EUROPEAN ASSESSMENT DOCUMENT

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POWER-ACTUATED FASTENER IN CONCRETE FOR REDUNDANT NON STRUCTURAL APPLICATIONS

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1 SCOPE OF THE EAD

1.1 Description of the construction product

The power-actuated fastener in concrete for redundant non-structural applications consist of a suitable nail made of metal which is placed into the concrete by use of a power-actuated fastening tool. The nail can be driven with or without previous drilling and anchored by sintering and mechanical interlock. The diameter of the nail is in the range of 3 mm to 5,5 mm.

The minimum and/or maximum dimensions based on relevance in practice. All assessment methods are developed / adjusted according to these dimensions on experiences and tests. Other dimensions could cause other failure modes which are not assessed according to this EAD.

The minimum anchorage depth depends on the fastener type of the power-actuated fastening system and is given in Table 1.1.1.

This EAD covers power-actuated fasteners installed perpendicular to the surface into pre-drilled holes perpendicular to the surface or without previous drilling.

The fasteners are made of carbon steel or stainless steel. For positioning and guidance during the driving process an additional plastic or metal washer can be used.

Fastenings may include fixtures made of metal or plastic (see Figure 1.2.1). As plastic material following polymeric material may be used:

- Polyamide PA6 and PA6.6,
- Polyethylene PE.

Only virgin material (material which has not been moulded before) shall be used. In the moulding process only reworked material (e.g., sprue) shall be added received as waste material from the same moulding process. This regenerated material is of the same feedstock and identical with the rest of the material.

Figure 1.1.1 shows examples of the product (with nail head or with external thread).

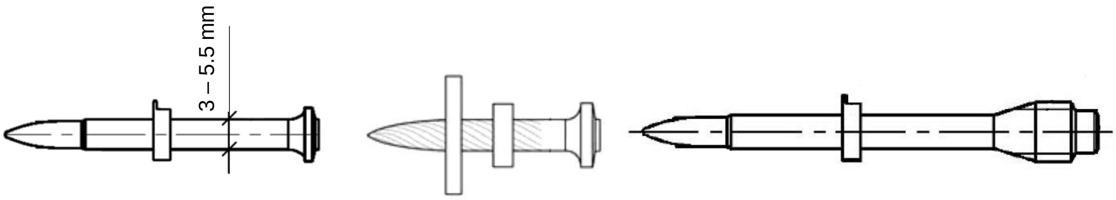

Figure 1.1.1 – Examples of a power-actuated fastener with washer (Fastener type 1 and 2)

Fasteners of Fastener type 3 and 4 includes only power-actuated nails but no power-actuated threaded studs.

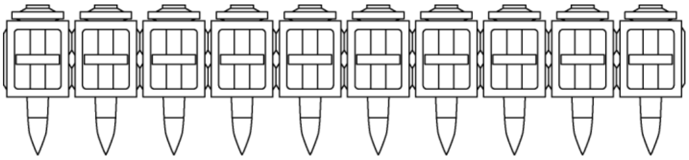

Figure 1.1.2 – Example of a power-actuated fastener (Fastener type 3)

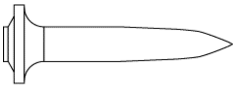

Figure 1.1.3 – Example of a power-actuated fastener (Fastener type 4)

The metal parts of the fasteners are described by reference to dimensions (external/internal diameter, thread length, etc.) and mechanical properties (tensile strength yield strength, fracture elongation, core and surface hardness and zinc plating) including possible tolerances.

The plastic parts of the fasteners are described by reference to dimensions (height, width, wall thickness etc.), melt volume-flow rate (MVR) and Charpy impact toughness.

If these data are not available from documentation, they can be established according to the Table 3.2.1.

Different versions of a fastener with respect to material, strength or dimensions are marked such that the relevant product characteristic is allocated to the corresponding anchor type.

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

The product is not fully covered by the following harmonised technical specification: EAD 330083-02-0601[1] [1]. Compared to the previous version of the EAD, the following changes are introduced: Specific assessment methods of fixture for fasteners type 1 and 2 and assessment methods for fastener type 4 are added as well as necessary improvements for the others.

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 of the construction product

1.2.1 Intended use

The power-actuated fasteners are intended for redundant non-structural applications in cracked or non-cracked, reinforced or unreinforced normal weight concrete between strength classes C12/15 and C50/60 according to EN 206-1 [12]. For fasteners of Fastener type 3 and 4 the minimum concrete strength class is C20/25. Damages on the concrete surface, caused by setting defects, have to be repaired according to technical rules, e.g., EN 1504-3 [13]. A new fastener is set at a minimum distance away of ≥ 150 mm and ≥ 3 h_{ef} of the edge of the damaged surface.

The fastener can also be used in composite slabs consisting of concrete and steel composite decking. The maximum thickness of the steel shell is 1,25 mm and its maximum steel grade is S350 according to EN 10346 [6]. If the fastener is used in composite slabs, an automatic detection of setting defects has to be used.

A power-actuated fastening tool according to EN 15895 [10], EN ISO 11148-13 [18] and EN 60745-2-16 [4] is used in order to install the fastener. The driving force of the fastening tool is provided by the power load of a cartridge in case of powder-actuated tools, compressed air in case of pneumatic tools, expanding gases in case of gas driven tools or by other kinds of mechanical energy provided by a power-actuated fastening tool.
For the installation of the product the necessary tools foreseen by the manufacturer shall be used and the relevant manufacturer’s instructions shall be followed to the detail. The performance of the fastener is assessed under the assumption that both these preconditions are met.

The fasteners are intended to be used for applications where the minimum thickness of concrete members in which the fasteners are installed is $h = 2h_{ef}$ and at least h = 80 mm.

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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.

The fasteners are intended to be used for anchorages in respect to durability for

- use in structures subjects to dry, internal conditions, concrete exposure class X0 or XC1 according to EN 206-1 [12] (Fastener types 1 to 4). No special corrosion protection is necessary for steel parts as coatings provided for preventing corrosion during storage prior to use and for ensuring proper functioning (zinc coating with a minimum thickness of 5 microns) is considered sufficient.
- use according EN 1993-1-4 [3], Annex A: Fasteners made of stainless steel according EN 1993-1-4 [3], Annex A, Tables A.3 and A.4 are considered to have sufficient durability for the corresponding Corrosion Resistance Class (CRC) (Fastener types 1 and 2).

The power-actuated fasteners and fixtures made of steel can be used in the temperature range -40 °C to + 80 °C without special assessment.

For fixtures made of plastic a maximum long-term temperature of +24 °C and a maximum short-term temperature of +40 °C apply. For plastic fixtures made of polyamide a minimum long-term temperature of -20 °C and for plastic fixtures made of polyethylene a minimum long-term temperature of 0 °C applies.

The EAD covers fixtures made of PE which are not exposed to UV-radiation for more than 6 weeks. If the fixtures are made of polyamide PA6 or PA6.6, the durability is given for uses within Fastener type 3.

Fastener type 1 and 2 is intended to be used ~~only~~ for anchorages subject to static or quasi-static loading ~~in reinforced or unreinforced concrete~~.

Fastener type 3 is intended to be used for anchorages subject to self-weight of cable or cable conduits. Fixtures made of plastic are intended to be used for anchorages subject to self-weight of cable or cable conduits.

Fastener type 4 is intended to be used for fastening of metal tracks (with a thickness of 0,6 mm ≤ t ≤ 2,0 mm) and a tensile strength of $R_m \geq 260$ N/mm²) for drywalls where the acting load is a shear dead load on the fastener.

The fastener is intended to be used for anchorages in two-dimensional load-bearing structures (slabs and walls). Fasteners of type 1 (according to Table 1.2.1) are also intended to be used in one-dimensional load-bearing structures (beams and columns) when the position of the existing reinforcement is known and the fastener will be driven without damaging of the reinforcement.

The power-actuated fastener is used for transmission of tensile loads, shear loads or a combination of both.

The definition of redundant systems depends on the Fastener type of the power-actuated fastening system and is given in Table 1.2.1.

Table 1.2.1 Types of power-actuated fastening systems

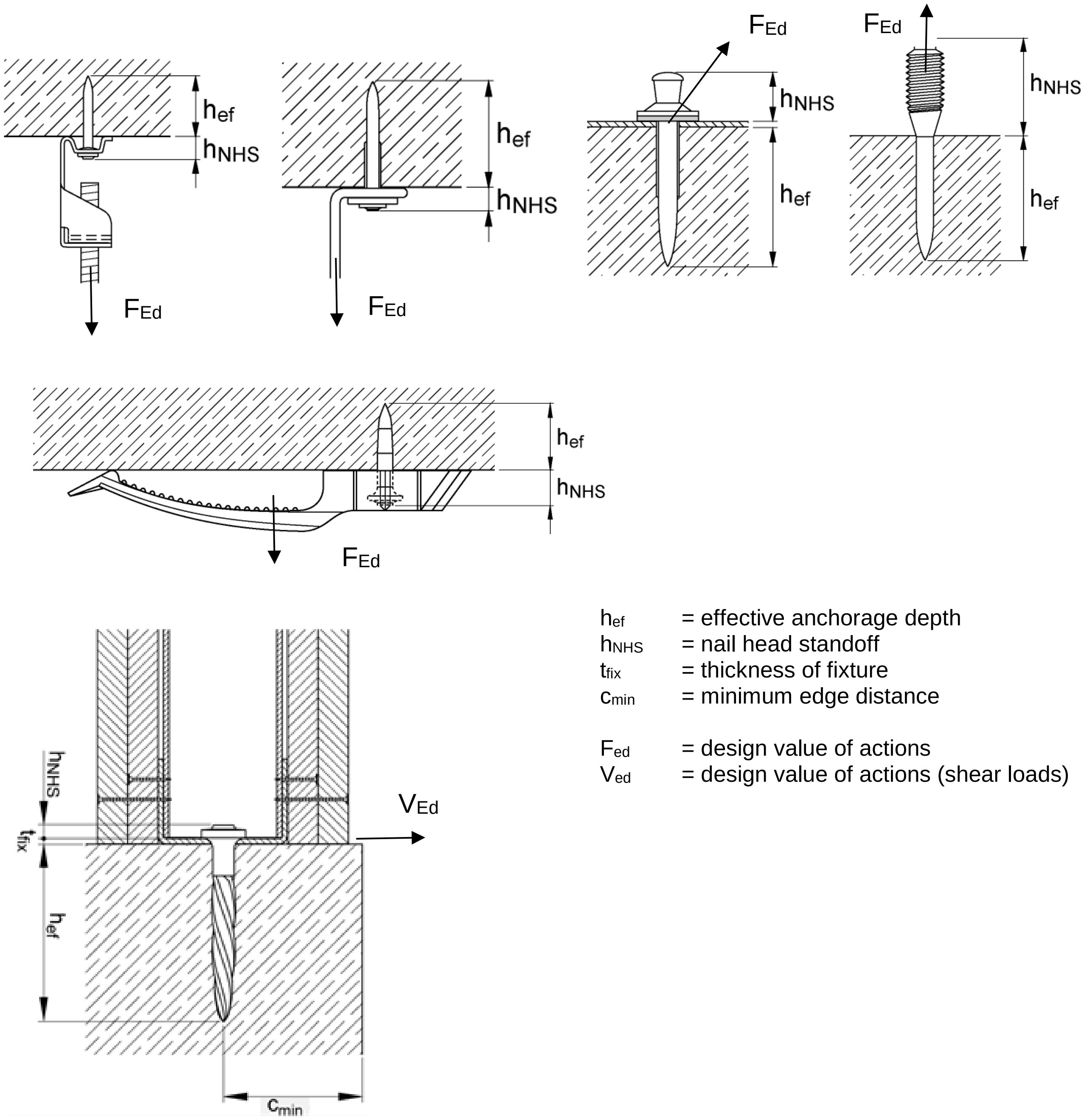
Fastener type	Minimum anchorage depth	Maximum anchorage depth	Definition of redundant systems
1	≥ 25 mm	-	According to CEN/TR 17079 [5]: $n_1 \geq 4$; $n_2 \geq 1$ and $F_{Ed,lim} \leq 3{,}00$ kN or $n_1 = 3$; $n_2 \geq 1$ and $F_{Ed,lim} \leq 2{,}00$ kN
2a	≥ 18 mm	-	$n_1 \geq 4$; $n_2 = 1$ and $F_{Ed,lim} \leq 0{,}60$ kN
2b	≥ 15 mm	-	$n_1 \geq 6$; $n_2 = 1$ and $F_{Ed,lim} \leq 0{,}30$ kN
3	11 mm	18 mm	Fastening of cables spanned in one direction $10 \leq n_1 \leq 100$; $n_2 = 1$ and $F_{Ed,lim,S} \leq 0{,}10$ kN maximum span 1000 mm
4	11 mm > 20 mm	20 mm -	Fastening of metal tracks for drywalls $n_1 \geq 5$; $n_2 = 1$ and $V_{Ed,lim} \leq 0{,}6$ kN $V_{Ed,lim} \leq 2{,}0$ kN

For fastener used in redundant systems it is assumed of Fastener type 1 and 2 that in the case of excessive slip or failure of one fastener the load can be transmitted to neighbouring fasteners without significantly violating the requirements on the fixture in the serviceability and ultimate limit state. By fastener used in redundant systems in case of Fastener type 3, the excessive slip or failure of one or more fasteners are assessed for the limit states according to section 2.2.3.3.

For example, the design of the fixture may specify the number n_1 of fixing points to fasten the fixture and the number n_2 of fasteners per fixing point. Furthermore, by specifying the design value of actions F_{Ed} (V_{Ed} for fastener type 4) on a fixing point to a value ≤ $F_{Ed,lim}$ ($V_{Ed,lim}$ for fastener type 4) (kN) according to Table 1.2.1 up to which the strength and stiffness of the fixture are fulfilled and the load transfer in the case of excessive slip or failure of one fastener need not to be taken into account in the design of the fixture.

Fixtures and fasteners can be pre-assembled with metal or plastic components. In this case the fixture is part of the fastener and fixture and fastener shall be assessed together regarding anchorage in base material. The construction of the fixture can be assessed together with the power-actuated fastener or separately.

Figure 1.2.1 shows examples of the installed product with different fixtures



h_{ef} = effective anchorage depth
h_{NHS} = nail head standoff
t_{fix} = thickness of fixture
c_{min} = minimum edge distance

F_{ed} = design value of actions
V_{ed} = design value of actions (shear loads)

Figure 1.2.1 – Power-actuated fastener with different fixtures or external thread anchored in a concrete slab

The fasteners of Fastener type 1 or 2 are intended to be used for anchorages which are designed according to design method C given in EN 1992-4 [11].

Supplemental description of Fastener type 3:

Fastener type 3 includes fastening uniaxially spanned flexible cables or conduits as well as rigid cables or conduits. Figure 1.2.2 shows the static system for the fixed cables. Flexible cables are assumed to have negligible moment of Inertia (I = 0) and correspond with the static behaviour of a chain. For rigid cables and conduits, the static system is a continuous beam with constant moment of inertia and constant bending stiffness. Cables up to an outer diameter of 12 mm are considered flexible. Cables with an outer diameter greater than 12 mm are considered as rigid.

Both ends of the chain are assumed as fixed supports (e.g., fixation in a cable-terminal box or cable support on rigid walls at locations, where cables are led through interior walls). For design, constant spacing of the cable fastenings is assumed. Also, the cable weight per unit length is constant. In case of variable spacing, the longest spacing within the chain shall be used for the assessment.

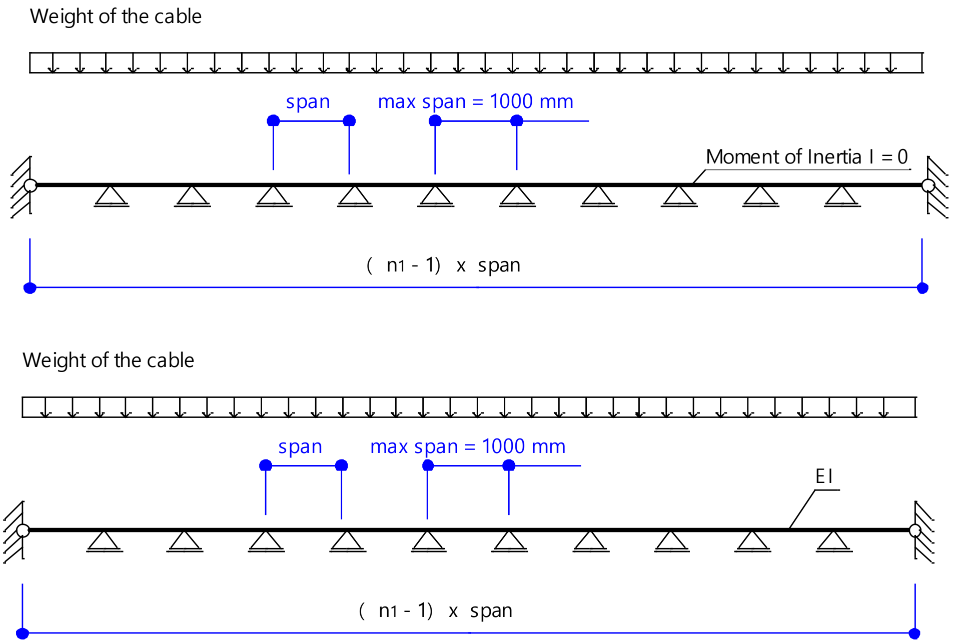


Figure 1.2.2 – Static system of uniaxially spanned cables of Fastener type 3

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 fastener for the intended use of 50 years when installed in the works (provided that the fastener 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.

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[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.

1.3 Specific terms used in this EAD

General

Fastener = a manufactured, assembled component for achieving anchorage between the base material (concrete) and the fixture

Fixture = component to be fixed to the concrete member

Anchorage = an assembly comprising base material (concrete), fastener and component fixed to the concrete member

Mean value = arithmetic average, sum of all test results in a test series divided by the total number of tests in this test series

Normal ambient temperature = 21 ± 3 °C

Short-term temperature: = Temperatures within the service temperature range which vary over short intervals, e.g., day/night cycles and freeze/thaw cycles.

Long-term temperature: = Temperatures within the service temperature range which will be approximately constant over significant periods of time. Long-term temperatures will include constant or near constant temperatures, such as those experienced in cold stores or next to heating installations.

