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EAD **330499-02-0601**

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European Assessment Document for

Bonded fasteners and bonded expansion fasteners for use in concrete

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

Contents

1 SCOPE OF THE EAD

1.1 Description of the construction product

This EAD covers bonded fasteners (BF) as well as bonded expansion fasteners (BEF) consisting of a bonding material and an embedded steel element placed in pre-drilled holes perpendicular to the surface (maximum deviation 5°) in concrete and anchored therein primarily by means of bond (BF) and bond and expansion forces (BEF). These fasteners are often used to connect structural elements and non-structural elements to structural components.

The embedded steel element (also called steel insert) may be a threaded rod, deformed reinforcing bar, internal threaded sleeve or other shape made of carbon steel, stainless steel or malleable cast iron.

The EAD applies also for threaded rods supplied by a party other than the manufacturer of the bonding material (commercial rods), if the material properties defined in the ETA are kept.

This EAD covers fasteners with an internal thread with a thread length of at least d + 5 mm.

This EAD applies to fasteners with the following dimensions:

- Minimum thread size of 6 mm (M6),
- Minimum embedment depth $h_{ef,min}$ larger or equal to 40 mm and larger or equal to 4 d; maximum embedment depth $h_{ef,max}$ smaller or equal to 20 d.

Note: The stated limit for the maximum embedment depth of 20 d is in accordance with EN 1992-4 [4][1]. For deeper embedment a constant distribution of bond stress over the embedment depth cannot be readily assumed.

BF are distinguished according to the operating principles, mixing techniques and installation techniques, which are outlined below.

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

Types and operating principles of fasteners

This EAD covers BF and BEF with the following mixing and installation techniques and operating principles:

<u>Mix proportions</u>

Only those fasteners in which the mix proportions are controlled by the packaging of the bonding material are covered. This includes, for example, the following types: glass capsule, soft-skin capsule, pre-packed injection (coaxial or side by side) cartridges or foil pack systems, bulk with mechanical proportioning and bulk where all components are mixed exactly as supplied.

Systems where the mix proportions are controlled by the installer, such as the bulk type where component volumes have to be measured by the installer, are not covered.

<u>Mixing techniques</u>

- controlled by the fastener system, e.g., injection cartridge with static mixer nozzle, bulk type with mechanical mixing,
- controlled by the installer - e.g., bulk type mixed in the pot with pre-determined controlled proportioning and mixing of all components,
- controlled during installation - e.g., capsule type.

<u>Volume of placed bonding material</u>

- controlled by the fastener, e.g., capsule type,
- controlled by the installer, e.g., injection and bulk types.

<u>Drilled hole</u>

- cylindrical hole,
- undercut hole.

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

Drilling techniques

- rotary hammer (electric drilling machine or driven by compressed air), including hollow drilling (rotary hammer drilling using a hollow drill bit with continuous vacuuming of the drilling dust); also referred to as "extraction drilling",
- diamond drilling.

Installation techniques

- Capsule placed in the hole and the steel elements driven by machine with simultaneous hammering and turning (Figure 1.1.1),
- Bonding material injected into the hole. Steel elements may be inserted manually or mechanically (Figure 1.1.2),
- Bonding material poured into the hole and steel elements inserted (Figure 1.1.3).

Installation of the fastener may be independent of torque control or dependent on torque control.

Operating principles

- BF: placed in cylindrical hole and anchored by bonding the steel elements to the sides of the drilled hole,
- BEF: placed into a cylindrical hole; the load transfer is a combination of bonding and expansion, where the expansion is achieved by a special rod. This type of fastener is also known as torque-controlled bonded fastener.

Examples of installation techniques for BF are given in Figure 1.1.1 to Figure 1.1.3. The same installation techniques apply to BEF.

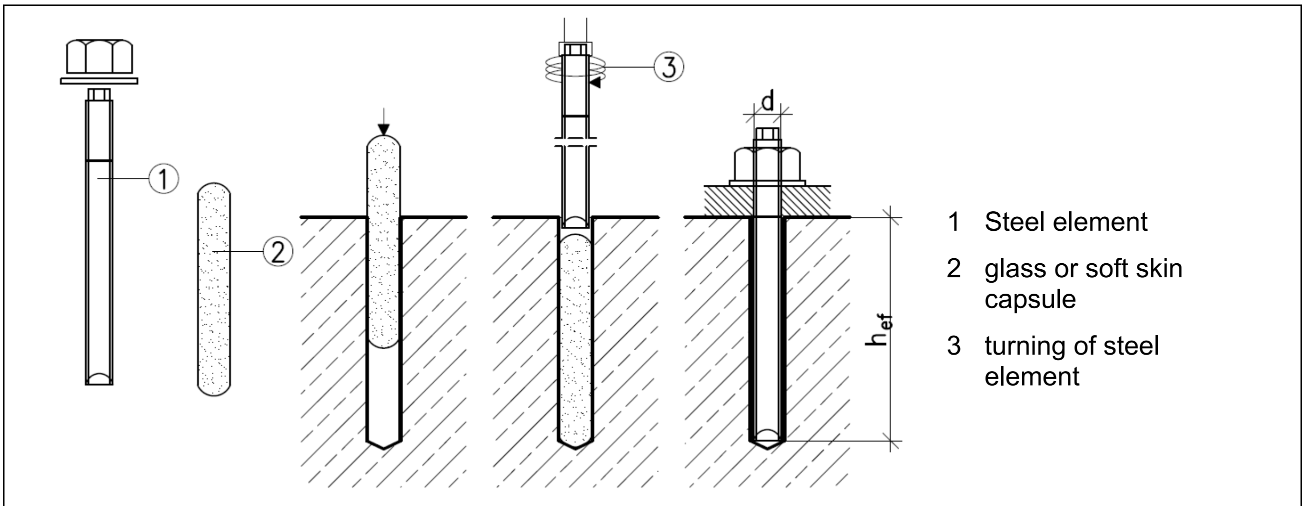


Figure 1.1.1 Capsule type

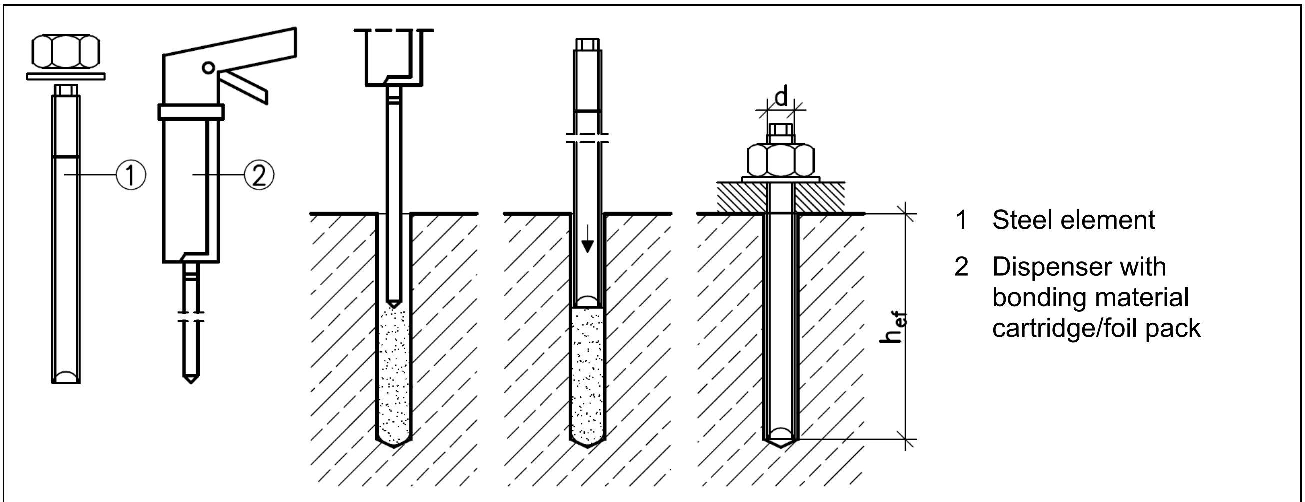


Figure 1.1.2 Injection type

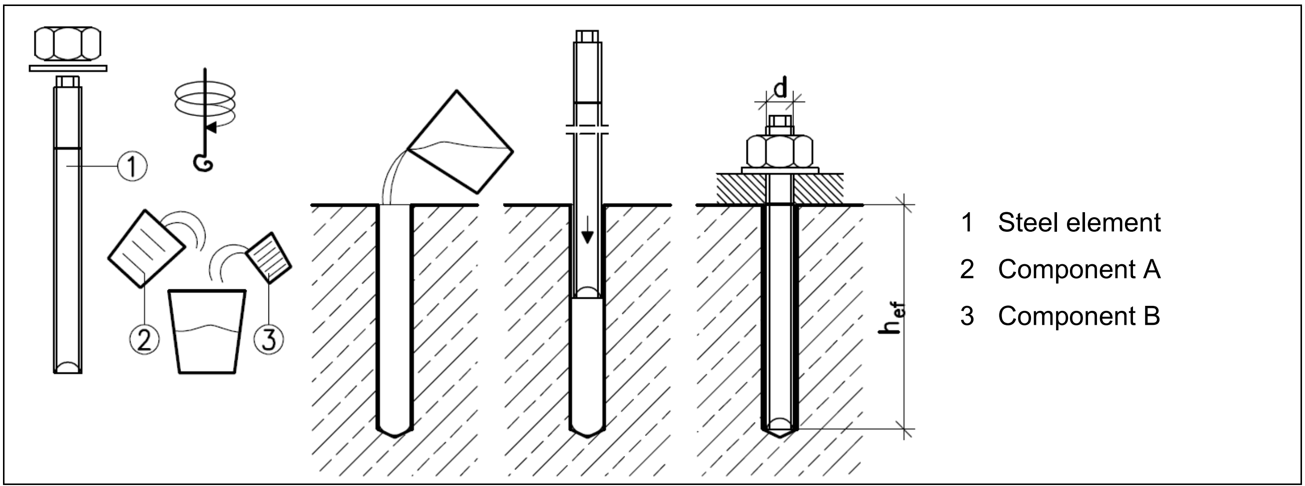


Figure 1.1.3 Bulk type

In this EAD the assessment is made to determine performance of bonded fastener BF and BEF which are needed as input for determination of mechanical resistance for calculation according to EN 1992-4 [4].

The performances which are assessed for fasteners in normal weight concrete without fibres can also be used as input for determination of mechanical resistance for calculation according to EN 1992-4 [4] for fasteners in steel fibre reinforced concrete (SFRC) with conditions given in clause 2.2.11.

Note: For other determination of mechanical resistance additional test series may be required which are not covered by this EAD (such as tests under combined tension and shear load, tests with groups of fasteners for characteristic spacing in tension and shear, etc.).

In addition to EAD 330499-01-0601 the following new assessments are added:

- Assessment of characteristic resistance in concrete C12/15 to C90/105 in accordance with EN 1992-4 [4],
- Assessment of characteristic resistance in steel fibre reinforced concrete,
- Assessment of characteristic resistance to fire exposure for BF,
- Integration of the new performance $\psi^0_{sus,100}$ (for working life up to 100 years) according to EAD 330499-01-0601-v01 [26],
- Improvement of description of assessment to ensure better reproducibility of test results.

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 product installation instructions MPII 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

BF and BEF are placed into pre-drilled holes for use in compacted reinforced or unreinforced normal weight concrete with strength classes in the range C12/15 to C90/105 all in accordance with EN 206 [1].

The fastener is intended for the following categories of uses (the use conditions):

- in uncracked concrete only (Table 1.2.1.1, option 7 – 12),
- in cracked and uncracked concrete (Table 1.2.1.1, option 1 – 6),
- under static or quasi-static actions in concrete of strength classes C12/15 to C90/105,
- under seismic actions (category C1, C2 according to Annex E) in concrete of strength classes C20/25 to C50/60,
- for use in steel fibre reinforced concrete in C20/25 to C50/60 with steel fibres in accordance with EN 14889-1 [23],
- for use with requirements related to resistance to fire for BF in C20/25 to C50/60.

Fasteners intended for use under impact loading (e.g., fasteners for the attachment of fall arresting devices) or fatigue loading are beyond the scope of this EAD and, therefore, not covered here.

The loading on the fastener resulting from actions on the fixture (e.g., tension, shear, bending or torsion moments or any combination thereof) will generally be axial tension or shear. When the shear force is applied with a lever arm, a bending moment on the fastener will arise. It is presumed, that compressive forces acting in the axis of the fastener are transmitted by the fixture directly to the concrete without acting on the fastener's load transfer mechanism.

The fastener is intended to be used under the following conditions:

<u>Concrete condition at time of installation of the fastener</u>:

I1 = installation in dry or wet (water saturated) concrete and use in service in dry or wet concrete;

I2 = installation in water-filled drill holes (not sea water) and use in service in dry or wet concrete.

Water-filled holes are pre-drilled holes (with drilling and cleaning according to the manufacturer's product installation instructions MPII), which are afterwards filled with water (e.g., overnight rain in outdoor applications). Underwater installation is different to this condition as the water pressure has to be accounted for and is therefore not covered in this EAD.

<u>Installation direction</u>:

D1 = downward only,

D2 = downward and horizontal installation,

D3 = downward and horizontal and upwards (e.g., overhead) installation.

<u>Installation temperature:</u>

The product is intended to be used for a range of temperatures during installation and curing of the bonding material in the concrete between minimum installation temperature not lower than -40 °C and the maximum installation temperature not higher than +40°C.

The installation under freezing conditions (< 0°C) is further detailed either as standard variation of temperature or rapid variation of temperature after installation. Standard variation temperature is defined as temperature variation within a time period longer than 12 hours from a low temperature less than 0 °C to a high temperature of +24 °C or more while rapid variation temperature is defined as temperature variation within a 12-hour period from a low temperature less than 0 °C to a high temperature of +24 °C or more.

Service temperature:

The product is intended to be used for service temperature ranges of the concrete during the working life as

T1: 24°C/40°C = temperature range from -40°C to +40°C, with a maximum long-term temperature of +24°C, and a maximum short-term temperature of +40°C,

T2: 50°C/80°C = temperature range from -40°C to +80°C, with a maximum long-term temperature of +50°C, and a maximum short-term temperature of +80°C,

T3: T_{mlt}/T_{mst} = possible other or additional temperature range from -40°C to $+T_{mst}$, with a maximum long-term temperature T_{mlt} = 0,6 to 1,0 T_{mst}, and a maximum short-term temperature of $T_{mst} \geq 40°C$ depending on the temperature range the product is intended for.

Note: Another temperature range T3 the maximum short-term temperature T_{mst} and the maximum long-term temperature T_{mlt} shall be assessed only in case of an application of the manufacturer.

Concrete:

The product is intended for the use in hardened concrete at least 21 days old.

The thickness of the concrete member in which the fastener is installed is $h \geq h_{ef} + \Delta h$ and $h \geq 80$ mm, with $\Delta h \geq 2\ d_0$ and $\Delta h \geq 30$ mm.

Note: Performance characteristics need to be consistent with the design provisions to achieve the required safety of the fastening application. For other determination of mechanical resistance than given in EN 1992-4 modified or additional performance characteristics may be necessary.

Base materials such as screeds or non-structural toppings can have properties that are uncharacteristic of the concrete and can be excessively weak. Therefore, fastenings in these base materials are not covered in this EAD.

Environmental conditions:

(1) 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) Fasteners for use according to EN 1993-1-4 [14], Annex A:

The intended use regarding environmental conditions of fasteners made of stainless-steel results from its corrosion resistance class (CRC) according to EN 1993-1-4 [14], Tables A.3 and A.4, in connection with EN 1993-1-4 [14], Tables A.1 and A.2.

Options for the intended use

According to the intended use the manufacturer may choose one of the options given in Table 1.2.1.1.

Table 1.2.1.1 Options for intended use covered by this EAD

<table>
<tr><th>Option</th><th>Cracked concrete</th><th>uncracked concrete</th><th>Resistance to fire</th><th>One value for all concrete strengths</th><th>Different values for different concrete strength classes</th><th>One value for load direction</th><th>Tension and shear capacity</th><th>c_{cr} / s_{cr}</th><th>c_{min} / s_{min}</th><th>Method 1)</th></tr>
<tr><td>1</td><td rowspan="6">✓</td><td rowspan="6">✓</td><td rowspan="6">✓</td><td>✗</td><td>✓</td><td rowspan="2">✗</td><td rowspan="2">✓</td><td rowspan="4">✓</td><td rowspan="4">✓</td><td rowspan="2">A</td></tr>
<tr><td>2</td><td>✓</td><td>✗</td></tr>
<tr><td>3</td><td>✗</td><td>✓</td><td rowspan="4">✓</td><td rowspan="4">✗</td><td rowspan="2">B</td></tr>
<tr><td>4</td><td>✓</td><td>✗</td></tr>
<tr><td>5</td><td>✗</td><td>✓</td><td rowspan="2">✓</td><td rowspan="2">✗</td><td rowspan="2">C</td></tr>
<tr><td>6</td><td>✓</td><td>✗</td></tr>
<tr><td>7</td><td rowspan="6">✗</td><td rowspan="6">✓</td><td rowspan="6">✗</td><td>✗</td><td>✓</td><td rowspan="2">✗</td><td rowspan="2">✓</td><td rowspan="4">✓</td><td rowspan="4">✓</td><td rowspan="2">A</td></tr>
<tr><td>8</td><td>✓</td><td>✗</td></tr>
<tr><td>9</td><td>✗</td><td>✓</td><td rowspan="4">✓</td><td rowspan="4">✗</td><td rowspan="2">B</td></tr>
<tr><td>10</td><td>✓</td><td>✗</td></tr>
<tr><td>11</td><td>✗</td><td>✓</td><td rowspan="2">✓</td><td rowspan="2">✗</td><td rowspan="2">C</td></tr>
<tr><td>12</td><td>✓</td><td>✗</td></tr>
</table>

1) Method according to EN 1992-4 [4]

Option 1-6 are intended for use with requirements related to resistance to fire, because concrete usually cracks under fire exposure.

Use of fastener in fastener groups according to EN 1992-4 [4]:

Use of fastener groups only, if all fasteners of the group show a similar displacement under load. The criteria for load-displacement behaviour are given in clauses 2.2.2 and 2.2.5. Only in case these criteria are met the use of the fasteners in fastener groups is covered by [4].

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 BF and BEF for use in concrete for the intended use of 50 years and/or 100 years[2] when installed in the works (provided that the BF and BEF for use in concrete are 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[3].

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 TAB 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.

2 Based on the application of the manufacturer the assessment may be based on 50 years working life (assessment according to clause 2.2), or based on 100 years working life (clause 2.2 and Annex Annex C) or both 50 and 100 years working life

3 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 the assumed working life.

