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POWER-ACTUATED FASTENER FOR MULTIPLE USE IN CONCRETE FOR NON-STRUCTURAL APPLICATIONS

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Contents

1   SCOPE OF THE EAD

1.1   Description of the construction product

The power-actuated fasteners 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 anchorage depth depends on the fastener type of the power-actuated fastening system and is given in Table 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). 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) is to 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 shows examples of the product (with nail head or with external thread).
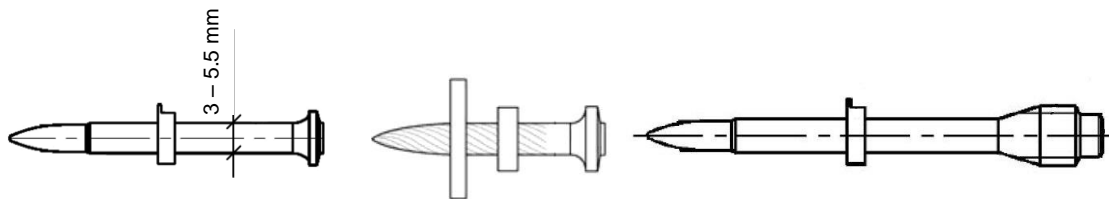
Figure 1.1 – Examples of a power-actuated fastener with washer (Fastener type 1 and 2)

Fasteners of Fastener type 3 includes only power-actuated nails but no power-actuated threaded studs.
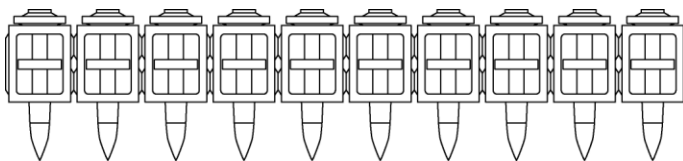
Figure 1.2 – Example of a power-actuated fastener (Fastener type 3)

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

The fastener–types as given by the manufacturer are determined by:
- material (e.g. galvanized steel, stainless steel),
- material grade (e.g. steel strength class),
- dimensions (e.g. diameter, shape),
- type (e.g. nail with head, nail with external thread).

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 fully covered by the following harmonised technical specification: EAD 330083-01-0601:March 2016 [27]. In EAD 330083-01-0601 fastener type 2b is not covered.

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 multiple use for non-structural applications in cracked or non-cracked normal weight concrete between strength classes C12/15 and C50/60 according to EN 206-1:2000 [12]. For fasteners of Fastener type 3 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 [13]. A new fastener is set at a minimum distance away of $\geq$ 150 mm and $\geq$ 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 10346:2009 [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] or C.I.P. [7] 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 kind of mechanical energy provided by a power-actuated fastening tool.
For the installation of the product the necessary tools foreseen by the manufacturer are to be used and the relevant manufacturer's instructions must be followed to the detail. The performance of the fastener is assessed under the assumption that both these preconditions are met.

This EAD applies to applications where the minimum thickness of concrete members in which the fasteners are installed is h = 2h_{ef} and at least h = 80 mm.

This EAD applies to anchorages in respect to durability for

- use in structures subjects to dry, internal conditions, concrete exposure class X0 or XC1 according to EN 206 [12] (Fastener types 1 to 3),
- use in structures subjects to external atmospheric exposure or exposure in permanently damp internal conditions, if no particular aggressive conditions exist (Fastener type 1 and 2) or
- use in structures subject to external atmospheric exposure or exposure in permanently damp internal conditions or particularly aggressive conditions (Fastener type 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.

The fastener is to be used only for anchorages subject to static or quasi-static loading in reinforced or unreinforced concrete. Fastener type 3 is only to be used for anchorages subject to self-weight of cable or cable conduits).

The fastener is to be used for anchorages in two-dimensional load-bearing structures (slabs and walls). Fasteners of type 1 (according to Table 1.1) can also 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 multiple fastener use depends on the Fastener type of the power-actuated fastening system and is given in Table 1.1.

**Table 1.1   Types of power-actuated fastening systems**

Fastener type	Minimum anchorage depth	Maximum anchorage depth	Definition of multiple fasteners
1	$\geq$ 25 mm	-	According to ETAG 001-6:2013, Annex 1 [5]: $n_1 \geq 4$; $n_2 \geq 1$ and $n_3 \leq 3{,}00$ kN or $n_1 \geq 3$; $n_2 \geq 1$ and $n_3 \leq 2{,}00$ kN
2a	$\geq$ 18 mm	-	$n_1 \geq 4$; $n_2 = 1$ and $n_3 \leq 0{,}60$ kN
2b	$\geq$ 15 mm	-	$n_1 \geq 6$; $n_2 = 1$ and $n_3 \leq 0{,}30$ kN
3	11 mm	18 mm	Fastening of cables spanned in one direction $10 \leq n_1 \leq 100$; $n_2 = 1$ and $n_{3S} \leq 0{,}10$ kN maximum span 1000 mm

For multiple fastener use 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 multiple fastener use 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 N_{Ed} on a fixing point to a value $\leq n_3$ (kN) according to Table 1.1 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 shows examples of the installed product with different fixtures.
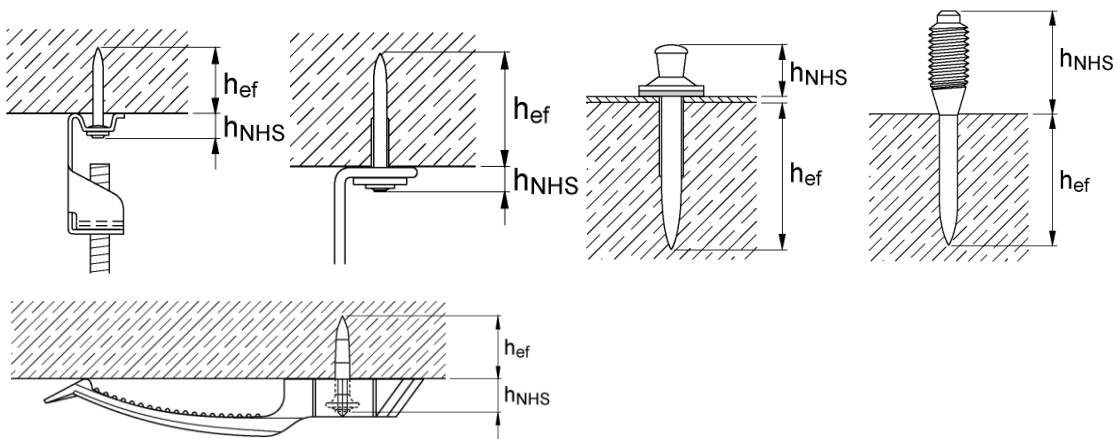
Figure 1.2 – Power-actuated fastener with different fixtures or external thread anchored in a concrete slab