Fasteners

The notations and symbols frequently used in this EAD are given below. Further particular notation and symbols are given in the text.

c = edge distance
c_{min} = minimum allowable edge distance
$c_{min,fi}$ = minimum allowable edge distance under fire exposure
d = fastener bolt diameter
d_{cut} = cutting diameter of drill bit
d_f = diameter of clearance hole in the fixture
h = thickness of concrete member
h_0 = depth of the drill hole
h_{min} = minimum thickness of concrete member
h_{ef} = effective anchorage depth
h_{NHS} = nail head standoff
L = overall length of the fastener
s = spacing of the fasteners
s_{min} = minimum allowable spacing
$s_{min,fi}$ = minimum allowable spacing under fire exposure
T = torque moment
T_{inst} = maximum installation torque moment
T_u = maximum torque moment during failure
t_{fix} = thickness of fixture

Base material (concrete) and metal parts of fastener

f_c = concrete compression strength measured on cylinders
$f_{c,cube}$ = concrete compression strength measured on cubes
$f_{c,test}$ = compression strength of concrete at the time of testing
f_{cm} = mean concrete compression strength
f_{ck} = nominal characteristic concrete compression strength (based on cylinder)
$f_{ck,cube}$ = nominal characteristic concrete compression strength (based on cubes)
$f_{y,test}$ = steel tensile yield strength in the test
f_{yk} = nominal characteristic steel yield strength
$f_{u,test}$ = steel ultimate tensile strength in the test

f_{uk} = nominal characteristic steel ultimate strength

Loads / Forces

F = force in general
N = normal force (+N = tension force)
V = shear force
M = moment

Tests / Assessment

F^t_u = ultimate load in a test in general
$F_{u,m}$ = mean ultimate load in a test series in general
$F_{5\%}$ = 5%-fractile of ultimate loads in a test series in general
$V^t_{u,Group}$ = ultimate shear load in a group test
$V_{u,Group,m}$ = mean ultimate shear load in a group test series
Δw = increase in crack width during loading of the anchor and crack width at the time of installing the anchor
n = number of tests of a test series
v = coefficient of variation
$\delta(\delta_N, \delta_V)$ = displacement (movement) of the fastener at the concrete surface relative to the concrete surface in direction of the load (tension, shear) outside the failure area. The displacement includes the steel and concrete deformations and a possible fastener slip.
δ_0 = displacement of the fastener under short-term loading
δ_∞ = displacement of the fastener under long-term loading
α = ratio of test value / reference value, for instance
N_{Rk}, V_{Rk} = characteristic fastener resistance under tension or shear force
F_{Rk} = characteristic fastener resistance in any load direction
$F_{Rk,fi}$ = characteristic fastener resistance in any load direction under fire exposure
$M^0_{Rk,s}$ = characteristic resistance for steel failure with lever arm
$M^0_{Rk,s,fi}$ = characteristic resistance for steel failure with lever arm under fire exposure

Redundant systems (see also CEN/TR 17079 [5])

n_1 = number of fixing points to fasten the fixture
n_2 = number of fasteners per fixing point
$F_{Ed,lim}$ = design value of actions on a fixing point
$F_{Ed,lim,S}$ = maximum service load acting on the power-actuated fastener
$V_{Ed,lim}$ = design value of actions resulting from shear loads on a fixing point

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 power-actuated fastener in concrete for redundant non-structural applications 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			
1	Characteristics resistance of Fastener type 1 and 2	2.2.1	Level F_{Rk} [kN], $M^0_{Rk,s}$ [Nm], c_{min} [mm], s_{min} [mm], h_{min} [mm], h_{ef} [mm]
2	Displacements of Fastener type 1 and 2	2.2.2	Level δ_{N0}, δ_{V0}, $\delta_{N\infty}$, $\delta_{V\infty}$ [mm]
3	Maximum service load of Fastener type 3	2.2.3	Level $N_{s,max}$ [kN], $V_{s,max}$ [kN], h_{ef} [mm], n_1 [-], span [mm], number of gaps for local failure, number of gaps for serviceability limit state
4	Characteristics resistance of Fastener type 4	2.2.4	Level V_{Rk} [kN], c_{min} [mm], s_{min} [mm], h_{min} [mm], h_{ef} [mm], min t_{fix} [mm]
Basic Works Requirement 2: Safety in case of fire			
5	Reaction to fire	2.2.5	Class
6	Resistance to fire Fastener type 1 and 2	2.2.6	Level Fasteners and fixtures made of metal: $F_{Rk,fi}$ [kN], $M^0_{Rk,s,fi}$ [Nm], $c_{min,fi}$ [mm], $s_{min,fi}$ [mm] Fixtures made of plastic: not specified in this version of EAD
Aspects of durability			
4	Durability	2.2.7	Description

2.2 Assessment methods and criteria for 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 of Fastener type 1 and 2

Purpose of the assessment

Determination of characteristic resistance of fastener type 1 and type 2 and corresponding anchorage depth, edge distances, spacing and minimum member thickness.

The characteristic resistance of a single fastener is assessed according to 2.2.1.1 to 2.2.1.4 and the characteristic resistance of a single fastener including fixture is assessed in addition according to 2.2.1.5.

Assessment method for characteristic resistance in any load direction

The test program for the assessment consists of

- Pre-tests (see 2.2.1.1, Table 2.2.1.1.1) in order to determine the scatter range of the ultimate load of the fastener system which is used for determination of the number of functioning tests and basic tests
- Functioning tests (see 2.2.1.1, Table 2.2.1.1.2) to assess the characteristic resistance regarding various effects for the relevant application range according to the intended use
- Basic tension tests and basic shear tests (see 2.2.1.2, Table 2.2.1.2.1) to assess basic values of characteristic resistance

2.2.1.1 Pre-tests and functioning tests

The test conditions, the number of required tests and the criteria applied to the results for pre-tests shall be taken as tension tests in accordance with the following Table.

Table 2.2.1.1.1 Pre-tests for power-actuated fasteners to be used in concrete

No	Purpose of test	Concrete	Crack width Δw (mm)	Thickness of fixture	Minimum number of tests	Criteria for the scatter of the measured ultimate loads	Scatter range
F0	Pre-test	C50/60 (1)	0	min. t_{fix}	50	$v \leq 20$ %	A
						$v > 20$ %	B

(1) If there is an application for anchorages in concrete strength class less than C50/60 only: tests are required in concrete with a compressive strength $f_{ck,test} \geq f_{ck,used}$ + 20 MPa (in case of C20/25) and $f_{ck,test} \geq f_{ck,used}$ + 10 MPa (in case of C40/50), interim values can be interpolated linear

Functioning tests, test conditions, the number of required tests and the criteria applied to the results shall be taken in accordance with the following Table.

Table 2.2.1.1.2 Functioning tests for power-actuated fasteners to be used in concrete

No	Purpose of test	Concrete	Crack width Δw (mm)	Thick-ness of fixture	Scatter range (5)	Minimum number of tests	Criteria req. α (2)	Refe-rence test (4)
F1	Contact with hard max. aggregate	C50/60 max. aggregate size 32 (6) (7)	0	min.t_{fix}	A	10	≥0,95 (8a) ≥0,8 (8b) ≥0,7 (8c)	F0
					B	20		
F2	Contact with reinforcement	C20/25	0	min.t_{fix}	A	5	≥0,85 (8a) ≥0,7 (8b) ≥ 0,6 (8c)	A1
					B	10		
F3	Functioning in low strength concrete	C20/25 (1)	0,35	max.t_{fix}	A	5	≥0,75	A3
					B	10		
F4	Repeated loads	C20/25	0	max.t_{fix}	A	5	≥1,0	A1
					B	10		
F5	Maximum torque moment (3)	C20/25	0	max.t_{fix}	A	5	≥0,9	A1
					B	10		
F6	Hydrogen embrittlement	C20/25	0	min.t_{fix}	-	5	≥0,9 (9)	A1 (10)
F7	Durability	See 2.2.3						

(1) If there is an application for anchorage in C 12/15; tests are also required in concrete with a compressive strength $f_{cm} \leq 20$ MPa (measured on cylinders) or $f_{cm} \leq 25$ MPa (measured on cubes).

(2) Calculation of α see 2.2.1.3

(3) Only for fasteners with external thread

(4) Referenced to test series as described in Table 2.2.1.1.2 and Table 2.2.1.2.1. Reference tests shall be performed with the same fastener type and in the same slab or same concrete batch as in the corresponding functioning tests.

(5) Scatter range according to Table 2.2.1.1.1.

(6) If there is an application in composite slabs: tests are also required in composite slabs. The tested thickness, hardness and strength of the steel shell shall be given in the ETA.

(7) If there is an application for anchorages in concrete strength class less than C50/60 only: tests are required in concrete with a compressive strength $f_{ck,test} \geq f_{ck,used} + 20$ MPa (in case of C20/25) and $f_{ck,test} \geq f_{ck,used} + 10$ MPa (in case of C40/50), interim values can be interpolated linear

(8) (8a) is valid for $\gamma_{inst} = 1,0$; (8b) is valid for $\gamma_{inst} = 1,2$; (8c) is valid for $\gamma_{inst} = 1,4$

(9) Calculation of α see 2.2.1.3, but only comparison of the mean values is required

(10) If there are different setting conditions between series F6 and A1 (e.g., concrete batches or anchorage depth because of the isolation) additional reference tests with setting conditions of test F6 are possible

Test procedure for all pre-tests and functioning tests

The tests shall be performed as single fastener tests in concrete members without any influence by edge and spacing effects under tension loading. The fasteners are installed according to the installation instructions of the manufacturer. The anchorage depth shall be measured in all tests of each test series (except for series F2 and F7 according to Table 2.2.1.1.2).

The tests shall be performed according to EAD 330232-01-0601 [7], Annex B unless otherwise specified for specific tests as follows.

- Test samples see [7], B.3.1.1,
- Test members see [7], B.3.1.2.1 to B.3.1.2.5 and B.3.1.2.8 for all tests,
- Test members see [7], B.3.1.2.6 for tests in cracked concrete,
- Test members see [7], B.3.1.2.7 for tests in uncracked concrete,
- Test setup see [7], B.3.1.3,
- Installation see [7], B.3.1.4,
- Test equipment see [7], B.3.1.5,
- Test procedure – general aspects see [7], B.3.2 for tests in cracked concrete.

The load shall increase in such a way that the average peak load of a test series is reached after 0,5 to 3,0 minutes. All tests shall be performed later than 10 minutes after setting.

The fasteners shall be driven with the energy recommended by the manufacturer. For powder-driven fasteners the cartridge recommendation and the corresponding tool energy settings shall be observed. The stand-off tolerance range for the given fastener shall be observed.

Further details of tests are described in EAD 330232-01-0601 [7], B.3.3. In all functioning tests displacements can be measured externally (e.g., by displacement transducers according to EAD 330232-01-0601 [7], B.3.3.1 or internally (e.g., measurement of piston stroke).

The single fasteners are tested in tension and loaded to failure.

Test procedure F1: Contact with hard aggregates of maximum size

The single fasteners are tested in tension and loaded to failure. Details of the test are described in EAD 330232-01-0601 [7], B.3.3.1. In deviation from EAD 330232-01-0601 [7], B.3.1.2.2 the maximum aggregate size of the concrete member shall be 32 mm and the grading curve between A32 and B32 according to Figure 2.2.1.1.1 shall be used. The hardness of the aggregate of the grading 15 to 30 mm or 16 to 32 mm respectively shall be at least 5 Mohs mineral hardness (for example quartzite or granite).

For the intended use of the fasteners under indoor conditions in building construction with a maximum thickness of the construction member of 250 mm, a grading curve in a range between A16 and B16 (see Figure 2.2.1.1.1) is used. The hardness of the aggregate of the grading 8 to 16 mm shall be at least 5 Mohs mineral hardness (for example quartzite or granite).

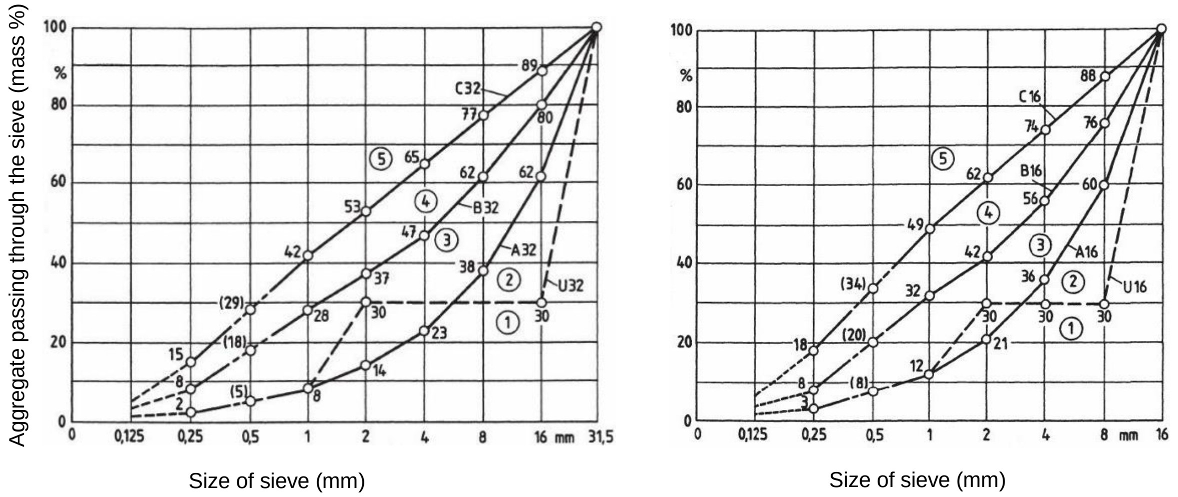
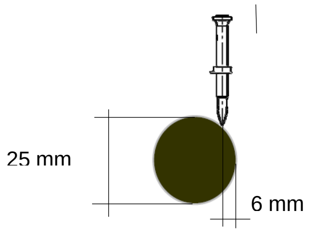


Figure 2.2.1.1.1: Grading curves for maximum aggregate size 32 mm and 16 mm

Test procedure F2: Contact with reinforcement

For these tests a special concrete member with reinforcement without ribs of a diameter of 25 mm (f_{uk} = 500 N/mm^2) is used. The concrete cover shall be chosen so, that the reinforcement is not touched by the previous drill. For power-actuated fasteners without previous drill the concrete cover shall be 10 mm. The setting position in the quarter point of the reinforcing bar (shown in Figure 2.2.1.1.2) shall be tested. The single fasteners are tested in tension and loaded to failure. Details of the test are described in EAD 330232-01-0601 [7], B.3.3.2.

Figure 2.2.1.1.2:
Setting position for contact with reinforcement



Test procedure F3: Functioning in low strength concrete

The single fasteners are tested in tension and loaded to failure. Details of the test are described in EAD 330232-01-0601 [7], B.3.3.1.

Test procedure F4: Repeated loads

The single fastener is subjected to 10^5 load cycles with a maximum frequency of approximately 6 Hz. During each cycle the load shall change as a sine curve between max N and min N with:

$$\max N = 0{,}60\ N_{Rk} \text{ and} \qquad (2.2.1.1.1)$$

$$\min N = 0{,}25\ N_{Rk}. \qquad (2.2.1.1.2)$$

with: N_{Rk} = minimum characteristic resistance evaluated from the results of tests A1, A2, A3 and A4 according to Table 2.2.1.2.1 (if the α-values in equation (2.2.1.4.1) are determined iteratively by previous investigations, the value $N_{Rk,p}$ according to equation (2.2.1.4.1) may be used)

Further details of the test are described in EAD 330232-01-0601 [7], B.3.3.4. After completion of the load cycles the fasteners shall be unloaded the displacement measured and a tension test to failure performed according to EAD 330232-01-0601 [7], B.3.3.1.

Test procedure F5: Maximum torque moment

For fasteners with external thread the torque moment is applied with a calibrated torque wrench. Details of the test are described in EAD 330232-01-0601 [7], B.3.5.

The single fastener is subjected to a torque moment. The torque moment is applied with a calibrated torque wrench up to the double installation torque moment T_{inst}. T_{inst} is the installation torque recommended by the manufacturer. If no installation torque is specified by the manufacturer, T_{inst} shall be taken as the maximum torque required to completely set the fastener.

After this a tension test to failure shall be performed according to EAD 330232-01-0601 [7], B.3.3.1.

Test procedure F6: Hydrogen embrittlement

Purpose and method of testing

This test for power-actuated fasteners can be omitted if fasteners are made of stainless steel (exception martensitic steel).

Fasteners of high strength can be sensitive to brittle fracture due to hydrogen embrittlement caused by the production process or by corrosion during (even short-time) exposure to moisture. The test is designed to detect fasteners with a high susceptibility to hydrogen induced brittle fracture and will be performed under conditions of constant mechanical load and hydrogen evolution on the surface of the fastener.

For this purpose, an electrolyte similar to concrete pore solution (saturated calcium hydroxide solution) will be applied while the sample is kept under constant and defined electrochemical conditions (at constant potential of –955 mV vs. normal hydrogen electrode (NHE)) by potentiostatic control or by other appropriate means. The potential is measured controlled by means of a reference electrode. The test setup is shown schematically in Figure 2.2.1.1.3.

Preparation of samples

The fasteners shall be driven into the concrete by means of the respective power-actuated tool.

Test conditions:

Test member: concrete strength C20/25

Test solution: saturated solution (in distilled water) of calcium hydroxide with small excess of $Ca(OH)_2$ powder to obtain a milky appearance. The pH will then attain about 12,6 (± 0,1) at 25 °C and remain constant during the test. Calcium hydroxide powder shall be kept in an air-tight containment and shall not be stored longer than one year.

The test solution shall be filled into a bottomless container covering an area of at least 96 cm^2 with a height of at least 25 mm, which shall be affixed to the concrete (see Figure 2.2.1.1.3). During the test the head of the fasteners shall be submerged in the fluid.

Sustained load:

$$N_{HE} = N_{Rk} \tag{2.2.1.1.3}$$

with: N_{Rk} = minimum characteristic resistance evaluated from the results of tests A1, A2, A3 and A4 according to Table 2.2.1.2.1 (if the α-values in equation (2.2.1.4.1) are determined iteratively by previous investigations, the value $N_{Rk,p}$ according to equation (2.2.1.4.1) may be used)

Electrochemical conditions:

Potential: -955 mV vs. NHE.

Reference electrode (RE): any kind of „second order“ electrode (calomel, silver/silver chloride etc.) can be used. The potential value shall be corrected according to the reference value given by the manufacturer of the reference electrode, e.g., for a saturated calomel electrode with E_{cal}= +245 mV vs. NHE the correct potential will be

E = –955 – 245 = -1200 mV (±10 mV).

Counter electrode (CE): stainless steel or activated titanium (used as anode for cathodic protection)

Temperature range: 20 to 25 °C

Duration of test: 100 hours. Following the test, after unloading the fastener, an unconfined tension test to failure shall be performed (see [7], B.3.3.1).

Test Criteria:

During the constant load portion of the test (100 hours), no fastener shall fail. The failure load of residual load bearing capacity shall be compared to reference tension tests according to reference tests in C20/25 (test series A1).

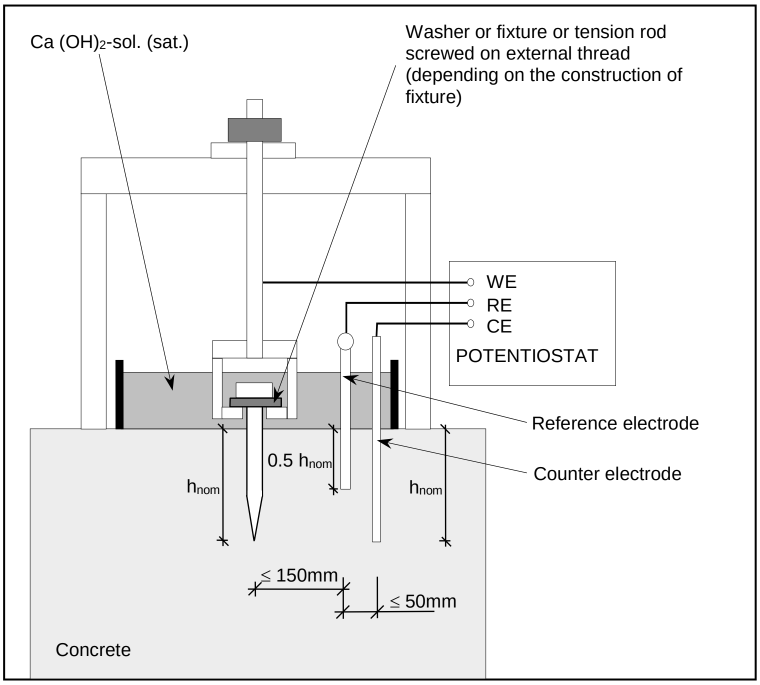


Figure 2.2.1.1.3 – Test setup (schematic)

Note: If possible, the working electrode (WE) shall be connected directly to the fastener and the fastener shall be electrically isolated from the pulling device.

If no electric isolation is made and the working electrode (WE) is connected to the pulling equipment, the electrical resistance needs to be compensated by the potentiostatic control. The potential between the fastener and the normal hydrogen electrode (NHE) needs to be measured by potentiostat and documented for each sample.

2.2.1.2 Basic tension tests and basic shear tests

The tests shall be performed as single fastener tests for each size in concrete members without any influence by edge and spacing effects under tension or shear loading. The fasteners shall be installed according to the installation instructions of the manufacturer. The anchorage depth shall be measured in all tests of each test series.

The load shall increase in such a way that the average peak load of a test series is reached after 0,5 to 3,0 minutes. All tests shall be performed later than 10 minutes after setting.

The types of tests for basic tests, test conditions, the number of required tests shall be taken in accordance with the following Table.