1.3 Specific terms used in this EAD

1.3.1 Abbreviations

BEF	=	bonded expansion fastener
BF	=	bonded fastener
C1	=	seismic performance category C1 (use in design according to EN 1992-4 [4])
C2	=	seismic performance category C2 (use in design according to EN 1992-4 [4])
Cv	=	coefficient of variation
F	=	Force
MPII	=	manufacturer's product installation instructions as published
N	=	normal force
SFRC	=	Steel Fibre Reinforced Concrete: concrete specified in accordance to EN 206 [1] with steel fibres according to EN 14889-1 [23] added to the mix (concrete matrix); residual flexural strength is determined in accordance with EN 14651 [22].
STC	=	Standard Temperature/Time curve
t	=	time
V	=	shear force

1.3.2 Notation

a,b	=	constants (tuning factors), evaluated by a regression analysis of the deformations measured during the sustained load tests
a_s	=	distance between fastener and nearest reinforcement bar (see Figure D.3.1.2.6.2)
A_5	=	percentage elongation after fracture (measured over a length of 5d)
A_g	=	cross section area of the concrete member used in a test
A_s	=	relevant stressed cross section of the embedded steel element+
A_{sp}	=	projecting area according to Figure 2.2.6.2
c_{cr}	=	characteristic edge distance
$c_{cr,N}$	=	characteristic edge distance for concrete cone failure in tension
$c_{cr,sp}$	=	characteristic edge distance for concrete splitting
$c_{cr,V}$	=	characteristic edge distance for concrete edge failure in shear
c_{min}	=	minimum edge distance
C_{ini}	=	initial centric compression force on concrete test member in test series C2.5
C_{test}	=	centric compression force on concrete test member during crack cycling in test series C2.5
cv_F (cv_δ)	=	coefficient of variation of failure loads (of displacements)
d	=	diameter of the steel element
d_0	=	nominal drill hole diameter

d_{cut}	=	drill bit diameter
d_f	=	diameter of the clearance hole of the fixture
d_{nom}	=	outside diameter of fastener for calculation of concrete edge failure
d_s	=	diameter of the reinforcing bar (see Figure D.3.1.2.6.3)
$f_{bm}(\theta)$	=	fitting curve adopted for the evaluation of the product according to EAD 330087-01-0601 [27]
$f_{c,i}$	=	mean compressive strength of concrete in test series i
f_{ck}	=	characteristic minimum concrete strength measured on cylinders according to EN 206 [1], Table 12
f_{cube}	=	concrete compressive strength measured on cubes with a side length of 150 mm
$f_{c,t}$	=	compressive strength of concrete at the time of testing
$f_{u,t}$	=	mean ultimate tensile steel strength of the batch for the tested fastener
f_{uk}	=	Nominal characteristic steel ultimate tensile strength as specified in the technical specification of the manufacturer for the fastener [N/mm²]
f_{yk}	=	Nominal characteristic steel yield strength as specified in the technical specification of the manufacturer for the fastener [N/mm²]
h	=	thickness of the concrete member
h_{iz}	=	interaction zone between fastener and concrete
h_{ltz}	=	effective load transfer zone of fasteners
h_{nom}	=	overall fastener embedment depth in the concrete
h_{ef}	=	effective embedment depth
$h_{ef,red}$	=	reduced effective embedment depth according to Figure A.2.1
h_{min}	=	minimum thickness of concrete member in which the fastener is installed
h_{sl}	=	thickness of slice, measured values
k	=	factor for Equation (2.2.6.1)
k_{cr}	=	factor for resistance to concrete failure cracked concrete
$k_{p,fi}(\theta)$	=	reduction factor for bond resistance under fire conditions
k_{sus}	=	factor for beneficial long-term effects
k_{ucr}	=	factor for resistance to concrete failure uncracked concrete
k_7	=	factor for ductility of the fastener
k_8	=	factor for calculation of characteristic resistance for pryout failure
ℓ_b	=	bond length (see Figure D.3.1.2.6.3)
ℓ_{db}	=	de-bonding length (see Figure D.3.1.2.6.3)
ℓ_f	=	effective length of fastener in shear loading (for calculation resistance for concrete edge failure)
$M^0_{Rk,s}$	=	characteristic resistance for steel failure with lever arm

$M^0_{Rk,s,fi(t)}$	=	characteristic shear resistance in case of shear load with lever arm at a given time t of exposure to fire conditions
m	=	normalisation exponent taking into account the effect of concrete strength on the resistance
n	=	number of tests in a test series
n_{test}	=	total number of tests for bond resistance at simulated fire conditions (tests according to Table A.1.1, line F2)
N_{C1}	=	maximum tension load to be applied in the seismic tension test series C1.1
N_i	=	intermediate tension load to be applied in the seismic tension test series C1.1
N_m	=	minimum tension load to be applied in the seismic tension test series C1.1
$N^0_{Rk,sp}$	=	characteristic resistance to concrete splitting under tension load
n_{cyc}	=	number of cycles
$N_{1,3Tinst,m}$	=	mean values of pre-stressing force of the embedded steel element at 1,3 T_{inst}
$N_{1,3Tinst,95\%}$	=	95 % fractile of pre-stressing force of the embedded steel element at 1,3 T_{inst}
N_{max}	=	upper load in repeated (pulsating) load tests
N_{min}	=	lower load in repeated load tests
N_p (τ_p)	=	load (stress) applied on the fastener during crack cycling tests
$N_{p,red}$ ($\tau_{p,red}$)	=	reduced load (stress) applied on the fastener during crack cycling tests
N_{Rk}	=	characteristic tension resistance as given in the ETA
$N_{Rk,c}$	=	characteristic concrete cone resistance in cracked concrete given in the ETA for static loading
$N_{Rk,p}$	=	characteristic tension pull-out resistance given in the ETA for static loading
$N_{Rk,s}$	=	characteristic steel tension resistance given in the ETA for static loading
$N_{Rk,s,fi(t)}$	=	characteristic tension resistance in case of steel failure at a given time t of exposure to fire conditions
$N_{Rk,p,Cx}$	=	characteristic tension pull-out resistance under seismic action reported in the ETA for seismic performance category C1, C2
$N_{Rk,p,fi}$	=	characteristic tension pull-out resistance under fire exposure
$N_{Rk,s,Cx}$	=	characteristic steel tension resistance under seismic action reported in the ETA for seismic performance category C1, C2
N_{test}	=	tension load applied in tests for bond strength at simulated fire conditions
N_{sust}	=	load applied on a fastener during sustained load test or freeze/thaw test
N_u	=	measured maximum ultimate load
N_{w1}	=	tension load to be applied in the serviceability range ($\Delta w \leq$ 0,5 mm) of the varying crack width test series C2.5
N_{w2}	=	tension load to be applied in the suitability range (0,5 mm < $\Delta w \leq$ 0,8 mm) of the varying crack width test series C2.5
$N_{u,adh}$	=	load at loss of adhesion (see Figure A.2.2.1.1 to Figure A.2.2.1.4)
$N_{u,m}$ ($N_{5\%}$)	=	mean (5 % fractile of) failure load in tests

$N_{u,t}$	=	maximum load (failure load) in a test
$N_{Ru,m,r}$ ($N_{5\%,r}$)	=	mean (5 % fractile of) failure load in the corresponding reference test series
$N_{Ru,m,mlt}$ ($N_{5\%,mlt}$)	=	mean (5 % fractile of) failure load at maximum long-term temperature
$N_{Ru,m,mst}$ ($N_{5\%,mst}$)	=	mean (5 % fractile of) failure load at maximum short-term temperature
s_{cr}	=	characteristic spacing
$s_{cr,N}$	=	characteristic spacing for concrete cone failure in tension
$s_{cr,sp}$	=	characteristic spacing for concrete splitting
$s_{cr,V}$	=	characteristic spacing for concrete edge failure in shear
s_{min}	=	minimum spacing
s_o	=	initial displacement under the sustained load at t=0 (measured directly after applying the sustained load)
max t_{fix}	=	maximum thickness of the fixture as requested by the manufacturer
$T_{i,min}$	=	minimum concrete temperature at the time of installation of the fastener as specified by the manufacturer
$T_{i,max}$	=	maximum concrete temperature at the time of installation of the fastener as specified by the manufacturer
max T_{inst}	=	maximum torque specified by the manufacturer for BF for fixing the attachment
T_{inst}	=	installation torque specified by the manufacturer for a BEF
t_{fix}	=	thickness of fixture
T_{mlt}	=	maximum long-term temperature
T_{mst}	=	maximum short-term temperature
t_u	=	time to failure in tests under fire exposure
V_{C1}	=	maximum shear load to be applied in the seismic shear test series C1.2
V_i	=	intermediate shear load to be applied in the seismic shear test series C1.2
V_m	=	minimum shear load to be applied in the seismic shear test series C1.2
V_{max}	=	maximum shear load to be applied in the alternating shear load test series C2.4
$V^0_{Rk,s}$	=	characteristic shear resistance for steel
$V_{Ru,m}$	=	mean value of failure loads in shear tests
$V_{5\%}$	=	5 % fractile of failure loads in shear tests
$V_{Rk,s}$	=	characteristic steel shear resistance given in the ETA for static loading
$V_{Rk,s,fi(t)}$	=	characteristic shear resistance in case of steel failure at a given time t of exposure to fire conditions
$V_{Rk,s,Cx}$	=	characteristic steel shear resistance under seismic action reported in the ETA for seismic performance category C1, C2

$V_{u,m}$	=	mean shear capacity
w_{ini}	=	initial crack width after applying N_{w1} in test series C2.5
W_{el}	=	elastic section modulus calculated from the stressed cross section of the embedded steel element
α	=	reduction factor, see Equation (A.2.1.7.1)
α_{ref}	=	factor taking into account sensitivity to different concrete batches according to Equation (A.2.1.4.2)
α_{setup}	=	factor taking into account the influence of confined test setup
α_1	=	criteria for loss of adhesion, see Equation (A.2.2.1.1)
α_2	=	ratio according to Equation (2.2.2.9.1), tests at maximum long-term temperature
α_3	=	ratio according to Equation (2.2.2.9.2), tests at maximum short-term temperature
α_4	=	ratio according to Equation (2.2.2.12.1), tests for checking durability of bonding material
α_p	=	reduction due to applied tension load during tests
$\alpha_{C2.x}$	=	reduction factor resulting from assessment of test series C2.x
$\alpha_{N,Cx}$	=	seismic reduction factor for tension resistance for seismic performance category C1, C2
$\alpha_{V,Cx}$	=	seismic reduction factor for shear resistance for seismic performance category C1, C2
rqd. α	=	required value for reduction factor α in the assessment
$\beta_{cv,C2.x}$	=	reduction factor resulting from large coefficients of variation in test series C2.x
$\beta_{cv,N}$	=	reduction factor for tension resistance resulting from large coefficients of variation
$\beta_{cv,V}$	=	reduction factor for shear resistance resulting from large coefficients of variation
β_{cv}	=	reduction factor for large scatter of failure loads
γ_{inst}	=	factor accounting for the sensitivity to installation (used in design according to EN 1992-4 [4])
γ_{Mc}	=	partial factor for concrete failure (to be given in the ETA)
$\delta(N)$	=	displacement of the fastener measured at tension load value N
$\delta_{N,lim}$	=	displacement limit corresponding to excessive displacement of the fastener in the assessment of the results of test series C2.3 and C2.5
$\delta_{N,C2}$	=	displacement of the fastener associated with the seismic test series C2.3 and C2.5
$\delta_{V,lim}$	=	displacement limit corresponding to excessive displacement of the fastener in the assessment of the results of test series C2.4
$\delta_{V,C2}$	=	displacement of the fastener associated with the seismic test series C2.4
δ_0	=	displacement of fastener under short-term loading
δ_∞	=	long-term displacement of fastener
δ_{20}	=	displacement of the fastener after 20 crack cycles

δ_{1000}	=	displacement of the fastener after 1000 crack cycles
$\delta_{N\infty}$	=	long-term tension displacement
$\delta_{N,\infty,m}$	=	mean value of the extrapolated displacements in the sustained load test at normal ambient temperature
$\delta_{1000,mean}$	=	mean fastener displacement after 10^3 crack movements
$\delta_{um,adh}$	=	mean displacement in tests at loss of adhesion.
Δw	=	crack width (in addition to the width of the hairline crack)
Δw_1	=	maximum crack width in the crack movement test
Δw_2	=	minimum crack width in the crack movement test
Δw_{hef}	=	crack width at embedment depth h_{ef}
Δw_{top}	=	crack width at the top side of the test member in which the fastener is installed
Δw_{bot}	=	crack width at the bottom side of the test member in which the fastener is installed
θ	=	temperature in the tests for bond resistance at simulated fire conditions (tests according to Table A.1.1, line F2)
θ_k	=	temperature in the tests for bond resistance at simulated fire conditions (tests according to Table A.1.1, line F2) up to which the mortar maintains the full capacity
θ_{max}	=	maximum temperature in the tests for bond resistance at simulated fire conditions, beyond which the bond resistance of the mortar is considered zero.
$\sigma_{Rk,s,fi(t)}$	=	characteristic tension strength of a fastener in case of steel failure a given time t of exposure to fire conditions
$\tau_{5\%}$	=	initial characteristic bond strength for Equation (2.2.2.14.2)
τ_p	=	acting stress on the fastener in crack cycling tests
$\tau_{Rk,cr}$	=	characteristic bond resistance for cracked concrete C20/25 for working life of 50 years
$\tau_{Rk,cr,fi}$	=	characteristic bond resistance under fire exposure in cracked concrete
$\tau_{Rk,ucr}$	=	characteristic bond resistance for uncracked concrete C20/25 for working life of 50 years
$\tau_{Rk,100,cr}$	=	characteristic bond resistance for cracked concrete C20/25 for working life of 100 years
$\tau_{Rk,100,ucr}$	=	characteristic bond resistance for uncracked concrete C20/25 for working life of 100 years
$\tau_{Rk,fi}(\theta)$	=	characteristic bond resistance for cracked concrete under fire exposure for a given temperature (θ)
$\tau_{Ru,m}(\theta)$	=	mean bond resistance of the mortar in the tests for bond resistance at simulated fire conditions (tests according to Table A.1.1, line F2)
$\tau_{Ru,m,ucr,21}$	=	mean bond resistance of the mortar in the 3 reference tests for bond resistance at simulated fire conditions (tests according to 2.2.18)
$\tau_{Rk,Cx}$	=	characteristic seismic bond resistance reported in the ETA for seismic performance category C1, C2

τ_{Ru}	=	bond strength at normal ambient temperature
$\tau_{Ru,m,B18}$	=	mean bond strength in test series B18
$\tau_{Ru,m,B19}$	=	mean bond strength in test series B19
$min\ \tau_{Ru,m,r,12}$	=	minimum value of average bond strength of all reference test series with diameter d = 12 mm normalized to minimum concrete strength, see Equation (A.2.1.4.2)
$\tau_{Ru,r,i}$ $(\tau_{5\%,r,i})$	=	mean (5 % fractile) of bond resistance of the corresponding reference test carried out in the same concrete member i or same batch
$\tau_{Ru,t,i}$ $(\tau_{5\%,t,i})$	=	mean (5 % fractile) of bond strength in test series t in concrete member i
$\tau_{Ru,m,i,12}$	=	mean bond resistance of reference test with diameter d = 12 mm carried out in the same concrete member or same batch as those used for the reference tension tests R1 to R4 or A1 to A4 normalized to minimum concrete strength
τ_{Rk}	=	characteristic bond resistance
τ_{test}	=	bond resistance applied in tests for bond resistance at simulated fire conditions
$\tau_{test,i}$	=	bond resistance applied in tests for bond resistance at simulated fire conditions at the i^{th} point
$\tau_{um}(\theta_i)$	=	calculated bond resistance determined according to adopted fitting curve in the tests for bond resistance at simulated fire conditions (tests according to Table A.1.1, line F2) based on the temperature of the i^{th} point
ψ_c	=	increasing factor accounting for concrete strength
ψ^0_{sus}	=	reduction factor for long-term bond resistance at maximum long-term temperature for working life of 50 years
$\psi^0_{sus,100}$	=	reduction factor for long-term bond resistance at maximum long-term temperature for working life of 100 years

1.3.3 Indices

21	=	at normal ambient temperature
100	=	working life of 100 years according to Annex C.
c	=	concrete
cr	=	cracked concrete;
conf	=	confined test setup
fi	=	fire
i	=	specific number of a test in a series.
LT	=	long-term with respect to assessment of bond strength
k	=	characteristic value
m	=	mean value
max	=	maximum
min	=	minimum
mlt	=	maximum long-term temperature of the concrete
mst	=	maximum short-term temperature of the concrete
p	=	pull-out

R	=	resistance
r	=	reference
s	=	steel
sust	=	sustained (permanent)
t	=	test
u	=	ultimate
ucr	=	uncracked concrete
unconf	=	unconfined test setup

1.3.4 Definitions

anchor	=	historically synonymous to fastener
component installation temperature range	=	temperature range of the bonding material and steel element immediately prior to installation.
confined test setup	=	close spacing of the support according to Figure D.3.1.4.1
curing time	=	the minimum time from the end of mixing to the time when the fastener may be torqued or loaded (whichever is longer). The curing time depends on the concrete temperature.
dry concrete	=	concrete cured under normal ambient conditions
fastener	=	steel element made of steel or malleable iron post-installed into hardened concrete and used to transmit applied load; as defined in EN 1992-4 [4]
fastening	=	assembly of fasteners and fixture used to transmit load to the concrete
fixture	=	assembly that transmits loads to the fastener
flooded hole	=	used synonymous to water filled hole; this is not synonymous with under water condition (as the pressure of the water is not considered)
long-term temperature	=	temperature of the concrete 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 rooms that keep a constant temperature or next to heating installations
maximum short-term temperature	=	upper limit of the service temperature range
maximum long-term temperature	=	specified by the manufacturer within the range of 0,6 times to 1,0 times the maximum short-term temperature.
non-structural element	=	building element, the failure of which results in medium consequence for loss of human life and considerable economic, social or environmental consequences, but does not result in the failure of the structure or part of the structure; examples: façade element, piping (PM)
normal ambient temperature	=	temperature of the concrete 21 °C ± 3 °C (for test conditions only)

open time	=	maximum time from end of mixing to end of insertion of the steel element into the bonding material (for bulk type fasteners);
	=	maximum time from start of injection to end of insertion of the steel element into the bonding material (for injection type fasteners);
	=	maximum time for setting (insertion of the steel element) (for capsule type fasteners);
rebar	=	deformed reinforcing bar
service temperature range	=	range of ambient temperatures in the area of the fastener after installation and during the lifetime of the anchorage.
short-term temperature	=	temperature of the concrete within the service temperature range which vary over short intervals, e.g., day/night cycles and freeze/thaw cycles.
structural element	=	building element, the failure of which may result in the failure of the structure or part of the structure; examples: column, beam, concrete member
test member	=	concrete member in which the fastener is tested
unconfined test setup	=	wide spacing of the support according to Figure D.3.1.3.1
working time	=	synonymous to open time or gel time

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1.1 shows how the performance of BF and BEF for use in concrete is assessed in relation to the essential characteristics.

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

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability			
Characteristic resistance to tension load (static and quasi-static loading)			
1	Resistance to steel failure	2.2.1	$N_{Rk,s}$ [kN]
2	Resistance to combined pull-out and concrete failure	2.2.2, C.5	τ_{Rk} or $\tau_{Rk,100}$ [N/mm²], ψ_c, ψ^0_{sus}, $\psi^0_{sus,100}$ [-] (BF)
	Resistance to pull-out failure		$N_{Rk,p}$ or $N_{Rk,p,100}$ [kN], ψ_c [-] (BEF)
3	Resistance to concrete cone failure	2.2.3	$c_{cr,N}$ [mm] $k_{cr,N}$, $k_{ucr,N}$ [-]
4	Edge distance to prevent splitting under load	2.2.4	$c_{cr,sp}$ [mm]
5	Robustness	2.2.5	γ_{inst} [-]
6	Maximum installation torque	2.2.1.2	max T_{inst} [Nm] (BF)
	Installation torque	2.2.1.2	T_{inst} [Nm] (BEF)
7	Minimum edge distance, spacing and member thickness	2.2.6	c_{min}, s_{min}, h_{min} [mm]
Characteristic resistance to shear load (static and quasi-static loading)			
8	Resistance to steel failure	2.2.7	$V^0_{Rk,s}$ [kN], $M^0_{Rk,s}$ [Nm], k_7 [-]
9	Resistance to pry-out failure	2.2.8	k_8 [-]
10	Resistance to concrete edge failure	2.2.9	d_{nom}, ℓ_f [mm]
Displacements under short-term and long-term loading			
11	Displacement factors under short-term and long-term loading	2.2.10	δ_0, δ_∞ [mm/(N/mm²)] or [mm/kN]
12	Resistance in steel fibre reinforced concrete	2.2.11	Description
Characteristic resistance and displacements for seismic performance categories C1 and C2			
12	Resistance to tension for seismic performance category C1	2.2.12	$N_{Rk,s,C1}$ [kN] (all) $\tau_{Rk,C1}$ [N/mm²] (BF) $N_{Rk,p,C1}$ [kN] (BEF)
13	Resistance to tension and displacements for seismic performance category C2	2.2.13	$N_{Rk,s,C2}$ [kN] (all) $\tau_{Rk,C2}$ [N/mm²] (BF) $N_{Rk,p,C2}$ [kN] (BEF) $\delta_{N,C2(50\%)}$, $\delta_{N,C2(100\%)}$ [mm] (all)

No	Essential characteristic	Assessment method	Type of expression of product performance
14	Resistance to shear load for seismic performance categories C1	2.2.14	$V_{Rk,s,C1}$ [kN] (all)
15	Resistance to shear load and displacements for seismic performance categories C2	2.2.15	$V_{Rk,s,C2}$ [kN] (all) $\delta_{V,C2(50\%)}$, $\delta_{V,C2(100\%)}$ [mm] (all)
Basic Works Requirement 2: Safety in case of fire			
16	Reaction to fire	2.2.16	Class
Resistance to fire			
17	Fire resistance to steel failure under tension loading	2.2.17	Level $N_{Rk,s,fi}$ [kN]
18	Fire resistance to bond failure under tension loading	2.2.18	Level $k_{fi,p}$ (θ) [-] $\tau_{Rk,fi}$ (θ) [N/mm²] (BF)
19	Fire resistance to steel failure under shear loading	2.2.19	Level $V_{Rk,s,fi}$ [kN], $M^0_{Rk,s,fi}$ [Nm]
Basic Works Requirement 3: Hygiene, health and the environment			
20	Content, emission and release of dangerous substances	2.2.20	Description/level

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

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

This clause covers a working life of 50 years. Additional provisions for the assessment for working life of 100 years are given in Annex C.

An overview of the test program for the assessment of the various essential characteristics of the product is given in Annex A.

Provisions valid for all tests for BF and general aspects of the assessment (determination of 5 % fractile values of resistance, determination of reduction factors, criteria for uncontrolled slip, etc.) are also given in Annex A.

Provisions for BEF are given in Annex B.

2.2.1 Resistance to steel failure (tension)

2.2.1.1 Steel capacity (test series N1)

Purpose of the assessment

The characteristic resistance to steel failure may be calculated for steel elements with constant strength over the length of the steel element as given in Equation (2.2.1.1.1). The smallest cross section in the area of load transfer applies.

$$N_{Rk,s} = A_s \cdot f_{uk} \quad [N] \qquad (2.2.1.1.1)$$

Tests are needed only if

- The steel element is part of the manufacturer's product (CE marking) and the material properties deviate from standardized strength classes.
- The calculation of the characteristic resistance to steel failure is not reasonable because the distribution of the steel strength of the finished product along the length of the fastener is not known or cannot easily be determined.

