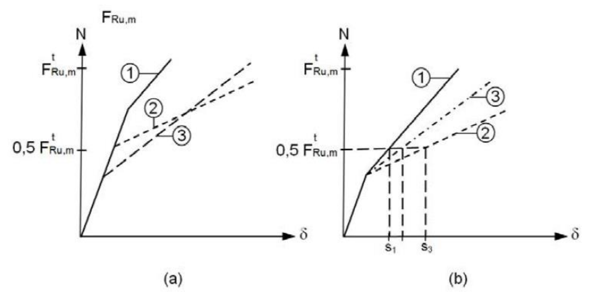
The coefficient of variation of the mean displacement at the load level of 0,5 $N_{u,m}$ in service condition tests shall fulfil the criteria given in equation (A.6.2.1) and equation (A.6.2.2).

$cv\delta \leq 0{,}25$ (test series 1 to 4) (A.6.2.1)

$cv\delta \leq 0{,}40$ (test series 5 to 6) (A.6.2.2)

The load displacement curves shall be shifted according to Figure A.6.2.1 for determination of the displacement at 0,5 $N_{u,m}$.

It is not necessary to observe limitation of the scatter of the load/displacement curves in a test series if in this test series all displacements at a load of 0,5 $N_{u,m}$ are smaller than or equal to 0,4 mm.



(a) original curves
(b) shifted curves for evaluation of scatter at N = 0,5 $N_{u,m}$

Figure A.6.2.1: Influence of pre-stressing on load/displacement curves

A.7 System tests for shear connection

The system tests for shear connection shall show compliance with the function given in Figure 1.2.1.2.

A.7.1 Test members for system test for shear connection

For the test, the test member shown in section 0 is designed in that way that the shear interface is subject to highest loading. The effective embedment depth $h_{ef, ex}$ and $h_{ef, ov}$ should be selected so that the connector in the area of the joint is loaded in its most critical area (weakest geometry = lowest cross section, lowest strength, ...). This is confirmed by the failure mode "interface failure" in the tests.

For tests according Table A.1.1, line S2, the combination of concrete strengths (existing concrete: C__/__, concrete overlay: C__/__) is up to the manufacturer within the given limits (see Table A.7.1.1). The assessed performance applies to the concrete compressive strength equal or larger than the tested concrete. The values of $f_{c,test}$ shall be clustered according to Table A.7.1.1. Both concrete classes (existing concrete and concrete overlay) need to be clustered separately.

Table A.7.1.1 Concrete strength classes

Concrete strength class	f_c [N/mm²] (cylinder: d 150 mm, h 300 mm)	f_{cube} [N/mm²] (cube: 150 x 150 x 150 mm)
C20/25	20 to 30	25 to 35
C30/37	30 to 40	35 to 50
C40/50	40 to 50	50 to 60
C50/60	50 to 60	60 to 70

A.7.2 Test setup

The test setup comprises of a 3-point-bending-test.

The test member is designed in that way that failure in the shear interface is likely to occur. This is regarding length of the test member as well as for the cross section and the concrete strengths. The specific details on the test member are given in Figure A.7.2.1. To consider the use of multiple connectors the test member shall use a minimum number of connectors representing the minimum reinforcement content of 0,1%. The maximum distance of the connectors to each other shall be 600 mm. The connectors shall be evenly distributed over the shear interface.