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 FprEN 1992-4:2016 [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 1.4 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 (e.g. NYM 3x1.5 or NYM 5x1.5 according to VDE 0250-204 [x]). 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 verification.
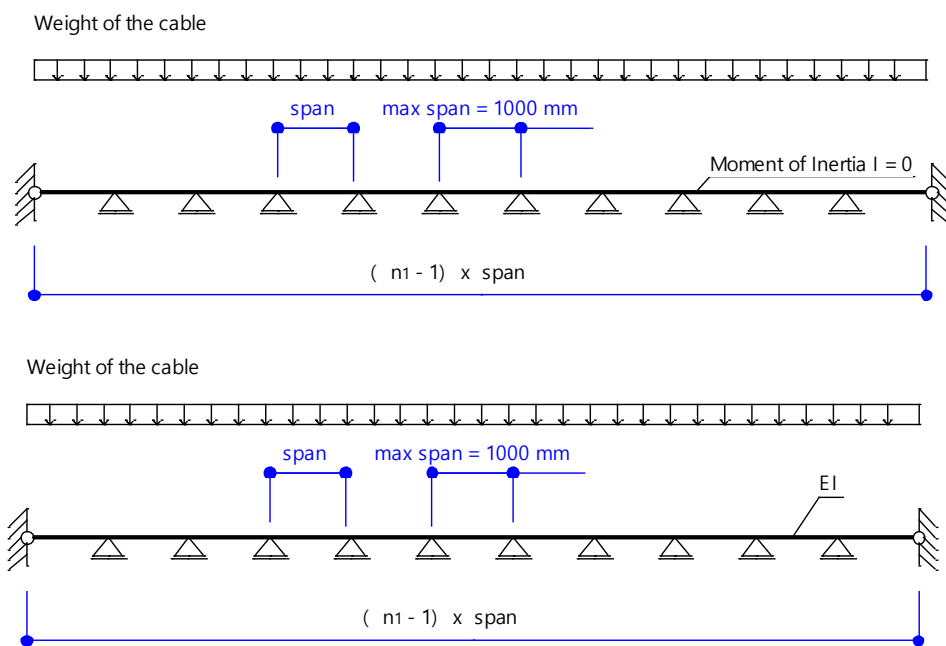
Figure 1.4 – Static system of uniaxially spanned cables of Fastener type 3

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[1].

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

1.3   Specific terms used in this EAD

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

Normal ambient temperature = $21 \pm 3\,°C$

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. The notations of EAD 330232-00-0601:2016-10 [25] may also be noticed.

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

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[1]   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.

$s_{min,fi}$ = 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_{Ru} = ultimate load in a test

$F_{Ru,m}$ = mean ultimate load in a test series

F^t_{Rk} = 5 %-fractile of the ultimate load in a 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

Multiple use

n_1 = number of fixing points to fasten the fixture

n_2 = number of fasteners per fixing point

n_3 = design value of actions on a fixing point

n_{3S} = maximum service load acting on the power-actuated fastener

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1 shows how the performance of this product is assessed in relation to the essential characteristics.

Table 2.1 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 for resistance of Fastener type 1 and 2	2.2.1	F_{Rk} [kN]
			$M^0_{Rk,s}$ [Nm]
			c_{min}, s_{min} [mm]
			h_{min} [mm]
			h_{ef} [mm]
2	Displacements of Fastener type 1 and 2	2.2.2	δ_0, δ_∞ [mm]
3	Maximum service load of Fastener type 3	2.2.3	$F_{s,max}$ [kN]
			h_{ef} [mm]
			n_1 [-]
			span [mm]
			number of gaps for local failure
			number of gaps for serviceability limit state
4	Durability	2.2.4	Description
	Basic Works Requirement 2: Safety in case of fire		
5	Reaction to fire	2.2.5	Fasteners and fixtures made of metal: Class (A1)
			Fixtures made of plastic: Class
6	Resistance to fire	2.2.6	Fasteners and fixtures made of metal: $F_{Rk,fi}$ [kN]
			Fasteners and fixtures made of metal: $M^0_{Rk,s,fi}$ [Nm]
			Fasteners and fixtures made of metal: $c_{min,fi}$, $s_{min,fi}$ [mm]
			Fixtures made of plastic: not specified in this version of EAD

2.2 Assessment methods and criteria for the performance of the product in relation to essential characteristics of the product

2.2.1 Characteristic load bearing capacity of Fastener type 1 and 2

The test program for the assessment consists of

- Basic tension tests and basic shear tests to assess basic values of characteristic resistance and
- Functioning tests to assess the characteristic resistance regarding various effects for the relevant application range according to the intended use.

2.2.1.1 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 2.4).

The tests should be performed according to EOTA TR 048:2016-08 [26].

The load should 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 should be performed later than 10 minutes after setting.

Pre-qualification tests are performed in order to determine the scatter of the ultimate load of the fastener system.

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

Further details of tests are described in EOTA TR 048:2016-08 [26]. In all functioning tests displacements can be measured externally (e.g. by displacement transducers according to EOTA TR 048:2016-08 [26] or internally (e.g. measurement of piston stroke).

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

The test conditions, the number of required tests and the criteria applied to the results should be taken in accordance with Table 2.3.

Table 2.3 Pre-qualification 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-qualification	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

Further functioning tests, test conditions, the number of required tests and the criteria applied to the results should be taken in accordance with Table 2.4.

Table 2.4   Functioning tests for power-actuated fasteners to be used in concrete

No	Purpose of test	Concrete	Crack width Δw (mm)	Thickness of fixture	Scatter range (5)	Minimum number of tests	Criteria req. α (2)	Reference 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 2.3 and Table 2.5; 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 2.3.

(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 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 EOTA TR 048:2016-08, Section 3.3.1 [26]. In deviation from EOTA TR 048:2016-08 [26] the maximum aggregate size of the concrete member shall be 32 mm and the grading curve A32 according to Figure 2.1 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).
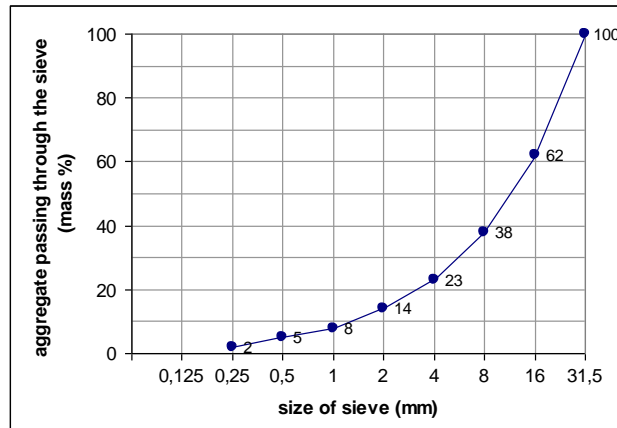
Figure 2.1:
Grading curve A32

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 should be chosen so, that the reinforcement is not touched by the previous drill. For power-actuated fasteners without previous drill the concrete cover should be 10 mm. The setting position in the quarter point of the reinforcing bar (shown in Figure 2.2) should be tested. The single fasteners are tested in tension and loaded to failure. Details of the test are described in EOTA TR 048:2016-08, 3.3.1 [26].
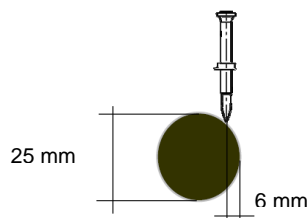
Figure 2.2:
Setting position for contact
with reinforcement

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 EOTA TR 048:2016-08, 3.3.1 [26].