Test conditions

Perform at least 5 steel tension tests with the finished product according to EN ISO 6892-1 [19].

Assessment

Determine the 5 %-fractile of the failure loads. This value shall be normalized to the specified nominal strength to account for over-strength of tested samples according to Equation (A.2.1.2.8).

Expression of results: Resistance to steel failure: $N_{Rk,s}$ [kN]

2.2.1.2 Installation torque (test series N2)

Purpose of the assessment

The tests are performed in order to verify that steel failure (yielding) of the steel element as determined in 2.2.1.1 is not affected by application of the installation torque T_{inst}.

Test conditions

The tests shall be performed according to D.3.5.

The tests are performed with all diameter sizes of the fastener in uncracked concrete of strength class C50/60.

The diameter of the clearance hole in the fixture shall correspond to the values given in Table 2.2.7.1.1.

Assessment

Failure loads

- Determine the mean value of the tension force $N_{1,3Tinst,m}$ [kN] and the 95 % fractile of the tension force $N_{1,3Tinst,95\%}$ [kN] at 1,3 T_{inst} (1,3 max T_{inst}, respectively).

Criteria

All following criteria shall be fulfilled.

1. The 95 %-fractile of the tension force generated in the torque tests at an installation torque T = 1,3 T_{inst} (1,3 max T_{inst}, respectively) shall be smaller than the nominal yield force ($A_s \cdot f_{yk}$) of the embedded steel element.
2. The 95 %-fractile of the tension force generated in the torque tests at T = 1,3 T_{inst} (1,3 max T_{inst}, respectively) shall be smaller than the characteristic resistance for pull-out failure for minimum embedment depth.

$$N_{Rk,p} = \pi \cdot d \cdot \min h_{ef} \cdot \tau_{Rk,ucr} \qquad (2.2.1.2.1)$$

3. The 95 %-fractile of the tension force generated in the torque test at T = 1,3 T_{inst} (1,3 max T_{inst}, respectively) shall be smaller than the characteristic concrete cone capacity according to EN 1992-4 [4] for minimum embedment depth for uncracked concrete C20/25 and for the lowest concrete strength class applied for.
4. At the end of the test, the connection shall be capable of being unscrewed.

Expression of results:

Maximum installation torque (BF): max T_{inst} [Nm],

Installation torque (BEF): T_{inst} [Nm]

2.2.2 Resistance to combined pull-out and concrete failure

2.2.2.1 Reference (test series R1 to R4)

Purpose of the assessment

These tests are performed to establish a reference for the assessment of the test series B1 to B5, B10 to B13 and B17 . The test series R1 to R4 are also performed to establish the increasing factor ψ_c accounting for concrete strength according to A.2.1.2. Furthermore, for Options 8, 10 and 12 according to Table 1.2.1.1 the test series R2 is used to assess the functioning in high strength concrete.

If unconfined tests for BF according to 2.2.2.2 are omitted, then the test series R1 to R4 shall be used to establish the initial characteristic bond strength to be used in 2.2.2.14 / 2.2.2.15.

In addition, reference tension tests (R1) on medium size (diameter 12 mm) as described in clause A.2 have to be performed to take into account the possible influence of different concrete parameters (in various batches) on the failure load.

Test conditions

The tests are performed with confined test setup according to Annex D.

For the assessment of tests in 2.2.2.11 the reference test R1 shall be performed with a "long curing time", i.e., 24 hours for resins and 14 days for cementitious mortars.

Test series R3 and R4 may be omitted if the intended use of the product is for uncracked concrete only (Option 7 to 12 according to Table 1.2.1.1).

Assessment

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN] and bond strength $\tau_{u,m}$ [N/mm²], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- If the basic tension tests with unconfined test setup (2.2.2.2) are not performed, then determine the increasing factor $\psi_{c,50}$ according to Equation (A.2.1.2.7).
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN] and bond strength $\tau_{5\%}$ [N/mm²], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 15 % (cv_F > 15 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.
- If the 5 % fractile of failure loads in reference tests in concrete C50/60 (Line R2 or R4 of Table A.1.1) is smaller than the 5 % fractile of failure loads in the corresponding test series in concrete C20/25 (Line R1 or R3 of Table A.1.1), then the smaller value shall be assigned to the $\tau_{5\%}$ for minimum concrete strength in explanations for Equations (2.2.2.14.1) or (2.2.2.15.1) because concrete strength is a minimum value and by aging, concrete strength increases $\psi_{c,xx} \geq 1{,}0$).

Load displacement behaviour

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results:

$N_{5\%}$ [kN], $\tau_{5\%}$ [N/mm], ψ_c , $ß_{cv}$ [-], α_1, to be used in 2.2.2.14 / 2.2.2.15. $\delta_{0,5Nu,m}$ [mm], cv_δ [%]

2.2.2.2 Basic tension tests with unconfined test setup (test series A1 to A4)

Purpose of the assessment

The tests are required for determination of the following characteristics using the factor α_{setup} = 1,0.

- basic characteristic bond strength $\tau_{5\%}$ (see explanations for Equation (2.2.2.14.2)
- the increasing factors accounting for concrete strength ψ_c
- short-term displacement δ_{N0}

This test series may be omitted for BF if the characteristics given above are determined by confined test series R1 to R4.

Test conditions

The tests are performed with unconfined test setup according to D.3.1.3.

Assessment

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN] and bond strength $\tau_{u,m}$ [N/mm²], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Determine the increasing factor $\psi_{c,50}$ according to Equation (A.2.1.2.7).
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN] and bond strength $\tau_{5\%}$ [N/mm²], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 15 % (cv_F > 15 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.
- If the 5 % fractile of failure loads in reference tests in concrete C50/60 (Line A2 or A4 of Table A.1.1) is smaller than the 5 % fractile of failure loads in the corresponding test series in concrete C20/25 (Line A1 or A3 of Table A.1.1), then the smaller value shall be assigned to the $\tau_{5\%}$ for concrete C20/25 in explanations for Equations (2.2.2.14.1) or (2.2.2.15.1) because concrete strength is a minimum value and by aging, concrete strength increases $\psi_{c,xx} \geq 1,0$).

Load displacement behaviour

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results:

$\tau_{5\%}$ (BF), $N_{5\%}$ (BEF), ψ_c , α_{setup} [-], $ß_{cv,}$ α_1 [-] to be used in 2.2.2.14 / 2.2.2.15; $\delta_{0,5Nu,m}$ [mm], cv_δ [%]

2.2.2.3 Increased crack width (test series B10, B11, E6 and E7)

Purpose of the assessment

These tests are performed to assess the sensitivity of the fastener to a wide crack in the concrete passing through the location of the fastener. The test series may be omitted for fasteners intended to be used in uncracked concrete only (option 7-12).

Test conditions

The tests are carried out in low strength cracked concrete (test series B10) and high strength cracked concrete (test series B11), with a crack width of Δw = 0,5 mm. The tests with BF shall be carried out with confined test setup according to Figure D.3.1.4.1.

Assessment

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to paragraphs A.2.1.2 and A.2.1.4, respectively.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to paragraphs A.2.1.2 and A.2.1.4, respectively.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5..
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1.1 line R3 for tests in C20/25 and according to Table A.1.1 line R4 for tests in C50/60.

- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1.1, line R3, for tests in C12/15 and according to Table A.1.1, line R4, for tests in the highest concrete strength class.
- Determine the reduction (α/rqd. α) by using rqd. α = 0,8

Load displacement behaviour

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results: $ß_{cv,}$ (α/rqd. α), α_1 [-] to be used in 2.2.2.14 / 2.2.2.15.

2.2.2.4 Repeated loads (test series B12)

Purpose of the assessment

These tests are performed to determine the performance of BF under repeated loads simulating service loads that are subject to variation over time.

The tests may be omitted for fasteners intended to be used in cracked concrete (option 1-6 according to Table 1.2.1.1).

Test conditions

The tests shall be carried out in uncracked concrete according to clause D.3.3.3. The tests are performed as confined tests with diameter 12 mm or smallest size if that is larger than diameter 12 mm.

The maximum load N_{max} on the fastener shall be calculated as given in Equation (2.2.2.4.1) and the minimum load N_{min} is calculated according to Equation (2.2.2.4.2). The characteristic capacity $\tau_{Rk,ucr}$ in Equations (2.2.2.4.1) and (2.2.2.4.2) is likely not known at the start of the repeated load test series as it may depend on the results of these tests. Therefore, the tests can be performed with an assumed sustained load $N_{max,test}$, which is then properly accounted for in the assessment (in terms of the factor α_p). For the selection of the assumed sustained loads $N_{max,test}$ and $N_{min,test}$, available information from already conducted test series (e.g., reference test results $\tau_{5\%}$, (see Equation (2.2.2.14.3)) reduction factors α, α_2, α_3, α_4), as far as applicable, may be considered. If the factors cannot be estimated, it is recommended to perform the tests according to 2.2.2.1, 2.2.2.9 and 2.2.2.12 in advance.

Note: The required applied load for the test represents 110% of the design resistance of the fastener considering the given test conditions.

Consideration of results from already conducted test series allows for a selection of the assumed maximum and minimum loads closer to the target values. This may also reduce the testing effort.

If there is no experience, it is recommended to estimate N_{max} on a safe side, e.g. 80% of $\tau_{5\%}$. If the test criteria are passed, then an optimization may be done with tests on a higher level. A choice is to start on a higher level and accept a delay in time, if the tests must be repeated to pass the criteria.

The applied maximum load may limit the final characteristic capacity τ_{Rk}. Therefore, the assumed maximum load $N_{max,test}$ should be selected reasonably high. As a guidance value, the concrete cone resistance valid for the embedment depth to be tested and converted into a bond strength may be taken.

$$N_{max} = \frac{1{,}1 \cdot \tau_{\mathrm{Rk,ucr}} \cdot \pi \cdot \mathrm{d} \cdot \mathrm{h_{ef}}}{1{,}5 \cdot \gamma_{inst}} \cdot \frac{1}{\alpha_2} \cdot \frac{1}{\alpha_3} \cdot \frac{1}{\alpha_4} \quad (2.2.2.4.1)$$

$$N_{min} = \max(0{,}25\ \tau_{Rk,ucr} \cdot \pi \cdot d \cdot h_{ef};\ N_{max} - A_s \cdot \Delta\sigma_s) \quad (2.2.2.4.2)$$

where

$\Delta\sigma_s$ = 120 N/mm²

$\tau_{Rk,ucr}$ = characteristic bond strength as given in the ETA for use in uncracked concrete for normal ambient temperature

α_2 = reduction factor according to Equation (2.2.2.9.1)

α_3 = reduction factor according to Equation (2.2.2.9.2)

α_4 = reduction factor according to Equation (2.2.2.12.1)

Assessment

Displacements and applied load during repeated loading

During the repeated load portion of the test no failure is allowed to occur and the increase of displacements during the cycling shall stabilize in a manner that failure is unlikely to occur after some additional cycles. If these requirements are not met, then repeat the test with a reduced load N_{max} (and corresponding N_{min}) until the requirements are met.

The reduction factor is determined as follows:

$$\alpha_{p,B12} = \min(1{,}0; \frac{\tau_{suc}}{\tau_{Rk,0,ucr}}) \quad (2.2.2.4.3)$$

$$\tau_{suc} = N_{max} \cdot 1{,}5 \cdot \gamma_{inst} \cdot (\alpha_2 \cdot \alpha_3 \cdot \alpha_4) / (1{,}1 \cdot \pi \cdot d \cdot h_{ef}) \quad (2.2.2.4.4)$$

where

τ_{suc} = bond strength corresponding to the maximum load applied in successful test series B12

N_{max} = maximum load $N_{max,test}$ applied in the test series fulfilling the stabilization of displacements during repeated loads

$\tau_{Rk,0,ucr}$ = basic value $\tau_{Rk,0}$ determined according to Equation (2.2.2.14.2) at completion of all tests for uncracked concrete and temperature range T1

Failure loads in the residual load test

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1.1, line R1, for tests in C20/25 and with line R1 for tests in C12/15.
- Determine the reduction (α/rqd. α) by using rqd. α = 1,0

Load displacement behaviour in the residual load test

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results:

α_p, $ß_{cv,}$ (α/rqd. α), α_1 to be used in 2.2.2.14 / 2.2.2.15.

2.2.2.5 Crack cycling under load (test series B13, E8)

Purpose of assessment

Fasteners intended for use in cracked concrete, in the long-term, shall continue to function effectively when the width of the crack is subject to changes. The test series may be omitted for fasteners intended to be used in uncracked concrete only (option 7-12).

Test conditions

The tests shall be carried out in cracked concrete according to Annex D with loading details as of D.3.3.2.

The required constant tension load N_p shall be calculated from Equation (2.2.2.5.1). The characteristic capacity $\tau_{Rk,cr}$ in Equation (2.2.2.5.1) is likely not known at the start of the crack cycling test series as it may depend on the results of these tests. Therefore, the tests can be performed with an assumed constant load $N_{p,test}$, which is then properly accounted for in the assessment (in terms of the factor α_p). For the selection of the assumed constant load $N_{p,test}$, available information from already conducted test series (e.g., reference test results $\tau_{5\%}$, reduction factors α, α_2, α_3, α_4), as far as applicable, may be considered.

Note: The required applied load for the test represents approximately the maximum loading at serviceability level considering the given test conditions.

Consideration of results from already conducted test series allows for a selection of the assumed load closer to the target values. This may also reduce the testing effort.

The applied constant load may limit the final characteristic capacity τ_{Rk} ($N_{Rk,p}$). Therefore, the assumed constant load $N_{p,test}$ should be selected reasonably high. As a guidance value, the concrete cone resistance valid for the embedment depth to be tested and converted into a bond strength may be taken.

The sustained load N_p shall be applied with unconfined test setup.

$$N_p = \frac{0{,}75 \cdot \tau_{Rk,cr} \cdot \pi \cdot d \cdot h_{ef}}{1{,}5 \cdot \gamma_{inst}} \cdot \frac{1}{\alpha_2} \cdot \frac{1}{\alpha_3} \cdot \frac{1}{\alpha_4} \qquad (2.2.2.5.1)$$

where

$\tau_{Rk,cr}$ = characteristic bond strength as given in the ETA for use in cracked concrete for normal ambient temperature

For BEF replace the term ($\tau_{Rk,cr} \cdot \pi \cdot d \cdot h_{ef}$) by $N_{Rk,cr}$.

α_2 = reduction factor according to Equation (2.2.2.9.1)

α_3 = reduction factor according to Equation (2.2.2.9.2)

α_4 = reduction factor according to Equation (2.2.2.12.1)

The residual load test after crack movements shall be done as a confined test.

Assessment

Displacements and applied load during crack cycles

In each test the rate of increase of fastener displacements, plotted in a half-logarithmic scale (see Figure 2.2.2.5.1 shall either decrease or be almost constant: the criteria of the allowable displacement after 20 (δ_{20}) and 1000 (δ_{1000}) cycles of crack opening are graduated as a function of the number of tests as follows:

5 to 9 tests: $\delta_{20} \leq 2$ mm and $\delta_{1000} \leq 3$ mm

≥ 10 tests $\delta_{20,mean} \leq 2$ mm and $\delta_{20,max} \leq 3$ mm

$\delta_{1000,mean} \leq 3$ mm and $\delta_{1000,max} \leq 4$ mm

Where

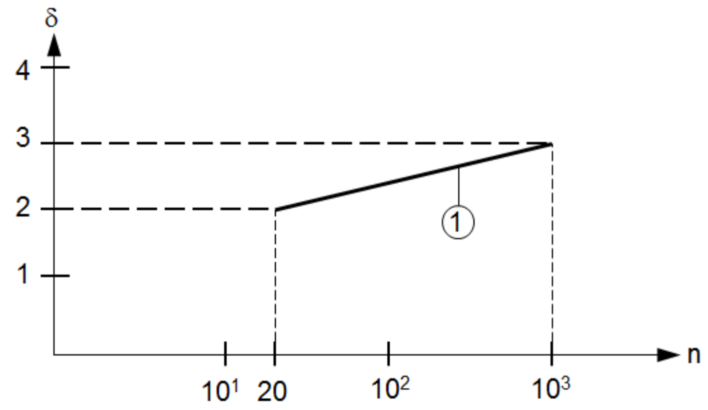
$\delta_{20,mean}$ mean displacement of all tests after 20 cycles

$\delta_{20,max}$ max displacement in one test after 20 cycles

$\delta_{1000,mean}$ mean displacement of all tests after 1000 cycles

$\delta_{1000,max}$ max displacement in one test after 1000 cycles

Note: The displacements are considered to be stabilized if the increase of displacements during cycles 750 to 1000 is smaller than the increase of displacements during cycles 500 to 750.



1 maximum allowable displacement

Figure 2.2.2.5.1 Criteria for results of tests with variable crack width

If in the tests the above given requirements on the displacement behaviour, i.e., rate of increase and allowable displacements, are not fulfilled, then the test series shall be repeated with a reduced tension load $N_{p,red}$ until the requirements are fulfilled.

The reduction factor is determined as follows:

$$\alpha_{p,B13} = \min\left(1{,}0; \frac{\tau_{suc}}{\tau_{Rk,0,cr}}\right) \text{ for BF} \quad (2.2.2.5.2)$$

$$\alpha_{p,E8} = \min\left(1{,}0; \frac{N_p}{N_{Rk,0,cr}}\right) \text{ for BEF} \quad (2.2.2.5.3)$$

$$\tau_{suc} = N_p \cdot 1{,}5 \cdot \gamma_{inst} \cdot (\alpha_2 \cdot \alpha_3 \cdot \alpha_4) / (0{,}75 \cdot \pi \cdot d \cdot h_{ef}) \quad (2.2.2.5.4)$$

where

τ_{suc} = bond strength corresponding to the constant load applied in successful test series B13

N_p = constant load $N_{p,test}$ applied in successful test series

$\tau_{Rk,0,cr}$ = basic value $\tau_{Rk,0}$ determined according to Equation (2.2.2.14.2) at completion of all tests for cracked concrete and temperature range T1

$N_{Rk,p,0,cr}$ = basic value $N_{Rk,p,0}$ determined according to Equation (2.2.2.15.2) at completion of all tests for cracked concrete and temperature range T1

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5..
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1.1, line R3 for tests in C20/25 and with line R3 for tests in C12/15.
- Determine the reduction (α/rqd. α) by using rqd. α = 0,9

Load displacement behaviour in the residual load tests

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results:

α_p, $ß_{cv}$, (α/rqd. α), α_1 to be used in 2.2.2.14 / 2.2.2.15, $\delta_{1000,mean}$ to be used in 2.2.10

2.2.2.6 Sustained loads and factor ψ^0_{sus} (test series R6, B14, B15, E9, E10)

Purpose of the assessment

The tests are performed to check the creep behaviour of the loaded fastener at normal ambient temperature (test series B14 and E9) and at maximum long-term temperature (test series B15 and E10). For BF only, based on these tests for each temperature range the factor ψ^0_{sus} (see EN 1992-4 [4], clause 7.2.1.6) accounting for the influence of sustained loads at maximum long-term temperature on the bond strength is determined.

Test conditions

The tests shall be carried out as confined tests according to Figure D.3.1.4.1 in uncracked concrete C20/25, both at normal ambient temperature and maximum long-term temperature with diameter 12 mm or smallest size if that is larger than 12 mm.

The permanent load N_{sust} can be applied by e.g., a hydraulic jack, springs or dead loads (e.g., applied via a lever arm).

In reference tests the fasteners are stored unloaded under normal ambient temperature having the same curing time until the pull-out test is performed.

a) Tests at normal ambient temperature (test series R6 a), B14 and E9)

Install fasteners at normal ambient temperature (+21°C ±3°C).

The required load applied on the fastener, $N_{sust,21}$, is given in Equation (2.2.2.6.1). The characteristic capacity $\tau_{Rk,ucr}$ (and $N_{Rk,0,ucr}$ for BEF) in Equation (2.2.2.6.1) is likely not known at the start of the sustained load test series as it may depend on the results of these tests. Therefore, the tests can be performed with an assumed sustained load $N_{sust,test}$, which is then properly accounted for in the assessment (in terms of the factor α_p). For the selection of the assumed sustained load $N_{sust,test}$, available information from already conducted test series (e.g., reference test results $\tau_{5\%}$, reduction factors α, α_2, α_3, α_4), as far as applicable, may be considered.

$$N_{sust,21} \geq \frac{1{,}1 \cdot \tau_{Rk,ucr} \cdot \pi \cdot d \cdot h_{ef}}{1{,}5 \cdot \gamma_{inst}} \cdot \frac{1}{\alpha_2} \cdot \frac{1}{\alpha_3} \cdot \frac{1}{\alpha_4} \qquad (2.2.2.6.1)$$

where

$\tau_{Rk,ucr}$ = characteristic bond strength as given in the ETA for use in uncracked concrete for normal ambient temperature

For BEF replace the term ($\tau_{Rk,ucr} \cdot \pi \cdot d \cdot h_{ef}$) by $N_{Rk,0,ucr}$.