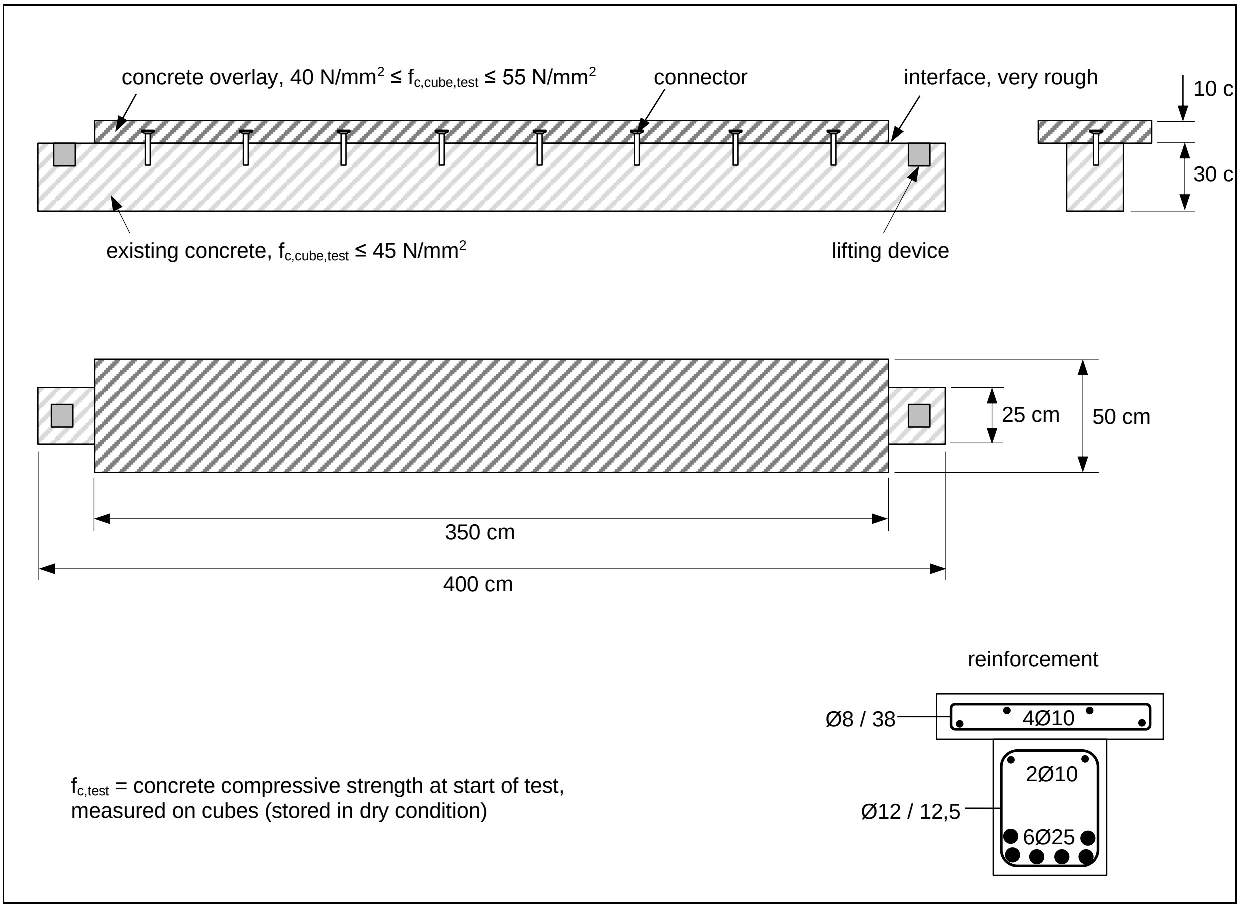


Figure A.7.2.1: Test member

To ensure the maximum stress in the shear interface, bonding of the surface area may be reduced with de-bonding agent. This could be liquid substances used for waterproofing applications like special impregnators that protect surfaces against the penetration of oil, grease, dirt and water, and prevent staining.