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} and   (2.1)

min N = 0,25 N_{Rk}.   (2.2)

Further details of the test are described in EOTA TR 048:2016-08, 3.3.4 [26]. After completion of the load cycles the fasteners should be unloaded the displacement measured and a tension test to failure performed according to EOTA TR 048:2016-08, 3.3.1 [26].

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 EOTA TR 048:2016-08, 3.5 [26].

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$_{inst}$. After this a tension test to failure shall be performed according to EOTA TR 048:2016-08, 3.3.1 [26].

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 2.3.

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 almost constant during the test. Calcium hydroxide powder should be kept in an air-tight containment and should not be stored longer than one year.

The test solution should 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 2.3). During the test the head of the fasteners shall be submerged in the fluid.

Sustained load:

$$N_{HE} = N_{Rk} \qquad\qquad\qquad\qquad (2.3)$$

with: N_{Rk} -   characteristic resistances in C20/25 under tension loading according to
                2.2.1.4 (without reduction factor from functioning test F6)

Electrochemical conditions:

Potential: -955 mV vs. NHE.

Reference electrode: 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, e.g. for a saturated calomel electrode with E_{cal}= +245 mV vs. N_{HE} the correct potential will be

E = –955 – 245 = -1200 mV (±10 mV).

Counter electrode: 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.

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.
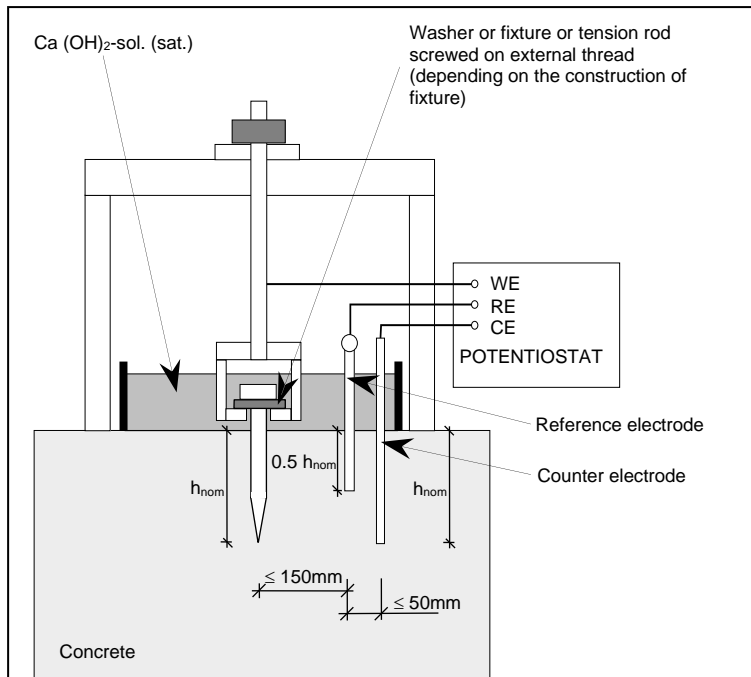
Figure 2.3 – Test setup (schematic)

Note: If possible the working electrode (WE) should be connected directly to the fastener and the fastener should 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 need to be compensated by the potentiostatic control. The potential between the fastener and the normal hydrogen electrode needs to be measured 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 should 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 should 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 should be performed later than 10 minutes after setting.

The types of tests for service condition tests, test conditions, the number of required tests and the criteria applied to the results should be taken in accordance with Table 2.5.

Table 2.5   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 2.3

(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 2.4 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 EOTA TR 048:2016-08, 3.3.1 [26]. 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 EOTA TR 048:2016-08, 3.6.1 [26].

2.2.1.3 Assessment of test results

5%-fractile of the ultimate loads:

The 5%-fractile of the ultimate loads measured in a test series is to 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.

$$F^t_{Rk} = F_{ln5\%} = F_{Ru,m\ ln(x)} - k_s \cdot s_{ln(x)} \qquad (2.4)$$

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

n = 10 tests: $k_s = 2{,}57$

n = 20 tests: $k_s = 2{,}21$

with: $F_{ln5\%}$ =   5%-logarithmic fractile of the ultimate load calculated by the logarithmic test values

$F_{Ru,m\ ln(x)}$ =   mean value of ultimate load in a test series calculated by the logarithmic test values

k_s =   statistical factor

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

note: setting defects which can visually not be recognised (e.g. failure during installation of the test equipment) should be considered by $F_{Ru} = 0{,}001$ kN

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:

$$F_{Ru}(f_c) = F^t_{Ru}(f_c / f_{c,test})^n \qquad (2.5)$$

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 should 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:

$$F_{Ru}(f_{uk}) = F^t_{Ru} \cdot f_{uk} / f_{u,test} \qquad (2.6)$$

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

Load/displacement behaviour

The requirement on the load/displacement curves in EAD 330232-00-0601, A.2.5 [25] 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:

$N_1 = 0{,}4\ N_{Ru}$ (instead of $0{,}7\ N_{Ru}$ according to Equation (A.12) [25])

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 2.4 and 2.5 exceptional for maximum torque moment and sensitivity to brittle failure, the coefficient of variation of the ultimate load shall be calculated and should 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:

$$\alpha_v = 1 / (1 + 0,03 \cdot (v_u\,[\%] - 20)) \tag{2.7}$$

with: v_u = coefficient of variation of ultimate load of tests according Table 2.4 and 2.5

Reduction factor α

For test series F1, F2, F3, F4 and F6 according to Table 2.4 the factor α shall be calculated according to following Equation.

$$\alpha = \min ((F_{u,m,t} / F_{u,m,r}) ; (F_{u,m,t} / F_{u,m,r})) \tag{2.8}$$

with: $F_{u,m,t}$ = mean failure load in a test series

          $F_{u,m,r}$ = mean failure (ultimate) load in a reference test series (reference test see Table 2.4)

with: $F_{u,5\%,t}$ = 5% fractile of failure (ultimate) loads of a test series

          $F_{u,5\%,r}$ = 5% fractile of failure (ultimate) loads of a reference test series (reference test see Table 2.4)

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 should be larger than req.α given in Table 2.4 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:

$$\alpha_u = \alpha / \text{req. } \alpha \tag{2.9}$$

with: α = lowest value according to Equation (2.8) of test series F1- F4 and F6

          req. α = required α according to Table 2.4

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} should be reduced with the factor max N (applied) / max N.