α_2 = reduction factor according to Equation (2.2.2.9.1)

α_3 = reduction factor according to Equation (2.2.2.9.2)

α_4 = reduction factor according to Equation (2.2.2.12.1)

Maintain the load at N_{sust} (maximum temporary variation due to test setup - e.g., spring pot: -5 %; no active permanent steering on lower load level is allowed) and maintain temperature at normal ambient temperature and measure the displacements until they appear to have stabilised, but at least for three months

Temperatures in the room may vary by ± 3 °C due to day/night and seasonal effects but the required temperature level of the test member shall be achieved as a mean over the test period.

The frequency of monitoring displacements shall be chosen so as to demonstrate the characteristics of the fastener. As displacements are greatest in the early stages, the frequency shall be high initially and reduced with time.

The following regime shall be kept as a minimum:

During first hour: every 10 minutes

During next 6 hours: every hour

During next 10 days: every day

From then on: every 5-10 days.

To check the remaining load capacity after the sustained load test, unload the fastener and carry out a confined tension test.

The results of the residual load capacity test shall be compared with the load capacity of reference test series R6 a) and at normal ambient temperature having the same curing time.

b) Tests at maximum long-term temperature (test series R6 b) and B15 or E10)

These tests are not needed for temperature range T1, see 1.2.1 (-40 °C to +40 °C), because the effect of the maximum long-term temperature (+24 °C) is tested under normal ambient temperature.

Install fasteners at normal ambient temperature (+21°C ±3°C).

The required load to be applied on the fastener, $N_{sust,mlt}$, is given in Equation (2.2.2.6.2).The characteristic capacity $\tau_{Rk,ucr,mlt}$ (and $N_{Rk,0,ucr,mlt}$ for BEF) in Equation (2.2.2.6.2) is likely not known at the start of the sustained load test series as it may depend on the results of these tests. Therefore, the tests can be performed with an assumed sustained load $N_{sust,mlt,test}$, which is then properly accounted for in the assessment (in terms of the factor α_p). For the selection of the assumed sustained load $N_{sust,mlt,test}$, available information from already conducted test series (e.g., reference test results $\tau_{5\%}$, reduction factors α, α_3, α_4), as far as applicable, may be considered.

$$N_{sust,mlt} \geq \frac{1{,}1 \cdot \tau_{Rk,ucr,mlt} \cdot \pi \cdot d \cdot h_{ef}}{1{,}5 \cdot \gamma_{inst}} \cdot \frac{1}{\alpha_3} \cdot \frac{1}{\alpha_4} \qquad (2.2.2.6.2)$$

where

$\tau_{Rk,ucr,mlt}$= characteristic bond strength as given in the ETA for use in uncracked concrete for maximum long-term temperature

For BEF replace the term ($\tau_{Rk,ucr,mlt} \cdot \pi \cdot d \cdot h_{ef}$) by $N_{Rk,0,ucr,mlt}$.

α_3 = reduction factor according to Equation (2.2.2.9.2)

α_4 = reduction factor according to Equation (2.2.2.12.1)

Raise the temperature of the test member to reach the maximum long-term temperature at a rate of 5 K per hour in the concrete in the area of the anchorage.

Maintain the load at N_{sust} (maximum variation: -5 %) and maintain the temperature at the maximum long-term temperature. For the duration of the tests, the allowed variation of the temperature of the test chamber and the frequency of monitoring displacements 2.2.2.6 a) apply.

To check the remaining load capacity after the sustained load test, unload the fastener and carry out a confined tension test at the maximum long-term temperature.

The results of the residual load capacity test shall be compared with the load capacity of reference test series R6 b) and at maximum long-term temperature having the same curing time.

Note: The required applied load for the test represents 110% of the design resistance of the fastener considering the given test conditions.

Consideration of results from already conducted test series allows for a selection of the assumed sustained load closer to the target value. This may also reduce the testing effort.

The applied sustained load may limit the final characteristic capacity τ_{Rk} ($N_{Rk,p}$). Therefore, the assumed sustained load $N_{sust,test}$ should be selected reasonably high. As a guidance value, the concrete cone resistance valid for the embedment depth to be tested and, in case of BF, converted into a bond strength may be taken.

Assessment: see 2.2.2.6.1 to 2.2.2.6.4

2.2.2.6.1 Displacements in sustained load tests and applied load

The displacements measured in the tests have to be extrapolated according to Equation (2.2.2.6.1.1) (Findley approach) to 50 years (tests at normal ambient temperature), or 10 years (tests at maximum long-term temperature), respectively. The trend line according to Equation (2.2.2.6.1.1) may be constructed with data from not less than the last 20 days and not less than 20 data points of the sustained load test. The extrapolated displacements shall be less than the mean value of the displacements $\delta_{um,adh}$ in the corresponding reference tests at normal ambient temperature or maximum long-term temperature respectively. $\delta_{u,adh}$ is the displacement at $N_{u,adh}$ (loss of adhesion).

$$\delta(t) = \delta_o + a \cdot t^b \qquad (2.2.2.6.1.1)$$

where

δ_o: = initial displacement under sustained load at t = 0

a,b: = constants determined by a regression analysis of the deformations measured during the sustained load test

If the test criteria are not fulfilled, then the test may be repeated with modified parameters (e.g., reduced load $N_{sust,red}$ or reduced temperature.

The reduction factor is determined as follows:

a) Tests at normal ambient temperature (test series R6 a), B14 and E9)

$$\alpha_{p,B14} = \min(1{,}0; \frac{\tau_{suc}}{\tau_{Rk,0,ucr}}) \text{ for BF} \qquad (2.2.2.6.1.2)$$

$$\alpha_{p,E9} = \min(1{,}0; \frac{N_{sust}}{N_{Rk,0,ucr}}) \text{ for BEF} \qquad (2.2.2.6.1.3)$$

$$\tau_{suc} = N_{sust} \cdot 1{,}5 \cdot \gamma_{inst} \cdot (\alpha_2 \cdot \alpha_3 \cdot \alpha_4) / (1{,}1 \cdot \pi \cdot d \cdot h_{ef}) \qquad (2.2.2.6.1.4)$$

where

τ_{suc} = bond strength corresponding to the sustained load applied in successful test series B14

N_{sust} = sustained load $N_{sust,test}$ applied in the test series fulfilling the displacement criteria

$\tau_{Rk,0,ucr}$ = basic value $\tau_{Rk,0}$ determined according to Equation (2.2.2.14.2) at completion of all tests for uncracked concrete and temperature range T1

$N_{Rk,p,0,ucr}$ = basic value $N_{Rk,p,0}$ determined according to Equation (2.2.2.15.2) at completion of all tests for uncracked concrete and temperature range T1

Note: α_p will be used in Equation (2.2.2.14.1) for BF or in Equation (2.2.2.15.1) for BEF. If N_{sust} was estimated because $\tau_{Rk,ucr,mlt}$ was not yet known when the tests with sustained loads were started, then the requirements of Equation (2.2.2.6.1) and in Equation (2.2.2.14.1) for BF or in Equation (2.2.2.15.1) for BEF will fit together using α_p.

b) Tests at maximum long-term temperature (test series R6 b), B15 and E10)

$$\alpha_{p,B15} = \min(1{,}0; \frac{\tau_{suc}}{\tau_{Rk,0,ucr}}) \text{ for BF} \qquad (2.2.2.6.1.5)$$

$$\alpha_{p,E10} = \min(1{,}0; \frac{N_{sust}}{N_{Rk,0,ucr}}) \text{ for BEF} \qquad (2.2.2.6.1.6)$$

$$\tau_{suc} = N_{sust} \cdot 1{,}5 \cdot \gamma_{inst} \cdot (\alpha_3 \cdot \alpha_4) / (1{,}1 \cdot \pi \cdot d \cdot h_{ef}) \qquad (2.2.2.6.1.7)$$

where

τ_{suc} = bond strength corresponding to the sustained load applied in successful test series B15

N_{sust} = sustained load $N_{sust,test}$ applied in the test series fulfilling the displacement criteria

$\tau_{Rk,0,ucr}$ = basic value $\tau_{Rk,0}$ determined according to Equation (2.2.2.14.2) at completion of all tests for uncracked concrete and temperature range T2 or T3

$N_{Rk,p,0,ucr}$ = basic value $N_{Rk,p,0}$ determined according to Equation (2.2.2.15.2) at completion of all tests for uncracked concrete and temperature range T2 or T3

Note: With the determination of α_p Equation(2.2.2.6.2) is satisfied.

Determine the displacement after 42 days for assessment of test series B20, see 2.2.2.13.

Expression of results:

- α_p to be used in 2.2.2.14 / 2.2.2.15,
- displacement after 42 days $\delta_{sust,42d,m}$ to be used in Equation (2.2.2.13.4),
- Mean value of the extrapolated displacements in the sustained load test at normal ambient temperature $\delta_{N,\infty,m}$ to be used in 2.2.10

2.2.2.6.2 Residual capacity at normal ambient temperature and maximum long-term temperature

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to paragraphs A.2.1.2 and A.2.1.4, respectively.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to paragraphs A.2.1.2 and A.2.1.4, respectively.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1.1, line R6 a) or b), respectively, for tests in C20/25 and with line R6 a) or b), for tests in C12/15. The fasteners in the sustained load tests (series B14, B15, E9 or E10) and in corresponding reference series R6 a) or b) shall have undergone the same curing time and temperature history.
- Determine the reduction (α/rqd. α) by using rqd. α = 0,9

Expression of results: $ß_{cv,}$ (α/rqd. α) to be used in 2.2.2.14 / 2.2.2.15.

2.2.2.6.3 Load displacement behaviour in the residual load tests at normal ambient temperature and maximum long-term temperature

- Determine the reduction factor α1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load δ0,5Nu,m [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cvδ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cvδ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results: α_1 to be used in 2.2.2.14 / 2.2.2.15.

2.2.2.6.4 Factor ψ^0_{sus} for combined pull-out and concrete failure for BF

The factor ψ^0_{sus} accounting for the influence of sustained tension load on the bond strength of BF for combined pull-out and concrete failure is assessed for the intended working life based on test series B14 (2.2.2.6.2) and B15 (2.2.2.6.3). The factor ψ^0_{sus} shall be determined for the maximum long-term temperature of every temperature range T1, T2 or T3. Please note that normal ambient temperature corresponds to maximum long-term temperature of temperature range T1.

Determine the factor ψ^0_{sus} with the applied constant tension load normalized to C20/25 using Equations (2.2.2.6.4.1) and (2.2.2.6.4.2). The conversion of failure loads to the nominal concrete strength shall be done according to A.2.1.2.

The bond stress τ_{sus} applied in the sustained load tests, normalized to the nominal concrete strength, is obtained as given in Equation (2.2.2.6.4.1):

$$\tau_{sust} = \frac{N_{sust}}{\pi \cdot d \cdot h_{ef}} \cdot \min\left(1; \frac{\alpha}{0,9}\right) \qquad (2.2.2.6.4.1)$$

where α = reduction factor as determined in clause 2.2.2.6.2 for the corresponding test series B14 or B15

N_{sust} = sustained load applied in sustained load tests at maximum long-term temperature, which meets the criteria, normalized to C20/25 concrete strength (according to clause A.2.1.2)

The basic characteristic long-term bond resistance is assumed to be equal to the bond stress applied in the sustained load tests (survival value), which meets the criteria.

$$\tau^0_{Rk,LT} = \tau_{sust} \qquad (2.2.2.6.4.2)$$

where $\tau^0_{Rk,LT}$ = basic characteristic long-term bond resistance at maximum long-term temperature

The characteristic long-term bond resistance is determined accounting for the relevant (reduction) factors as follows:

$$\tau_{Rk,LT} = \tau^0_{Rk,LT} \cdot \alpha_3 \cdot \alpha_4 \cdot k_{sus} \cdot \alpha_{setup} \cdot min\ \beta_{CV} \qquad (2.2.2.6.4.3)$$

where $\tau_{Rk,LT}$ = characteristic long-term bond resistance (LT) at maximum long-term temperature for the corresponding temperature range

α_3 = reduction factor according to Equation (2.2.2.9.2)

α_4 = reduction factor according to Equation (2.2.2.12.1)

α_{setup} = 0,75, reduction factor for uncracked concrete according to clause 2.2.2.14.

k_{sus} = 1,135

min β_{CV} = minimum of reduction factors β_{CV} according to Equation (A.2.1.5.2)

The factor ψ^0_{sus}, accounting for the influence of sustained tension load on the bond strength for combined pull-out and concrete failure, is then determined as given in Equation (2.2.2.6.4.4).

$$\psi^0_{sus} = \frac{\tau_{Rk,LT}}{\tau_{Rk,ucr}} \cdot 1,15 \leq 1,0 \qquad (2.2.2.6.4.4)$$

where ψ^0_{sus} = reduction factor of long-term bond resistance at maximum long-term temperature

$\tau_{Rk,ucr}$ = characteristic value of short-term bond resistance at maximum long-term temperature, as given in the ETA for uncracked concrete

Note: The factor k_{sus} takes account of beneficial effects under long-term loading. The influence of the confinement on the pull-out resistance decreases under long-term loading and an increase of 13,5 % of the reduction factor α_{setup} has been evaluated from tests.

Expression of results:

Factors ψ^0_{sus} for temperature ranges according to the intended use.

2.2.2.7 Freeze/thaw conditions (test series R7, B16, E11)

Purpose of the assessment

These tests are performed to determine the performance of the fastener under freeze/thaw conditions simulating varying life conditions.

Test conditions

Perform the tests with confined test setup with diameter size 12 mm or smallest size if that is larger than 12 mm. The tests are performed in uncracked freeze-thaw resistant concrete C50/60 in accordance with EN 206 [1]. As test member a cube with side length of 15 d to 25 d or a steel encased concrete cylinder shall be used and splitting of concrete shall be prevented. Install just one fastener in the geometric centre of the test member.

Cover the top surface of the test member with tap water to a depth of at least 12 mm, other exposed surfaces shall be sealed to prevent evaporation of water. If the water layer evaporates, then refill tape water on the top of the test member.

Load fastener to N_{sust} according to Equation (2.2.2.7.1).

The required constant load to be applied on the fastener, N_{sust}, is given in Equation (2.2.2.7.1). The characteristic capacity $\tau_{Rk,ucr,60}$ (and $N_{Rk,ucr,60}$ for BEF) in Equation (2.2.2.7.1) is likely not known at the start of the freeze/thaw test series as it may depend on the results of these tests. Therefore, the tests can be performed with an assumed constant load $N_{sust,test}$, which is then properly accounted for in the assessment (in terms of the factor α_p). For the selection of the assumed constant load $N_{sust,test}$, available information from already conducted test series (e.g., reference test results $\tau_{5\%}$, reduction factors α, α_3, α_4), as far as applicable, may be considered.

Note: The required applied load for the test represents loading at serviceability level (1/1,4 of the ultimate design resistance of the fastener) considering the given test conditions.

Consideration of results from already conducted test series allows for a selection of the assumed constant loads closer to the target values. This may also reduce the testing effort.

The applied constant load may limit the final characteristic capacity τ_{Rk} ($N_{Rk,p}$). Therefore, the assumed constant load $N_{sust,test}$ should be selected reasonably high. As a guidance value, the concrete cone resistance valid for the embedment depth to be tested and converted into a bond strength may be taken.

A scetch of the principle test set-up is given in Figure D.3.3.4.1

In reference tests with the same diameter the fasteners are stored unloaded under normal ambient temperature having the same curing time until the pull-out test is performed.

$$N_{sust} = \frac{\tau_{Rk,ucr,60} \cdot d \cdot \pi \cdot h_{ef}}{1{,}5 \cdot 1{,}4 \cdot \gamma_{inst}} \qquad (2.2.2.7.1)$$

where

$\tau_{Rk,ucr,60}$ = characteristic bond strength for uncracked concrete of strength class C50/60

For BEF replace the term ($\tau_{Rk,ucr,60} \cdot \pi \cdot d \cdot h_{ef}$) by $N_{Rk,ucr,60}$.

γ_{inst} according to 2.2.5.6 based on 2.2.5.2

Carry out 50 freeze/thaw cycles as follows:

- Raise temperature of chamber to (+20 ± 2) °C within 1 hour, maintain chamber temperature at (+20 ± 2) °C for 7 hours (total of 8 hours).
- Lower temperature of chamber to (-20 ± 2) °C within 2 hours, maintain chamber temperature at (-20 ± 2) °C for 14 hours (total of 16 hours).

Note: It shall be checked that the test member is frozen at the end of the frost cycles and normal ambient temperature is reached at the end of the warm cycles. Otherwise, the duration of freeze and warm conditions shall be increased.

If the test is interrupted, then the samples shall always be stored at a temperature of (- 20 ± 2) °C between the cycles.

The displacements shall be measured during the temperature cycles.

Note: For this test series mechanical displacement transducers with a measuring bias not greater than 0,020 mm or 2,0 % for displacements > 1 mm are sufficient.

The displacement measurements may be influenced by moisture and temperature.

It is recommended to protect the displacement transducers from moisture (e.g., using plastic bags).

Read the displacements daily under the same climate conditions in the end of the 20 °C period to avoid an influence of temperature and moisture on the measurement equipment.

After completion of 50 freeze/thaw cycles as defined above a confined tension test shall be carried out at normal ambient temperature.

The results of the residual load capacity test shall be compared with the load capacity of reference test series R7.

Assessment

Displacements and applied load during freeze/thaw cycles

The rate of displacement increase shall reduce with increasing number of freeze/thaw cycles to a value almost equal to zero.

If the test criteria are not fulfilled, then the test shall be repeated with a reduced load $N_{sust,red}$. If no other information is given by the manufacturer, then the sustained load shall about 10% of N_{sust} according to Equation (2.2.2.7.1)

The reduction factor is determined as follows:

$$\alpha_{p,B16} = \min\left(1{,}0; \frac{\tau_{suc}}{\tau_{Rk,0,ucr,60}}\right) \text{ for BF} \quad (2.2.2.7.2)$$

$$\alpha_{p,E11} = \min\left(1{,}0; \frac{N_{sust}}{N_{Rk,p,0,ucr,60}}\right) \text{ for BEF} \quad (2.2.2.7.3)$$

$$\tau_{suc} = N_{sust} \cdot 1{,}4 \cdot 1{,}5 \cdot \gamma_{inst} / (\pi \cdot d \cdot h_{ef}) \quad (2.2.2.7.4)$$

where

τ_{suc} = bond strength corresponding to the constant load applied in successful test series B16

N_{sust} = constant load $N_{sust,test}$ applied in the test series fulfilling the displacement criteria

$\tau_{Rk,0,ucr,60}$ = basic value $\tau_{Rk,0}$ determined according to Equation (2.2.2.14.2) at completion of all tests for uncracked concrete of strength class C50/60 and temperature range T1

$N_{Rk,p,0,ucr,60}$ = basic value $N_{Rk,p,0}$ determined according to Equation (2.2.2.15.2) at completion of all tests for uncracked concrete of strength class C50/60 and temperature range T1

γ_{inst} according to 2.2.5.6 based on 2.2.5.2

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1.1 line R7 having the same curing time.
- Determine the reduction (α/rqd. α) by using rqd. α = 0,9.

Load displacement behaviour

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results:

α_{pB16}, $\alpha_{p,E11}$, $ß_{cv}$, (α/rqd. α), α_1 to be used in 2.2.2.14 / 2.2.2.15.

2.2.2.8 Installation directions (test series B17, E12)

Purpose of the assessment

The tests are performed to check the performance under unfavourable installation directions. The test series may be omitted for downward installation only (D1).

Test conditions

If the fastener is intended to be used in all installation directions (D3), then tension tests are needed with steel elements installed vertically upwards only. If the fastener is intended to be used in horizontal and vertical downward only (D2), then tension tests have to be done with steel elements installed in horizontal direction. Special devices to maintain the fastener in place are used only if stated in the MPII. Such special devices shall also be described in the ETA.

Install the fastener at the maximum installation temperature according to the MPII (or +40 °C, if no maximum installation temperature is specified).

For installation vertically upwards: If the manufacturer does not specify installation tools to avoid sagging of the steel element (e.g., by wedges) perform an additional test series at minimum installation temperature according to the MPII (or 0 °C, if no minimum installation temperature is specified).

After the minimum curing time, the test specimen may attain normal ambient temperature before the pull-out test is performed.

Perform the tests with confined test setup. The tests are performed with largest diameter size applied for by the manufacturer. The tension tests are performed according to Annex D.

Assessment

<u>Failure loads</u>

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1.1 line R1.
- Determine the reduction (α/rqd. α) by using rqd. α = 0,9

<u>Load displacement</u>

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results: $ß_{cv}$, (α/rqd. α), α_1 to be used in 2.2.2.14 / 2.2.2.15.

2.2.2.9 Increased temperature (test series B2 and B3)

Purpose of the assessment

These tests are performed to determine the performance of the fastener under increased temperature (maximum short-term temperature and maximum long-term temperature for all temperature ranges for which assessment is requested and performance is provided in the ETA) simulating service conditions that vary within the considered temperature range.

Test conditions

The tests shall be carried out with confined test setup in uncracked concrete at maximum long-term temperature and maximum short-term temperature a for each temperature range applied for.

The tests shall be carried out in concrete members or, where space of the heating chamber is restricted, in cubes or cylinders. Splitting of the concrete shall be prevented by means of confinement (dimensions, reinforcement or transverse pressure).

Tests are carried out with fastener diameter 12 mm (or smallest in range if smallest size is larger than 12 mm).

Install fasteners at normal ambient temperature according to MPII.