Table 2.2.1.2.1 Basic tension tests and shear tests

No	Purpose of test	Concrete	Crack width Δw (mm)	Thick-ness of fixture	Load direc-tion	Scatter range (3)	Number of tests
A1	Characteristic resistance to tension loading	C20/25 (1)	0	max.t_{fix}	N	A	10
						B	20
A2	Characteristic resistance to tension loading	C50/60 (2)	0	max.t_{fix}	N	A	10
						B	20
A3	Characteristic resistance to tension loading	C20/25 (1)	0,2	max.t_{fix}	N	A	10
						B	20
A4	Characteristic resistance to tension loading (4)	C50/60 (2)	0,2	max.t_{fix}	N	A	10
						B	20
A5	Characteristic resistance to shear loading	C20/25	0	max.t_{fix}	V	A	5
						B	10

(1) If there is an application for anchorage in C12/15; tests are also required in concrete with a compressive strength $f_{cm} \leq 20$ MPa (measured on cylinders) or $f_{cm} \leq 25$ MPa (measured on cubes).

(2) If there is an application for anchorage in concrete strength class less than C50/60 only; tests are required in concrete with a compressive strength $f_{ck,test} \geq f_{ck,used} + 20$ MPa (in case of C20/25) and $f_{ck,test} \geq f_{ck,used} + 10$ MPa (in case of C40/50), interim values can be interpolated linear

(3) Scatter range according to Table 2.2.1.1.1

(4) If $F_{Ru,m,A4} / F_{Ru,m,A2} > F_{Ru,m,A3} / F_{Ru,m,A1}$ than also test F3 according to Table 2.2.1.1.2 is required in concrete strength class C50/60.

Test procedure for characteristic resistance to tension loading

The tension tests are carried out at concrete members with normal strength C20/25 and in C50/60 (or the maximum grade the anchorage is applied for), cracked and non-cracked concrete according to EAD 330232-01-0601 [7], B.3.3.1. Displacements of series A2, A3 and A4 can also be measured internally (e.g., measurement of piston stroke). Reference tension tests for determination of the results of the functioning tests have to be carried out at the same concrete as it is given for the corresponding functioning tests (compressive strength).

Test procedure for characteristic resistance to shear loading

The shear tests are carried out at concrete members with normal strength C20/25, non-cracked concrete according to EAD 330232-01-0601 [7], B.3.6.1.

2.2.1.3 Assessment of test results

Conversion of ultimate loads to take account of concrete and steel strength:

In some cases, it can be necessary to convert the results of a test series to correlate with a concrete strength different from that of the test member (e.g., when comparing the results of repeated load tests with results of static tension tests performed on a different test member). When doing so, the type of failure shall be taken into account.

Normalize test results for the influence of the concrete compressive strength in accordance with Equation:

$$F_{Ru}\,(f_c) = F^t_{Ru}\,(f_c / f_{c,test})^{\,n} \tag{2.2.1.3.1}$$

with: $F_{Ru}\,(f_c)$ = failure load at concrete compression strength f_c

F^t_{Ru} = failure load at a test

$f_{c,test}$ = concrete compression strength at a test

n = 0,5 for concrete breakout and splitting failure,
in the case of pull-out failure the influence of concrete strength on the failure load shall be established from tests F0 and A1. In the absence of better information, the exponent 0,5 can be used as an approximation.

In the case of steel failure, the failure load shall be converted to the nominal steel strength by Equation:

$$F_{Ru}\,(f_{uk}) = F^t_{Ru} \cdot f_{uk} / f_{u,test} \tag{2.2.1.3.2}$$

with: $F_{Ru}\,(f_{uk})$ = failure load at nominal steel ultimate strength f_{uk}

F^t_{Ru} = failure load at a test

$f_{u,test}$ = steel ultimate strength at a test

5%-fractile of the ultimate loads:

The 5%-fractile of the ultimate loads measured in a test series shall be calculated according to statistical procedures for a confidence level of 90 % using logarithmical normal distribution of the single test results and unknown standard deviation of the population.

1) Determination the logarithmic values of the ultimate loads

$$\varphi_i = ln\,(F_{Ru}) \tag{2.2.1.3.3}$$

2) Perform the statistical analysis determining the fractile value based on logarithmic data

$$\varphi_m = \sum_{i=1}^{n} \left(\frac{\varphi_i}{n}\right) \tag{2.2.1.3.4}$$

$$s(\varphi) = \sqrt{\frac{\sum_{i=1}^{n} (\varphi_m - \varphi_i)^2}{(n-1)}} \tag{2.2.1.3.5}$$

$$\varphi_{5\%} = \varphi_m - k_s \cdot s(\varphi) \tag{2.2.1.3.6}$$

3) Determine the standard fractile value from the logarithmic fractile value

$$F_{5\%} = e^{\varphi 5\%} \tag{2.2.1.3.7}$$

with: φ_i = logarithmic values of the ultimate load of a test

F_{Ru} = ultimate loads of a test, if needed: converted to nominal values according to equation (2.2.1.3.1) or (2.2.1.3.2)

n = number of tests of a test series

φ_m = mean value of logarithmic values of a test series according to equation (2.2.1.3.4)

$s(\varphi)$ = standard deviation of logarithmic values of a test series according to equation (2.2.1.3.5)

$\varphi_{5\%}$ = 5%-fractile of logarithmic values of a test series according to equation (2.2.1.3.6)

k_s = statistical factor e. g., n = 5 tests: k_s = 3,40
n = 10 tests: k_s = 2,57
n = 20 tests: k_s = 2,21

$F_{5\%}$ = 5%-fractile of ultimate loads in a test series, if needed: converted to nominal values according to equation (2.2.1.3.1) or (2.2.1.3.2) note: setting defects which can visually not be recognised (e.g., failure during installation of the test equipment) shall be considered by F_{Ru} = 0,001 kN

Load/displacement behaviour

The requirement on the load/displacement curves in EAD 330232-01-0601, A.2.5 [7] applies. However, a reduction in load and /or a horizontal or near-horizontal part in the curve by uncontrolled slip of the fastener is not acceptable up to a load of:

$$N_1 = 0{,}4\ N_{Ru} \quad \text{(instead of 0,7 } N_{Ru} \text{ according to Equation (A.12) [7])} \qquad (2.2.1.3.8)$$

Where the requirement is not met in a test, the reduction factor $\alpha_1 = N_1 / (0{,}4\ N_{Ru}) \leq 1{,}0$ shall be considered in Equation (2.2.1.4.1).

There are no requirements on the scatter of the load/displacement curves.

Coefficient of variation of ultimate load

In each test series for methods according to Table 2.2.1.1.2 and 2.2.1.2.1 exceptional for maximum torque moment (F5) and hydrogen embrittlement (F6), the coefficient of variation of the ultimate load shall be calculated and shall be smaller than $v_{u,S}$ = 20 %. If the requirements for the scatter are not fulfilled by the tension tests, a reduction factor α_v for each test series shall be calculated according to:

$$\alpha_v = 1 / (1 + 0{,}03 \cdot (v_u [\%] - 20)) \leq 1{,}0 \qquad (2.2.1.3.9)$$

with: v_u = coefficient of variation of ultimate load of tests according 2.2.1.1.2 and 2.2.1.2.1.

The reduction factor α_v amounts to 1,0 for $v_u \geq 20\%$ provided the number of the tests amounts to minimum 50 per test series.

Reduction factor α

For test series F1, F2, F3, F4 and F6 according to Table 2.2.1.1.2 the factor α shall be calculated according to following Equation.

$$\alpha = \min ((F_{um,t} / F_{um,r}) ; (F_{5\%,t} / F_{5\%,r})) \qquad (2.2.1.3.10)$$

with: $F_{um,t}$ = mean value of failure load in a test series

$F_{um,r}$ = mean value of failure load in the reference test series (reference test see Table 2.2.1.1.2)

$F_{5\%,t}$ = 5% fractile of failure loads of a test series

$F_{5\%,r}$ = 5% fractile of failure loads in the reference test series (reference test see Table 2.2.1.1.2)

This Equation for 5% fractiles is based on test series with a comparable number of test results in both series. If the number of tests in the two series is very different, then Equation for 5% fractiles may be omitted when the coefficient of variation of the test series is smaller than or equal to the coefficient of variation of the reference test series.

The factor α shall be larger than req.α given in Table 2.2.1.1.2 of this EAD. If the requirements on the ultimate load in the functioning tests are not fulfilled in one or more test series, then the reduction factor α_u shall be calculated according to:

$$\alpha_u = \alpha / \text{req. } \alpha \leq 1{,}0 \qquad (2.2.1.3.11)$$

with: α = lowest value according to Equation (2.2.1.3.10) of test series F1- F4 and F6

req. α = required α according to Table 2.2.1.1.2

Functioning under repeated loads

The increase of displacement during cycling shall stabilize in a manner indicating that failure is unlikely to occur after some additional cycles.

If the above condition on the displacement is not fulfilled, the tests have to be repeated with a lower maximum load (max N (applied)) until this condition is fulfilled. Then the characteristic resistance N_{Rk} shall be reduced with the factor max N (applied) / max N. The characteristic resistance shall be reduced by applying the reduction factor α_p = max N (applied) / 0,6 N_{Rk} in Equation (2.2.1.4.1).

Maximum torque moment

For test series F5 according to Table 2.2.1.1.2 the factor α according to Equation (2.8) shall be calculated. The factor α shall be larger than req.α given in Table 2.2.1.1.2 of this EAD. If the requirements on the ultimate load in the functioning tests are not fulfilled in one or more test series, then the installation torque moment T_{inst} have to be reduced accordingly.

2.2.1.4 Evaluation of the characteristic resistance of a single fastener

Pull-out failure under tension load

The characteristic resistances of single fasteners ~~in C20/25~~ under tension loading shall be calculated as follows:

$$N_{Rk,p} = N_{Rk,0} \cdot \min \alpha_u \cdot \min \alpha_V \cdot \min \alpha_1 \cdot \min \alpha_p \qquad (2.2.1.4.1)$$

with: $N_{Rk,0}$ = $F_{5\%}$ according to equations (2.2.1.3.7) evaluated from the results of tests A1, A2, A3 and A4 according to Table 2.2.1.2.1

min α_u = minimum α_u (reduction factor from the ultimate loads in the functioning tests) according to 2.2.1.3 for functioning tests F1, F2, F3, F4 and F6 according to Table 2.2.1.1.2; ($\leq$ 1,0),

min α_v = minimum α_v to consider a coefficient of variation of the ultimate loads in the functioning and basic tests larger than 20 % according to 2.2.1.3; ($\leq$ 1,0)

min α_1 = minimum α_1 to consider the load/displacement behaviour according to 2.2.1.3; ($\leq$ 1,0)

min α_p = minimum α_p to consider a lower maximum repeated load according to 2.2.1.3; ($\leq$ 1,0)

Steel failure under shear load without lever arm

The characteristic resistance $V_{Rk,s}$ shall be determined for the cross-section of fastener as follows:

$$V_{Rk,s} = \alpha \cdot A_s \cdot f_{uk} \qquad (2.2.1.4.2)$$

with: α = 0,5

A_s = stressed cross-section of the fastener

f_{uk} = characteristic tensile strength of the fastener

Concrete failure under shear load

The characteristic resistances of single fasteners ~~in C20/25~~ under shear loading shall be calculated as follows:

$$V_{Rk,c} = V_{Rk,0} \cdot \alpha_V \qquad (2.2.1.4.3)$$

with: $V_{Rk,0}$ = $F_{5\%}$ according to equations (2.2.1.3.7) evaluated from the results of tests A5 according to Table 2.2.1.2.1

α_v = value α_v to consider a coefficient of variation of the ultimate loads in basic tests larger than 20 % according to 2.2.1.4; ($\leq$ 1,0).

Characteristic resistance in any load direction

For determination of the characteristic resistance in any load direction the characteristic resistance is controlled by the failure mode resulting to the minimum design strength $F_{Rd,min}$.

$$F_{Rd,min}\,[\text{kN}] = \min (N_{Rk,p} / \gamma_{Mc};\ V_{Rk,s} / \gamma_{Ms};\ V_{Rk,c} / \gamma_{Mc}) \qquad (2.2.1.4.4)$$

with: $N_{Rk,p}$; $V_{Rk,s}$; $V_{Rk,c}$ according to Equations above

γ_{Mc}; γ_{Ms} according to EN 1992-4 [11]

The characteristic resistance (in kN) shall be determined by following Equation and rounded down to zero or five on the second place after the decimal point:

$$F_{Rk}\,[\text{kN}] = F_{Rd,min} \cdot \gamma_M \qquad (2.2.1.4.5)$$

with: $F_{Rd,min}$ according to Equation above

γ_M depends on decisive failure mode (see Equation 2.2.1.4.4)

Assessment of steel failure under shear load with lever arm

The characteristic resistance $M^0_{Rk,s}$ shall be determined for the cross-section of the fastener as follows:

$$M^0_{Rk,s} = 1{,}2 \cdot W_{el} \cdot f_{uk} \qquad (2.2.1.4.6)$$

with: W_{el} = section modulus of the fastener

$W_{el} = \pi \cdot r^3/4$

f_{uk} = characteristic tensile strength of fastener

Expression of results for a single fastener: F_{Rk} [kN], $M^0_{Rk,s}$ [Nm]

2.2.1.5 Test procedure and evaluation of the characteristic resistance of a single fastener including fixture

Purpose of the assessment

Determination of characteristic resistance of fastener type 1 and type 2 including fixtures.

The characteristic resistances resulting from tests with the fastener (according to 2.2.1.4) are used as basis, the influence of eccentricity of the load resulting from the fixture is assessed separately and then superimposed on the characteristic resistance according to 2.2.1.4 accordingly.

The relation between force acting on eccentric fixture F_{FIX} and the force acting on the fastener F_{PAF} is assessed and given as their ratio $\alpha_e = F_{FIX} / F_{PAF}$. which allows the calculation of the force acting on the fastener from known load imposed on eccentric fixture.

Test procedure

Tests according to Table 2.2.3.2.1 test series A9 to A14 are performed. Details of test procedure are given in 2.2.3.2 and Annex D.

In case of plastic parts, the load shall be increased in such a way that the peak load occurs after 1 to 3 minutes from commencement.

In these tests failure of the fastener shall be avoided. The load acting on the fixture $F_{FIX,test}$ and the force acting on the fastener $F_{PAF,test}$ are measured continuously from the beginning.

For fixtures made of polyamide PA6 test series A10 and A13 may be omitted if the short-term temperature up to 35° C is considered by a factor of 0,8.

Tests series A11 and A14 are only necessary for fixtures, were an eccentric tension or shear loading is possible (the load on the fixture is not directly transferred to the fastener without an increasing effect).

Assessment fixture

The characteristic resistance of the fixture $F_{Rk,FIX}$ is the minimum of the 5%-fractile according to Equation (2.2.1.3.7) of test series A9, A10, A12 and A13.

If test series A10 and A13 are not performed $F_{Rk,FIX}$ = is the minimum of the 5%-fractile according to Equation (2.2.1.3.7) of test series A9, and A12 multiplied by the factor 0,8.

For the assessment of the effect of sustained loading on the fixture made of plastic the following material properties are required:

- Static stress-strain relationship of the plastic for standard humidity (equilibrium water content at T = +23 °C and 50 % relative humidity) based on tension coupon tests according to EN ISO 527-1 [15] with a test speed of 50 mm/min.
- Isochrone stress-strain relationship at 23 °C and 50 % relative humidity for 1000 hours according to EN ISO 899-1 [16]

The reduction factor α_{pt} (reduction factor considering the effect of long-term plastic behaviour) is derived from comparison of the static stress-strain behaviour with the isochrone stress-strain behaviour at 1000 hours. If material failure controls the resistance of the fixture (e.g., fracture or pull-over of the plastic fixture), the ratio of the ultimate strength of the plastic determines the reduction factor α_{pt}. If deformation of the plastic controls the resistance of the fixture without fracture of plastic components (e.g., when excessive deformation of plastic cantilever cable holders leads to a release of the cables from the fixture), the stress ratio in the initial linear stress-strain range determines the reduction factor α_{pt}.

Assessment of eccentric loading of the fixture

The assessment of the reduction for the fastener due to eccentric loading of the fixture is done with the following 5 steps for tension ($a_{eN,5\%}$; test series A11) and shear loading ($a_{eV,5\%}$; test series A14):

Step 1:

First, the test results of the couples of measured power-actuated fastener force $F_{PAF,test}$ and force $F_{FIX,test}$ acting on the fixture (for tension test series A11, for shear test series A14) are plotted for all samples.

The test results of all individual tests are then approximated with a polynomium with a degree of 3 or higher (see also Equation (2.2.3.3.12) and Annex B/Step1 for a polynomium of the degree of 4).

Step 2:

For increasing accuracy in the range of very small forces, the values $F_{FIX,test}$ are calibrated to the origin by subtracting a_0 from $F_{FIX,test}$ (see also Equation (2.2.3.3.13)).

Step 3:

The test results of all individual and new calibrated tests are then again approximated with a polynomium with a degree of 3 or higher (see also Equation (2.2.3.3.14)).

Step 4:

Calculation of the reduction factor $a_e = F_{FIX}/F_{PAF}$ and mathematical description of a_e as polynomium with a degree of at least 3 for all individual samples (see also Equation (2.2.3.3.15)).

Step 5:

a) First, the reduction factor a_e is calculated for every measured force $F_{PAF,i}$ up to the maximum relevant force F_{PAF}.
b) For all measured forces $F_{PAF,i}$ the 5%-quantile $a_{e,5\%}$ of the reduction factor is calculated assuming normal distribution. The minimum value of the 5%-quantile $a_{e,5\%}$ up to the failure load F_{PAF} are taken as relevant for $a_{e,5\%}$.

Characteristic resistance in any load direction

For determination of the characteristic resistance in any load direction the characteristic resistance is controlled by the failure mode resulting to the minimum design strength $F_{Rd,min}$.

$$F_{Rd,min}\ [kN] = \min\left(a_{eN,5\%} \cdot N_{Rk,p}/\gamma_{Mc};\ a_{eV,5\%} \cdot V_{Rk,s}/\gamma_{Ms};\ a_{eV,5\%} \cdot V_{Rk,c}/\gamma_{Mc};\ \alpha_{pt} \cdot F_{Rk,FIX}/\gamma_{Mpol}\right) \qquad (2.2.1.5.1)$$

with:

$N_{Rk,p}$; $V_{Rk,s}$; $V_{Rk,c}$	according to 2.2.1.4
$F_{Rk,FIX}$; α_{pt}	see 2.2.1.5 Assessment fixture
$a_{e,5\%,N}$:	Reduction factor for tension loading due to the eccentric loading of the fixture
$a_{e,5\%,V}$:	Reduction factor for shear loading due to the eccentric loading of the fixture
γ_{Mc}; γ_{Ms}:	according to EN 1992-4 [11]
γ_{Mpol}	= 2,5 (recommended according to TR 064 [19])

The characteristic resistance (in kN) shall be determined by following Equation and rounded down to zero or five on the second place after the decimal point:

$$F_{Rk}\ [kN] = F_{Rd,min} \cdot \gamma_M \qquad (2.2.1.5.2)$$

with:

$F_{Rd,min}$	according to Equation (2.2.1.5.1)
γ_M	depends on decisive failure mode (see Equation 2.2.1.5.1)

Assessment method for steel failure under shear load with lever arm: $M^0_{Rk,s}$ see Equation (2.2.1.4.6)

Expression of results for a single fastener including fixture: F_{Rk} [kN], $M^0_{Rk,s}$ [Nm]

2.2.1.6 Spacing and edge distances

Assessment method for edge distances and spacings

Tests for determination of required spacing and edge distances can be omitted if the following limits are observed:

spacing s_{min}	= max (200 mm; 4 h_{ef})
edge distance c_{min}	= max (150 mm; 3 h_{ef})
thickness of concrete member h_{min}	= max (80 mm; 2 h_{ef})

Smaller spacing end edge distances have to be tested and assessed according to EAD 330232-01-0601 [7], 2.2.5, Assessment for all other fasteners.

Expression of results: c_{min} [mm], s_{min} [mm], h_{min} [mm],

2.2.1.7 Anchorage depth

Assessment method for anchorage depth

The minimum anchorage depth shall be assessed as the 5% fractile of the measured anchorage depth of each test series (except for test series F2 and F7 according to Table 2.2.1.1.2) by using a confidence level of 75 % and an unknown standard deviation. Series with the same concrete strength class can be evaluated together. The minimum anchorage depth is given in the ETA.

Expression of results: h_{ef} [mm]

2.2.2 Displacements of Fastener type 1 and 2

Purpose of the assessment

Determination of displacements of fastener type 1 and type 2.