Maximum torque moment

For test series F5 according to Table 2.4 the factor α according to Equation (2.8) shall be calculated. The factor α shall be larger than req.α given in Table 2.4 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 should be calculated as follows:

$$N_{Rk,p} = N_{Rk,0} \cdot \min \alpha_u \cdot \min \alpha_V \tag{2.10}$$

with: $N_{Rk,0}$ = characteristic resistance evaluated from the results of tests according to Table 2.5, line 1, 2, 3 and 4

$\min \alpha_u$ = minimum α_u (reduction factor from the ultimate loads in the functioning tests) according to 2.2.1.4 for functioning tests F1, F2, F3, F4 and F6 according to Table 2.4; ($\leq 1,0$),

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

Steel failure under shear load without lever arm

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

$$V_{Rk,s} = \alpha \cdot A_s \cdot f_{uk} \tag{2.11}$$

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 should be calculated as follows:

$$V_{Rk,c} = V_{Rk,0} \cdot \alpha_V \tag{2.12}$$

with: $V_{Rk,0}$ = characteristic resistance evaluated from the results of tests according to Table 2.5, line 5

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 $F_{Rd,min}$.

$$F_{Rd,min} \text{ [kN] } = \min (N_{Rk,p} / \gamma_{Mc}; V_{Rk,s} / \gamma_{Ms}; V_{Rk,c} / \gamma_{Mc}) \tag{2.13}$$

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

$\gamma_{Mc}; \gamma_{Ms}$　　according to FprEN 1992-4:2016 [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:

$$F_{Rk} \text{ [kN] } = F_{Rd,min} \cdot \gamma_M \tag{2.14}$$

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

γ_M　　depends on decisive failure mode (see Equation 2.13)

Steel failure under shear load with lever arm

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

$$M^0_{Rk,s} = 1,2 \cdot W_{el} \cdot f_{uk} \tag{2.15}$$

with: W_{el} = section modulus of the fastener
W_{el} = $\pi \cdot r^3/4$
f_{uk} = characteristic tensile strength of fastener

2.2.1.5 Spacing and edge distances

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 330232-00-0601:2016-10 [25].

2.2.1.6 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 2.4) 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.

2.2.2 Characteristic displacements of Fastener type 1 and 2

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

$$F = F_{Rk} / (\gamma_F \cdot \gamma_M) \qquad (2.16)$$

with: F_{Rk} = characteristic resistance

γ_F = partial safety factor for actions = 1,4

γ_M = partial safety factor for material according FprEN 1992-4:2016 [11]

The displacements δ_{N0} and δ_{V0} under short-term loading are evaluated from test series Table 2.5, line 1 and line 5. They should correspond to the mean value of these test series. The displacements (in mm) should 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.

2.2.3 Maximum service load of Fastener type 3

2.2.3.1 Functioning tests

Power-actuated fasteners

The execution of following functioning tests according to Table 2.4. is <u>not</u> 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 should 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 2.6.

- 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 3.1 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 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 are to 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.
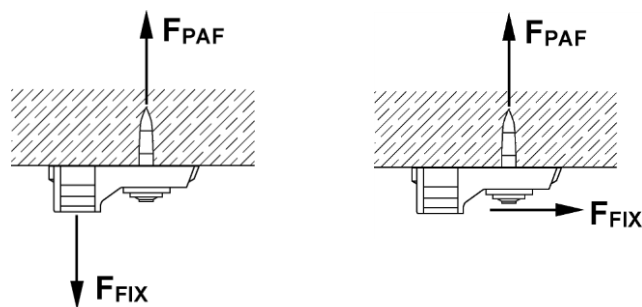
Figure 2.4 – Eccentric load introduction in case of tension and shear loads

$$F_{PAF} \;=\; (1/\alpha_e) \cdot F_{FIX} \tag{2.17}$$

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 should be taken in accordance with Table 2.6.

Table 2.6   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 to the description of the test procedure in section 2.2.3.2 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.

Performance of test till maximum load is reached. The test equipment has to be suitable to determine also very small individual resistances with the required accuracy.

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 nail shall be avoided. The load acting on the fixture and the force acting on the fastener are measured continuously from the beginning.

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). In case the assessment which test controls the reliability index is not obviously possible by comparing the cumulated probability of the results of A6 and A7, 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.

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

(2.18)

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:

$R_1, \ldots R_i, \ldots R_n$ = 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 $P(R)^*$.

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

(2.19)

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

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

(2.20)

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 ($\nu = S/\overline{R}$) 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:

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

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

$$P(R) = 1 - \exp\left[-\left(\frac{R}{b}\right)^c\right] \qquad (2.21)$$

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

The shape parameter c is determined as follows:

$$c = v^{-1.083} \qquad (2.22)$$

with: v =   coefficient of variation, $v = \dfrac{\sigma}{\mu}$ $\qquad$ (2.23)

The scaling parameter b is determined as follows:

$$b = \frac{\mu}{\Gamma\left(1 + \dfrac{1}{c}\right)} \qquad (2.24)$$

with: μ = mean value

Γ = Gamma function, $\Gamma(x) = \displaystyle\int_0^\infty t^{x-1} e^{-t} dt$ $\qquad$ (2.25)

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.

$$d = \left\{1 - \exp\left[-\left(\frac{R_{max}}{b}\right)^c\right]\right\}^{-1} \qquad (2.26)$$

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.

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

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 $\alpha_{eN,5\%}$.

$$R_{e,i} = \alpha_{eN,5\%,i} \cdot R_{MC,i} \quad \text{for i = 1 to n} \tag{2.27}$$

with: $\quad R_{e,I}$ $\quad$ = $\quad$ reduced random pull-out resistance at the support i used for the individual calculation run of a Monte Carlo simulation

$\quad\quad R_{MC,i}$ $\quad$ = $\quad$ randomly allocated axial pull-out resistance at the support i

$\quad\quad \alpha_{eN,5\%,I}$ $\quad$ = $\quad$ reduction factor of pull-out resistance at the support i in order to take the effect of eccentric tension load introduction into account

$\quad\quad n$ $\quad$ = $\quad$ 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:

$$\alpha_{eN,5\%} = c_0 + c_1 \cdot F_{PAF} + c_2 \cdot (F_{PAF})^2 + c_3 \cdot (F_{PAF})^3 + c_4 \cdot (F_{PAF})^4 \tag{2.28}$$

with: $\quad \alpha_{eN,5\%}$ $\quad$ = $\quad$ 5%-quantile function of the reduction factor due to eccentric load

$\quad\quad F_{PAF}$ $\quad$ = $\quad$ 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}.

$$F_{FIX} = a_0 + a_1 \cdot F_{PAF} + a_2 \cdot (F_{PAF})^2 + a_3 \cdot (F_{PAF})^3 + a_4 \cdot (F_{PAF})^4 \tag{2.29}$$

Step 2: For increasing accuracy in the range of very small forces, the experimental values F_{FIX} are calibrated as follows:

$$F_{FIX} = F_{FIX,exp} - a_0 \tag{2.30}$$

with: $\quad F_{FIX}$ $\quad$ = $\quad$ calibrated test data

$\quad\quad F_{FIX,exp}$ $\quad$ = $\quad$ measured test data

$\quad\quad a_0$ $\quad$ = $\quad$ 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.

$$F_{FIX} = b_1 \cdot F_{PAF} + b_2 \cdot (F_{PAF})^2 + b_3 \cdot (F_{PAF})^3 + b_4 \cdot (F_{PAF})^4 \tag{2.31}$$

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

$$\alpha_{eN} = b_1 + b_2 \cdot F_{PAF} + b_3 \cdot (F_{PAF})^2 + b_4 \cdot (F_{PAF})^3 \tag{2.32}$$

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.

$$\alpha_{eN,5\%,i} = \alpha_{eN,\mu,i} - 1.645 \cdot \alpha_{eN,\sigma,i} \tag{2.33}$$