Raise test member temperature to required test temperature at a rate of approximately 20 K per hour. Keep the test member at this temperature for 24 hours.

Perform a confined tension test immediately after storage of the test member.

> *Note: The check that the requirement on the temperature in the test member is fulfilled shall be done once and then the test procedure shall be kept constant.*

Number of tests: n ≥ 5 tests per temperature.

Assessment

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.

Load displacement

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Influence factors for temperature

The influence of increased temperature is determined based on a comparison of mean failure loads as well as 5 %-fractile of failure loads. Results of test series R1 shall be used for reference, if no separate reference tests in the same concrete member are performed.

Maximum long-term temperature

From the failure loads measured in the tests at maximum long-term temperature the factor α_2 shall be calculated according to Equation (2.2.2.9.1).

$$\alpha_2 = \min\left(\frac{N_{Ru,m,mlt}}{N_{Ru,m,r}};\frac{N_{u,5\%,mlt}}{N_{u,5\%,r}}\right) \le 1{,}0 \qquad (2.2.2.9.1)$$

Maximum short-term temperature

From the failure loads measured in the tests at maximum short-term temperature the factor α_3 shall be calculated according to Equation (2.2.2.9.2).

$$\alpha_3 = \min\left(\frac{N_{Ru,m,mst}}{0{,}8 \cdot N_{Ru,m,mlt}};\frac{N_{u,5\%,mst}}{0{,}8 \cdot N_{u,5\%,mlt}}\right) \le 1{,}0 \qquad (2.2.2.9.2)$$

For temperature range T1 according to 1.2.1 the results of tests at normal ambient temperature are taken for $N_{Ru,m,mlt}$; $N_{u,5\%,mlt}$.

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

Expression of results: α_2, α_3, $ß_{cv}$, α_1 to be used in 2.2.2.14 / 2.2.2.15.

2.2.2.10 Minimum curing time at minimum installation temperature (test series B4)

Purpose of the assessment

The test is required to check sufficient load bearing capacity at minimum installation temperature after specified minimum curing time. The minimum installation temperature is 0°C if not requested by the manufacturer otherwise. The test series may be omitted for minimum installation temperature 0 °C or higher.

Test conditions

The tests are performed in uncracked concrete. For test member dimensions, see "Increased temperature" clause 2.2.2.9.

Perform the test with diameter size 12 mm (or the diameter next to 12 mm if size 12 mm is not applied for).

Drill and clean hole according to MPII then cool test member to the minimum installation temperature specified by the manufacturer and the bonding material and steel elements to the lowest fastener component installation temperature specified by the manufacturer.

Install the fastener and maintain the temperature of the test member at the lowest installation temperature for the curing time quoted by the manufacturer at that temperature.

If no information on curing time is given in the MPII or provided by the manufacturer, then the curing time at that temperature shall be assumed by the TAB based on experience with this type of resin. If the MPII does not specify otherwise, the concrete member, bonding material and steel elements shall be conditioned to the minimum installation temperature.

> *Note: The curing time depends on the specific chemistry of the bonding material and may be quite different for different products. For proper use of a product, the information addressing curing time as well as storage conditions is typically given in the MPII. If this is not the case, then the information should preferably be obtained from the manufacturer to avoid unnecessary costs resulting from additional testing loops.*

Carry out confined tension test at the end of the curing time while maintaining the temperature of the test member in the area of the steel element at a distance of 1d from the concrete surface at the specified lowest installation temperature ± 2K.

> *Note: It may be that some cartridge-in-cartridge systems do not ensure the correct mixing ratio over the full content of the cartridge because of a failure of the seam which cause opening of one of the cartridges especially at low installation temperature. Therefore, additional benchmark tests with these systems are recommended; especially at the lowest installation temperature.*
>
> *The check that the requirement on the temperature in the test member is fulfilled shall be done once and then the test procedure shall be kept constant.*

Number of tests: $n \geq 5$ tests

Assessment

The mean failure loads and the 5 % fractile of failure loads measured in tests at the minimum installation temperature and corresponding minimum curing time (Table A.1.1, series B4) shall be at least equal to the corresponding values of the test R9 at normal ambient temperature and corresponding minimum curing time. These requirements apply also for the tests at other installation temperatures and corresponding minimum curing times (Table A.1.1, series B4).

If the condition is not fulfilled, then the minimum curing time at the minimum installation temperature shall be increased and the tests at minimum installation temperature shall be repeated until the condition is fulfilled.

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

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.

Load displacement

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results:

$ß_{cv}$, α_1 to be used in 2.2.2.14 / 2.2.2.15.

The minimum installation temperature, the lowest fastener component installation temperature (if different from the minimum installation temperature) and the corresponding minimum curing time shall be stated in the ETA.

2.2.2.11 Minimum curing time at normal ambient temperature (test series B5)

Purpose of the assessment

The test is required to check sufficient load bearing capacity after specified minimum curing time.

Test conditions

Perform confined tension tests in uncracked concrete at normal ambient temperature at the corresponding minimum curing time specified by the manufacturers. If no information on curing time is given in the MPII or provided by the manufacturer, then the curing time at that temperature shall be assumed by the TAB based on experience with this type of resin (see also *Note given in 2.2.2.10*).

Test with diameter size 12 mm or smallest size if that is larger than 12 mm.

Number of tests: $n \geq 5$ tests

Assessment

The mean failure loads and the 5 % fractile of failure loads measured in tests at the normal ambient temperature and corresponding minimum curing time shall be at least 0,9 times the values measured in reference tests (series R1) for the same concrete strength class according to Table A.1.1 with a "long curing time" (24 hours for resins, 14 days for cementitious mortars).

If this condition is not fulfilled, then the minimum curing time at normal ambient temperature shall be increased and the corresponding tests shall be repeated.

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

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.

Load displacement

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 25 %.Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results:

The minimum curing time at normal ambient temperature shall be stated in the ETA.

2.2.2.12 Sensitivity to sulphurous atmosphere and high alkalinity (tests series R8, B18 and B19)

Purpose of the assessment

These tests are performed to determine the performance of the bonding material under sulphurous atmosphere and high alkalinity.

Test conditions

Perform the test with diameter size 12 mm or smallest size if that is larger than 12 mm.

The concrete compressive strength class shall be C20/25. The diameter or side length of the concrete specimen shall be equal or greater than 150 mm. The test specimen may be manufactured from cubes or cylinders or may be cut from a larger concrete member. They can be cast; it is also allowed to diamond core concrete cylinders from concrete members.

One fastener shall be installed per cylinder or cube on the central axis in dry concrete according to the MPII. The steel element shall be made of stainless steel.

After curing of the bonding material according to MPII the concrete cylinders or cubes are carefully sawn into 30mm thick slices with a diamond saw. The top slice shall be discarded.

To gain sufficient information from the slice tests, at least 30 slices are necessary (10 slices for every environmental exposure test and 10 slices for the comparison tests under normal climate conditions).

Storage of the test specimen under environmental exposure:

The slices with bonding fasteners are subjected to water with high alkalinity and condensed water with sulphurous atmosphere. For comparison tests slices stored under normal climate conditions (dry / +21 °C ± 3 °C / relative humidity 50 ± 5 %) for 2000 hours are necessary.

<u>High Alkalinity (test series B18)</u>

The slices are stored under standard climate conditions in a container filled with an alkaline fluid (pH = 13,2). All slices shall be completely covered for 2.000 hours. The alkaline fluid is produced by mixing water with KOH (potassium hydroxide) powder or tablets until the pH-value of 13,2 is reached. The alkalinity of pH = 13,2 shall be kept as close as possible to 13,2 during the storage and not fall below a value of 13.0. Therefore, the pH-value has to be checked and monitored in regular intervals (at least daily). The producing of alkaline fluid by mixing water with KOH (potassium hydroxide) powder or tablets could be given as an example. If other materials are used, then it has to be shown that same results and comparable assessment are achieved.

<u>Sulphurous atmosphere (test series B19)</u>

The tests in sulphurous atmosphere shall be performed according to EN ISO 6988 [2]. The slices are put into the test chamber, however in contrast to EN ISO 6988 [2] the theoretical sulphur dioxide concentration shall be 0,67 % at beginning of a cycle. Continuous or interrupted storage are allowed. This theoretical sulphur dioxide concentration corresponds to 2 dm^3 of SO_2 for a test chamber volume of 300 dm^3. At least 80 cycles shall be carried out.

<u>Slice tests</u>

After removal from storage the thickness of the slices is measured and the metal segments of the BF are pushed out of the slice, the slice is placed centrally to the hole of the steel rig plate. If slices are unreinforced, then splitting may be prevented by confinement. Care shall be taken to ensure that the loading punch acts centrally on the fastener rod.

The results of at least 10 tests shall be taken for every environmental exposure and for comparison. Results with splitting failure shall be ignored.

<u>Reference test series (tests series R8)</u>

The reference test series R8 shall be performed under the same test conditions as given above with the exception that the slices are stored under normal ambient conditions.

Assessment

Determine α_4 according to Equation (2.2.2.12.1)

$$\alpha_4 = min\left(\frac{\tau_{Ru,m,B18}}{\tau_{Rum,r}};\frac{\tau_{Ru,m,B19}}{0{,}9\cdot\tau_{Rum,r}}\right) \leq 1{,}0 \qquad (2.2.2.12.1)$$

The reference bond strength $\tau_{um,r}$ is gained in the test series Table A.1.1, line R8.

The bond strength in the slice tests shall be calculated according to Equation (2.2.2.12.2).

$$\tau_u = \frac{N_u}{\pi \cdot d \cdot h_{sl}} \quad (2.2.2.12.2)$$

Expression of results: α_4 to be used in 2.2.2.14 / 2.2.2.15.

2.2.2.13 Installation at freezing condition (test series B20)

Purpose of the assessment

The tests are performed to check the performance of the fastener when installed and cured under freezing conditions. The minimum installation temperature according to test series B20 shall be given in the ETA together with the corresponding curing time (test series B4).

The tests may be omitted if the MPII specify installation in concrete with a minimum installation temperature ≥ 0 °C.

Test conditions

For standard variation temperature (see 1.2.1, temperature variation within longer than 12-hour period from a low temperature less than 0 °C to a high temperature of +24 °C or more) standard tests are performed.

For rapid variation temperature (see 1.2.1, temperature variation within a 12-hour period from a low temperature less than 0 °C to a high temperature of +24 °C or more) tests for rapid variation of temperature are performed.

Standard variation of temperature

Perform the tests in uncracked concrete with diameter of the steel element d = 12 mm or smallest diameter, if that is larger than 12 mm. A thermocouple cast in the middle of the test member, not in the area of the planned bore hole shall be used to confirm temperature of the whole test member during the test.

a) Prior to installation, condition the steel element and the test member to the minimum installation temperature as given in the MPII and maintain that temperature for a minimum of 24 hours. Cool the bonding material to the lowest fastener component installation temperature specified by the manufacturer.

b) Install the fasteners in accordance with the MPII and allow them to cure at the stabilized minimum installation temperature for the curing time according to the MPII.

c) Apply a constant tension load N_{sust} (with a tolerance of -5 %; no active permanent steering on lower load level is allowed) as given by Equation (2.2.2.6.1) with confined test setup. Raise the temperature of the test chamber at a constant rate to normal ambient temperature over a period of minimum 72 to maximum 150 hours while monitoring the displacement response for each fastener in the test chamber.

   Once the test member attains normal ambient temperature and the displacements stabilize, conduct a confined tension test to failure with continuous measurement of load and displacement. If the displacements do not stabilize within 150 hours from the start of the temperature rise, then the test shall be discontinued and the test may be repeated with modified parameters (e.g., reduced load $N_{sust,red}$ or increased minimum installation temperature). If the test is repeated with a reduced load, then calculate the reduction factor $\alpha_p = N_{sust,red} / N_{sust}$.

Rapid variation of temperature (42 days test)

If the MPII allow a temperature variation within a 12-hour period from a low of 0 °C or less to a high of +24 °C or more, then perform the following test.

Perform the tests in uncracked concrete with diameter size d = 12 mm or smallest diameter, if that is larger than 12 mm. The concrete test member shall be a cuboid with the maximum dimensions of 750 mm by 450 mm by 300 mm or a 300 mm high cylinder with maximum diameter of 330 mm. Both conditions are equivalent. In case of dispute, a cuboid with maximum dimensions of 750 mm by 450 mm by 300 mm shall be used as concrete test member. A thermocouple cast in the middle of the test member, not in the area of the planned bore hole shall be used to confirm temperature of the whole test member during the test.

The test shall be performed as follows:

a) Prior to installation, condition the steel element and the test member to the minimum installation temperature as given in the MPII and maintain that temperature for a minimum of 24 hours. Cool the bonding material to the lowest fastener component installation temperature specified by the manufacturer.

b) Install the fasteners in accordance with the MPII and allow them to cure at the stabilized minimum installation temperature for the curing time according to the MPII.

c) Immediately after the curing period has elapsed, remove the test members from the cooling chamber and apply a tension preload not exceeding 5 % of N_{sust} as given by Equation (2.2.2.6.1) or 1,5 kN to the fastener prior to zeroing displacement readings (at any loading speed). Then increase the load on the fastener to a constant load N_{sust} as given by Equation (2.2.2.6.1), raise the temperature of the test member at a constant rate of 5 K/hr to normal ambient temperature and maintain the load N_{sust} (maximum variation: -5 %) over a duration of the minimum of 42 days while monitoring the displacement response for each fastener. If the sustained load in test series B14 (BF) or E9 (BEF) is reduced to $N_{sust,red}$ (see 2.2.2.6), then perform the test series with the same reduced load as successfully performed in test series B14 (BF) or E9 (BEF). As displacements are greatest in the early stages, the frequency shall be high initially and reduced with time. As an example, the following regime would be acceptable:

During first hour:	every 10 minutes,
During next 6 hours:	every hour,
During next 10 days:	every day,
From then on:	every 5-10 days.

d) If the displacements do not stabilize, then the test shall be discontinued and the test shall be repeated with modified parameters (e.g., reduced load $N_{sust,red}$ or increase the minimum installation temperature until the displacements are stabilized in the end of the test). If the test is repeated with a reduced load, then calculate the reduction factor $\alpha_p = N_{sust,red} / N_{sust}$).

e) Report the displacement $\delta_{dt,42d}$ of the sustained load portion of the test at 42 days.

f) Immediately following the sustained load portion of the test, conduct a confined tension test to failure at normal ambient temperature with continuous measurement of load and displacement.

Assessment

Applied sustained load and displacements for standard variation of temperature

If the displacements do not stabilize within 150 hours from the start of the temperature rise, then the test shall be discontinued and the test may be repeated with modified parameters (e.g., reduced load $N_{sust,red}$ or increased minimum installation temperature until the displacements are stabilized in the end of the test).

The reduction factor in case of reduced sustained load is determined as follows:

$$\alpha_{p,B20} = \min(1{,}0; \frac{\tau_{suc}}{\tau_{Rk,0,ucr}}) \text{ for BF} \quad (2.2.2.13.1)$$

$$\alpha_{p,B20} = \min(1{,}0; \frac{N_{sust}}{N_{Rk,p,0,ucr}}) \text{ for BEF} \quad (2.2.2.13.2)$$

$$\tau_{suc} = N_{sust} \cdot 1{,}5 \cdot \gamma_{inst} \cdot (\alpha_2 \cdot \alpha_3 \cdot \alpha_4) / (1{,}1 \cdot \pi \cdot d \cdot h_{ef}) \quad (2.2.2.13.3)$$

where

τ_{suc} = bond strength corresponding to the sustained load applied in successful test series B20

N_{sust} = sustained load $N_{sust,test}$ applied in the test series B20 fulfilling the displacement criteria

$\tau_{Rk,0,ucr}$ = basic value $\tau_{Rk,0}$ determined according to Equation (2.2.2.14.2) at completion of all tests for uncracked concrete and temperature range T1

$N_{Rk,p,0,ucr}$ = basic value $N_{Rk,p,0}$ determined according to Equation (2.2.2.15.2) at completion of all tests for uncracked concrete and temperature range T1

α_2 = reduction factor according to Equation (2.2.2.9.1)

α_3 = reduction factor according to Equation (2.2.2.9.2)

α_4 = reduction factor according to Equation (2.2.2.12.1)

Applied sustained load and displacements for rapid variation of temperature:

The condition given in Equation (2.2.2.13.4) shall be satisfied.

$$\delta_{N\infty,m} \leq \delta_{u,adh,m} - \left(\delta_{dt,42d,m} - \delta_{sust,42d,m}\right) \quad (2.2.2.13.4)$$

where

$\delta_{N,\infty,m}$ mean value of the extrapolated displacements in the sustained load test at normal ambient temperature (test series B14 (BF) or E9 (BEF)) according to 2.2.2.6.1

$\delta_{u,adh,m}$ mean displacement in the tension tests at loss of adhesion according to A.2.2.1

$\delta_{dt,42d,m}$ mean displacement measured in sustained load tests for rapid variation of temperature at 42 days (test series B20)

$\delta_{sust,42d,m}$ mean displacement measured in the sustained load tests at normal ambient temperature at 42 days (test series B14 (BF) or E9 (BEF))

If the displacements do not stabilize, then the test shall be discontinued and the test may be repeated with modified parameters (e.g., reduced load $N_{sust,red}$ or increase of the minimum installation temperature). In the case of reduced sustained load, the reduction factor is determined as given in Equation (2.2.2.13.1) and Equation (2.2.2.13.2**)**.

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.1.2 and A.2.1.4, respectively.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1.1, line R10, for tests in C20/25 and with line R10 for tests in C12/15. The fasteners in the corresponding test series shall have undergone the same curing time and the same temperature history.
- Determine the reduction (α/rqd. α) by using rqd. α = 0,9

Load displacement behaviour in the residual load tests

- Determine the reduction factor α1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load δ0,5Nu,m [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cvδ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cvδ shall not exceed 40 %.Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Displacement under sustained load for rapid variation of temperature:

- The condition given in Equation (2.2.2.13.4) shall be satisfied.

Expression of results:

α_p, $ß_{cv}$, (α/rqd. α), α_1 to be used in 2.2.2.14 / 2.2.2.15.

Text proposal to be given in the ETA for the case of assessment with standard variation of temperature only:

"The fastener is assessed for installation at minimum concrete temperature of -xx°C, where subsequently the temperature in the concrete does not rise at a rapid rate, i.e., from the minimum installation temperature to 24°C within a 12-hour period."

Text proposal to be given in the ETA for the case of assessment of rapid variation of temperature:

"The fastener is assessed for installation at minimum concrete temperature of -xx°C, including the case where subsequently the temperature in the concrete rises at a rapid rate, i.e., from the minimum installation temperature to 24°C within a 12-hour period."

2.2.2.14 Determination of the characteristic bond resistance for BF

The characteristic bond resistance τ_{Rk} shall be determined according to Equation (2.2.2.14.1) using the basic value $\tau_{Rk,0}$ determined from monotonic (residual load) pull-out test according to Equation (2.2.2.14.2) and potential reductions min α_p due to applied tension loads during specific tests according to Equation (2.2.2.14.3).

$$\tau_{Rk} = \tau_{Rk,0} \cdot \min \alpha_p \qquad (2.2.2.14.1)$$

Where

$$\tau_{Rk,0} = \tau_{5\%} \cdot \alpha_{setup} \cdot \min ß_{cv} \cdot \min \{1; \min \frac{\alpha}{rqd.\alpha}; \min \alpha_1\} \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_4 \qquad (2.2.2.14.2)$$

$\min \alpha_p$ = $\min (\alpha_{p,B12}; \alpha_{p,B14}; \alpha_{p,B16}; \alpha_{p,B20})$ for uncracked concrete and temperature range T1 (2.2.2.14.3)

= $\min (\alpha_{p,B12}; \alpha_{p,B15}; \alpha_{p,B16}; \alpha_{p,B20})$ for uncracked concrete and temperature range(s) ≥ T2

= $\min (\alpha_{p,B13}; \alpha_{p,B14}; \alpha_{p,B16}; \alpha_{p,B20})$ for cracked concrete and temperature range T1

= $\min (\alpha_{p,B13}; \alpha_{p,B15}; \alpha_{p,B16}; \alpha_{p,B20})$ for cracked concrete and temperature range(s) ≥ T2

$\alpha_{p,B12}$ to $\alpha_{p,B20}$ Reduction factors assessed for series B12, B13, B14, B15, B16 and B20

$\tau_{5\%}$ = Smaller 5% fractile of bond strength of test series R1 or R2 (normalized to minimum concrete strength) for intended use in uncracked concrete (or test series A1 and A2 with α_{setup} = 1,0) or from common assessment of series R1 and R2 (normalized to minimum concrete strength) (or test series A1 and A2 with α_{setup} = 1,0), if statistical equivalence is shown.

= Smaller 5% fractile of bond strength of test series R3 or R4 (normalized to minimum concrete strength) for intended use in cracked concrete (or test series A3 and A4 with α_{setup} = 1,0) or from common assessment of series R3 and R4 (normalized to minimum concrete strength) (or test series A3 and A4 with α_{setup} = 1,0), if statistical equivalence is shown.

Statistical equivalence is shown, if the results of series R2 lay in the same scatter band (5% fractile as a lower boundary and 95% fractile as a higher boundary with a confidence level of 90%) of test series R1.