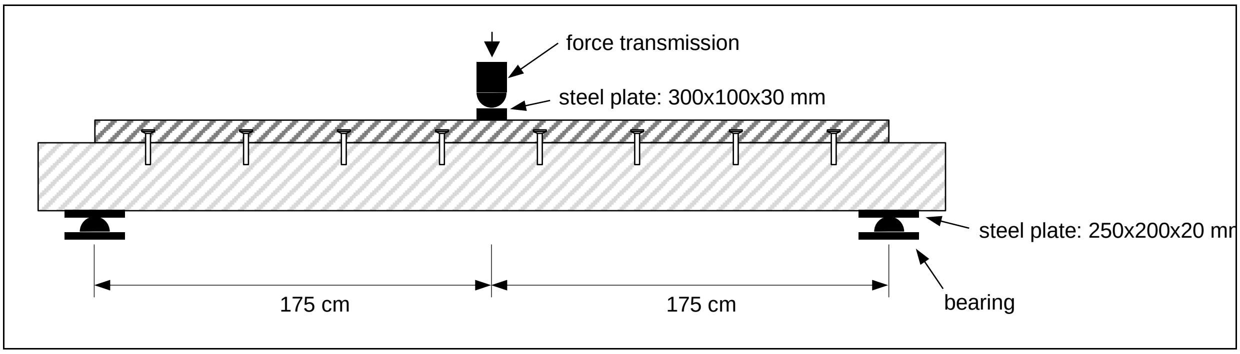


Figure A.7.2.2: Test setup

A.7.3 Test execution

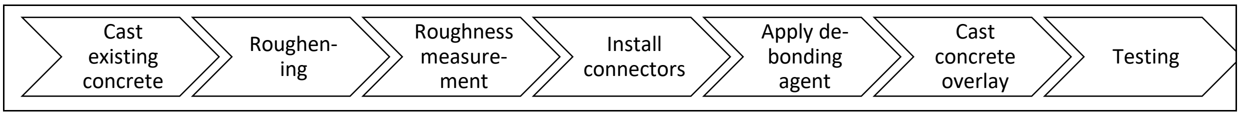


Figure A.7.3.1: Proposed workflow

Concrete strength and roughness of the interface in the tests are the minimum values which are valid for the determined performance.

Existing concrete shall have been casted at least 21 days before roughening. Testing earliest after 21 days after casting of the concrete overlay.

The static tests shall be loaded in intervals of 10 to 15% of the expected failure load to allow crack inspection and determination of shear cracks. The tests specimens intended for the cycling tests shall be initially loaded to approximately 70% of the static failure load to initially crack the shear interface and to ensure cracking of the interface. Crack forming must be validated, e.g., by measurement of the displacements or the stress in the connector.

Following parameters are required to be measured before, during or after testing:

- Applied fatigue loading F_{up} [1)] and F_{lo} [1)],
- Failure load F_u,
- Deflection at failure δ_u,
- Concrete strength f_c or f_{cube} on test specimens,
- Roughness in the interface $R_{t,test}$,
- Relative displacement of existing concrete and concrete overlay during the cycles (vertical and horizontal) [2)],
- Mean stress in the connector [2)],
- Number of cycles in fatigue test,
- Failure mode.

Notes:

[1)] *The lower load F_{lo} may not exceed 20% of the upper load F_{up}.*
To ensure the correct recording of the values related to the load peaks, a measuring rate of 50 Hz is proposed. To capture the peak values of all measured parameters during a full cycle this procedure shall be repeated after at least 200 load cycles.
A reduction of measurement data in the post processing is accepted. Recording of the data at peak loads after at least 200 cycles is required.

[2)] *The measurement of the relative displacement of the two concrete layers and the stress of the connector allows to differentiate a real run-out from a test that is already in failure process.*

A.7.4 Assessment

<u>Range of roughness</u>

The assessment result applies for the roughness $R_{t,m}$ measured on the test members or for higher roughness.

The roughness of each test members shall be measured at areas distributed evenly over the interface. The minimum number of areas is associated with the number of connectors used in the test. The mean value of the measurements is $R_{t,i}$, the roughness of the test member i. The scatter of the roughness values measured is $cv_{R,i}$. The value of $cv_{R,i}$ shall not be higher than 40%.

The roughness of the test members assessed together is $R_{t,m}$. $R_{t,m}$ is the mean value of the roughness values $R_{t,i}$ of each test member. The scatter of the roughness values $R_{t,i}$ is $cv_{R,m}$. The value of $cv_{R,m}$ shall not be higher than 30%.

<u>Assessment of static and fatigue test</u>

The specimen shall be inspected during and after the tests to check that shear failure was the predominating failure mode.

The assessment comprises the compliance with the given function for fatigue behaviour (Figure A.7.4.1)

Compliance with the given function for fatigue behaviour is given, when:

- all fatigue failure test results are higher than the characteristic function given in Figure A.7.4.1,
- the maximum ratio $F_{up,\infty} / F_{um,st}$ of a run-out is $F_{up,\infty} / F_{um,st} \geq 0{,}42$.

Then the reduction factor for system performance under fatigue loading $\eta_{sc} = 0{,}40$ applies.

The criteria for run-outs are:

- Achieving 2 x 10^6 load cycles,
- Decreasing deflection with the number of cycles,

Note: During the cycling a larger increase of deflection might occur. This indicates a final cracking of the shear interface. This shall not contribute to the assessment of the deflection criteria.

- Constant or decreasing behaviour of the relative displacement between the two concrete layers,
- Stabilized or decreasing stress in the connector over the last 1.8 million cycles,
- Reloading in a static test and passing 75% of the mean failure load $F_{um,st}$ in short term tests. If the 75% of the mean failure load are not passed, the test shall be repeated at a lower loading until the 75% of the mean failure load $F_{um,st}$ are met.