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 admissible service condition test 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:

$$F_{Ru} = F_{Ru}^{t} \cdot \frac{f_{u,min}}{f_{u,test}} \cdot \frac{t_{min}}{t_{test}}$$ (2.34)

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 2.7. 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 2.7   Distribution function of fixture (for sample size n = 10 and confidence level $1-\alpha$ = 0.9)

Weibull distribution with 3 parameters a, b and c	Weibull distribution with 2 parameters b and c
$P(R)_{\lambda-\alpha} = 1 - \exp\left[-\left(\frac{R-a}{b}\right)^{c}\right]$ (2.35)	$P(R)_{\lambda-\alpha} = 1 - \exp\left[-\left(\frac{R}{b}\right)^{c}\right]$ (2.36)
$v = \dfrac{\sigma}{\mu} < 0.134$	$v = \dfrac{\sigma}{\mu} \geq 0.134$
$a = \mu - 7.437 \cdot \sigma$ $c = 7.1614$ $b = 7.367 \cdot \sigma$	$c = 0.671 \cdot v^{-1.18}$ $b = 1.218 \cdot \mu \cdot \left(v^{0.0656} - 0.538 \cdot v^{1.0656}\right)$
$\mu := \overline{R}$ ... 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.

$$P(R)_{(1-\alpha),pt} = \alpha_{pt} \cdot P(R)_{(1-\alpha),p} \qquad\qquad (2.37)$$

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 are to 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 [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 [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 [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. 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 behaviour 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 failure of all fixtures of the chain) due to overload.

The static systems according to Figure 1.4 are to 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 are to be considered in the calculation.

- The model must 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 occurrence 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:

$$p_f = \phi(-\beta) \tag{2.38}$$

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 is to be used.

<u>5% fractile of reliability index β</u>

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 is to be calculated according to statistical procedures for a confidence level of 90 % using normal distribution and unknown standard deviation of the population.

$$\beta_{5\%} = \beta_m - k_s \cdot s \tag{2.39}$$

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

<u>Functioning in low and higher strength concrete with crack width $\Delta w = 0.35$ mm</u>
<u>(Assessment of Test series A15 and A16)</u>

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 n_{3S}.

The following criterion is to be fulfilled:

$$\overline{R} \geq 2.4 \cdot n_{3S} \tag{2.40}$$

with: $\overline{R}$ = mean value of test sample for crack width $\Delta w = 0.35$ mm

   n_{3S} = maximum service load acting on the powder-actuated fastener with $n_{3S} \leq 0.10$ kN according to Table 1.1

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.

Table 2.8 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 2.8   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 $\beta \geq 1.5$	1		
	2		
Acceptable gap for local failure $\beta \geq 3.3$	2		
	3		
	4		

The maximum tension service load $N_{S,max}$ given in Table 2.8 is limited by

- the maximum tension service load assessed for the limit state of global collapse (ULS with $\beta \geq 3.8$) or
- the maximum tension service load n_{3S} equal or less than 0.10 kN acting on the power-actuated fastener according to Fastener type 3 (Table 1.1) 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. No verification is required in design.

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.
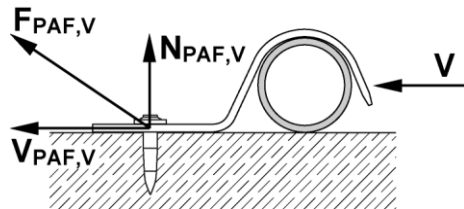
Figure 2.5 – Forces in case of eccentric shear loading of the fixture

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 admissible service condition test 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:

$$N_{PAF,V} = (1/\alpha_{eV,5\%}) \cdot V_{PAF,V} \tag{2.41}$$

$$F_{PAF,V} = (N_{PAF,V}^2 + V_{PAF,V}^2)^{0,5} \tag{2.42}$$

$$\alpha_{eF.5\%} = V_{PAF,V}/F_{PAF,V} \tag{2.43}$$

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 $\alpha_{eF.5\%}$.

$$V_{e,i} = \alpha_{eF,5\%,i} \cdot V_{MC,i} \quad \text{for } i = 1 \text{ to } n \tag{2.44}$$

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 admissible service condition test 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.

Table 2.9 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 2.9   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 2.9 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 n_{3S} equal or less than 0.10 kN acting on the power-actuated fastener according to Fastener type 3 (Table 1.1) 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. No verification is required in design.

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 and has to be checked after installation of the fastener in the works.

2.2.4 Durability

Steel parts

The assessment/testing required with respect to corrosion resistance will depend on the specification of the anchor in relation to its use. Supporting evidence that corrosion will not occur is not required if the steel parts of the metal anchor are protected against corrosion, as set out below:

(1) Power-actuated fastener intended for use in structures subject to dry, internal conditions:

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.

(2) Power-actuated fastener for use in structures subject to external atmospheric exposure (including industrial and marine environments), or exposure in permanently damp internal conditions, if no particular aggressive conditions according to (3) exist:

Metal parts of the anchor made of stainless steel material 1.4401, 1.4404, 1.4578, 1.4571, 1.4362, 1.4062, 1.4162, 1.4662, 1.4439, 14462 or 1.4539 according to EN 10088-4 and 5:2014 [3] are considered to have sufficient durability.

(3) Power-actuated fastener for use in structures subject to external atmospheric exposure or exposure in permanently damp internal conditions or particularly aggressive conditions such as permanent or alternate immersion in seawater or the splash zone of seawater, chloride atmosphere of indoor swimming pools or atmosphere with extreme chemical pollution (e.g. in desulfurization plants or road tunnels, where de-icing materials are used):

Metal parts of the anchor of stainless steel material 1.4529, 1.4565 and 1.4547 according to EN 10088-4 and 5:2014 [3] are considered to have sufficient durability.

Plastic parts

The durability of the plastic fixtures shall be assessed against high alkalinity (pH = 13.2) according to EAD 330196-00-0604 [20].

The durability has to be tested at maximum service temperature.

The plastic parts of fixtures need to be durable against UV-radiation. If the fixtures are made of polyamide PA6 or PA6.6, the durability is given for uses within Fastener type 3.

2.2.5 Reaction to fire

Steel parts

The power-actuated fastener is considered to satisfy the requirements for performance class A1 of the characteristic reaction to fire, in accordance with the provisions of EC Decision 96/603/EC (as amended) without the need for testing on the basis of its listing in that Decision.

Plastic parts

The fixtures made of plastic shall be tested, using the test method(s) relevant for the corresponding reaction to fire class, in order to be classified according to EN 13501-1 [24].

2.2.6 Resistance to fire

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 330232-00-0601 [25], 2.2.13, 2.2.14 and 2.2.15.

Plastic parts

Not specified in this version of EAD.

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: 97/463/EC

The system to be applied is: 2+

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of the product in the process of verification of constancy of performance are laid down in Table 3.1.