α_{setup} = 0,75 for confined basic tension tests in uncracked concrete (test series R1 and R2)

= 0,70 for confined basic tension tests in cracked concrete (test series R3 and R4)

= 1,00 for unconfined basic tension tests (test series A1 to A4)

$\min ß_{cv}$ = Minimum $ß_{cv}$ determined in 2.2.2.1 to 2.2.2.13 and 2.2.5

$\frac{\alpha}{rqd.\alpha}$ = Minimum ratio determined in 2.2.2.3 to 2.2.2.8, 2.2.2.13 and 2.2.5

$\min \alpha_1$ = Minimum α_1 determined in 2.2.2.1 to 2.2.2.13 and 2.2.5

α_2 = as determined in 2.2.2.9

α_3 = as determined in 2.2.2.9

α_4 = as determined in 2.2.2.12

The assessment of the characteristic bond resistance τ_{Rk} shall be performed for the following range of concrete strength classes:

(1) The standard assessment shall be made for C20/25 to C5060.

(2) Separate assessment for C12/15

(3) For an assessment beyond C50/60, it shall be checked if the resistance to combined pull-out and concrete failure for concrete class C50/60 is or is not valid. If this condition is not fulfilled, then the maximum concrete strength class is C50/60.

If the test data show that the bond strengths vary in a regularly definable way (not randomly) with respect to fastener diameter, then the values τ_{Rk} may be evaluated as a continuous function of the fastener diameter (see A.2.1.6).

The characteristic bond resistance in N/mm^2 shall be rounded down to the next decimal place.

The factor ψ_c according to Equation (A.2.1.2.7) can be used as an increasing factor to express the bond strength for different concrete strength classes.

Expression of results:

Resistance to combined pull-out and concrete failure (BF): τ_{Rk} or $\tau_{Rk,100}$ according to Annex C [N/mm²]

Increasing factor accounting for concrete strength ψ_c [-]

2.2.2.15 Determination of the characteristic resistances for BEF

The characteristic resistance for pull-out failure of BEF, $N_{Rk,p}$, shall be determined according to Equation (2.2.2.15.1) using the basic value $N_{Rk,p,0}$ determined from monotonic (residual load) pull-out test according to Equation (2.2.2.15.2) and potential reductions min α_p due to applied tension loads during specific tests according to Equation (2.2.2.15.3).

$$N_{Rk,p} = N_{Rk,p,0} \cdot \min \alpha_p \text{ [kN]} \qquad (2.2.2.15.1)$$

Where

$$N_{Rk,p,0} = N_{5\%} \cdot \min ß_{cv} \cdot \min \{1; \min \frac{\alpha}{rqd.\alpha}; \min \alpha_1\} \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_4 \text{ [kN]} \qquad (2.2.2.15.2)$$

min α_p = min ($\alpha_{p,E9}$; $\alpha_{p,E11}$; $\alpha_{p,B20}$) for uncracked concrete and temperature range T1 (2.2.2.15.3)
= min ($\alpha_{p,E10}$; $\alpha_{p,E11}$; $\alpha_{p,B20}$) for uncracked concrete and temperature range(s) ≥ T2
= min ($\alpha_{p,E8}$; $\alpha_{p,E9}$; $\alpha_{p,E11}$; $\alpha_{p,B20}$) for cracked concrete and temperature range T1
= min ($\alpha_{p,E8}$; $\alpha_{p,E10}$; $\alpha_{p,E11}$; $\alpha_{p,B20}$) for cracked concrete and temperature range(s) ≥ T2

$\alpha_{p,E8}$ to $\alpha_{p,E11}$; $\alpha_{p,B20}$ Reduction factors assessed for series E8, E9, E10, E11 and B20

$N_{5\%}$ = Smaller 5% fractile of bond strength of test series A1 or A2 (normalized to minimum concrete strength) for intended use in uncracked concrete or from common assessment of series A1 and A2 (normalized to minimum concrete strength), if statistical equivalence is shown.
= Smaller 5% fractile of bond strength of test series A3 or A4 (normalized to minimum concrete strength) for intended use in uncracked concrete or from common assessment of series A3 and A4 (normalized to minimum concrete strength), if statistical equivalence is shown.

min $ß_{cv}$ = Minimum $ß_{cv}$ determined in 2.2.2.1 to 2.2.2.13 and 2.2.5

$\frac{\alpha}{rqd.\alpha}$ = Minimum ratio determined in 2.2.2.3 to 2.2.2.8, 2.2.2.13 and 2.2.5

min α_1 = Minimum α_1 determined in 2.2.2.1 to 2.2.2.13 and 2.2.5

α_2 = as determined in 2.2.2.9

α_3 = as determined in 2.2.2.9

α_4 = as determined in 2.2.2.12

The assessment of the characteristic resistance $N_{Rk,p}$ shall be performed for the following range of concrete strength classes:

(1) The standard assessment shall be made for C20/25 to C5060.

(2) Separate assessment C12/15

For an assessment beyond C50/60, it shall be checked if the resistiance to combined pull-out and concrete failure for concrete class C50/60 is or is not valid. If this condition is not fulfilled, then the maximum concrete strength class is C50/60.The characteristic resistance to pull-out failure in kN shall be rounded down to the next decimal place.

The factor ψ_c according to Equation (A.2.1.2.7) can be used as an increasing factor to express the bond strength for different concrete strength classes.

Expression of results:

Resistance to pull-out failure (BEF): $N_{Rk,p}$ or $N_{Rk,p,100}$ according to Annex C [kN]

Increasing factor accounting for concrete strength ψ_c [-]

2.2.3 Resistance to concrete cone failure

2.2.3.1 Single Fasteners

Users of EN 1992-4 [4] may expect values of factors $k_{ucr,N}$ and $k_{cr,N}$ from the ETA. The following factors can be taken without further testing. They are related to concrete cylinder strength.

$k_{ucr,N}$ = 11,0

$k_{cr,N}$ = 7,7

$c_{cr,N}$ = 1,5 h_{ef}

2.2.3.2 Minimum embedment depth (test series A6)

Purpose of the assessment

This test series is performed to check whether a group of 4 fasteners with a minimum embedment depth below the standard default values are consistent with the design provisions in EN 1992-4 [4] .

Note: Groups of fasteners with short embedment depth may not create the calculated resistance of concrete cone capacity according to EN 1992-4 [4] with the factors given in 2.2.3 which were derived for larger embedment depth.

The test series may be omitted if the default minimum embedment depth according to Table 2.2.3.2.1 is kept. If the manufacturer applies for embedment depth smaller than the default values but still larger or equal to $h_{ef,min}$ = min (4 d; 40 mm), then the test series according to Table A.1.1 line A6 are required.

Table 2.2.3.2.1 Absolute minimum embedment depth and default minimum embedment depth

Diameter d	Absolute minimum embedment depth $h_{ef,min}$	Default minimum embedment depth $h_{ef,min}$
[mm]	[mm]	[mm]
≤ 10	min (4 d; 40 mm)	60
12		70
16		80
20		90
≥ 24		4 d

Note: In cases of such low values of minimum embedment depth (and hence small amount of bonding material) special attention should be paid to the mixing quality of bonding material under various temperature conditions.

Test conditions

The fasteners shall be installed at absolute minimum embedment depth $h_{ef,min}$ according to Table 2.2.3.2.1 as a quadruple group with a spacing $s_{cr,N}$ = 3h_{ef}. The tension test until failure shall be carried out as unconfined test setup in uncracked concrete in accordance with D.3.1.3.

At least the smallest 4 fastener sizes with 5 tests each shall be performed with quadruple fastener groups (80 fasteners).

Assessment

Determine the mean failure load $N_{u,m}$ of the quadruple fasteners group in the test series. Determine the theoretical concrete cone capacity $N_{Rk,c}$ according to EN 1992-4 [4], Equation (7.1) with $k_{ucr} = k_{ucr,N}$ = 11,0 for the group of fasteners as the reference using the concrete cylinder strength present in the test series.

Criteria:

- $N_{u,m} \geq 0,9\ N_{Rk,c} / 0,75$: min h_{ef} as tested is confirmed
- $N_{u,m} < 0,9\ N_{Rk,c} / 0,75$: min h_{ef} shall be increased and tested again (or shall be increased to the default minimum embedment depth $h_{ef,\ min}$ according to Table 2.2.3.2.1 without further testing)

where

$N_{Rk,c} / 0,75$ = calculated mean value of concrete cone failure according to EN 1992-4 [4], with cv_F = 15 %, k = 1,645: (1-0,15 · 1,645) = 0,75

Expression of results:

Resistance to concrete cone failure: $c_{cr,N}$ [mm], $k_{cr,N}$, $k_{ucr,N}$ [-] according to clause 2.2.3.1

2.2.4 Edge distance to prevent splitting under load (test series A5)

Purpose of the assessment

The test series is performed to determine the characteristic edge distance at which splitting is not decisive.

Test conditions

The tests are required for small, medium and large diameter size and the corresponding minimum embedment depths. Test the fasteners in uncracked concrete with unconfined test setup. Install the fasteners in the corner of the test member with minimum thickness h_{min} applied for the fastener at equal edge distances $c_1 = c_2$. Edge distance and minimum thickness of the concrete are proposed by the manufacturer. Perform a tension test according to clause D.3.3.1.

If not requested otherwise by the manufacturer, then test with

- Edge distance $c = c_{min} = 1{,}5\ h_{ef}$.
- Thickness of concrete member $h = h_{min} = \max\{80\ mm, h_{ef} + 2\ d_0; h_{ef} + 30\ mm\}$
- h_{ef} according to 2.2.3.2.

Assessment

The characteristic edge distance $c_{cr,sp}$ is evaluated from the results of tension tests on single fasteners at the corner ($c_1 = c_2 = c_{cr,sp}$). The mean bond strength in the test series with fasteners at the corner shall be statistically equivalent to a fastener without edge and spacing effects (Table A.1.1, line A1) for the same concrete strength. If this condition is not fulfilled, then the edge distance shall be increased.

Expression of results:

Edge distance to prevent splitting under load: $c_{cr,sp}$ [mm]

2.2.5 Robustness

Purpose of the assessment

These tests are performed to assess the sensitivity of the fastener tension capacity to installation conditions. In this context the sensitivity to the degree of hole cleaning in dry and water saturated concrete, to hole cleaning for applications where the hole contains standing water at the time of installation of the fastener and to mixing effort are considered.

Test conditions - general

The tests shall be carried out as confined tension tests for BF and unconfined tension tests for BEF in uncracked concrete.

The fasteners are installed with the maximum embedment depth $h_{ef,max}$ = 20 d or as defined by the manufacturer. To avoid steel failure, but still account properly for the installation aspects for $h_{ef,max}$ the procedure given in clause A.2 (see also Figure A.2.1) shall be applied.

Additional test conditions for the specific test series B6 to B9 and E2 to E5 are given in the following subclauses. The following test conditions are defined for drilling the hole with a hammer drilling technique producing drilling dust that has to be removed from the bore hole by blowing (sucking) and brushing. Other drilling techniques require different methods of reduced bore hole cleaning (e.g., reduced flushing for diamond drilled holes).

Assessment

The assessment for the test series B6 to B9 and E2 to E5 is carried out accounting for the normalization to the nominal concrete strength according to A.2.1.2. The reduction factor α for each test series is calculated using the corresponding reference test series R5.

Based on the results of these tests the factor γ_{inst} accounting for the sensitivity to installation is determined according to 2.2.5.6.

The factor γ_{inst} accounting for the sensitivity to installation for all sizes of the fastener shall follow a regular curve. , e.g., an increase or decrease of γ_{inst} over the diameter sizes if the same factor γ_{inst} for all sizes is not achieved.

2.2.5.1 Reference test series for BF (test series R5)

Purpose of the assessment

The test series is needed as reference for comparison of test results in test series B6 to B9 for BF. For BEF test series A3 is used as the reference test series.

Test conditions

The number of tests can be reduced according to the Table A.1.2.The tests shall be performed in dry concrete (equilibrium moisture content).

The test conditions as concrete batch, temperature, drilling method, embedment depth, curing time and setting torque shall be the same as for test series B6 to B9.

Drill downwards to the maximum embedment depth. Clean the drill hole according to the MPII. Place the bonding material and insert the steel element in accordance with the MPII.

Assessment

<u>Failure loads</u>

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.

<u>Load displacement behaviour</u>

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load is larger than 0,4 mm, then cv_δ shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results:

$N_{u,m}$, $N_{5\%}$ [kN] to be used as reference in 2.2.5.2, 2.2.5.3, 2.2.5.4, 2.2.5.5,

$ß_{cv}$, α_1 to be used in 2.2.2.14 / 2.2.2.15.

2.2.5.2 Robustness in dry concrete (test series B6, E2)

Purpose of the assessment

The test series is performed to assess the influence of reduced cleaning effort in dry concrete.

Test conditions

The tests shall be performed with fastener sizes s/m/l (see Table A.1.2). The tests shall be performed in dry concrete (equilibrium moisture content).

Drill downwards to the maximum embedment depth

The following cleaning process of the hole has to be carried out in the tests.

Clean the hole with the equipment supplied by the manufacturer using two blowing operations by hand pump or compressed air and one brushing operation, i.e., either blow-brush-blow or blow-blow-brush or brush-blow-blow. The type of blowing and the order of brushing/blowing shall be done as prescribed in the MPII. This test procedure is valid only if the MPII specify hole cleaning with at least four blowing and two brushing operations, meaning twice the operations given above. If the MPII specify less than this, then the above requirement (2 blows + 1 brush) shall be reduced proportionately and the number of blows/brushes shall be lowered to the next whole number. Therefore, where the MPII recommend two blowing and one brushing operations, the tests shall be carried out without the brushing operation and one blowing only.

If the MPII recommends a vacuum cleaning instead of a blowing operation, then the same procedure (including requirements and corresponding reduced operations) applies. If the vacuum cleaning is part of the drilling process, then the drilling shall be done without venting (meaning, airing out the dust by periodically moving the drill bit out of the hole) during the drilling process." If the cleaning is performed with suction bit or a hollow drill bit, then the vacuum with the smallest specified maximum flow rate shall be used during the drilling process.

Place the bonding material and insert the steel element in accordance with the MPII.

Assessment

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1.1, lines R5 (BF) or A3 (BEF)
- Determine the robustness factor γ_{inst} according to Table 2.2.5.6.1.
- If α < 0,70, then determine the reduction (α/rqd. α) by using rqd. α = 0,7 and γ_{inst} = 1,4

Load displacement behaviour

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load is larger than 0,4 mm, then cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results:

$ß_{cv,}$ (α/rqd. α), α_1 to be used in 2.2.2.14 / 2.2.2.15.

α resulting from test series B6 or E2 to be used in 2.2.5.6

2.2.5.3 Robustness in water saturated (wet) concrete (test series B7, E3)

Purpose of the assessment

The test series is performed to assess the influence of reduced cleaning effort in water saturated concrete.

Test conditions

The tests shall be performed with fastener sizes s/m/l (see Table A.1.2).

The concrete in the area of anchorage shall be water saturated when the hole is drilled, cleaned and the embedded steel element is installed and tested.

The following procedure shall be applied to ensure a water saturated concrete in the area of the anchorage:

1. A pilot hole is drilled in the concrete to the recommended depth.
2. The pilot hole is filled with water and and the water level shall be maintained for 8 days until water has percolated into the concrete.
3. The water is removed from the pilot hole.
4. The final hole is drilled at the recommended diameter d_0.

Note: The diameter of the pilot hole shall be chosen such that sufficient penetration of water into the concrete is achieved. Therefore, the diameter of the pilot hole of 0,5 d_0 to 0,8 d_0 is recommended.

Hollow drilling or diamond drilling into pilot holes may be not practicable. In this case the concrete shall be stored under water immediately after stripping off the formwork.

Clean the hole with the equipment supplied by the manufacturer using two blowing operations by hand pump or compressed air and one brushing operation, i.e., either blow-brush-blow or blow-blow-brush or brush-blow-blow. The type of blowing and the order of brushing/blowing shall be done as prescribed in the MPII. This test procedure is valid only if the MPII specify hole cleaning with at least four blowing and two brushing operations, meaning twice the operations given above. If the MPII specify less than this, then the above requirement (2 blows + 1 brush) shall be reduced proportionately and the number of blows/brushes shall be lowered to the next whole number. Therefore, where the MPII recommend two blowing and one brushing operation, the tests shall be carried out without the brushing operation and one blowing only.

If the MPII recommends a vacuum cleaning instead of a blowing operation, then the same procedure (including requirements and corresponding reduced operations) applies. If the vacuum cleaning is part of the drilling process, then the drilling shall be done without venting (meaning, airing out the dust by periodically moving the drill bit out of the hole) during the drilling process." If the cleaning is performed with suction bit or a hollow drill bit, then the vacuum with the smallest specified maximum flow rate shall be used during the drilling process.

Place the bonding material and insert the steel element in accordance with the MPII.

Assessment

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1.1, line R5 (BF) and A3 (BEF).
- Determine the robustness factor γ_{inst} according to Table 2.2.5.6.1.
- If α < 0,65, then determine the reduction (α/rqd. α) by using rqd. α = 0,65 and γ_{inst} = 1,4.

Load displacement behaviour

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results:

$ß_{cv,}$ (α/rqd. α), α_1 to be used in 2.2.2.14 / 2.2.2.15.

α resulting from test series B7 or E3 to be used in 2.2.5.6

2.2.5.4 Robustness in water-filled hole (test series B8, E4)

Purpose of the assessment

The test series is performed to assess the influence of reduced cleaning effort in water filled holes.

These tests are not required for fasteners where the MPII state that water shall be completely removed before the capsule is inserted or the injection mortar is injected.

Test conditions

The tests shall be performed with fastener sizes s/m/l (see Table A.1.2).

The tests are made in concrete which is water saturated in the area of the anchorage. To ensure a water saturated concrete in the area of the anchorage the procedure of 2.2.5.3 shall be applied.

Clean the hole with the equipment supplied by the manufacturer using two blowing operations by hand pump or compressed air and one brushing operation, i.e., either blow-brush-blow or blow-blow-brush or brush-blow-blow. The type of blowing and the order of brushing/blowing shall be done as prescribed in the MPII. This test procedure is valid only if the MPII specify hole cleaning with at least four blowing and two brushing operations, meaning twice the operations given above. If the MPII specify less than this, then the above requirement (2 blows + 1 brush) shall be reduced proportionately and the number of blows/brushes shall be lowered to the next whole number. Therefore, where the MPII recommend two blowing and one brushing operations, the tests shall be carried out without the brushing operation and one blowing only.

If the MPII recommends a vacuum cleaning instead of a blowing operation, then the same procedure (including requirements and corresponding reduced operations) applies. If the vacuum cleaning is part of the drilling process, then the drilling shall be done without venting (meaning, airing out the dust by periodically moving the drill bit out of the hole) during the drilling process.” If the cleaning is performed with suction bit or a hollow drill bit, then the vacuum with the smallest specified maximum flow rate shall be used during the drilling process.

After cleaning the hole, fill the hole with water. Without removing the water from the hole, place the bonding material and insert the steel element as described in the MPII.

Assessment

<u>Failure loads</u>

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1.1, line R5 (BF), and A3 (BEF).
- Determine the robustness factor γ_{inst} according to Table 2.2.5.6.1.
- If α < 0,65, then determine the reduction (α/rqd. α) by using rqd. α = 0,65 and γ_{inst} = 1,4.

<u>Load displacement behaviour</u>

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results:

$ß_{cv}$, (α/rqd. α), α_1 to be used in 2.2.2.14 / 2.2.2.15.

α resulting from test series B8 or E4 to be used in 2.2.5.6

2.2.5.5 Robustness of mixing technique (test series B9, E5)

Purpose of the assessment

The test series is performed to assess the influence of the mixing technique.

Tests are only required for those fastener types where the mixing technique is ensured by the installer, such techniques include:

a) mixing components until a colour change is achieved throughout the material.

b) mixing with recommended equipment for a specified time.

c) carrying out a repetitive mixing operation for a specified number of times.

The test may be omitted if the mixing of the mortar is ensured by use of capsule type systems according to Figure 1.1.1 or static mixers of injection type systems according to Figure 1.1.2.

Test conditions

Perform the test with diameter size 12 mm or smallest size if that is larger than 12 mm.

Tests shall be carried out on incomplete mixes, i.e., by reducing the specified process by 25 %. For example, in the case of missing technique a) mentioned above, the test is carried out after mixing for 75 % of the time taken to achieve an even colour throughout the material.

Assessment

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20 % (cv_F > 20 %), then determine the reduction factor for large scatter $ß_{cv}$ according to A.2.1.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1.1, line R5 (BF), and A3 (BEF).
- Determine the robustness factor γ_{inst} according to Table 2.2.5.6.1.
- If α < 0,70, then determine the reduction (α/rqd. α) by using rqd. α = 0,7 and γ_{inst} = 1,4.

Load displacement behaviour

- Determine the reduction factor α_1 according to A.2.2.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 40 %.Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results:

$ß_{cv,}$ (α/rqd. α), α_1 to be used in 2.2.2.14 / 2.2.2.15.