Assessment method

The characteristic displacements for short-term and quasi-permanent loading are specified for the load F in accordance with following equation:

$$F = F_{Rk} / (\gamma_F \cdot \gamma_M) \qquad (2.2.2.1)$$

with: F_{Rk} = characteristic resistance

γ_F = partial safety factor for actions = 1,4

γ_M = partial safety factor for material according EN 1992-4 [11]

The displacements δ_{N0} and δ_{V0} under short-term loading are evaluated from test series A1 and A5 of Table 2.2.1.2.1. They shall correspond to the mean value of these test series. The displacements (in mm) shall be rounded up to zero or five on the first place after the decimal point.

The displacements $\delta_{N\infty}$ under long-term tension loading are assumed to be approximately equal to 2,0-times the displacements δ_{N0}. The displacements $\delta_{V\infty}$ under long-term shear loading are assumed to be approximately equal to 1,5-times the displacements δ_{V0}. It shall be stated clearly in the ETA if the gap is taken into account in the assessment.

Expression of results: δ_{N0}, δ_{V0}, $\delta_{N\infty}$, $\delta_{V\infty}$ [mm]

2.2.3 Maximum service load of Fastener type 3

Purpose of the assessment

Determination of the maximum service load of fastener type 3 and corresponding anchorage depth, number of fixing points, length of span, number of gaps for local failure and number of gaps for serviceability limit state

Assessment method and expression of results

Assessment method general: see 2.2.3.1 and 2.2.3.2

Assessment method and expression of results for maximum service tension load: see 2.2.3.3

Assessment method and expression of results for maximum service shear load: see 2.2.3.4

Assessment method and expression of results for anchorage depth see 2.2.3.5

2.2.3.1 Functioning tests

Power-actuated fasteners

The execution of following functioning tests according to Table 2.2.1.1.2 is not required for Fastener type 3 for the following technical reasons:

- F1: Due to the small minimum concrete cover of 10 mm or the diameter of the reinforcing bar for concrete of the exposure class XC1, the use of concrete with maximum aggregate size of 32 mm is practically limited (the maximum aggregate size shall not exceed 1.25 times the concrete cover). Furthermore, the performance is determined by the presence of cracks, which usually develop around the aggregates. Therefore, the presence of cracks is adequately addressed by tests performed in concrete with maximum aggregate size of 16 mm.
- F2: Fastenings are made into the outer layer of the concrete with a maximum embedment of 18 mm and fastenings are limited to dry indoor conditions, exposure class XC1 (no contact with reinforcement).
- F3: The occurrence of greater crack width is covered by the tension tests A15 and A16 according to Table 2.2.3.2.1.
- F4: The fasteners are limited for anchorages subject only to self-weight of cables (no repeated load).
- F5: Only power-actuated nails and no threaded studs are used (no installation torque moment).
- F6: The stress utilization of the steel material of the power-actuated fasteners is below 3 % of the ultimate tensile strength. Furthermore, factory production control according to Table 3.2.1 has to be in place (sensitivity to brittle failure is not relevant).

Fixtures made of steel

No functioning tests are required.

Fixtures made of plastic

No functioning tests are required.

For the assessment of the effect of sustained loading the following material properties are required:

- Static stress-strain relationship of the plastic for standard humidity (equilibrium water content at T = +23 °C and 50 % relative humidity) based on tension coupon tests according to EN ISO 527-1 [15] with a test speed of 50 mm/min.
- Isochrone stress-strain relationship at 23 °C and 50 % relative humidity for 1000 hours according to EN ISO 899-1 [16]

2.2.3.2 Tension and shear tests

Tension and shear tests shall be performed to determine the resistance of the power-actuated fasteners including plastic and metal fixtures. The tests can be divided in order to determine the resistance of the individual components as follows:

- Tests to determine the axial tension resistance of the power-actuated fastener (N_{PAF})

  If the thickness of the fixture used in the tests deviates from the maximum thickness max.t_{fix} of the fixture to be assessed, power-actuated fasteners are allowed to use with a different length to ensure the same embedment depth as for max.t_{fix}. The diameter and shape over the embedment length shall be the same.

- Tests to determine the shear resistance of the power-actuated fastener (V_{PAF})

  The purpose of this test is to determine the pure shear resistance without effect of eccentric load introduction. If the thickness of the fixture used in the tests deviates from the maximum thickness max.t_{fix} of the fixture to be assessed, power-actuated fasteners are allowed to use with a different length to ensure the same embedment depth as for max.t_{fix}. The diameter and shape over the embedment length shall be the same.

- Tests to determine the tension resistance of the fixtures (N_{FIX})

  If the base material steel is used for those tests, power-actuated fasteners to fix the components to steel are allowed to use with a different length. The tension load introduction into the fixture has to correspond with the load introduction in the application from the self-weight of the cables.

- Tests to determine the shear resistance of the fixtures (V_{FIX})

  If the base material steel is used for those tests, power-actuated fasteners to fix the components to steel are allowed to use with a different length. The shear load introduction into the fixture has to correspond with the load introduction in the application from the self-weight of the cables.

- Tests to determine the load increase of the power-actuated fastener due to eccentric load introduction into the fixture (α_e)

  For the determination of this load increase, the load introduction into the fixture has to correspond with the load introduction into the fixture from the self-weight of the cables. Instead of fastening the fixture with a representative power-actuated fastener, it is acceptable to use a screw or bolt to attach the fixture in order to allow direct connection into a load cell measuring the force increase in the axis of the power-actuated fastener caused by eccentric load introduction. The screw or bolt has to have a diameter less than the clearance hole in the fixture. The fixture has to be compressed by the screw or bolt such as done by the power-actuated fastener in the application.

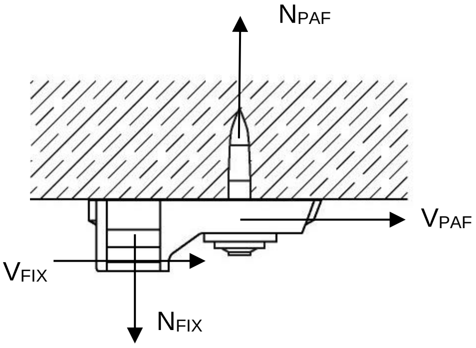


Figure 2.2.3.2.1 – Resistances of power-actuated fastener and fixture

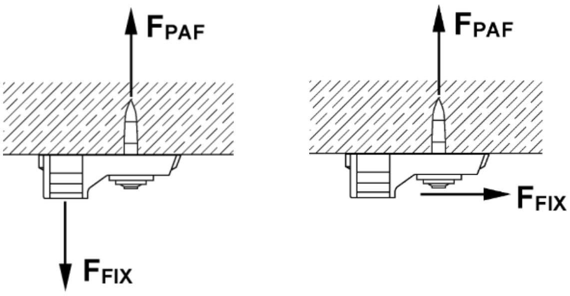


Figure 2.2.3.2.2 – Eccentric load introduction in case of tension and shear loads

$$F_{PAF} = (1/\alpha_e) \cdot F_{FIX} \qquad (2.2.3.2.1)$$

with:

F_{FIX} = Load acting on the fixture

F_{PAF} = Force acting on the power-actuated fastener

α_e = reduction factor α_{eN} according to section 2.2.3.3 in case of tension loads and α_{eV} according to section 2.2.3.4 in case of shear loads

The types of tests, test conditions, the number of required tests and the criteria applied to the results shall be taken in accordance with the following Table.

Table 2.2.3.2.1 Tension and shear tests

No	Purpose of test	Base material	Crack width Δw (mm)	Thickness of fixture	Load direction	Number of tests
A6	Distribution function of tension resistance of power-actuated fastener	C20/25	0,04 – 0,2 (2)	max. t_{fix}	N_{PAF}	80 / 200 (3)
A7	Distribution function of tension resistance of power-actuated fastener	C50/60 (1)	0,04 – 0,2 (2)	max. t_{fix}	N_{PAF}	80 / 200 (3)
A8	Distribution function of shear resistance of power-actuated fastener	C50/60 (1)	0,04 – 0,2 (2)	max. t_{fix}	V_{PAF}	80 / 200 (4)
A9	Distribution function of tension resistance of fixture at normal ambient temperature (5)	C20/25 or steel	0	actual	N_{FIX}	10
A10	Distribution function of tension resistance of fixture at maximum short-term temperature (6)	C20/25 or steel	0	actual	N_{FIX}	10
A11	Load increase in axis of power-actuated fastener due to eccentric tension load introduction into fixture (7)	-	0	actual	N_{FIX}	5
A12	Distribution function of shear resistance of fixture at normal ambient temperature (5)	C20/25 or steel	0	actual	V_{FIX}	10
A13	Distribution function of shear resistance of fixture at maximum short-term temperature (6)	C20/25 or steel	0	actual	V_{FIX}	10
A14	Tension force in axis of power-actuated fastener due to eccentric shear load introduction into fixture (7)	-	0	actual	V_{FIX}	5
A15	Functioning in low strength concrete	C20/25	0,35	max. t_{fix}	N_{PAF}	40 / 80 (8)
A16	Functioning in high strength concrete	C50/60 (1)	0,35	max. t_{fix}	N_{PAF}	40 / 80 (8)

(1) if there is an application for anchorage in concrete strength class less than C50/60 only; tests are required in concrete with a compressive strength $f_{ck,test} \geq f_{ck,used}$ + 20 MPa (in case of C20/25) and $f_{ck,test} \geq f_{ck,used}$ + 10 MPa (in case of C40/50), $f_{ck,test} \geq f_{ck,used}$ + 5 MPa (in case of C50/60), interim values can be interpolated linear.

(2) The distribution of crack widths for the tests shall be done as follows:

For sample size 80: Crack width range $0{,}04 \leq \Delta w < 0{,}08$ mm: 16 tests
Crack width range $0{,}08 \leq \Delta w < 0{,}12$ mm: 16 tests
Crack width range $0{,}12 \leq \Delta w < 0{,}16$ mm: 16 tests
Crack width range $0{,}16 \leq \Delta w < 0{,}20$ mm: 16 tests
Crack width range $0{,}20 \leq \Delta w < 0{,}24$ mm: 16 tests

For sample size 200: Crack width range $0{,}04 \leq \Delta w < 0{,}08$ mm: 40 tests
Crack width range $0{,}08 \leq \Delta w < 0{,}12$ mm: 40 tests
Crack width range $0{,}12 \leq \Delta w < 0{,}16$ mm: 40 tests
Crack width range $0{,}16 \leq \Delta w < 0{,}20$ mm: 40 tests
Crack width range $0{,}20 \leq \Delta w < 0{,}24$ mm: 40 tests

(3) 80 tests are required for both C20/25 and the maximum concrete grade. For the concrete grade controlling the performance (either C20/25 or the maximum concrete grade), the sample size shall be increased to a minimum of 200.

(4) If the shear performance derived from 80 tests exceeds the tension performance of test A6 and A7 (also derived from 80 tests), a further increase of the sample size to 200 is not required.

(5) To be performed for each individual fixture to be assessed in the ETA.

(6) To be performed for each individual fixture made of plastic to be assessed in the ETA.

(7) To be performed at nominal ambient temperature for each individual fixture to be assessed in the ETA.

(8) 40 tests are required for both C20/25 and the maximum concrete grade. For the concrete grade controlling the performance (either C20/25 or the maximum concrete grade), the sample size shall be increased to a minimum of 80.

For all tests the plastic parts have to be conditioned for standard humidity (equilibrium water content at T = +23 °C and 50 % relative humidity). For standard humidity the conditioning may be done according to ISO 1110 [17].

The anchorage depth shall be measured in all tests of each test series.

Test procedure: A6, A7, A8, A15 and A16

In addition, supplemental information on the test procedure for the service condition tests A6, A7, A8, A15 und A16 is summarized as follows:

The fastener embedment has to be determined for every fastener. Therefore, the total length and the respective fastener standoff h_{NHS} has to be determined and recorded for every fastener sample.

Tests are executed one crack section after the other as follows:

Development of a continuous unidirectional hair-crack e.g., by means of steel wedges.

After development of the hair-crack removal of the steel wedges.

Driving of power-actuated fasteners: At driving the power-actuated fastening tool has to be positioned such, that the power-actuated fastener is driven into the hair-crack. The spacing between the fasteners has to be reported.

Displacement gauges to measure the crack width are attached left and right of every fastener, with the fastener located approximately in the middle between the displacement gauges.

Opening of the crack e.g., by means of steel wedges till the target crack-width Δw is reached. The crack width is determined per fastener and calculates as the average crack width of the readings from the displacement gauges located left and right of the power-actuated fastener (see Figure 2.2.3.2.3).

Performance of test till maximum load is reached. The load is measured continuously with a load cell device with an accuracy of 1%.

In case of shear tests, the orientation of the shear force needs to be parallel with the crack at the location of the respective fastener.

Test procedure: A9 to A14

In case of plastic parts, the load shall be increased in such a way that the peak load occurs after 1 to 3 minutes from commencement.

In these tests failure of the fastener shall be avoided. The load acting on the fixture and the force acting on the fastener are measured continuously from the beginning with a load cell device with an accuracy of 1%. Examples of test setup and details of tests are given in Annex D.

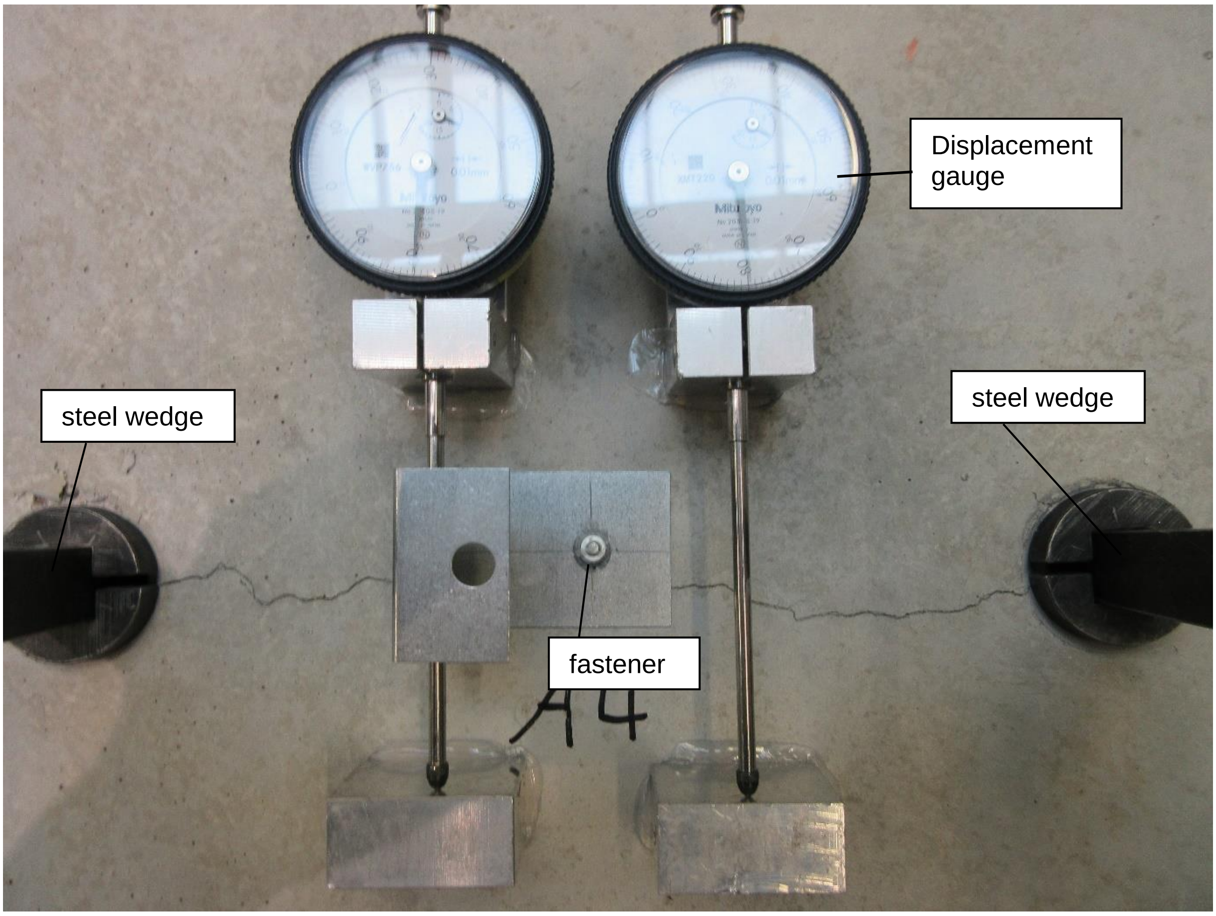


Figure 2.2.3.2.3 – Measurement of crack width in case of tension and shear loads

2.2.3.3 Assessment of test results of all tension tests

The following sections describe for tension loading on the fixture:

- the calculation of the distribution functions based on the test results for the power-actuated fastener and the fixture,
- the defined limit states,
- the calculation method,
- the procedure for the calculation of the reliability index and
- the concept of the service loads be published in the European Technical Assessment.

<u>Distribution function of power-actuated fastener for axial loading (Assessment of Test series A6 and A7)</u>

The evaluation of the distribution function is done either with the results of the service condition test A6 or A7 (depending if A6 or A7 controls the reliability index of the cable fastenings). The determination of the decisive test is done by comparing the cumulated probability of the results of A6 and A7. If no test is clearly decisive, the sample size has to be increased to 200 tests for both concretes and the reliability calculations have to be executed for both concretes.

The distribution function of the axial pull-out strength follows a Weibull distribution function described with the parameters b and c. Furthermore, the distribution function needs to be adjusted with the factor d. This adjusted distribution function $P(R)^*$ describes the estimated population and is used for the Monte-Carlo simulations for the calculation of the reliability index.

$$P(R)^* = d \cdot \left\{ 1 - \exp\left[-\left(\frac{R}{b} \right)^c \right] \right\} \tag{2.2.3.3.1}$$

The adjustment has to made that all calculated quantiles $R_{i,calc}$ of the distribution function are equal or less than the corresponding pull-out resistances R_i of the sample, with:

$R_1,\dots R_i,\dots R_n$ = Pull-out resistance of the sample sorted in ascending order from sample 1 to sample n.

$R_{i,calc}$ = Calculated quantiles of the inverse and adjusted Weibull distribution P(R)*.

$$R_{i,calc} = b \cdot \left[\ln\left(\frac{1}{1 - H_{Ri}/d} \right) \right]^{\frac{1}{c}},\ (1 \le i \le n) \tag{2.2.3.3.2}$$

with: H_{Ri} as the relative cumulated probability of the sample.

$$H_{Ri} = \frac{i - 0.5}{n},\ 1 \le i \le n \tag{2.2.3.3.3}$$

The procedure for the calculation of the adjusted distribution function P(R)* is described as follows (example see Annex A).

Step 1: Evaluation of the test sample with sample size n

- Sort all discrete pull-out resistances R_i in ascending order from R_1 to R_n ($R_n = R_{max}$)
- Calculation of the relative cumulated probability H_{Ri} for all samples
- Calculation of the mean value $\overline{R}$ and standard deviation S of test sample
- Calculation of coefficient of variation ν (ν = S/$\overline{R}$) of test sample

Step 2: Approximation of the discrete sample distribution by means of a Weibull distribution P(R)

The mean value μ and the standard deviation σ of the Weibull distribution are defined as the mean value $\overline{R}$ and the standard deviation S of the sample, respectively:

$\mu := \overline{R}$ and $\sigma := S$

The following formula gives the Weibull distribution function P(R) approximating the discrete distribution of the test sample:

$$P(R) = 1 - \exp\left[-\left(\frac{R}{b} \right)^{c} \right] \tag{2.2.3.3.4}$$

with: P(R) = approximated probability function of axial pullout resistance R

The shape parameter c is determined as follows:

$$c = \nu^{-1.083} \tag{2.2.3.3.5}$$

with: ν = coefficient of variation, $\nu = \frac{\sigma}{\mu}$ (2.2.3.3.6)

The scaling parameter b is determined as follows:

$$b = \frac{\mu}{\Gamma\left(1 + \frac{1}{c}\right)} \tag{2.2.3.3.7}$$

with: μ = mean value

Γ = Gamma function, $\Gamma(x) = \int_0^{\infty} t^{x-1} e^{-t} dt$ (2.2.3.3.8)

Note: Evaluation of gamma function in general covered by commercial spreadsheet programs.