Table 3.1 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 manufacturing batch or 100000 fasteners
2	Tensile Load (N_p) or tensile strength (f_{uk})	According to EN ISO 898-1[14]		3	
3	Yield strength (f_{yk} or $N_{p0.2}$)	According to EN ISO 898-1[14]		3	
4	Core hardness and Surface hardness (at specified functioning relevant points of the product; where relevant)	Tests according to EN ISO 6507 [8] or EN ISO 6508 [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.)	Measuring or optical	Laid down in control plan	3	Every manufacturing batch or 100000 fasteners
10	Melt Volume-flow rate MVR	EN ISO 1133-1 [21]		1	Every manufacturing batch
11	Charpy impact toughness	EN ISO 179-1 [22]		1	

3.3   Tasks of the notified body

The cornerstones of the actions to be undertaken by the notified body in the process of verification of constancy of performance for the product are laid down in Table 3.2.

Table 3.2   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					
1	Ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the fastener	-	Laid down in control plan	-	1
Continuous surveillance, assessment and evaluation of factory production control					
2	Verifying that the system of factory production control and the specified automated manufacturing process are maintained taking account of the control plan.	-	Laid down in control plan	-	1/year

4   Reference documents

As far as no edition date is given in the list of standards thereafter, the standard in its current version at the time of issuing the European Technical Assessment is of relevance.
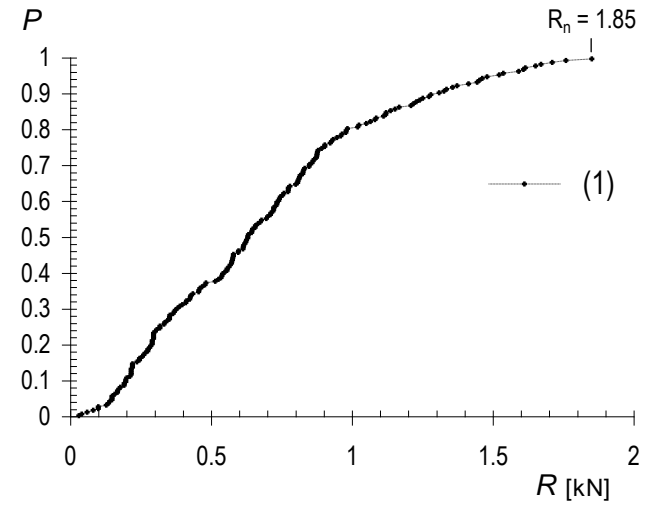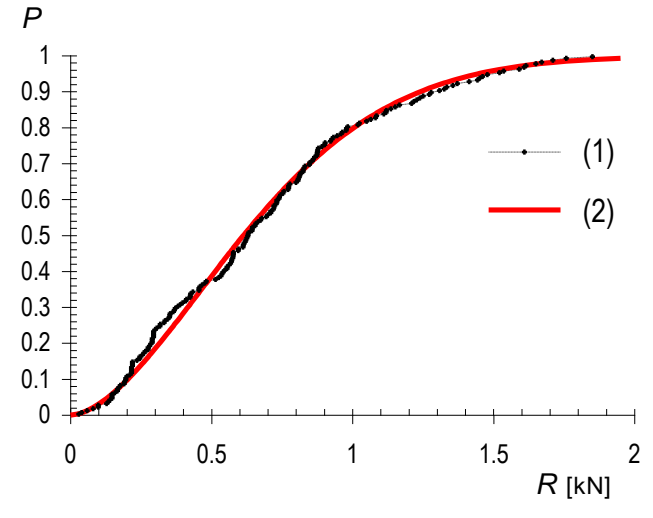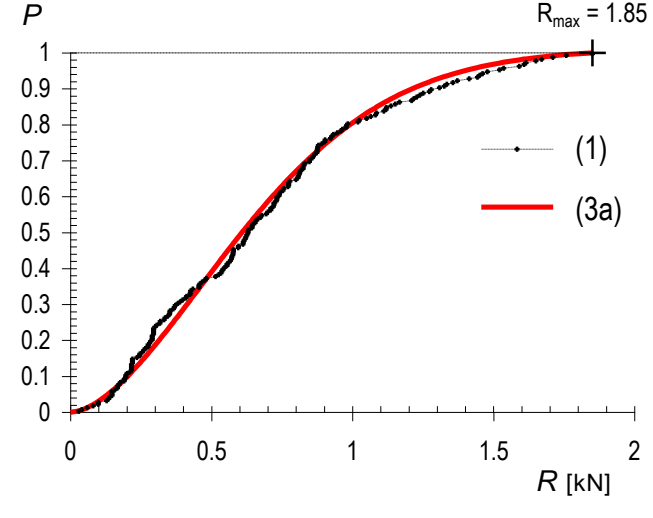
[1]   Regulation (EU) No 305/2011 of the European Parliament and of the council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/ECC

[2]   EN ISO 3506-1 and -2:2014: Mechanical properties of corrosion-resistant stainless-steel fasteners – Part 1: Bolts, screws and studs; Part 2: Nuts

[3]   EN 10088-4 and -5:2009: Stainless steels – Part 4: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for construction purposes; Part 5: Technical delivery conditions for bars, rods, wire, sections and bright products of corrosion resisting steels for construction purposes

[4]   EOTA TR 020:2004: Evaluation of Anchorages in Concrete concerning Resistance to Fire, Edition May 2004

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

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

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.