α resulting from test series B9 or E5 to be used in 2.2.5.6

2.2.5.6 Assessment of the factor for sensitivity to installation

The factor γ_{inst} accounting for the sensitivity to installation is evaluated from the results of the tests for robustness i.e., test series B6 to B9 for BF and test series E2 to E5 for BEF.

For each test series B6 to B9 (BF) or E2 to E5 (BEF) as applied by the manufacturer the factor γ_{inst} shall be determined according to Table 2.2.5.6.1 by comparing the factor α with the value of rqd α for the specific test. The largest resulting factor γ_{inst} applies.

Table 2.2.5.6.1 Values of rqd. α in the sensitivity to robustness tests

factor γ_{inst}	rqd. α for tests according to Table A.1.1	
	lines B6, B9, E1, E2	lines B7, B8, E3, E4
1,0	0,95, if $\alpha \geq$ 0,95	0,90, if $\alpha \geq$ 0,90
1,2	0,80, if 0,95 > $\alpha \geq$ 0,80	0,75, if 0,90 > $\alpha \geq$ 0,75
1,4	0,70, if α < 0,80	0,65, if α < 0,75

Expression of results:

Robustness, Factor for installation: γ_{inst}

2.2.6 Minimum edge distance, spacing and member thickness (test series B1)

Purpose of the assessment

The tests are performed to check that splitting of the concrete does not occur during the installation of the fastener. If the manufacturer does not specify an installation torque, then the TAB shall recommend a reasonable T_{inst} for use in the tests and stated in the ETA.

Test conditions

The tests are required for small, medium and large diameter size. The tests shall be performed according to clause 0 in uncracked concrete with the embedment depth requested by the manufacturer. For BF and BEF with several embedment depths (variable embedment depth for BF) the minimum requested embedment depth shall be used. The fasteners shall be placed on an uncast side of the concrete test member with a distance ≥ 3 h_{ef} between neighbouring groups.

Install two fasteners at minimum edge distance c_{min} and minimum spacing s_{min} in a test member with the minimum thickness h_{min}:

c_{min} ≥ max {35 mm; 4 d_0}

s_{min} ≥ max {35 mm; 4 d_0}

h_{min} ≥ max [80 mm, min (h_{ef} +(max {30 mm; 2 d_0})]

Edge distance and c_{min} and minimum spacing shall be rounded to at least 5 mm.

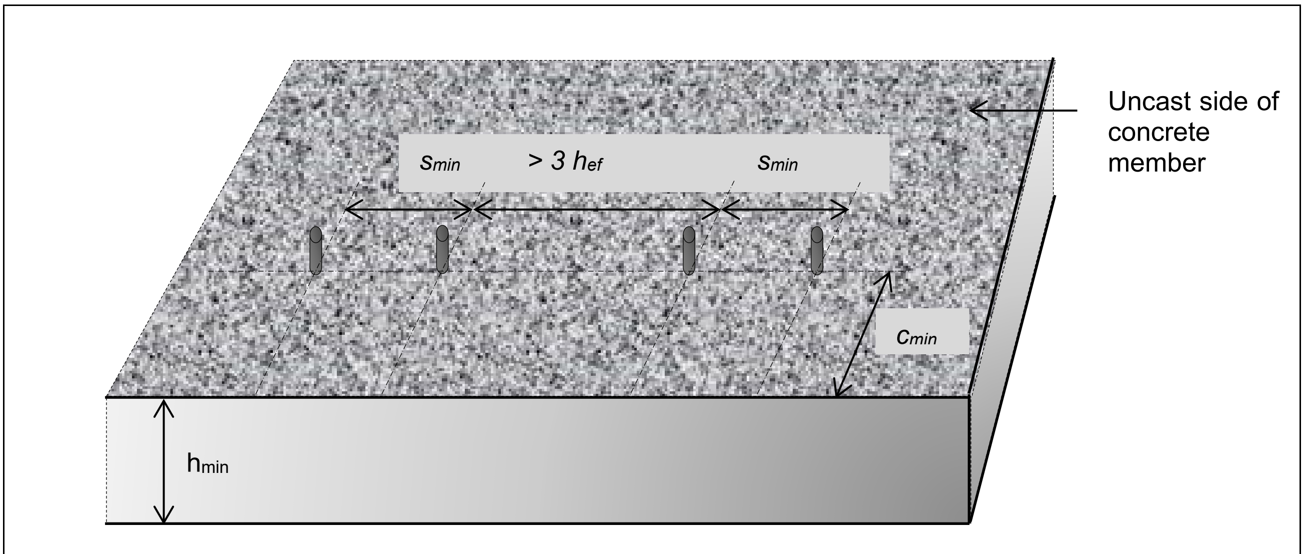


Figure 2.2.6.1 Installation of fasteners at the edge of concrete member

Assessment

For applications in cracked concrete, it is assumed that reinforcement will be activated once the first crack occurs. Consequently, a lower margin between the applied torque at crack formation and the specified installation torque is accepted. This may lead to different values of (s_{min}, c_{min}) for applications in cracked or uncracked concrete.

The minimum spacing s_{min} and minimum edge distance c_{min} shall be evaluated from the results of tests with double fastener groups (c = c_{min}, s = s_{min}). The 5 %-fractile of the installation torque, $T_{5\%}$, calculated according to clause A.2.1.4) at which a hairline crack has been observed at one fastener of the double fastener group, shall fulfil Equation (2.2.6.1).

$$T_{5\%} \geq k \cdot \max T_{inst} \, (f_{c,t} / f_{ck})^{0,5} \quad \text{(for concrete failure)} \qquad (2.2.6.1)$$

where: max T_{inst} as specified by the manufacturer or recommended by the TAB.

The following values for k shall be taken:

(a) Scatter of the friction coefficients which determine the magnitude of the splitting forces at the required or recommended installation torque respectively is controlled during production to the values present with the fasteners used in the tests

rqd. k =	1,3	fastenings in cracked concrete
=	1,7	fastenings in uncracked concrete.

(b) Scatter of the friction coefficients which determine the magnitude of the splitting forces at the required or recommended installation torque respectively is not controlled during production to the values present with the fasteners used in the tests

rqd. k =	1,5	fastenings in cracked concrete
=	2,1	fastenings in uncracked concrete.

The choice of (a) or (b) in the assessment has to be reflected in the FPC.

The splitting forces at the required or recommended installation torque respectively depend on the pre-stressing force generated during torquing and the ratio splitting force to pre-stressing force. Pre-stressing force and splitting force may be measured in the tests (see 2.2.1.2).

If steel failure occurs in this test series, then increase of the edge distance and spacing will not change the failure mode and the tested edge distance and spacing apply.

If the criteria are not fulfilled, then the minimum edge distance and minimum spacing may be increased without further testing according to the following assessment:

- Calculate the projecting area $A_{sp,t} = (3\ c_{min} + s_{min})(1{,}5\ c_{min} + h_{ef})$ with edge distances and spacing as tested.
- Back calculate k from Equation (2.2.6.1) as tested
- Calculate A_{sp} with enlarged c_{min} or s_{min} and verify A_{sp} > (rqd. k / k) $A_{sp,t}$.

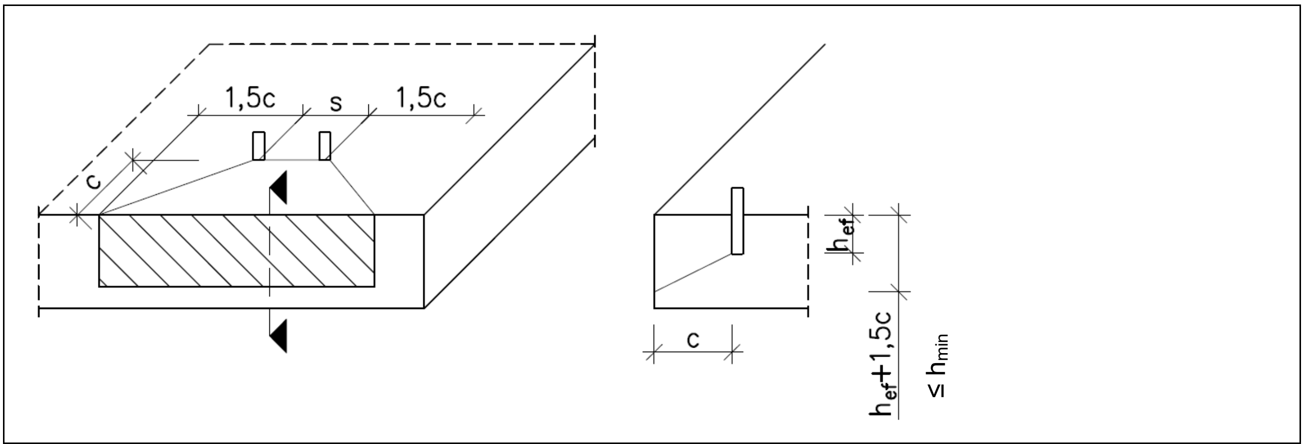


Figure 2.2.6.2 Projecting Area A_{sp}

Expression of results

Minimum edge distance and spacing: c_{min}, s_{min} [mm]

minimum thickness of the concrete member: h_{min} [mm]

Installation torque max T_{inst} [Nm]

2.2.7 Resistance to steel failure under shear load (test series V1)

2.2.7.1 Single fastener (test series V1)

Purpose of the assessment

The characteristic resistance to steel failure may be calculated in accordance with EN 1992-4 [4]. clause 7.2.2.3.1. for steel elements with constant strength over the length of the steel element as given below. The smallest cross section in the area of load transfer applies.

$$V^0_{Rk,s} = k_6 \cdot A_s \cdot f_{uk} \text{ [N]} \quad (2.2.7.1.1)$$

$$M^0_{Rk,s} = 1{,}2 \cdot W_{el} \cdot f_{uk} \text{ [Nm]} \quad (2.2.7.1.2)$$

where

k_6 = 0,6 for fasteners made of carbon steel with $f_{uk} \leq 500$ N/mm²

= 0,5 for fasteners made of carbon steel with $500 < f_{uk} \leq 1000$ N/mm²

= 0,5 for fasteners made of stainless steel

If Equation (2.2.7.1.1) is not applicable, then the characteristic resistance to steel failure $V^0_{Rk,S}$ shall be determined with tests.

The tests are required if the fastener shows different strength over the length of the element and if the fastener has a significantly reduced section along the load transfer zone of the fastener with respect to shear loads or when more than one part of the fastener is used for the transfer of shear loads. $M^0_{Rk,s}$ shall be calculated according to Equation (2.2.2.7.2) for the smallest cross section and smallest strength of the fastener in the area of load transfer.

The test series is also used for determination of the displacements δ_{V0} in clause 2.2.10.

Test conditions

The tests shall be performed in uncracked concrete according to clause D.3.6.1.

The tests shall be performed with all diameter sizes at minimum embedment depth. The clearance hole in the fixture shall not be larger than specified in Table 2.2.7.1.1.

Table 2.2.7.1.1 Diameter of clearance hole in the fixture

external diameter[1)] d or d_{nom} [mm]	6	8	10	12	14	16	18	20	22	24	27	30	> 30
diameter d_f of clearance hole in the fixture [mm]	7	9	12	14	16	18	20	22	24	26	30	33	d+3 mm or d_{nom} +3 mm

1) d if bolt bears against the fixture
d_{nom} if sleeve bears against the fixture

Assessment

The following assessment shall be made for each fastener size and for the smallest embedment depth where steel failure occurs:

Failure loads

- Determine the mean value of failure loads $V_{Ru,m}$.
- Determine $V^0_{Rk,s} = V_{5\%}$ as the 5 % fractile of the failure loads $V_{5\%}$ [kN], converted to the nominal steel strength, according to Equation (A.2.1.2.8).

Load displacement behaviour

- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Vu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%].

Expression of results:

Resistance to steel failure under shear load: $V^0_{Rk,s}$ [kN], $M^0_{Rk,s}$ [Nm], $\delta_{0,5Vu,m}$ [mm], cv_δ [%]

2.2.7.2 Group of fasteners (ductility factor k7)

The characteristic resistance of a group of fasteners in case of steel failure is influenced by the ductility of the fastener. The factor k_7 accounts for this influence and is required in EN 1992-4 [4].

The factor k_7 may be assumed as follows:

k_7 = 1,0 for ductile steel characterized by a rupture elongation A > 8%;

k_7 = 0,8 for steel characterized by a rupture elongation A ≤ 8%.

The percentage elongation after fracture A according to EN ISO 6892-1 [19], clause 20.1 shall be taken for the elder nomination given as A_5 in EN 1992-4, clause 7.2.2.3.1.

Expression of results:

Resistance to steel failure under shear load, ductility factor: k_7 [-]

2.2.8 Resistance to pry-out failure (test series V2)

Purpose of the assessment

The test series is performed to determine the k_8 factor for design according to EN 1992-4 [4], clause 7.2.2.4 for pry-out failure. The test series may be omitted if the default values for k_8 according to Table 2.2.8.1 apply.

Table 2.2.8.1 Default values for k_8

Effective embedment depth h_{ef} [mm]	k_8 [-]
< 60 mm	1,0
≥ 60 mm	2,0

Test conditions

The tests shall be performed with a group of 4 fasteners in uncracked concrete according to clause D.3.6.2. The spacing is selected as $s = s_{cr,N}$ and the edge distance $c \geq c_{cr,N}$. If steel failure occurs, then the spacing may be reduced.

Assessment

The 5 % fractile of failure loads in the test series $V_{u,5\%}$ are compared to the characteristic resistance of the fastener group to tension load in uncracked concrete $N_{Rk,ucr}$ according to Equations (2.2.8.1) and (2.2.8.2).

$$k_8 = \frac{V_{u,5\%}}{N_{Rk,ucr}} \quad (2.2.8.1)$$

$$N_{Rk,ucr} = k_{ucr} \cdot h_{ef}^{1,5} \cdot \sqrt{f_{c,t}} \cdot \frac{(s + 3h_{ef})^2}{9h_{ef}^2} \quad (2.2.8.2)$$

Expression of results:

Resistance to pry-out failure, Factor k_8 [-]

2.2.9 Resistance to concrete edge failure

Purpose of the assessment

Determination of outside diameter and effective length of fastener for calculation of resistance to concrete edge failure.

Assessment

Geometrical data d_{nom} and ℓ_f shall be determined according to EN 1992-4 [4] clause 7.2.2.5.

d_{nom}	=	outside diameter of the fastener
l_f	=	h_{ef} in case of a uniform diameter of the fastener
	≤	12 d_{nom} in case of d_{nom} ≤ 24 mm
	≤	max (8 d_{nom}; 300 mm) in case of d_{nom} > 24 mm

Expresion of results:

Resistance to concrete edge failure: outside diameter of fastener d_{nom}, effective length of fastener ℓ_f [mm]

2.2.10 Displacements under short-term and long-term loading

Assessment

As a minimum the displacement factors under short-term loading and long-term loading shall be determined for the load corresponding to 0,5 of the mean value of test results of test series according to Table A.1.1, lines R1 to R4. They shall be given as relative values either per unit bond stress given in [mm/(N/mm²)] or per unit load given in [mm/kN].

The displacements under short-term tension and shear loading are evaluated from the tests on single fasteners without edge or spacing effects separately for cracked (test series according to Table A.1.1, lines R3 to R4) and uncracked concrete (test series according to Table A.1.1, lines R1 to R2, V1). The value derived shall correspond to the 95 %-fractile for a confidence level of 90 %.

The displacement factor $\delta_{N0} = \delta_{0,5Nu,95\%}$ / (0,5 $\tau_{u,m}$) for BF or $\delta_{N0} = \delta_{0,5Nu,95\%}$ / (0,5 $N_{u,m}$) for BEF considering results as defined above shall correspond to the 95 %-fractile of the displacements $\delta_{0,5Nu,m}$ (tension load) for a confidence level of 90 %.

The displacement factor $\delta_{V0} = \delta_{0,5Vu,95\%}$ / (0,5 $V_{u,m}$) considering results as defined above shall correspond to the 95 %-fractile of the displacements $\delta_{0,5Vu,m}$ (shear load) for a confidence level of 90 %.

The short-term tension and shear displacement factors δ_{NO} and δ_{VO} depend on the concrete strength class and state of the concrete (uncracked, cracked). However, it is sufficient to give one value each for the tension and shear displacement which represents the most unfavourable condition and which is valid for all concrete strength classes and cracked and uncracked concrete.

In the absence of other information $\delta_{N\infty}$ may be calculated as follows:

For fasteners to be used in <u>cracked</u> concrete the long-term displacement factors under tension loading, $\delta_{N\infty}$, shall be calculated from the results of tests with crack cycling under load (see Table A.1.1, line B13) according to Equation (2.2.10.1) or (2.2.10.2).

$$\delta_{N\infty} = \frac{\delta_{1000,mean}/(N_p/(\pi \cdot d \cdot h_{ef}))}{1,5} \text{ [mm/N/mm}^2\text{] for BF} \qquad (2.2.10.1)$$

$$\delta_{N\infty} = \frac{\delta_{1000,mean}/(N_p)}{1,5} \text{ [mm/kN] for BEF} \qquad (2.2.10.2)$$

where

$\delta_{1000,mean}$ = mean value of displacements after crack movements in tests according to clause 2.2.2.5

N_p = sustained load applied in tests with crack cycling under load (see clause 2.2.2.5)

For fasteners to be used in uncracked concrete only, the long-term displacement factors under tension loading, $\delta_{N\infty}$, shall be calculated from the results of sustained load tests (see Table A.1.1, line B14 and B15) according to Equation (2.2.10.3) or (2.2.10.4) .

$$\delta_{N\infty} = \frac{\delta_{N,\infty,m}/(N_{sust}/(\pi \cdot d \cdot h_{ef})}{2{,}0} \text{ [mm/N/mm}^2\text{]} \qquad (2.2.10.3)$$

$$\delta_{N\infty} = \frac{\delta_{N,\infty,m}/(N_{sust})}{2{,}0} \text{ [mm/kN] for BEF} \qquad (2.2.10.4)$$

where

$\delta_{N,\infty,m}$ = mean value of displacement in the tests according to clause 2.2.2.6.1.

N_{sust} = sustained load applied in sustained load tests according to clause 2.2.2.6.1.

The larger value is decisive.

The long-term shear displacements $\delta_{V\infty}$ may be assumed to be approximately equal to 1,5-times the value δ_{VO}.

If displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] are larger than 0,4 mm and the coefficient of variation of displacements at 50% of the failure loads cv_δ [%] in any of the test series lines R1 to R5, and B2 to B5 of Table A.1.1 is larger than 25 % or in any of the test series lines B6 to B17 and B20 of Table A.1.1 (BF) or Table B.2.1 lines E1 to E12 (BEF) is larger than 40 %, then the ETA shall include the statement:

"The fastener is not intended to be used in groups of fasteners."

Expression of results:

Displacements under short-term and long-term loading: δ_{N0}, δ_{V0}; $\delta_{N\infty}$, $\delta_{V\infty}$ [mm/(N/mm²)]

2.2.11 Resistance in steel fibre reinforced concrete

Purpose of the assessment

The assessment is made to verify the validity of the performance of the BF or BEF system in SFRC as assessed for use in compacted normal weight concrete without fibres of strength classes C20/25 to C50/60 for static and quasi-static loading.

The essential characteristics of BF and BEF in steel fibre reinforced concrete assessed according to Annex F may be used for design according to EN 1992-4 [4].

Test conditions

The test conditions are given in F.2.

Assessment

The assessment is given in F.2.

Expression of results

Specification of the intended use (shall be given in Annex B of the ETA):

- The fastener is intended to be used in fibre reinforced concrete according to EN 206:2013 + A2:2021 including steel fibres according to EN 14889-1:2006, clause 5, fibre group xxx.

  Note: Fibre group xxx specifies the steel fibres used in the tests (e.g., Group I for steel fibres made from cold-drawn wire).

- The maximum content of steel fibres [kg/m³]

2.2.12 Resistance to tension for seismic performance category C1 (Series C.1.1)

Purpose of the assessment

These tests are intended to evaluate the performance of fasteners under simulated seismic tension loading, including the effects of cracks, and without edge effects for seismic performance category C1.

Test conditions

The general test conditions are given in clause E.3.1. Explanations for fastener types to be tested are given in clause E.3.2. Specific test conditions are given in clause E.3.3.2.

Assessment

The assessment of tests is given in clauseE.4.1. The reduction factor $\alpha_{N,C1}$ for seismic performance category C1 shall be calculated according to clause E.4.1.1. Determine $N_{Rk,s,C1}$ [kN] and $\tau_{Rk,C1}$ [N/mm^2] for BF according to E.4.3.1.1.2, Determine $N_{Rk,s,C1}$ [kN] and $N_{Rk,p,C1}$ [kN] for BEF according to E.4.3.1.1.1,

Expression of results: Resistance to tension load for seismic performance category C1:

$N_{Rk,s,C1}$ [kN] (all), $\tau_{Rk,C1}$ [N/mm^2] (BF), $N_{Rk,p,C1}$ [kN] (BEF)

2.2.13 Resistance to tension and displacements for seismic performance category C2 (Series C.2.1, C2.3, C2.5)

Purpose of the assessment

These tests are intended to evaluate the performance of fasteners under simulated seismic tension loading, including the effects of cracks, and without edge effects for seismic performance category C2.

Test conditions

Test series C2.1, C2.3 and C2.5 shall be performed with the same embedment depths and test set-up (confinement conditions).