Step 3: Adjustment of the approximated Weibull distribution

a) First an upper limit of the pull-out resistance has to be set with a subsequent adjustment of the approximated Weibull distribution P(R). Conservatively the upper limit is selected with the maximum pull-out resistance R_{max} determined in the test sample. The corresponding adjustment is made with the factor d as follows.

$$d = \left\{1 - \exp\left[-\left(\frac{R_{max}}{b}\right)^{c}\right]\right\}^{-1} \qquad (2.2.3.3.9)$$

with: d = adjustment factor for the Weibull distribution P(R)
R_{max} = Maximum pull-out resistance of the test sample

In general the following further adjustments of the approximated Weibull distribution function are necessary in order to ensure that all calculated quantiles $R_{i,calc}$ of the distribution function are equal or less than the corresponding pull-out resistance R_i.

b) Increase of the standard deviation σ^* greater than the standard deviation σ of the approximated Weibull distribution P(R),

c) Further reduction of the maximum pull-out resistance R_{max}^*.

with: σ^* = Adjusted standard deviation with $\sigma^* > \sigma$
R_{max}^*= Adjusted maximum resistance with $R_{max}^* < R_{max}$

A combination of step 3b) and 3c) is allowed for the adjustment. The adjustment factor d needs to be recalculated for the selected values of σ^* and R_{max}^*, respectively.

Annex A shows a worked example of all steps 1, 2, 3a, 3b and 3c resulting in the adjusted Weibull distribution $P(R)^*$ based on the results of the test sample.

With the inverse and adjusted Weibull distribution function, a Monte-Carlo simulation is done to calculate the resistance of the fastener (see Annex A/(3c)).

Reduction function in order to take the effect of eccentric load introduction into account (Assessment of test series A11)

Eccentric load introduction into the fixture leads to a respective load increase in the power-actuated fastener. In the Monte Carlo simulations this load increase is considered as an equivalent reduction of the pull-out resistance of the power-actuated fastener. This reduction itself depends on the load and is described as a polynomium.

For each calculation run of a Monte Carlo simulation, pull-out resistances R_{MC} are randomly allocated to all fixing points from the adjusted and inverted Weibull distribution function $P(R)^*$. After this random allocation all resistances R_{MC} have to be reduced with the respective reduction factor $\alpha_{eN,5\%}$.

$$R_{e,i} = \alpha_{eN,5\%,i} \cdot R_{MC,i} \quad \text{for } i = 1 \text{ to } n \qquad (2.2.3.3.10)$$

with: $R_{e,I}$ = reduced random pull-out resistance at the support i used for the individual calculation run of a Monte Carlo simulation
$R_{MC,i}$ = randomly allocated axial pull-out resistance at the support i
$\alpha_{eN,5\%,I}$ = reduction factor of pull-out resistance at the support i in order to take the effect of eccentric tension load introduction into account
n = number of fixing points

The evaluation of the reduction function $\alpha_{e,5\%}$ is done using the results of the service condition test A11. For the Monte-Carlo simulations it is required to know the reduction factor dependent on the axial force of the power-actuated fastener F_{PAF}. This dependency is described by means of a polynomium with a degree of 4 as follows:

This dependency is described by means of a polynomium with a degree of 4 as follows:

$$\alpha_{eN,5\%} = c_0 + c_1 \cdot F_{PAF} + c_2 \cdot (F_{PAF})^2 + c_3 \cdot (F_{PAF})^3 + c_4 \cdot (F_{PAF})^4 \qquad (2.2.3.3.11)$$

with: $\alpha_{eN,5\%}$ = 5%-quantile function of the reduction factor due to eccentric load
F_{PAF} = tensile force of the power-actuated fasteners caused by eccentric loading F_{FIX}

This 5%-quantile function $\alpha_{eN,5\%}$ is determined as follows:

Step 1: The experimental test results $F_{FIX,exp}$ of all individual tests are approximated with a polynomium with a degree of 4. The result is a graph for each the 5 samples showing the relationship between F_{FIX} and F_{PAF}.

$F_{FIX} = a_0 + a_1 \cdot F_{PAF} + a_2 \cdot (F_{PAF})^2 + a_3 \cdot (F_{PAF})^3 + a_4 \cdot (F_{PAF})^4$ (2.2.3.3.12)

Step 2: For increasing accuracy in the range of very small forces, the experimental values F_{FIX} are calibrated as follows (see also Annex B/Step 2):

$F_{FIX} = F_{FIX,exp} - a_0$ (2.2.3.3.13)

with: F_{FIX} = calibrated test data
$F_{FIX,exp}$ = measured test data
a_0 = constant from the approximated polynomium of step 1

Step 3: New approximation of the calibrated test data with a polynomium with a degree of 4 without constant a_0.

$F_{FIX} = b_1 \cdot F_{PAF} + b_2 \cdot (F_{PAF})^2 + b_3 \cdot (F_{PAF})^3 + b_4 \cdot (F_{PAF})^4$ (2.2.3.3.14)

Step 4: Calculation of the reduction factor α_e (F_{FIX}/F_{PAF}) and mathematical description of α_e as polynomium with a degree of 3 for all individual 5 samples

$\alpha_{eN} = b_1 + b_2 \cdot F_{PAF} + b_3 \cdot (F_{PAF})^2 + b_4 \cdot (F_{PAF})^3$ (2.2.3.3.15)

Step 5: Iterative calculation of the 5%-quantile reduction function $\alpha_{e,5\%}$.

a) First the reduction factor α_e is calculated for every individual test at defined forces F_{PAF} in incremental steps (approximately 100 increments up to the maximum relevant force F_{PAF})

b) For all selected forces $F_{PAF,i}$ (following the incremental steps) the 5%-quantile $\alpha_{e,5\%,i}$ of the reduction factor is calculated assuming normal distribution as follows.

For the Monte-Carlo simulations it is sufficient to use the statistically confirmed mean-value of the actions as deterministic input. This calculated 5%-quantile covers the mean value with a 99% confidence level based on a sample size of 5.

$\alpha_{eN,5\%,i} = \alpha_{eN,\mu,i} - 1.645 \cdot \alpha_{eN,\sigma,i}$ (2.2.3.3.16)

with: $\alpha_{eN,\mu,I}$ = mean value of the reduction factor for all individual tests for all selected forces $F_{PAF,i}$ (following the incremental steps)
$\alpha_{eN,\sigma}$ = standard deviation of the reduction factor for all individual tests for all selected forces $F_{PAF,i}$ (following the incremental steps)

c) The values of the 5%-quantile $\alpha_{eN,5\%,i}$ are then approximated with the polynomium $\alpha_{eN.5\%}$ with a degree of 4 as shown above.

An example is given in Annex B.

Distribution function of fixture (Assessment of Test series A9 and A10)

The evaluation of the distribution function $P(R)_{1-\alpha}$ is done using the results of the test series A9 and A10 (supplemental function at maximum temperature only required in case of plastic fixtures). The distribution function $P(R)_{1-\alpha}$ describes the estimated population and is used for the Monte-Carlo simulations for the calculation of the reliability index.

In case of steel failure, the failure loads shall be converted to nominal steel strength with equation:

$$F_{Ru} = F_{Ru}^{t} \cdot \frac{f_{u,\min}}{f_{u,test}} \cdot \frac{t_{\min}}{t_{test}} \quad (2.2.3.3.17)$$

with: F_{Ru} = failure load at nominal specification
F_{Ru}^t = failure load at test
$f_{u,test}$ = steel ultimate strength at test
$f_{u,min}$ = minimum specified steel strength of steel fixture
t_{test} = steel sheet thickness at test
t_{min} = minimum specified steel thickness

The tests results of this sample have to follow a normal distribution with a maximum coefficient of variation of 20 %. The evaluation has to consider a confidence level $1-\alpha = 0.9$ assuming unknown standard deviation. For the sample size of n = 10, the distribution function $p(R)_{1-\alpha}$ follows the Weibull distribution given in the following Table. The distribution function is determined with the mean value and the standard deviation of the test sample. If the coefficient of variation of the sample is less than 3 % a coefficient of variation of 3 % has to be applied for the calculation. If the coefficient of variation of the sample is less than 13,4% the Weibull distribution described with the 3 parameters a, b and c is used. If the coefficient of variation of the sample is equal or greater than 13,4% the Weibull distribution described with the 2 parameters b and c is used.

Table 2.2.3.3.1 Distribution function of fixture (for sample size n = 10 and confidence level 1-α = 0.9)

Weibull distribution with 3 parameters a, b and c	Weibull distribution with 2 parameters b and c
$P(R)_{1-\alpha} = 1 - \exp\left[-\left(\frac{R-a}{b}\right)^{c}\right]$ (2.2.3.3.18)	$P(R)_{1-\alpha} = 1 - \exp\left[-\left(\frac{R}{b}\right)^{c}\right]$ (2.2.3.3.19)
$v = \frac{\sigma}{\mu} < 0.134$	$v = \frac{\sigma}{\mu} \geq 0.134$
$a = \mu - 7.437 \cdot \sigma$ $c = 7.1614$ $b = 7.367 \cdot \sigma$	$c = 0.671 \cdot v^{-1.18}$ $b = 1.218 \cdot \mu \cdot \left(v^{0.0656} - 0.538 \cdot v^{1.0656}\right)$
$\mu := \overline{R}$ ... mean value of sample $\sigma := S$ … standard deviation of sample	

An example is given in Annex C.

Adjustment for long-term behaviour:

In case of fixtures made of plastic, the distribution function $P(R)_{1-\alpha}$ at room temperature has to be adjusted with a long-term reduction factor α_{pt} as follows.

$$P(R)_{(1-\alpha),pt} = \alpha_{pt} \cdot P(R)_{(1-\alpha),p} \tag{2.2.3.3.20}$$

with:

$P(R)_{(1-\alpha),pt}$ = Distribution function for plastic fixture at normal ambient temperature considering long-term behaviour

$P(R)_{(1-\alpha),p}$ = Distribution function for plastic fixture at normal ambient temperature according to test results of A9

α_{pt} = Reduction factor considering the effect of long-term plastic behaviour

The reduction factor α_{pt} is derived from comparison of the static stress-strain behaviour with the isochrone stress-strain behaviour at 1000 hours (see section 2.2.3.1). If material failure controls the resistance of the fixture (e.g., fracture or pull-over of the plastic fixture), the ratio of the ultimate strength of the plastic determines the reduction factor α_{pt}. If deformation of the plastic controls the resistance of the fixture without fracture of plastic components (e.g., when excessive deformation of plastic cantilever cable holders leads to a release of the cables from the fixture), the stress ratio in the initial linear stress-strain range determines the reduction factor α_{pt}.

Limit states and reliability index

The maximum service load is determined by probabilistic verification method applying Monte-Carlo-simulation (MC-simulation). The following limit states shall be observed.

- Limit state of global collapse (ULS). This limit state corresponds with the failure of all fixtures and has to be verified with a reliability index β ≥ 3.8 according to reliability class RC2 of EN 1990, B.3.2 [23].
- Limit state of local failure. This limit states corresponds with the local failure of max 4 adjacent fixtures. The number of acceptable adjacent failures depends on the individual situation. The limit state of local

failure has to be verified with a reliability index β ≥ 3.3 according to reliability class RC1 of EN 1990, B.3.2 [23].

- Serviceability limit state (SLS). This limit state corresponds with the local failure of max 2 adjacent fixtures. The number of acceptable adjacent failures depends on the individual situation. The serviceability limit state has to be verified with a reliability index β ≥ 1.5 according to EN 1990, B.3.2 [23].

Calculation method

The target of the assessment is to determine of the maximum service load $F_{s,max}$ for all limit states mentioned above by means of probabilistic design according to EN 1990, Annex C [23]. Monte-Carlo simulation shall be used for the determination of the failure probability for a given configuration of power-actuated fastener and fixture.

A configuration is built with:

- Distribution function of the power-actuated fastener tension or shear resistance
- Reduction function of the pull-out resistance in order to take the effect of eccentric load introduction into account.
- Distribution function of the fixture in case of fixtures made of plastic, either the distribution function at maximum service temperature (A10 or A13) or the distribution function for long-term behavior at room temperature is used for the calculations (A9 or A12 considering long-term reduction factor α_{pt})
- Number of fixing points n_1 = 100
- Length of the gap of failed fixtures. This length corresponds with the number of adjacent failures of fixtures (1, 2, 3, 4 etc. up to the number of failures of all fixtures of the chain) due to overload.

The static systems according to Figure 1.2.2 shall be applied for the calculation of the support forces. For the MC-simulation no statistical correlation between the distribution function of the power-actuated fastener and the distribution function of the fixture has to be assumed (r = 0).

The static calculation model has to consider the following features:

- All fixtures along the fastening chain shall be considered in the calculation.
- The model shall allow the simultaneous occurrence of gaps along the entire length of the cable due to local overload. Therefore, every fixture is potentially affected from a gap developing from both adjacent sides of the fixture.
- The length of the gaps varies from 1, 2, 3, 4 etc. Gaps with different gap length may develop in one individual MC-simulation along the chain of fixtures.
- In case of gaps due to local overload, the forces have to be iteratively redistributed considering the changes in the static system until the system reaches equilibrium or until the chain of fixtures totally collapses.
- For the calculation of the probability of failure for one MC-simulation, the number of occurrences of the gap under consideration is counted and compared with the total number of calculation runs performed in this MS-simulation. In case the gap under consideration occurs twice or more often in the simulation run, it is only counted once for the calculation of the probability of failure.
- The reliability index β is then allocated to the calculated probability of failure according to EN 1990 [23] as follows:
- $$p_f = \varphi(-\beta) \qquad (2.2.3.3.21)$$

  with: p_f = calculated probability of failure

  ϕ = distribution function of standardized normal-distribution

- For each individual parameter configuration at least 10 MC-simulations have to be repeated. The minimum number of calculation runs within one MC-simulation amounts to 1 million runs.
- Random simulator: Park-Miller random number generator shall be used.

5% fractile of reliability index β

For every individual parameter configuration 10 MC-simulations have to be repeated. The setting of the random simulator has to be selected such, that for each MC-simulation a new set of random numbers is generated. The 5% fractile of reliability index β shall be calculated according to statistical procedures for a confidence level of 90 % using normal distribution and unknown standard deviation of the population.

$$\beta_{5\%} = \beta_m - k_s \cdot s \qquad (2.2.3.3.22)$$

with: $\beta_{5\%}$ = 5 %-fractile of the calculated reliability index

β_m = mean value of calculated reliability index

k_s = 2,57 for n = 10 simulations, statistical factor

s = Standard deviation of the calculated reliability index per configuration

Functioning in low and higher strength concrete with crack width Δw = 0,35 mm
(Assessment of Test series A15 and A16)

The evaluation is done either with the results of the service condition test A15 or A16 depending if A15 or A16 controls the maximum allowed service load $F_{Ed,lim,S}$.

The following criterion shall be fulfilled:

$$\bar{R} \geq 2{,}4 \cdot F_{Ed,lim,S} \qquad (2.2.3.3.23)$$

with: $\bar{R}$ = mean value of test sample for crack width Δw = 0.35 mm

$F_{Ed,lim,S}$ = maximum service load acting on the Power-actuated fastener with $F_{Ed,lim,S} \leq 0{,}10$ kN according to Table 1.2.1

Maximum tension service load

The maximum tension service load $N_{S,max}$ is given in the assessment for the respective fixture used in combination with the respective power-actuated fastener. The service load N_S corresponds with the load acting on the fixture and is calculated as the cable weight per length multiplied with the span.

The service load N_S depends on:

- the stiffness of the cables (flexible cables or rigid cables and conduits)
- the acceptable gap for the serviceability limit state and the limit state of local failure.

The following Table shows an example of a load table to be shown in the European Technical Assessment for a fixture in combination with a power-actuated fastener.

Table 2.2.3.3.2 Example of load table of ETA: Maximum tension service

Maximum tension service load $N_{S,max}$ [kN] for fastening cables			
		Flexible cable	Rigid cables or conduits
Acceptable gap for serviceability limit state β ≥ 1,5	1		
	2		
Acceptable gap for local failure β ≥ 3,3	2		
	3		
	4		

The maximum tension service load $N_{S,max}$ given in Table 2.2.3.2.2 is limited by

- the maximum tension service load assessed for the limit state of global collapse (ULS with β ≥ 3,8) or
- the maximum tension service load $F_{Ed,lim\ S}$ equal or less than 0.10 kN acting on the power-actuated fastener according to Fastener type 3 (Table 1.2.1) taking an eccentric load introduction from the fixture to the power-actuated fastener into account.

Considering the intended use of cable fastenings and the small resistance for fasteners of fastener type 3 displacements are negligible.

Expression of results:

$N_{S,max}$ [kN], n_1 [-], span [mm], number of gaps for local failure, number of gaps for serviceability limit state

2.2.3.4 Assessment of test results of shear tests

General

Fundamentally the calculation of the reliability index β follows the same concept as described in section 2.2.3.3 for tension loading. However, in case of shear loading, the power-actuated fastener is in general simultaneously loaded in shear and tension. The fastener has to transfer the shear load acting on the fixture and has to resist the tension force resulting from the eccentric shear load introduction.

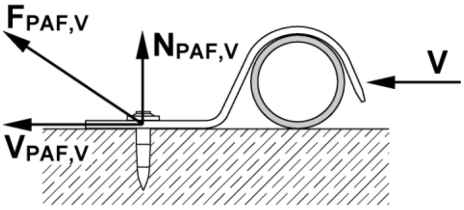


Figure 2.2.3.4.1 – Forces in case of eccentric shear loading of the fixture

with: V = shear load acting on fixture

$V_{PAF,V}$ = shear force acting on power-actuated fastener due to shear load on fixture, $V_{PAF,V} = V$

$N_{PAF,V}$ = tension force acting on power-actuated fastener due to shear load on fixture, $N_{PAF,V} = (1/\alpha_{eV})\cdot V$, with α_{eV} … reduction factor considering the effect of eccentric shear load introduction into the fixture according to section 2.2.3.2

$F_{PAF,V}$= Resulting force acting $F_{PAF,V} = (N_{PAF,V}^2 + V_{PAF,V}^2)^{0,5}$ on power-actuated fastener due to shear load on fixture

The following sections describe for shear loading on the fixture:

- the calculation of the distribution functions based on the test results for the power-actuated fastener and the fixture
- the defined limit states,
- the calculation method
- the procedure for the calculation of the reliability index and
- the concept of the service loads be published in the European Technical Assessment.

Distribution function of power-actuated fastener for shear loading (Assessment of Test series A8)

For the Monte-Carlo simulations either the distribution function for tension or shear resistance is used. Conservatively the one resulting to the smaller shear service force has to be applied.

The evaluation of the shear distribution function is done using the results of the test series A8. For the calculation of the adjusted shear distribution function $P(R)^*$ the same procedure as given in section 2.2.3.3 for tension loading applies. If the shear distribution function exceeds the tension distribution function established from tests A6 and A7, the adjusted tension distribution function $P(R)^*$ (calculated for tension resistance according to section 2.2.3.3) has to be used in the calculation of the maximum shear service force.

Reduction function in order to take the effect of eccentric load introduction into account (Assessment of Test series A14)

Eccentric load introduction of the shear load leads to a respective tension force $N_{PAF,V}$ in the power-actuated fastener. The evaluation of the reduction function $\alpha_{eV.5\%}$ for shear loading follows steps 1 to 5 as shown in section 2.2.3.3 for tension loading.

The resulting force $F_{PAF,V}$ is conservatively used for the design. With that concept no detailed determination of the shear tension interaction relationship is required. For consideration of the resulting force in the Monte-Carlo simulations the reduction function $\alpha_{eF.5\%}$ will be used. The calculation of $\alpha_{eF.5\%}$ follows the following procedure:

$$N_{PAF,V} = (1/\alpha_{eV,5\%})\cdot V_{PAF,V} \quad (2.2.3.4.1)$$

$F_{PAF,V} = (N_{PAF,V}^2 + V_{PAF,V}^2)^{0,5}$ (2.2.3.4.2)

$\alpha_{eF.5\%} = V_{PAF,V}/F_{PAF,V}$ (2.2.3.4.3)

For each calculation run of a Monte-Carlo simulation the power-actuated fastener resistances V_{MC} are randomly allocated to all fixing points from the adjusted and inverted Weibull distribution function $P(R)^*$ (the controlling tension or shear distribution of the power-actuated fastener is used). After this random allocation all resistances V_{MC} have to be reduced with the respective reduction factor $\alpha_{eF.5\%}$.