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

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

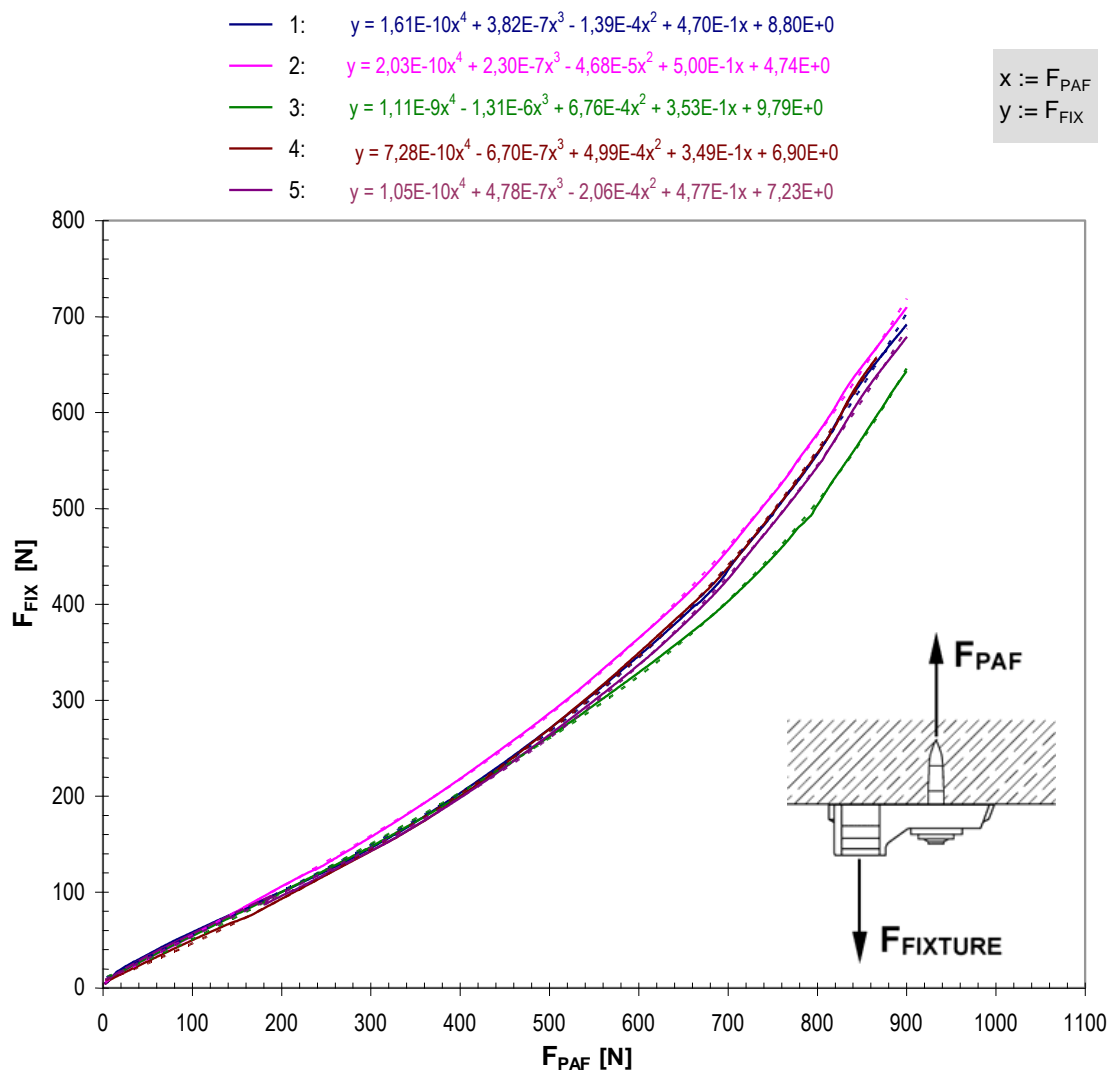|		
——	1:	$y = 1{,}61E\text{-}10x^4 + 3{,}82E\text{-}7x^3 - 1{,}39E\text{-}4x^2 + 4{,}70E\text{-}1x + 8{,}80E\text{+}0$
——	2:	$y = 2{,}03E\text{-}10x^4 + 2{,}30E\text{-}7x^3 - 4{,}68E\text{-}5x^2 + 5{,}00E\text{-}1x + 4{,}74E\text{+}0$
——	3:	$y = 1{,}11E\text{-}9x^4 - 1{,}31E\text{-}6x^3 + 6{,}76E\text{-}4x^2 + 3{,}53E\text{-}1x + 9{,}79E\text{+}0$
——	4:	$y = 7{,}28E\text{-}10x^4 - 6{,}70E\text{-}7x^3 + 4{,}99E\text{-}4x^2 + 3{,}49E\text{-}1x + 6{,}90E\text{+}0$
——	5:	$y = 1{,}05E\text{-}10x^4 + 4{,}78E\text{-}7x^3 - 2{,}06E\text{-}4x^2 + 4{,}77E\text{-}1x + 7{,}23E\text{+}0$

$x := F_{PAF}$
$y := F_{FIX}$

Figure 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:

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

Step 3:

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

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

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

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

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

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

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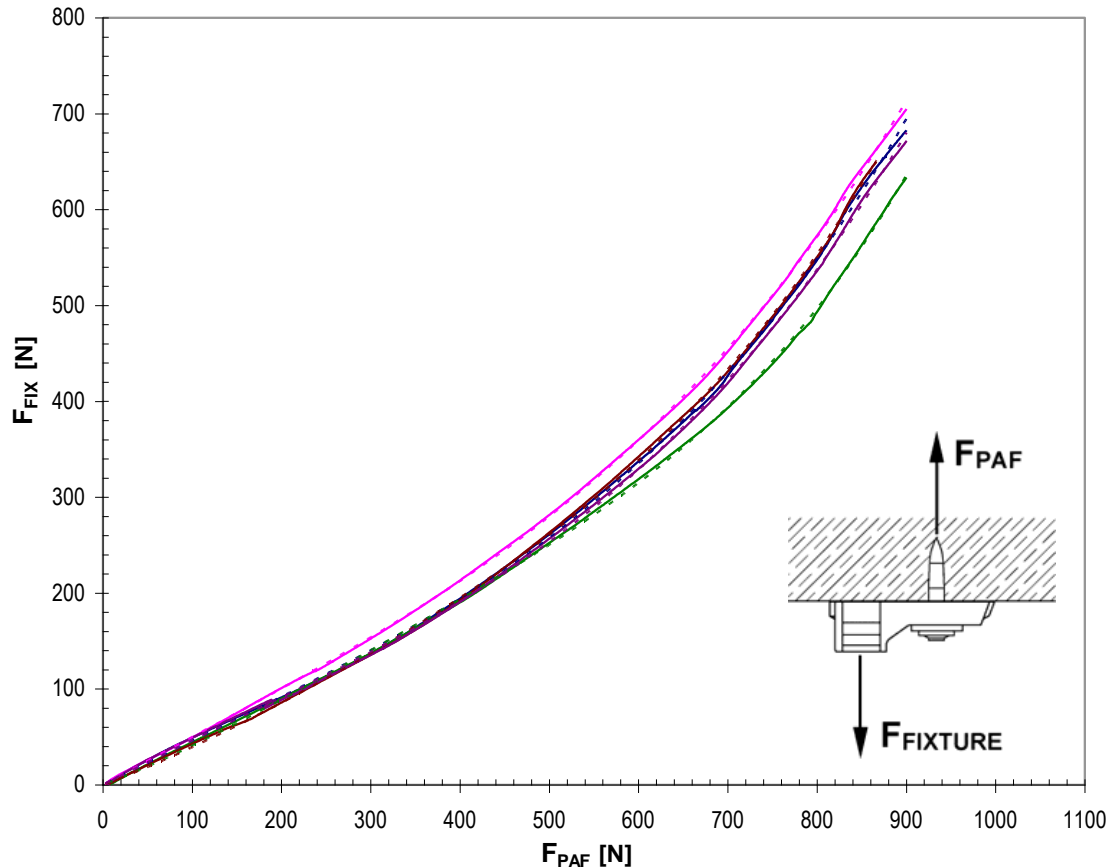
$x := F_{PAF}$
$y := F_{FIX}$