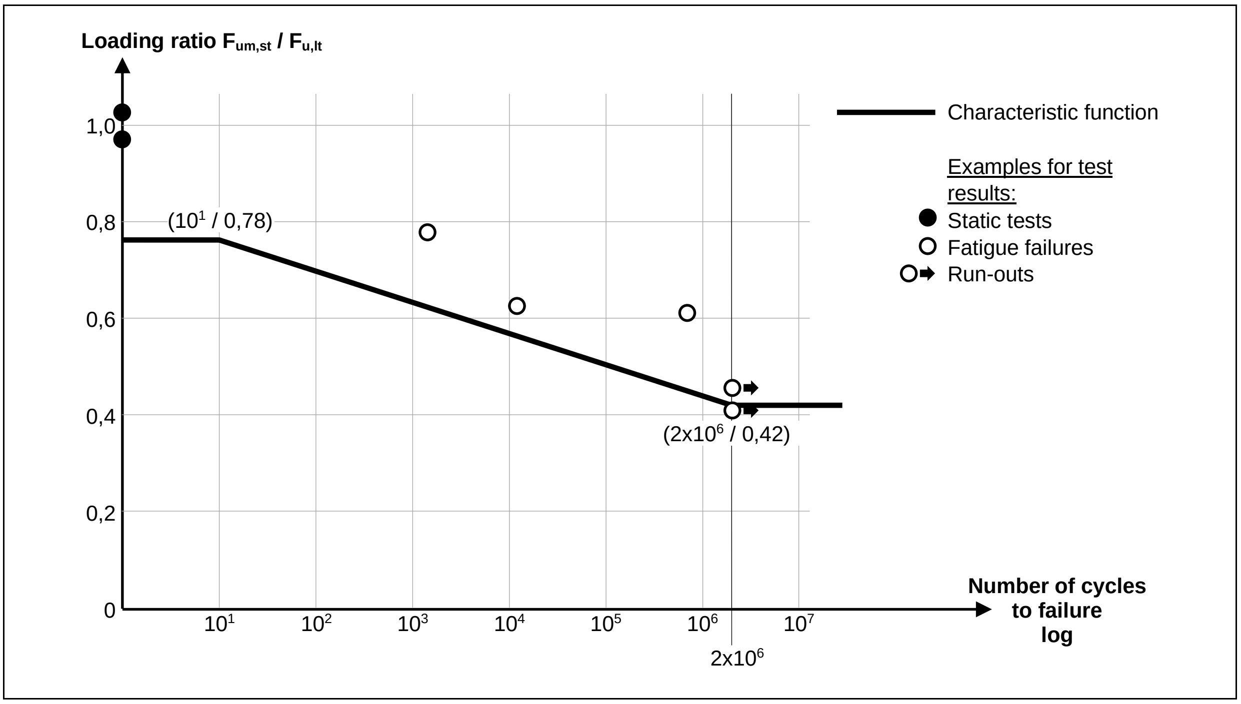


Figure A.7.4.1: Compliance with given function for fatigue behaviour

A.8 Fatigue cyclic loading test for steel failure

Purpose is to determine the characteristic steel fatigue resistance for bonded fasteners and concrete screws in existing concrete and in concrete overlay $\Delta N_{Rk,s,0,\infty}$ according to EAD 330250-00-0601, clauses 2.2.1 or 2.2.9.

On the safe side, for connectors only, tests may be done without concrete and without 3° inclination as pure steel test. The test setup is given in Figure A.8.1. The assessment is done according to EAD 330250-00-0601 [3], clauses 2.2.1. or 2.2.9.

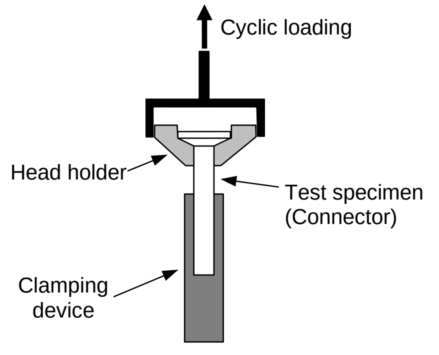


Figure A.8.1: Test setup