$V_{e,i} = \alpha_{eF,5\%,i} \cdot V_{MC,i}$ for i = 1 to n (2.2.3.4.4)

with: $V_{e,I}$ = reduced random power-actuated fastener resistance at the support i used for the individual calculation run of a Monte-Carlo simulation

$V_{MC,i}$ = randomly allocated power-actuated fastener resistance at the support i

$\alpha_{eF,5\%,I}$ = reduction factor for shear load verification in order to take the effect of eccentric shear load introduction as well as shear tension interaction into account

Distribution function of fixture (Assessment of Test series A12 and Test series A13)

The evaluation of the distribution function $P(R)_{1-\alpha}$ is done using the results of the test series A12 and A13 (supplemental function at maximum temperature only required in case of plastic fixtures). The distribution function $P(R)_{1-\alpha}$ describes the estimated population for the shear resistance of the fixture and is used for the Monte-Carlo simulations for the calculation of the reliability index.

The further calculation of the distribution function as well as the adjustment for long-term behaviour corresponds with the procedure for tension loading according to section 2.2.3.3.

Limit states and reliability index
See section 2.2.3.3

Calculation method

See section 2.2.3.3

5% fractile of reliability index and random simulator

See section 2.2.3.3

Maximum shear service load

The maximum shear service load $V_{S,max}$ is given in the assessment for the respective fixture used in combination with the respective power-actuated fastener. The service load V_S corresponds with the load acting on the fixture and is calculated as the cable weight per length multiplied with the span.

The service load V_s depends on:

- the stiffness of the cables (flexible cables or rigid cables and conduits)
- the acceptable gap for the serviceability limit state and the limit state of local failure.

The following Table shows an example of a load table to be shown in the European Technical Assessment for a fixture in combination with a power-actuated fastener.

Table 2.2.3.4.1 Example of load table of ETA: Maximum shear service loads

Maximum shear service load $V_{S,max}$ [kN] for fastening cables			
		Flexible cable	Rigid cables or conduits
Acceptable gap for serviceability limit state β ≥ 1,5	1		
	2		
Acceptable gap for local failure β ≥ 3,3	2		
	3		
	4		

The maximum shear service load $V_{S,max}$ given in Table 2.2.3.4.1 is limited by

- the maximum tension service load assessed for the limit state of global collapse (ULS with β ≥ 3,8) or
- the maximum shear service load $F_{Ed,lim,S}$ equal or less than 0,10 kN acting on the power-actuated fastener according to Fastener type 3 (Table 1.2.1) taking an eccentric load introduction from the fixture to the power-actuated fastener into account.

Considering the intended use of cable fastenings and the small resistance for fasteners of fastener type 3 displacements are negligible.

Expression of results:

$V_{S,max}$ [kN], n_1 [-], span [mm], number of gaps for local failure, number of gaps for serviceability limit state

2.2.3.5 Anchorage depth

The minimum anchorage depth shall be assessed as the 5% fractile of the measured anchorage depth of each series by using a confidence level of 75 % and an unknown standard deviation. Series with the same concrete strength class can be evaluated together. The minimum anchorage depth is given in the ETA.

Expression of results: h_{ef} [mm]

2.2.4 Characteristic resistance of Fastener type 4

Purpose of the assessment

Determination of characteristic resistance under shear loading of Fastener type 4 and corresponding anchorage depth, edge distances, spacing and minimum member thickness.

Assessment method

2.2.4.1 Functioning tests

The tests shall be performed as group tests or as single tests in concrete members without any influence by edge and spacing effects under shear loading. A group consists of 5 fasteners per fixture. The load is applied transverse to the fixture.

The types of tests, test conditions, the number of required tests and the criteria applied to the results shall be taken in accordance with the following Table.

Table 2.2.4.1.1 Functioning tests

No	Purpose of test	Base material	Crack width Δw (mm)	Thickness of fixture	Load direction	Number of tests	Criteria α (2)	Reference test
F8	Functioning in low strength concrete	C20/25	0,35	min. t_{fix}	V	5/20 (3)	≥ 0,75	A17
F9	Functioning in high strength concrete	C50/60 (1)	0,35	min. t_{fix}	V	5/20 (3)	≥ 0,75	A18
F10	Contact with hard max. aggregate (5)	C50/60 (1)	0	min t_{fix}	V	5/20 (3)	≥ 0,95 (4a) ≥ 0,8 (4b) ≥ 0,7 (4c)	A19

(1) if there is an application for anchorage in concrete strength class less than C50/60 only; tests are required in concrete with a compressive strength $f_{ck,test} \geq f_{ck,used}$ + 20 MPa (in case of C20/25) and $f_{ck,test} \geq f_{ck,used}$ + 10 MPa (in case of C40/50), $f_{ck,test} \geq f_{ck,used}$ + 5 MPa (in case of C50/60), interim values can be interpolated linear.

(2) Calculation of α according to 2.2.4.3

(3) 5 group tests or 20 single tests are required for both C20/25 and the maximum concrete grade.

(4) (4a) is valid for γ_{inst} = 1,0; (4b) is valid for γ_{inst} = 1,2; (4c) is valid for γ_{inst} = 1,4

(5) Only required for fasteners with an embedment depth h_{ef} > 20mm

Following functioning tests according to Table 2.2.1.2.1 are not required for Fastener type 4 for the following technical reasons:

- F1: For fasteners with an embedment depth of $h_{ef} \leq$ 20 mm, same as for Fastener type 3 listed under 2.2.3.1. Only for fasteners with an embedment depth h_{ef} > 20mm functioning tests F1 is replaced by test F10.
- F2: The shear resistance of fasteners is not sensitive in case of fastener in contact with reinforcement.
- F3: For fastener type 4 functioning test 3 is replaced by test F8.
- F4 and F5: Same as for Fastener type 3 listed under 2.2.3.1.
- F6: The intended use of Fastener type 4 is in dry indoor condition only and the fastening is inside the wall. Furthermore, factory production control according to Table 3.2.1 has to be in place (sensitivity of brittle failure is not relevant).

Test procedure:

For test procedure F1 tests see 2.2.1.1.

The tests are carried out at the bottom side (formwork side) of the concrete plate.

For group tests, metal tracks with a thickness of min t_{fix} and a tensile strength of $R_m \geq 260$ N/mm^2 and for single tests, metal sheets with a thickness of min t_{fix} and a tensile strength of $R_m \geq 260$ N/mm^2 representative for the intended application, shall be used.

Before installing a group test, the friction force due to the weight of the test frame needs to be measured and detracted from the test result.

2.2.4.2 Basic shear tests

The tests shall be performed as group tests or as single tests in concrete members without any influence by edge and spacing effects under shear loading. A group consists of 5 fasteners per fixture or metal track, whatever is intended for the application. The load is applied transvers to the fixture.

The types of tests, test conditions, the number of required tests and the criteria applied to the results shall be taken in accordance with the following Table.

Table 2.2.4.2.1 Basic shear tests

No	Purpose of test	Base material	Crack width Δw (mm)	Thickness of fixture	Load direction	Number of tests
A17	Characteristic resistance to shear loading	C20/25	0,2	min. t_{fix}	V	5/20 (2)
A18	Characteristic resistance to shear loading	C50/60 (1)	0,2	min. t_{fix}	V	5/20 (2)
A19 (3)	Reference-Test	C50/60 (1)	0	min. t_{fix}	V	5/20
A20	Bearing capacity of the metal track	C50/60 (1)	0	min. t_{fix}	V	5/20

(1) If there is an application for anchorage in concrete strength class less than C50/60 only; tests are required in concrete with a compressive strength $f_{ck,test} \geq f_{ck,used}$ + 20 MPa (in case of C20/25) and $f_{ck,test} \geq f_{ck,used}$ + 10 MPa (in case of C40/50), $f_{ck,test} \geq f_{ck,used}$ + 5 MPa (in case of C50/60), interim values can be interpolated linear.

(2) 5 group tests or 20 single tests are required for both C20/25 and the maximum concrete grade.

(3) Only required for fasteners with an embedment depth h_{ef} > 20mm

The tests A17 to A19 are carried out at the bottom side (formwork side) and test A20 at the top side of the concrete plate.

For group tests, metal tracks with a thickness of min t_{fix} and a tensile strength of $R_m \geq 260$ N/mm^2 and for single tests, metal sheets with a thickness of min t_{fix} and a tensile strength of $R_m \geq 260$ N/mm^2 representative for the intended application, shall be used.

Before installing a group test, the friction force due to the weight of the test frame needs to be measured and detracted from the test result.

The anchorage depth shall be measured in all tests of each test series.

Test procedure:

The shear tests are carried out at concrete members according to EAD 330232-01-0601 [7], B.3.1.2 and B.3.6.1.

The fastener embedment has to be determined for every fastener. Therefore, the total length and the respective fastener standoff h_{NHS} has to be determined and recorded for every fastener sample.

Fastener installation for group tests with metal tracks are executed one fixture after the other with 5 fasteners each as follows:

- Develop 5 continuous unidirectional hair-cracks e.g., by means of steel wedges.
- After development of the hair-crack remove of the steel wedges.
- Position of the fixture transverse to the hair-cracks.
- Drive power-actuated fasteners: At driving the power-actuated fastening tool has to be positioned such, that the power-actuated fastener is driven into the hair-crack in the middle of the fixture. The spacing between the fasteners has to be reported.

After fastener installation, the test set up shall be continued as follows:

Displacement gauges to measure the crack width are attached on both sides of every fastener, with the fastener located approximately in the middle between the displacement gauges.

Zero gauges for crack width measurement.

Open of the crack e.g., by means of steel wedges till the target crack-width Δw is reached. The crack width is determined per fastener and calculates as the average crack width of the readings from the displacement gauges located left and right of the power-actuated fastener.

The cross beam of the test frame has to be fixed by screws and free of clearance to the metal track. Free movement of the fasteners has to be ensured, see Figure 2.2.4.2.1, Detail A-A.

Performance of test till maximum load is reached.

The orientation of the shear force needs to be parallel with the cracks.

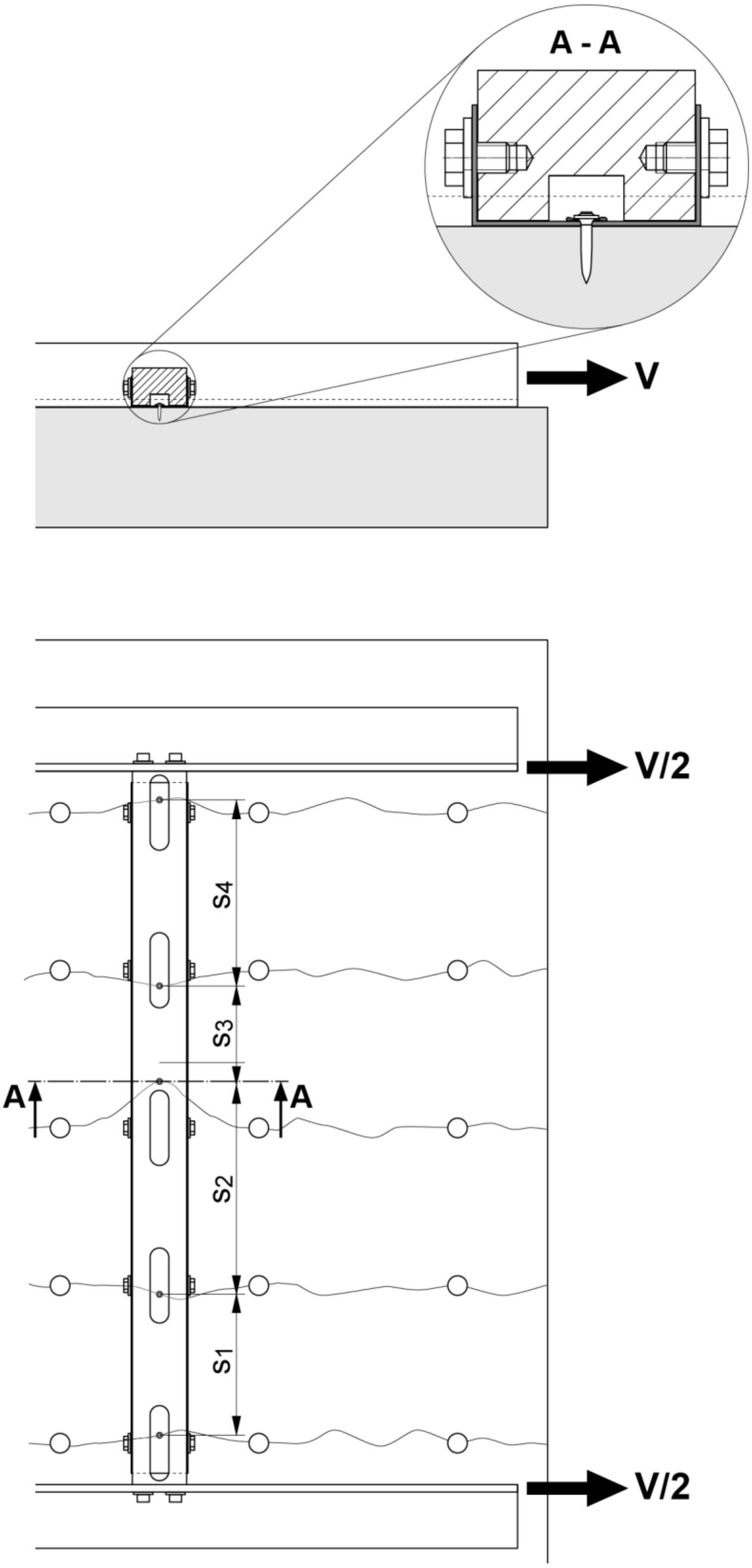


Figure 2.2.4.2.1 - Group test setup of metal track (schematic)

2.2.4.3 Assessment of test results

The 5%-factile of the ultimate loads per fastener shall be calculated according to statistical procedures for a confident level of 90% using logarithmical normal distribution of the single test results and unknown standard deviation of the population.

From the load measured in a group test the ultimate test load per fastener has to be calculated.

$$V_{um} = V_{u,Group,m} / 5 \qquad (2.2.4.3.1)$$

$$V^{t}_{Rk} = V_{5\%} = V_{um\ ln(x)} - k_s \cdot s_{ln(x)} \qquad (2.2.4.3.2)$$

with:

$V_{u,Group,m}$ = mean ultimate load in a group test series

$V_{\sout{ln}5\%}$ = 5%-logarithmic fractile of the ultimate load per fastener calculated by the logarithmic test values

$V_{um\ ln(x)}$ = mean value of the ultimate load per fastener in a group test series calculated by the logarithmic test values

k_s = statistical factor

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

n = 20 tests: k_s = 2,21

$s_{ln(x)}$ = standard deviation calculated by the logarithmic test values

Coefficient of variation

In each test series for methods according to Table 2.2.4.1.1 and 2.2.4.2.1 the coefficient of variation of the ultimate load shall be calculated and shall be smaller than $v_{u,S}$ = 20%. If the requirements for the scatter are not fulfilled by the shear tests, a reduction factor α_v for each test series shall be calculated according to:

$$\alpha_v = 1 / (1 + 0{,}03 \cdot (v_u[\%] - 20)) \qquad (2.2.4.3.3)$$

with:

v_u = coefficient of variation of ultimate load of tests according to Table 2.2.4.1.1 and 2.2.4.2.1

The reduction factor α_v amounts to 1,0 also for $v_u \geq 20\%$ provided the number of the tests amounts to minimum 50 per test.

Reduction factor α

For test series F8, F9 and F10, the factor α shall be calculated according to following equation.

$$\alpha_{min} = \min((V_{um,t} / V_{um,r}) ; (V_{5\%,t} / V_{5\%,r})) \qquad (2.2.4.3.4)$$

with:

$V_{um,t}$ = mean failure load per fastener in a test series

$V_{um,r}$ = mean failure (ultimate) load per fastener in a reference test series (see table 2.2.4.2.1)

$V_{5\%,t}$ = 5% fractile of failure (ultimate) load per fastener of a test series

$V_{5\%,r}$ = 5% fractile of failure (ultimate) load per fastener in a reference test series (see table 2.2.4.2.1)

The factor α shall be larger than req.α given in table 2.2.4.1.1. If the requirements on the ultimate load in the functioning tests are not fulfilled in one or more test series, then the reduction factor α_u shall be calculated according to:

$$\alpha_u = \alpha / \text{req.}\alpha \qquad (2.2.4.3.5)$$

with:

α_u = value according to Equation (2.2.4.3.3) of series F8, F9 and F10

req.α = required according to Table 2.2.4.1.1

For the bearing capacity of the metal track (test A20), the mean failure load shall be converted to the nominal steel strength by Equation:

$$V_{um}(f_{uk}) = V^{t}_{um} \cdot f_{uk} / f_{u,test} \qquad (2.2.4.3.6)$$

with: $V_{um}(f_{uk})$ = mean failure load at nominal steel ultimate strength f_{uk}

V^{t}_{um} = mean failure load of test series

$f_{u,test}$ = ultimate strength of steel used in test series

$f_{uk} / f_{u,test} \leq 1$

2.2.4.4 Evaluation of the characteristic shear resistance of a single fastener

The characteristic shear resistance of a single fastener shall be calculated as follows:

$$V_{Rk} = \min(V_{Rk,0,17} ; V_{Rk,0,18} ; V_{Rk,0,20}) \cdot \min \alpha_v \qquad (2.2.4.4.1)$$

with: $V_{Rk,0,17}$ = $V^{t}_{Rk,17} \cdot \min(\alpha_{u,F8} ; \alpha_{u,F10})$

$V_{Rk,0,18}$ = $V^{t}_{Rk,18} \cdot \min(\alpha_{u,F9} ; \alpha_{u,F10})$

$V_{Rk,0,20}$ = $V^{t}_{Rk,20}(f_{uk})$

$\alpha_{u,F8}$ = reduction factor from the ultimate loads for the functioning test F8

$\alpha_{u,F9}$ = reduction factor from the ultimate loads for the functioning test F9

$\alpha_{u,F10}$ = reduction factor from the ultimate loads for the functioning test F10 (only for an embedment depth > 20 mm).

$\min \alpha_v$ = minimum α_v to consider a coefficient of variation of the ultimate loads in the functioning and basic tests larger than 20% according to 2.2.4.3; (≤ 1.0):

2.2.4.5 Spacing and edge distances

Same rules as in chapter 2.2.1.7 applies.

Expression of results:

V_{Rk} [kN], c_{min} [mm], s_{min} [mm], h_{min} [mm], h_{ef} [mm], min t_{fix} [mm]

2.2.5 Reaction to fire

Purpose of the assessment: Determination of fire class

Assessment method for steel parts

The power-actuated fastener in concrete for redundant non-structural applications is considered to satisfy the requirements for performance class A1 of the characteristic reaction to fire in accordance with the Commission Decision 96/603/EC, as amended 2000/605/EC and 2003/424/EC, without the need for testing on the basis of it fulfilling the conditions set out in that Decision and its intended use being covered by that Decision.

Therefore, the performance of the product is Class A1.

Expression of results: Class A1

Assessment method for plastic parts

The fixtures made of plastic which are assessed together with the power-actuated fastener in concrete for redundant non-structural applications shall be tested, using the test method(s) relevant for the corresponding reaction to fire class according to EN 13501-1 [24]. The fixture shall be classified according to Commission Delegated Regulation (EU) No 2016/364 [27] in connection with EN 13501-1 [24].

Expression of results: fire class according to EN 13501-1 [24]

2.2.6 Resistance to fire

Purpose of the assessment: Determination of fire resistance

Assessment method for steel parts

The functioning of a power-actuated fastener for use in a system that is required to provide a specific fire resistance class, shall be tested and assessed according to the EAD 330232-01-0601 [7], 2.2.17, 2.2.18 and 2.2.19.

Assessment method for plastic parts: Not specified in this version of EAD. When plastic parts are involved, resistance to fire cannot be assessed.

2.2.7 Durability

The durability of the plastic fixtures shall be assessed against high alkalinity (pH = 13.2) according to EAD 330196-01-0604 [20], 2.2.2.12.