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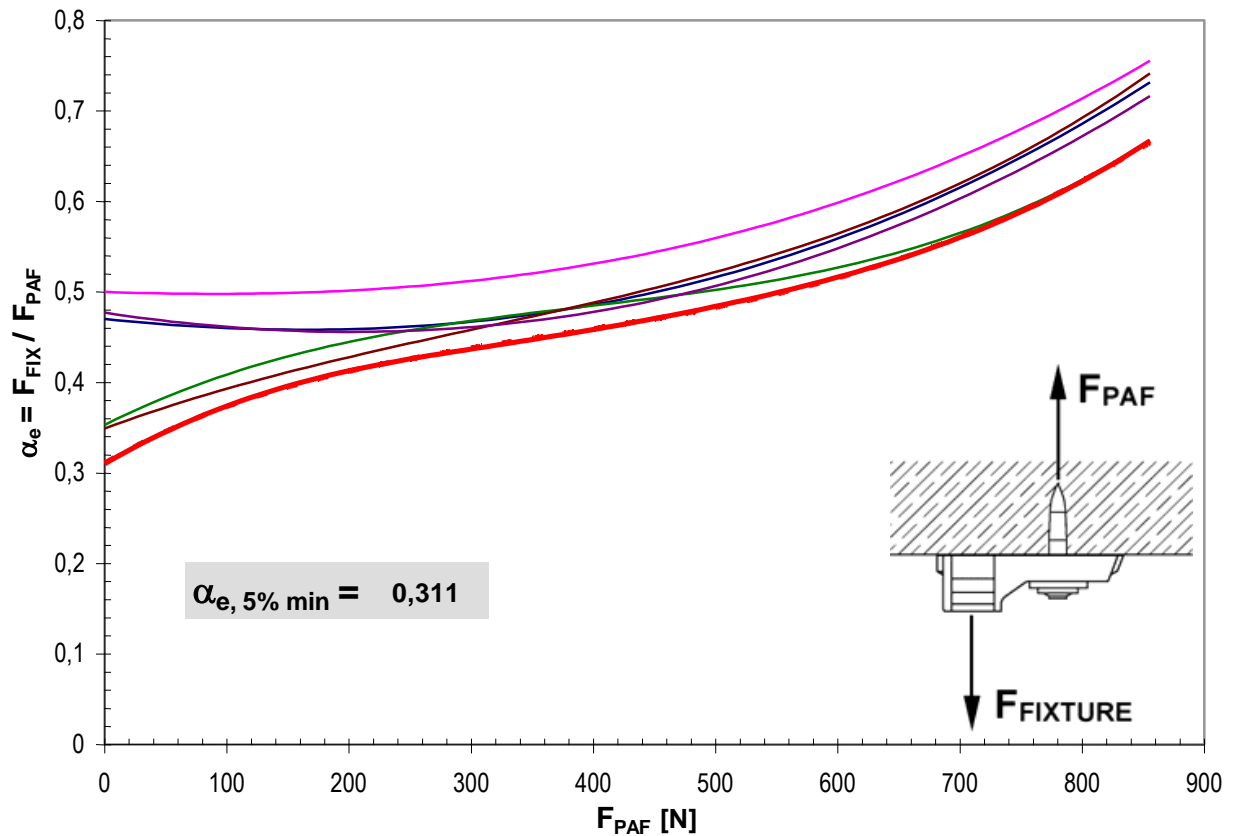

$\alpha_{e, 5\% min} = 0{,}311$

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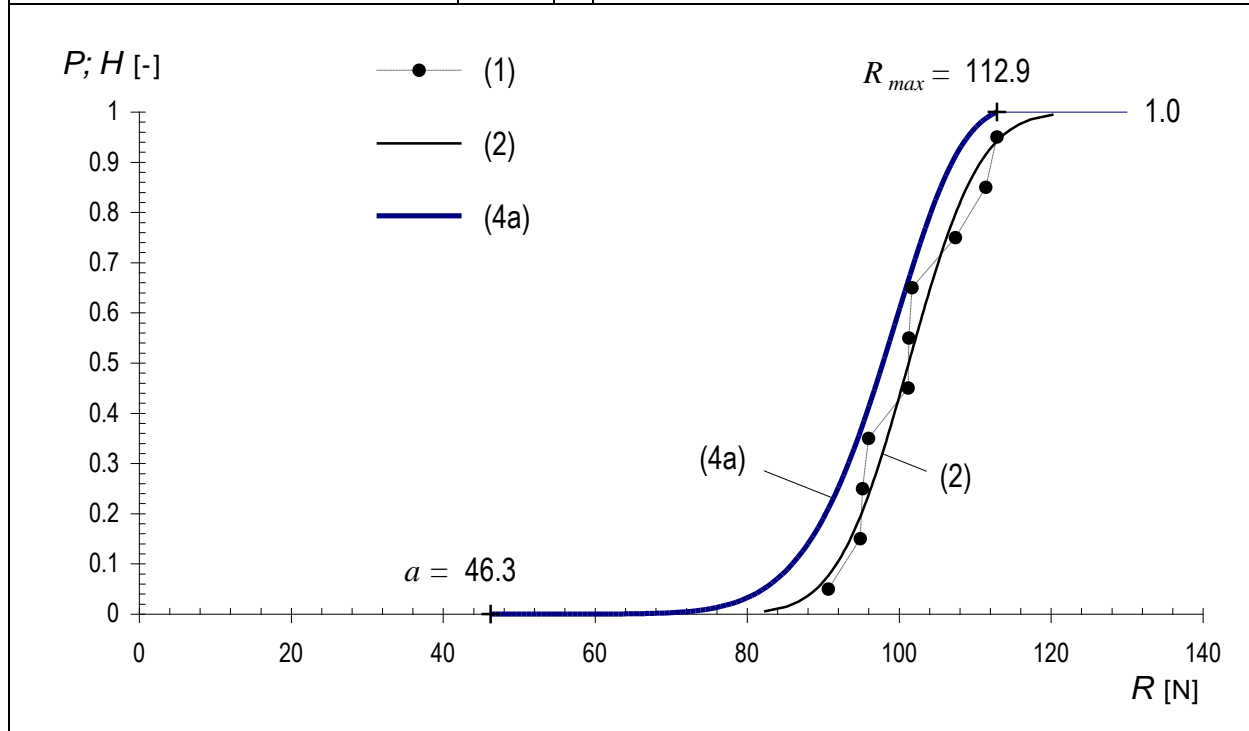
f) The values of the 5%-quantile $\alpha_{e,5\%,i}$ are then approximated with the polynomium $\alpha_{e.5\%}$ with a degree of 4 as shown above (red line in Figure 3).

Annex C: Fastener type 3 - Distribution function of fixture

Example for assessment of test series A9 and A10:

sample size n = 10, confidence level $1-\alpha = 0.9$, H_R ..cumulated probability of sample

Sort experimental results R ascending order [N]			Distribution function of population	
	R	H_R		
1	90.7	0.05	$\nu = 0.073 < 0.134$	
2	94.9	0.15		
3	95.2	0.25	$P(R)^*_{1-\alpha} = d \cdot \left\{ 1 - \exp\left[-\left(\dfrac{R-a}{b} \right)^c \right] \right\}$	
4	96.0	0.35		
5	101.2	0.45	$a = 101.3 - 7.437 \cdot 7.40 = 46.3$	
6	101.3	0.55		
7	101.7	0.65	$c = 7.1614$	
8	107.4	0.75		
9	111.4	0.85	$b = 7.367 \cdot 7.40 = 54.5$	
10	112.9	0.95		
Mean value $\mu := \overline{R} = $ **101.3**			$d = \left\{ 1 - \exp\left[-\left(\dfrac{112.9 - 46.3}{54.5} \right)^{7.1614} \right] \right\}^{-1} = 1.015$	
Standard dev. $\sigma := S = $ **7.40**				
COV $\nu = $ **0.073**			Remark: $R_{max} = R_{10} = 112{,}9$	

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