The durability has to be tested at maximum service temperature.

3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

3.1 System of assessment and verification of constancy of performance

For the products covered by this EAD the applicable European legal act is Commission Decision 97/161/EC.

The system is 2+.

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of power-actuated fastener in concrete for redundant non-structural applications in the process of verification of constancy of performance are laid down in Table 3.2.1.

Table 3.2.1 Control plan for the manufacturer of the fastener; 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**]					
Metal parts					
1	Dimensions (outer diameter, inner diameter, thread length, etc.)	Measuring or optical	Laid down in control plan	3	Every manufac-turing batch or 100000 fasteners
2	Tensile Load (N_p) or tensile strength (f_{uk})	According to EN ISO 898-1 [14] EN ISO 3506-1 [2]		3	
3	Yield strength (f_{yk} or $N_{p0.2}$)	According to EN ISO 898-1 [14] EN ISO 3506-1 [2]		3	
4	Core hardness and Surface hardness (at specified functioning relevant points of the product; where relevant)	Tests according to EN ISO 6507-1,2,3,4 [8] or EN ISO 6508-1 [9]		3	
5	Zinc plating (where relevant)	x-ray measurement		3	
6	Fracture elongation A_5	According to EN ISO 898-1[14]		3	
7	Hydrogen embrittlement (where relevant)	According to the control plan		3	
8	Bending ductility for fasteners	According to the control plan		3	
Plastic parts					
9	Dimensions (height, width, wall thickness, etc.) (A)	Measuring or optical	As defined in the Control plan	3	Every manufac-turing batch or 100000 fasteners
10	Melt Volume-flow rate MVR	EN ISO 1133-1 [21]		1	Every manufac-
11	Charpy impact toughness	EN ISO 179-1 [22]		1	

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
12	Flame retardant quantity (A) (when relevant)	Quantity measurement		-	turing batch
13	Density (A)	EN ISO 1183-1 [25]		1	Once per day
14	Reaction to fire				
	Class A1	EN ISO 1182 [26]	As defined in the Control plan	According to test method and the Control Plan (i)	Once per two years or as defined in (ii)
	Class A1 or A2	EN ISO 1716 [27]	As defined in the Control plan	According to test method and the Control Plan (i)	Once per two years or as defined in (ii)
	Class A2, B, C or D	EN 13823 [28]	As defined in the Control plan	According to test method and the Control Plan (i)	Once per year or as defined in note (ii)
	Class B, C, D, E or F	EN ISO 11925-2 [29]	As defined in the Control plan	According to test method and the Control Plan (i)	Once per week or as defined in note (ii)

(A) Indirect characteristic related to reaction to fire.

(i) The necessary number of specimens shall be more detailed in the control plan depending on the test method and the class to be verified within the FPC. The tests shall be performed on randomly taken specimens from the consecutive production process.

(ii) The standardized tests shall be carried out whenever the performance is not verified by means of indirect tests (see tests identified with (A)) and, at least, once each five years when the indirect tests are used to verify the reaction to fire performance of the product. For this minimum frequency, the correlation between indirect test results and the direct test results shall be stated in the Control Plan. Otherwise, the minimum frequency of direct tests within the FPC defined in the table above shall apply.

3.3 Tasks of the notified body

The cornerstones of the actions to be undertaken by the notified body of the power-actuated fastener in concrete for redundant non-structural applications in the procedure of assessment and verification of constancy of performance are laid down in Table 3.3.1.

Table 3.3.1 Control plan for the notified body; cornerstones

Nr	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 *(for systems 1+, 1 and 2+ only)*					
1	Notified Body will ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the fastener.	Verification of the complete FPC as described in the control plan agreed between the TAB and the manufacturer	Accor-ding to Control plan	According to Control plan	When starting the production or a new line
Continuous surveillance, assessment and evaluation of factory production control *(for systems 1+, 1 and 2+ only)*					
2	The Notified Body will ascertain that the system of factory production control and the specified manufacturing process are maintained taking account of the control plan.	Verification of the controls carried out by the manufacturer as described in the control plan agreed between the TAB and the manufacturer with reference to the raw materials, to the process and to the product as indicated in Table 3.2.1	Accor-ding to Control plan	According to Control plan	1/year

4 Reference documents

[1] EOTA EAD 330083-02-0601:09/2019 Power-actuated fastener for multiple use in concrete for non-structural applications

[2] EN ISO 3506-1:2020: Mechanical properties of corrosion-resistant stainless-steel fasteners – Part 1: Bolts, screws and studs with specified grades and property classes

[3] EN 1993-1-4:2006 + A1:2015 + A2:2020; Eurocode 3: Design of steel structures, Part 1-4: General rules – Supplementary rules for stainless steels

[4] EN 60745-2-16:2010: Hand-held motor-operated tools – Safety Part 2-16: Particular requirements for trackers

[5] CEN/TR 17079:2018: Design of fastenings for use in concrete – Redundant non-structural systems

[6] EN 10346:2015: Continuously hot-dip coated steel flat products for cold forming - Technical delivery conditions

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

[8] EN ISO 6507-1,2,3,4:2018: Metallic materials – Vickers hardness test

[9] EN ISO 6508-1:2016: Metallic materials – Rockwell hardness test - Part 1: Test method (ISO 6508-1:2016)

[10] EN 15895:2011 Cartridge-operated hand-held tools – Safety requirements – Part 1: Fixing and hard marking tools

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

[12] EN 206-1:2000: Concrete - Part 1: Specification, performance, production and conformity

[13] EN 1504-3:2005 Products and systems for the protection and repair of concrete structures – Definitions, requirements, quality control and evaluation of conformity - Part 3: Structural and non-structural repair

[14] EN ISO 898-1:2013: Mechanical properties of fasteners made of carbon steel and alloy steel – Part 1: Bolts, screws and studs with specified properly classes – coarse thread & fine pitch thread

[15] EN ISO 527-1:2012 Plastics – Determination of tensile properties – Part 1: General principles

[16] EN ISO 899-1:2017: Plastics – Determination of creep behaviour – Part 1: Tensile creep

[17] EN ISO 1110:1997: Plastics – Polyamides – Accelerated conditioning of test specimens (ISO 1110:1995)

[18] EN ISO 11148-13:2018: Hand-held non-electric power tools - Safety requirements - Part 13: Fastener driving tools (ISO 11148-13:2017)

[19] EOTA Technical Report 064:2018 Design of plastic anchors in concrete and masonry

[20] EOTA EAD 330196-01-0604:06-2016: Plastic anchors for fixing of External Thermal Insulation Composite Systems with rendering

[21] EN ISO 1133-1:2011: Plastics - Determination of the melt mass-flow rate (MFR) and melt volume-flow rate (MVR) of thermoplastics - Part 1: Standard method (ISO 1133-1:2011)

[22] EN ISO 179-1:2010: Plastics - Determination of Charpy impact properties - Part 1: Non-instrumented impact test (ISO 179-1:2010)

[23] EN 1990:2002+A1:2005/AC:2010: Basis of structural design

[24] EN 13501-1:2018: Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests

[25] EN ISO 1183-1:2019-09: Plastics - Methods for determining the density of non-cellular plastics - Part 1: Immersion method, liquid pycnometer method and titration method (ISO 1183-1:2019, Corrected version 2019-05)

[26] EN ISO 1182:2020: Reaction to fire tests for products - Non-combustibility test (ISO 1182:2020)

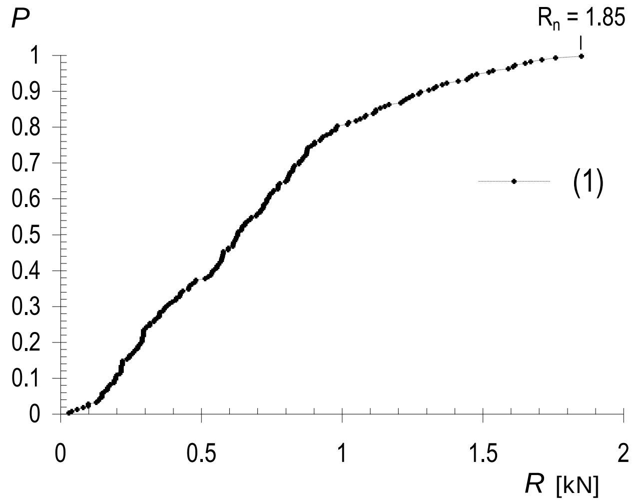
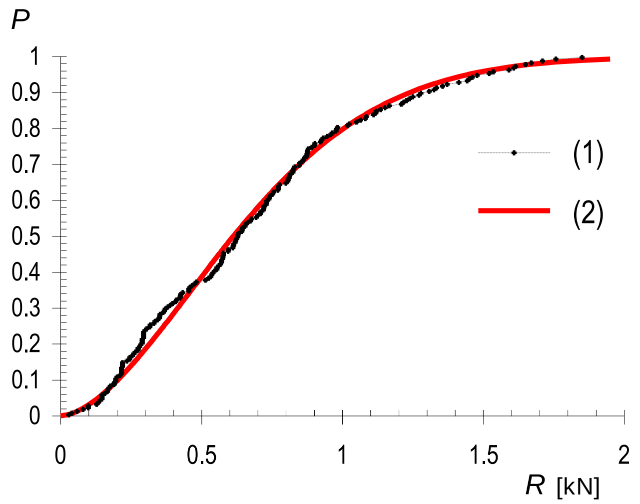
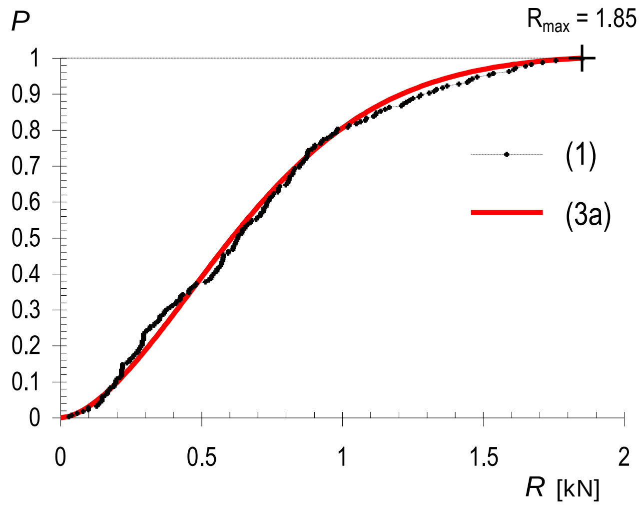
[27] EN ISO 1716:2018: Reaction to fire tests for products - Determination of the gross heat of combustion (calorific value) (ISO 1716:2018)

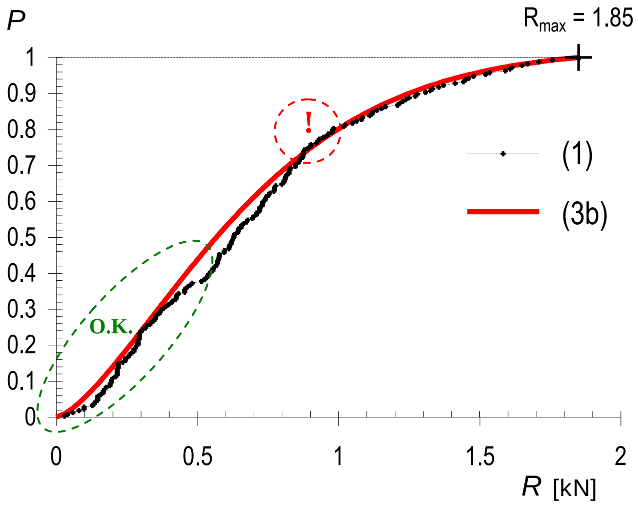
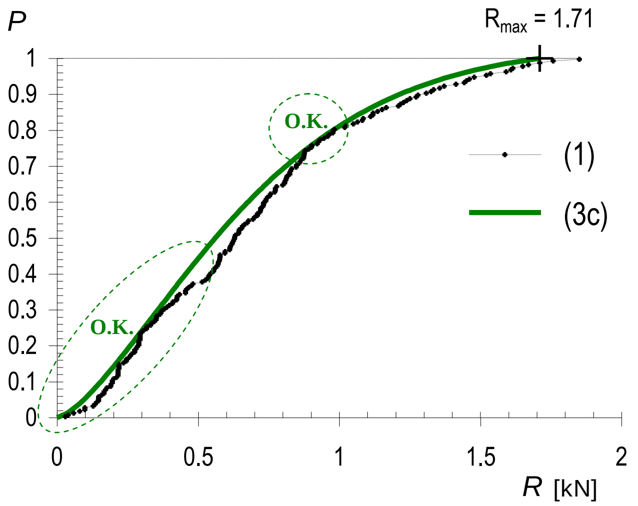
[28] EN 13823:2020: Reaction to fire tests for building products - Building products excluding floorings exposed to the thermal attack by a single burning item

[29] EN ISO 11925-2:2020: Reaction to fire tests - Ignitability of products subjected to direct impingement of flame - Part 2: Single-flame source test (ISO 11925-2:2020)

Annex A: Fastener type 3 - Distribution function of the power-actuated fastener

Example for the assessment of test series A6 and A7: Distribution function of power-actuated fastener for axial loading, Steps 1, 2 and 3. The result describes distribution of the estimated population.

(1)	**Evaluation of the test sample with sample size n** $n = 200$ $R_n = 1.85 kN$ - (R_n = maximum value R_{max}) $\bar{R} = \frac{1}{n}\sum_{i=1}^{n} R_i = 0.678\ kN$ $S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(R_i-\bar{R})^2} = 0.414\ kN$ $\nu = \frac{0.414}{0.678} = 0.61$	
(2)	**Approximation of the discrete sample distribution by means of Weibull distribution P(R)** $\mu := \bar{R}, \quad \sigma := S$ $P(R) = 1-\exp\left[-\left(\frac{R}{b}\right)^{c}\right]$ $c = \nu^{-1.083} = 0.61^{-1.083} = 1.708$ $b = \frac{\mu}{\Gamma\left(1+\frac{1}{c}\right)} = \frac{0.678}{0.892} = 0.760$	
(3a)	**Adjustment of the approximated Weibull distribution** ***Upper limit of pull-out resistance R_{max}*** $R_{max} = R_n = 1.85\ kN$ $d = \left\{1-\exp\left[-\left(\frac{1.85}{0.76}\right)^{1.708}\right]\right\}^{-1} = 1.01$ $P(R)^{*} = 1.01\cdot\left\{1-\exp\left[-\left(\frac{R}{0.76}\right)^{1.708}\right]\right\}$	

(3b)	**Further adjustment of the approximated Weibull distribution** ***b) measure 1: Increase of standard deviation*** from $\sigma = 0.414\,kN$ to $\sigma^* = 0.480\,kN$ $c = \nu^{-1.083} = 0.708^{-1.083} = 1.453$ $b = \frac{\mu}{\Gamma\left(1+\frac{1}{c}\right)} = \frac{0.678}{0.906} = 0.748$ $d = \left\{1-\exp\left[-\left(\frac{1.85}{0.748}\right)^{1.453}\right]\right\}^{-1} = 1.025$ $P(R)^* = 1.025 \cdot \left\{1-\exp\left[-\left(\frac{R}{0.748}\right)^{1.453}\right]\right\}$	
(3c)	**Further adjustment of the approximated Weibull distribution** ***c) measure 2 (when required): Reduction of R_{max}*** from $R_{\max} = 1.85kN$ to $R^*_{\max} = 1.71kN$ $c = \nu^{-1.083} = 0.708^{-1.083} = 1.453$ $b = \frac{\mu}{\Gamma\left(1+\frac{1}{c}\right)} = \frac{0.678}{0.906} = 0.748$ $d = \left\{1-\exp\left[-\left(\frac{1.71}{0.748}\right)^{1.453}\right]\right\}^{-1} = 1.037$ $P(R)^* = 1.037 \cdot \left\{1-\exp\left[-\left(\frac{R}{0.748}\right)^{1.453}\right]\right\}$	

Annex B: Fastener type 3 - Reduction function for eccentric loading

Example for assessment of test series A11:
Reduction function in order to take the effect of eccentric load introduction into account, Steps 1 to 5

Step 1:

First, the test results – couples of measured power-actuated fastener force $F_{PAF,exp}$ and force F_{FIX} acting on the fixture – are plotted for all 5 samples.

The experimental test results of all individual tests are then approximated with a polynomium with a degree of 4.

$$y = a_4 x^4 + a_3 x^3 + a_2 x^2 + a_1 x + a_0, \qquad \text{with} \quad x := F_{PAF}, \quad y := F_{FIX}$$

The result is a graph for each the 5 samples (# 1 to #5) showing the relationship between F_{FIX} and F_{FIX}.

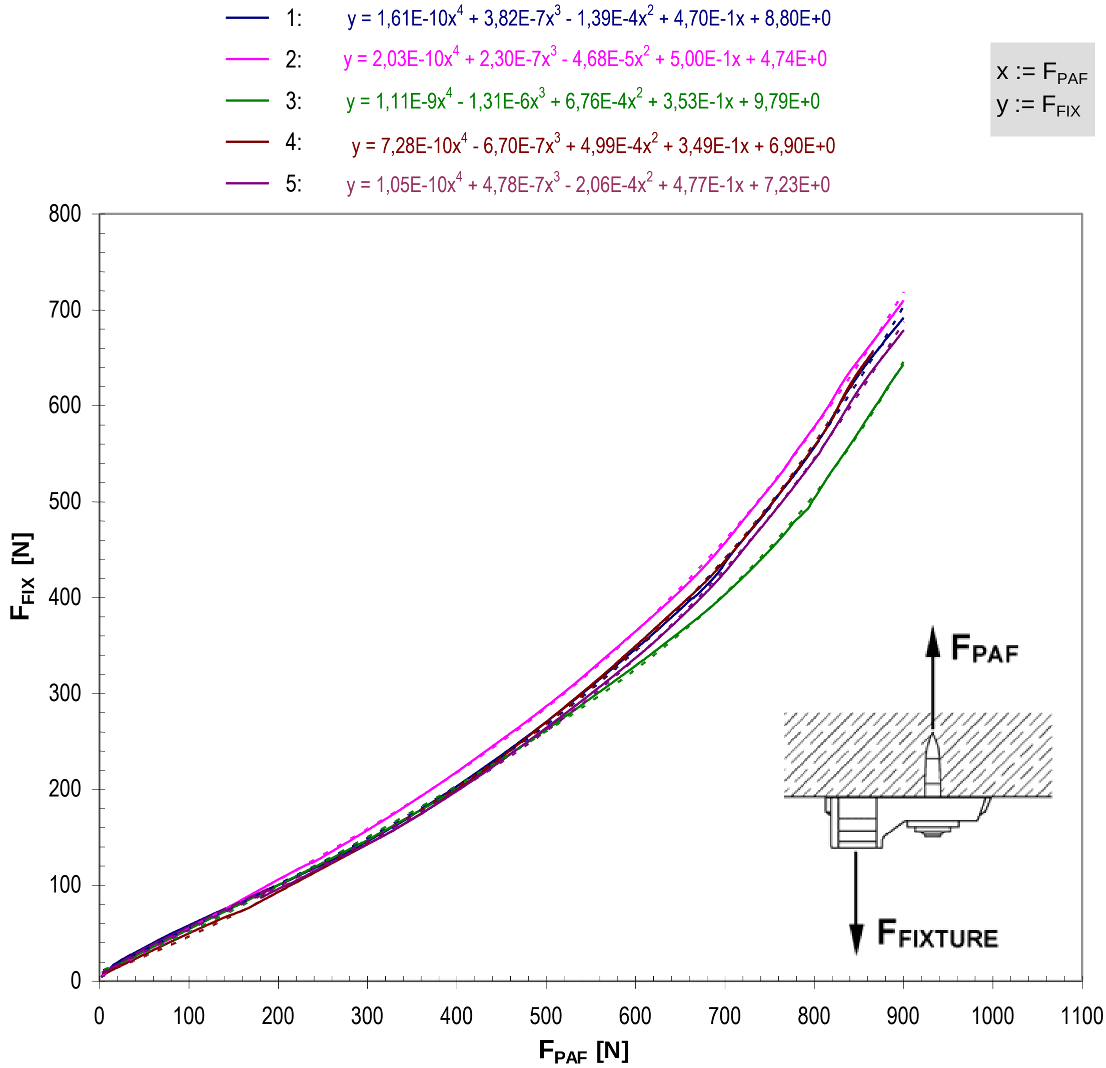


Figure B.1: Example of plot of relationship between F_{FIX} and F_{PAF} for test samples 1 to 5. The graphs show the measured test results (dashed line) and the approximation of the results with a polynomium of the degree of 4.

Step 2:

For increasing accuracy in the range of very small forces, the experimental values $F_{FIX,exp}$ are calibrated to the origin as follows:

$$F_{FIX} = F_{FIX,\exp} - a_0$$

Step 3:

New approximation of the calibrated test data with a polynomium with a degree of 4 without constant a_0.

$$y = b_4 x^4 + b_3 x^3 + b_2 x^2 + b_1 x, \qquad with \quad x := F_{PAF}, \quad y := F_{FIX}$$

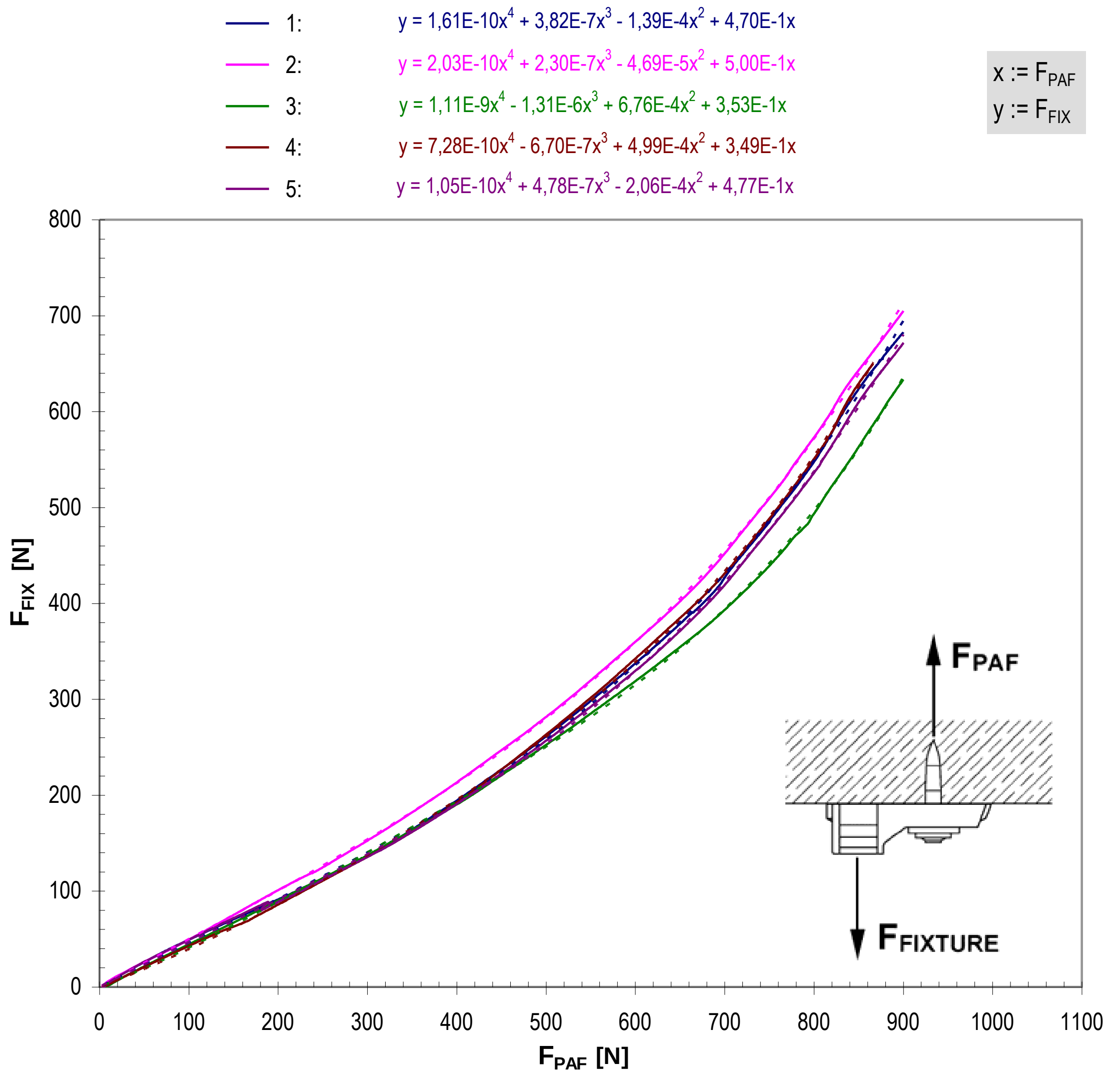


Figure B.2: Example of plot of relationship between F_{FIX} and F_{PAF} for test samples 1 to 5. The graphs show the calibrated measured test results (dashed line) and the approximation of the results with a polynomium of the degree of 4 without constant.

Step 4:

Calculation of the reduction factor $\alpha_e = F_{FIX}/F_{PAF}$ and mathematical description of α_e as polynomium with a degree of 3 for all individual 5 samples

$$y = b_4 x^3 + b_3 x^2 + b_2 x + b_1, \qquad with \quad x := F_{PAF}, \quad y := \alpha_e$$

1: $y = 1,61E-10x^3 + 3,82E-7x^2 - 1,39E-4x + 4,70E-1$

2: $y = 2,03E-10x^3 + 2,30E-7x^2 - 4,69E-5x + 5,00E-1$

3: $y = 1,11E-9x^3 - 1,31E-6x^2 + 6,76E-4x + 3,53E-1$

4: $y = 7,28E-10x^3 - 6,70E-7x^2 + 4,99E-4x + 3,49E-1$

5: $y = 1,05E-10x^3 + 4,78E-7x^2 - 2,06E-4x + 4,77E-1$

6: $y = -5,71E-13x^4 + 2,01E-9x^3 - 1,73E-6x^2 + 7,76E-4x + 3,11E-1$ $x := F_{PAF}$ $y := \alpha_{e, 5\%}$

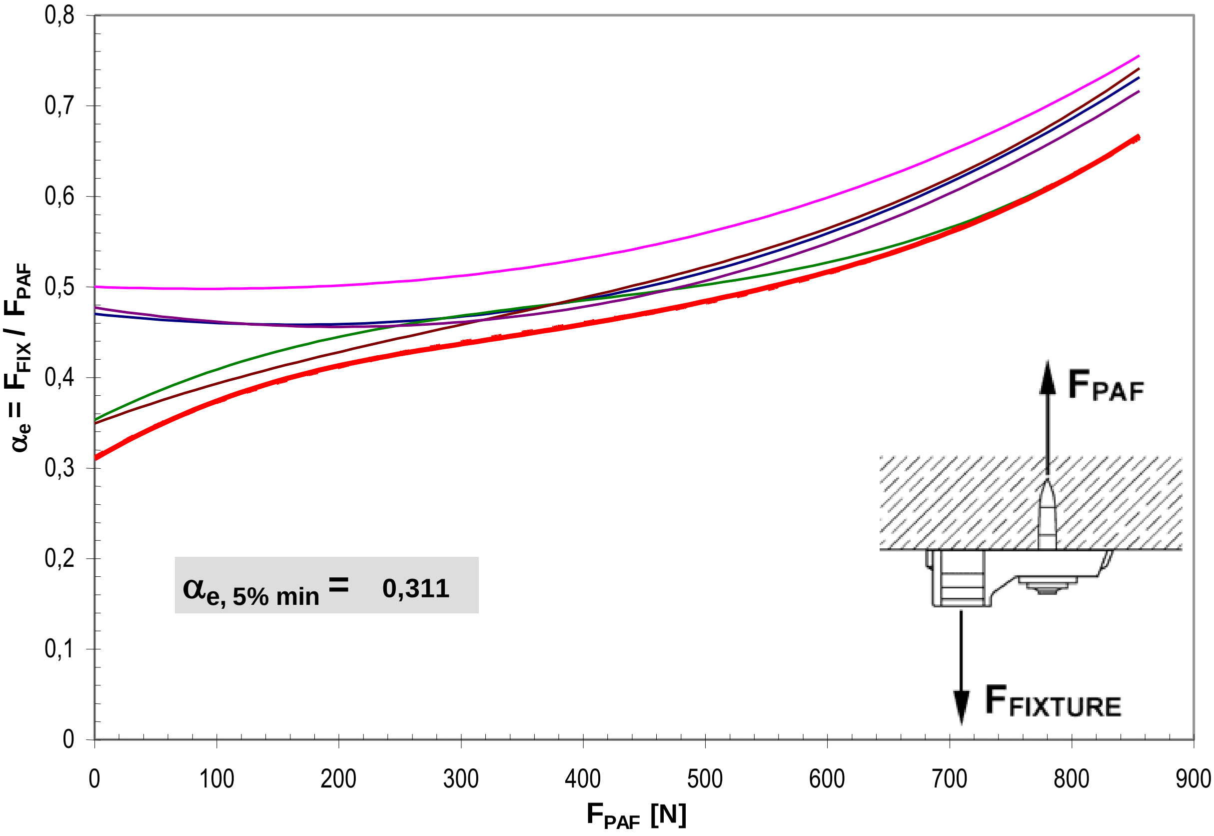


Figure B.3: Example of reduction functions α_e. The graph shows the approximated functions for the samples 1 to 5 and further shows the allocated 5%-quantile function $\alpha_{e,5\%}$. Additionally, the minimum value of this function is indicated in the graph (here: $\alpha_{e,5\% \min} = 0.311$). Evaluation of the quantile function see step 5 below.

Step 5:

Iterative calculation of the 5%-quantile reduction function $\alpha_{e,5\%}$.

d) First the reduction factor α_e is calculated for every individual test at defined forces F_{PAF} in incremental steps (approximately 100 increments up to the maximum relevant force F_{PAF})

e) For all selected forces $F_{PAF,i}$ (following the incremental steps) the 5%-quantile $\alpha_{e,5\%,i}$ of the reduction factor is calculated assuming normal distribution as follows:

$$\alpha_{e,5\%,i} = \alpha_{e,\mu,i} - 1.645 \cdot \alpha_{e,\sigma,i}$$

with:

$\alpha_{e,\mu,i}$ …mean value of the reduction factor for all individual tests for all selected forces $F_{PAF,i}$ (following the incremental steps)

$\alpha_{e,\sigma}$ …standard deviation of the reduction factor for all individual tests for all selected forces $F_{PAF,i}$ (following the incremental steps)

f) The values of the 5%-quantile $\alpha_{e,5\%,i}$ are then approximated with the polynomium $\alpha_{e.5\%}$ with a degree of 4 as shown above (red line in Figure B.3).

Annex C: Fastener type 3 - Distribution function of fixture

Example for assessment of test series A9 and A10:

sample size n = 10, confidence level 1–α = 0.9, H_R ..cumulated probability of sample

Sort experimental results R ascending order [N]		
	R	***H_R***
1	90.7	0.05
2	94.9	0.15
3	95.2	0.25
4	96.0	0.35
5	101.2	0.45
6	101.3	0.55
7	101.7	0.65
8	107.4	0.75
9	111.4	0.85
10	112.9	0.95
Mean value $\mu := \overline{R} =$ **101.3**		
Standard dev. $\sigma := S =$ **7.40**		
COV $\nu =$ **0.073**		

Distribution function of population

$\nu = 0.073 < 0.134$

$$P(R)^{*}_{1-\alpha} = d \cdot \left\{ 1 - \exp\left[-\left(\frac{R-a}{b} \right)^{c} \right] \right\}$$

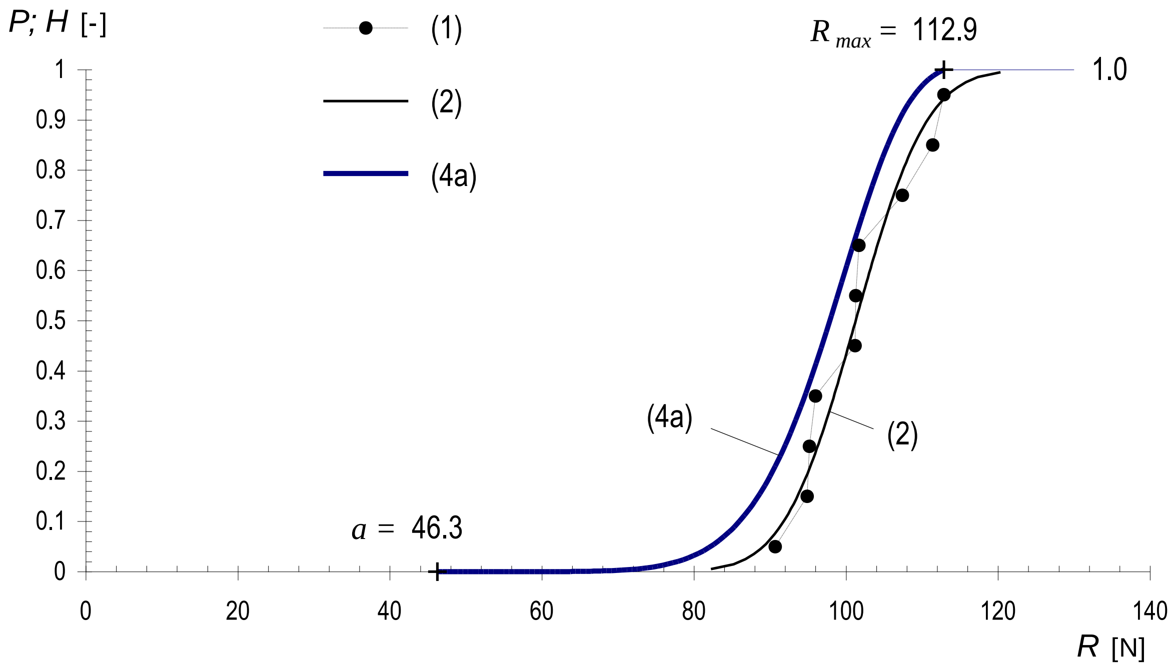
$a = 101.3 - 7.437 \cdot 7.40 = 46.3$

$c = 7.1614$

$b = 7.367 \cdot 7.40 = 54.5$

$$d = \left\{ 1 - \exp\left[-\left(\frac{112.9 - 46.3}{54.5} \right)^{7.1614} \right] \right\}^{-1} = 1.015$$

Remark: $R_{\max} = R_{10} = 112{,}9$



(1) … test results,
(2) …. Approximation of empiric test results with normal distribution
(4a) …Distribution function of population

Annex D: Test details for tests on fasteners including fixtures

For test series A9 to A14 an example for test setup for load acting on the fixture and the force acting on the fastener is given in following figures.

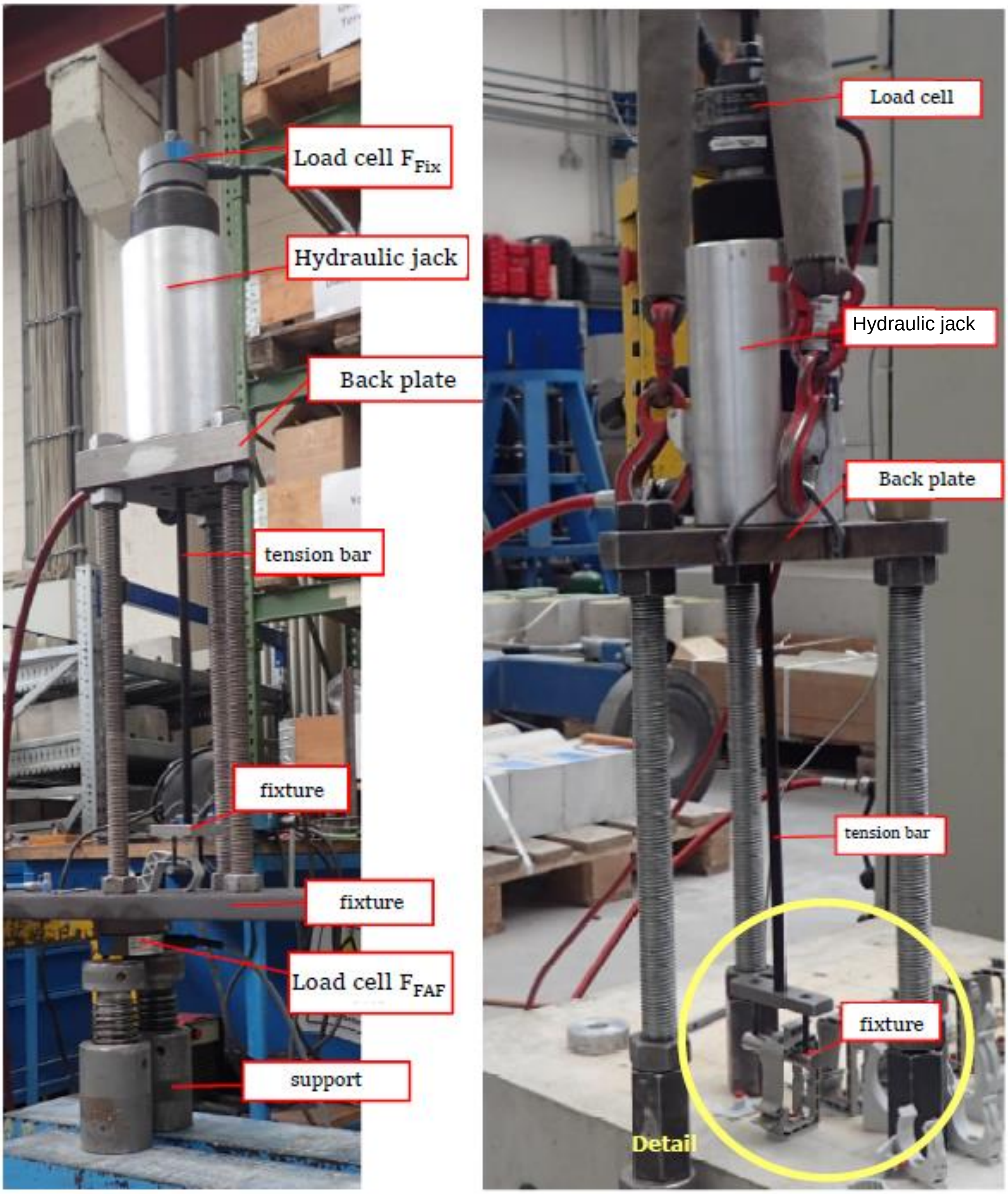


Figure D.1 Example of test setup

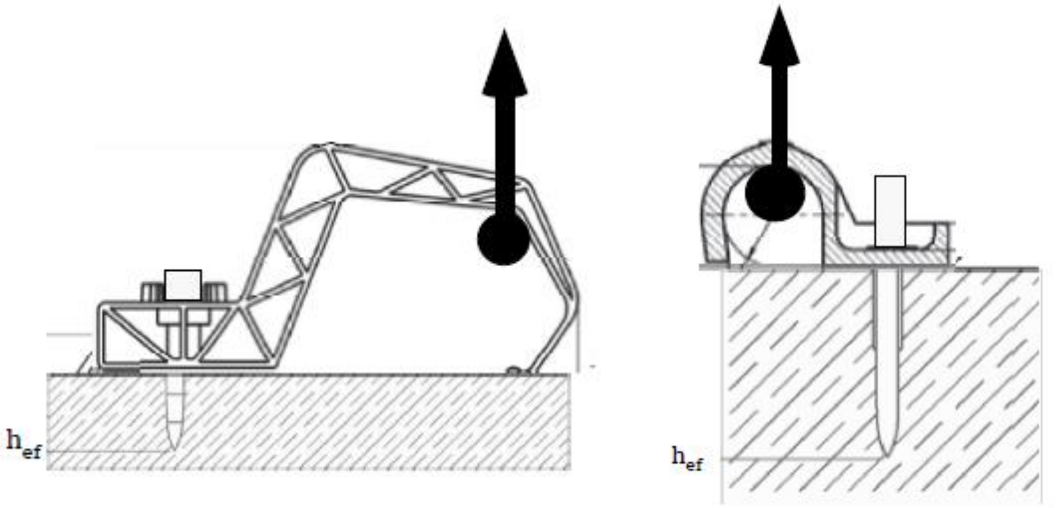


Figure D.2 Examples of test details of the load acting on the fixtures