The general test conditions are given in clause E.3.1. Explanations for fastener types to be tested are given in clause E.3.2. Specific test conditions are given in clause E.3.4.2 for reference test series C2.1, in clause E.3.4.3 for tests under pulsating tension loading (test series C2.3) and in clause E.3.4.5 for tests with tension load and varying crack width (test series C2.5).

Assessment

The assessment of test series is given in clause E.4.2. The characteristic resistance to tension load for seismic performance category C2 $N_{Rk,s,C2}$ [kN] and $\tau_{Rk,C2}$ [N/mm^2] for BF shall be determined according to clause Ê.4.3.2.1.2. The characteristic resistance to tension load for seismic performance category C2 $N_{Rk,s,C2}$ [kN] and $N_{Rk,p,C2}$ [kN] for BF shall be determined according to clause Ê.4.3.2.1.1. The displacements $\delta_{N,C2(50\%)}$ $\delta_{N,C2(100\%)}$ shall be assessed according to clause E.4.3.2.3.

Expression of results: Resistance to tension load and displacements for seismic performance category C2:

$N_{Rk,s,C2}$ [kN] (all), $\tau_{Rk,C2}$ [N/mm^2] (BF), $N_{Rk,p,C2}$ [kN] (BEF), $\delta_{N,C2(50\%)}$ $\delta_{N,C2(100\%)}$ [mm] (all)

2.2.14 Resistance to shear load for seismic performance categories C1 (Series C1.2)

Purpose of the assessment

These tests are intended to evaluate the performance of fasteners under simulated seismic shear loading, including the effects of cracks, and without edge effects for seismic performance category C1.

Test conditions

The general test conditions are given in clause E.1.1. Explanations for fastener types to be tested are given in clause E.3.2. Specific test conditions are given in clause E.3.3.3.

Assessment

The assessment of test series is given in clause E.4.1. The characteristic resistance to shear load for seismic performance category C1 $V_{Rk,s,C1}$ [kN] shall be determined according to clause E.4.3.1.2.

Expression of results: Resistance to shear load for seismic performance category C1: $V_{Rk,s,C1}$ [kN] (all)

2.2.15 Resistance to shear load and displacements for seismic performance categories C2 (Series C2.2, C2.4)

Purpose of the assessment

These tests are intended to evaluate the performance of fasteners under simulated seismic shear loading, including the effects of cracks, and without edge effects for seismic performance category C2.

Test series C2.2 and C2.4 shall be performed with the same embedment depths and test set-up (confinement conditions).

Test conditions

The general test conditions are given in clause E.3.1. Explanations for fastener types to be tested are given in clause E.3.2. Specific test conditions are given in clause E.3.4.2 for the reference test series C2.2 and in clause E.3.4.4 for test series under alternating shear load (series C2.4).

Assessment

The assessment of test series is given in clause E.4.2. The characteristic resistance to shear load for seismic performance category C2 $V_{Rk,s,C2}$ [kN] shall be determined according to clause E.4.3.2.2. The displacements $\delta_{V,C2(50\%)}$ $\delta_{V,C2(100\%)}$ [mm] shall be assessed according to clause E.4.3.2.3.

Expression of results: Resistance to shear load and displacements for seismic performance category C2:

$V_{Rk,s,C2}$ [kN] (all), $\delta_{V,C2(50\%)}$ $\delta_{V,C2(100\%)}$ [mm] (all)

2.2.16 Reaction to fire

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

The bonding material (synthetic mortar, cementitious mortar or a mixture of the two including fillers and/or additives) is located between the steel element and the wall of the drilled hole in the end use. The bonding material is considered as a small component which has no influence on the reaction to fire of the product and which does not need to be tested and classified separately.

It can be assumed that the bonding material (synthetic mortar or a mixture of synthetic mortar and cementitious mortar) in connection with BF or BEF in the end use application do not make any contribution to fire growth or to the fully developed fire and they have no influence to the smoke hazard.

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Therefore, the performance of such fasteners is class A1.

2.2.17 Fire resistance to steel failure under tension loading (test series F1)

Purpose of the test

The tests are performed to determine the resistance to steel failure of the fasteners under tension load and fire exposure. The determination of the duration of the fire resistance is according to the conditions given in EN 1363-1 [30] using the “Standard Temperature/Time Curve” (STC).

If resistance to steel failure is calculated in accordance with EN 1992-4 [4], Annex D.4.2.1, then tests may be omitted for steel types covered therein.

Test conditions

The tests are carried out according to D.4.1. Install fasteners at normal ambient temperature according to MPII. The fastener shall be tested with the shallowest embedment depth that leads to steel failure (where steel failure may occur as failure of the shaft of the metal part or failure of the nut by melting of the threads). Based on current experience an embedment depth of 10 d may be used as initial value.

If the tests result in failure modes other than steel failure for the initially tested embedment depth (e.g., of 10 d), then the embedment depth shall be increased with increments of 1 d until steel failure occurs.

Assessment

From the fire tests pair of variates [test load F / duration of failure $\boldsymbol{t_u}$] shall be determined. The test loads F shall be converted into steel stresses $\boldsymbol{\sigma_s}$ and drawn for each fastener size in a diagram depending on the determined fire resistance duration $\boldsymbol{t_u}$ (see Figure 2.2.17.1). The tests shall be performed with different load levels such that the obtained results are reasonably distributed along the $\boldsymbol{t_u}$-axis within the interval [30 min, 120 min]. For the determination of the trend line, the data are displayed in terms of $\boldsymbol{\sigma_s}$ vs. $\boldsymbol{1/t_u}$ (see Figure 2.2.17.2). By linear regression of the pair of variates $\boldsymbol{\sigma_s/(1/t_u)}$ (see Figure 2.2.17.2) the formula of the trend line according to Equation (2.2.17.1) shall be determined. The trend line shall represent the test results as shown in Figure 2.2.17.1. If the fastener does not fail during the test, then the result cannot be used for determination of the trend line according to Figure 2.2.17.1.

$$\sigma_{s1} = p_1 + p_2/t_u \qquad (2.2.17.1)$$

Where:

p_1 = is the value where the trend line cuts the y-axis (Figure 2.2.17.2)

p_2 = is the gradient of the trend line (Figure 2.2.17.2)

The trend line according to Equation (2.2.17.1) shall be reduced with an additional shift factor $p_3 < 1$ in such a way, that the trend line runs through the pair of variates of the most unfavourable test result. As a result, the lower limit value curve according to Equation (2.2.17.2) is obtained.

$$\sigma_{s2} = p_3(p_1 + p_2/t_u) \qquad (2.2.17.2)$$

The characteristic steel stress for the duration of fire resistance of 60 min, 90 min and 120 min shall be calculated using Equation (2.2.17.2) as follows:

$$\sigma_{Rk,s,fi(60)} = p_3(p_1 + p_2/60\ min)$$

$$\sigma_{Rk,s,fi(90)} = p_3(p_1 + p_2/90\ min)$$

$$\sigma_{Rk,s,fi(120)} = p_3(p_1 + p_2/120\ min)$$

Using the two pair of variates $t_u = 60\ min/\sigma_{Rk,s,fi(60)}$ and $t_u = 90\ min/\sigma_{Rk,s,fi(90)}$ the following linear Equation shall be derived:

$$\sigma_{s3} = p_4 - p_5 \cdot t_u \qquad (2.2.17.3)$$

Where:

$\boldsymbol{p_4}$ = is the value where the straight line (red line in Figure 2.2.17.1) cuts the y-axis

$\boldsymbol{p_5}$ = is the gradient of the straight line (red line in Figure 2.2.17.1)

The characteristic resistance to steel failure shall be calculated using Equations (2.2.17.4) to (2.2.17.8).

$$\sigma_{Rk,s,fi(30)} = p_4 - p_5 \cdot 30\ min \qquad (2.2.17.4)$$

$$N_{Rk,s,fi(30)} = \sigma_{Rk,s,fi(30)} \cdot A_s \qquad (2.2.17.5)$$

$$N_{Rk,s,fi(60)} = \sigma_{Rk,s,fi(60)} \cdot A_s \qquad (2.2.17.6)$$

$$N_{Rk,s,fi(90)} = \sigma_{Rk,s,fi(90)} \cdot A_s \qquad (2.2.17.7)$$

$$N_{Rk,s,fi(120)} = \sigma_{Rk,s,fi(120)} \cdot A_s \qquad (2.2.17.8)$$

If there are tests carried out with two fastener sizes only (d_1 and d_2), then the characteristic steel stress for intermediate sizes ($d_1 < d < d_2$) shall be calculated by linear interpolation without additional tests only (see Figure 2.2.17.3), if the ratio of the steel strength $\sigma_{Rk,s,d2}/\sigma_{Rk,s,d1}$ is not larger than 2,0. For fastener sizes $d > d_2$ the characteristic steel stress calculated for d_2 shall be taken without further testing.

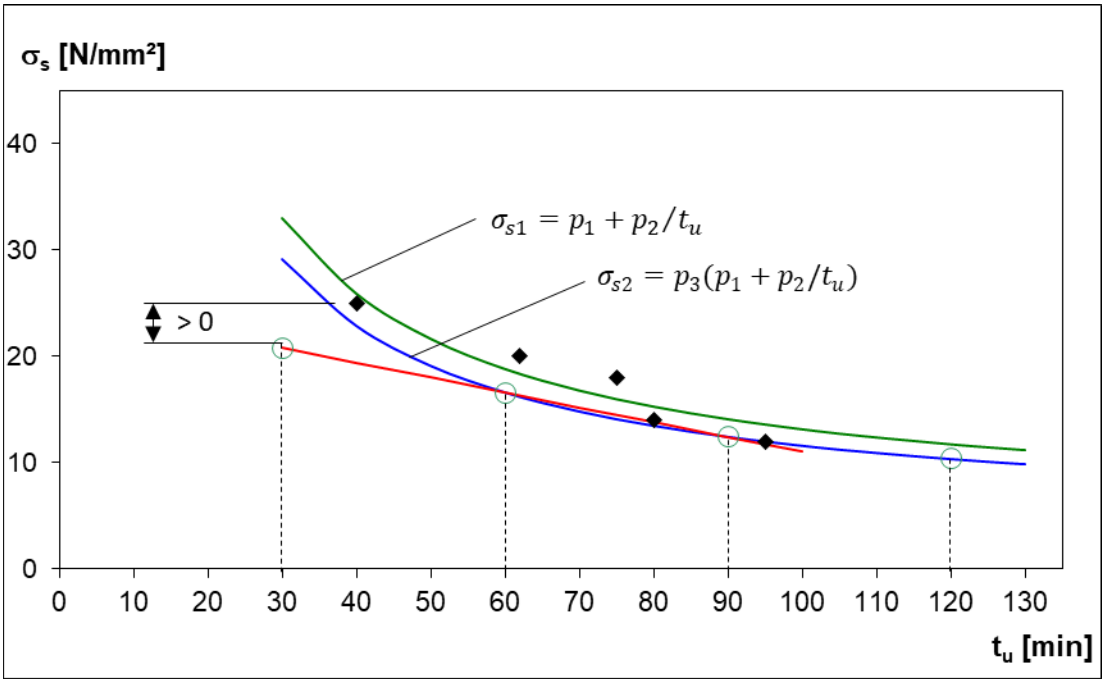

Figure 2.2.17.1 Determination of the characteristic steel stress

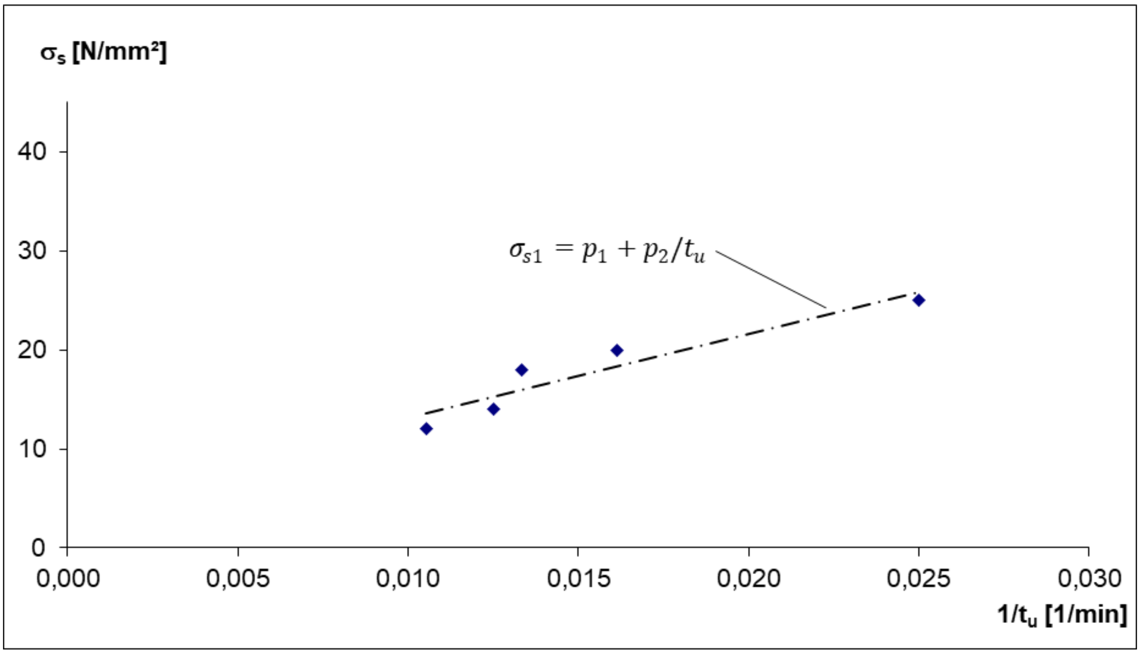

Figure 2.2.17.2 Determination of the regression equation

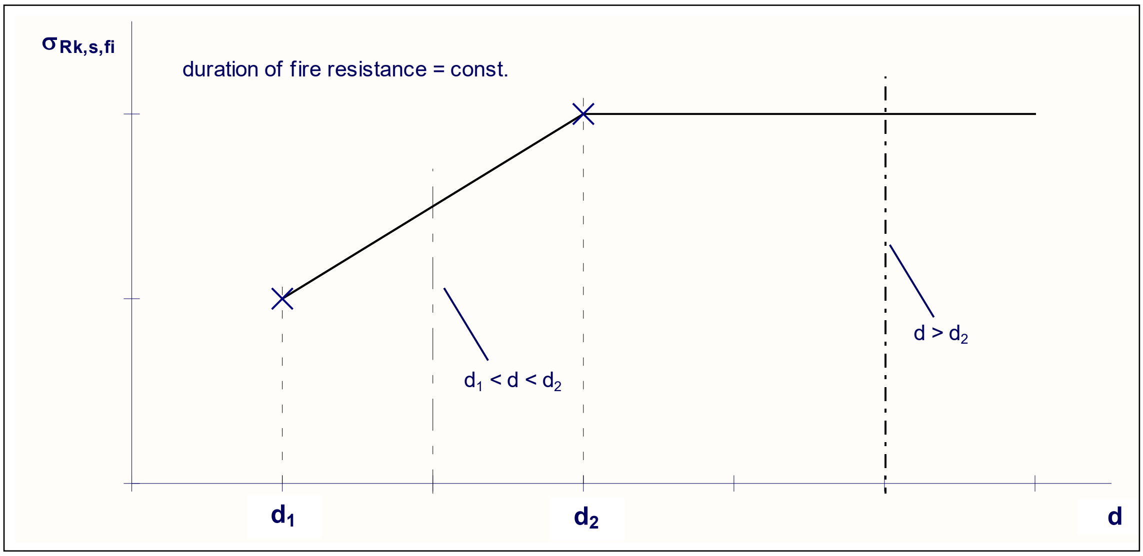

Figure 2.2.17.3 Interpolation of intermediate sizes for constant duration of fire resistance

Expression of results:

$N_{Rk,s,fi}$ [kN]

2.2.18 Fire resistance to bond failure under tension loading (test series R10, F2)

Purpose of the test

The tests are intended to determine the fire resistance with respect to bond resistance of the BF under tension load. The bonded part of the fastener which is installed in the concrete is not directly exposed to fire. Nevertheless with increased temperature the bond resistance of the mortar decreases and a temperature dependent bond strength shall be determined.

Test procedure

Test members

The tests are performed in uncracked concrete C20/25. The concrete used for testing shall comply with EN 206 [1] and meet the requirements of Annex D. The test setup is specified in Figure D.4.2.1. Splitting of the concrete shall be prevented (e.g., steel jacket around the lateral sides of the cylinder). Spalling shall not occur during the heating. Therefore, dry concrete is required. Concrete shall be dried before testing (e.g., keep cylinders under indoor ambient conditions at least 90 days before testing, or store at maximum +80°C until the concrete specimen no longer loses more than 0,2% weight within 24 hours, then cool down to normal ambient temperature).

Installation

The tests shall be performed using each drilling method applied for by the manufacturer. If the equivalency of two different drilling methods has been shown, then the results can be transferred to the equivalent drilling method for assessment in this clause.

Tests shall be performed with fastener size 12 mm. Drill and clean the hole in accordance with the MPII. The hole shall be centred in the face of the cylinder with the fastener installed along the axis of the cylinder. The embedment depth shall be equal to 120 mm.

Two type K thermocouples (TC1 and TC2) shall be positioned along the fastener at 10 mm from the concrete surface for TC1 and at the bottom of the fastener (120 mm below the concrete surface) for TC2 as illustrated in Figure D.4.2.1.

To ensure accurate placement of the thermocouples, TC1 and TC2 shall be secured on the fastener before installation.

General description of the test

The tests shall be performed within 2 weeks after the specified minimum curing time of the mortar (bonding material) has been reached. During this time period, the test specimens shall be stored indoors at normal ambient temperature. Prior to testing, position the member inside the test device. Apply a constant tension load N_{test} (see below for load levels) on the fastener and maintain the load throughout the duration of the test. Ensure that the load is kept constant (within +5% of the target load); a servo controlled hydraulic jack with load control or dead load are suitable. The test set-up is shown in Figure D.4.2.1.. An assessment of displacements is not required. After reaching the target load, apply thermal loading on the lateral sides of the concrete cylinder to heat up the concrete at a minimum rate of 5°C/min (temperature of the external steel surface of the steel jacket of the cylinder), while maintaining the load N_{test}. Heating shall be continuously applied until pull-out of the fastener occurs (caused by the increase of the temperature of the mortar).

The measurement of the load N_{test} and of the temperatures of the bond (at TC1 and TC2) shall be recorded continuously during the heating until pull-out occurs. Additionally, the temperatures of the oven (applied at the lateral sides of the concrete cylinder) shall be recorded during the test.

At the time of pull-out failure of the fastener (drop of the load indicating failure) the temperature and load shall be read and recorded.The failure temperature $\theta_{failure}$ is calculated as the weighted average of TC1 and TC2 temperatures when pull-out occurs. The weighted average θ is calculated as the 1/3 of the higher measured temperature plus 2/3 of the lower measured temperature of TC1 and TC2. For each test, the failure temperature $\theta_{failure}$ is associated to the load N_{test} and corresponding bond stress τ_{test}.

Heating sequence requirements

Heat shall be introduced to the lateral sides of the cylinder through the steel jacket only. The main thermal flux should be oriented towards the lateral sides of the concrete cylinder. The external extended part of the fastener shall not be directly exposed to the heat source. This may be achieved by protecting the fastener with thermal insulating material.

The heating rate of the oven or the performance of a heating jackets shall be chosen to ensure a test duration of less than 3 hours in order to prevent excessive post curing of the mortar. Repeatability of the test procedure shall be ensured by using the same heating rate of the oven for every test in the same test series.

Load values

A minimum number of 20 tests shall be carried out. The tests shall be performed at different load levels. For each applied load N_{test} the corresponding bond stress τ_{test} is calculated according to Equation (2.2.18.1).

$$\tau_{test} = \frac{N_{test}}{\pi \cdot d \cdot h_{ef}} \qquad (2.2.18.1)$$

The load levels shall be selected to ensure:

a) a maximum difference of the applied bond stress τ_{test} of 1 N/mm² between two neighbouring data points in the interval $[\tau_{test,min}; \frac{1{,}1 \cdot \psi^0_{sust} \cdot \tau_{Rk,ucr}}{1{,}5 \cdot \gamma_{inst}} \cdot \frac{1}{\alpha_2} \cdot \frac{1}{\alpha_3} \cdot \frac{1}{\alpha_4}]$

Where

$\tau_{test,min}$ = lowest tested bond stress

and

b) a maximum difference of two neighbouring failure temperatures $\theta_{failure}$ of ≤ 50°C. if this requirement is not fulfilled, repeat an additional test with a load between to achieve one more data point in between.

As reference tests at least 3 confined pull-out tests at normal ambient temperature shall be carried out according to Table A.1.1, test series R1, in the same concrete batch. All single test results shall be considered in the determination of the fitting curve (Figure 2.2.18.1).

Tests conducted in a different concrete batch may be used if bond resistances values of each individual reference test points are normalized to the compressive strength of the tested specimens in series F2 according to Equation (A.2.1.2.2), for diameter 12 mm only (based on R1 and R2 test series on 12 mm).

Figure 2.2.18.1 presents an example of the loads in terms of bond stress τ_{test}.

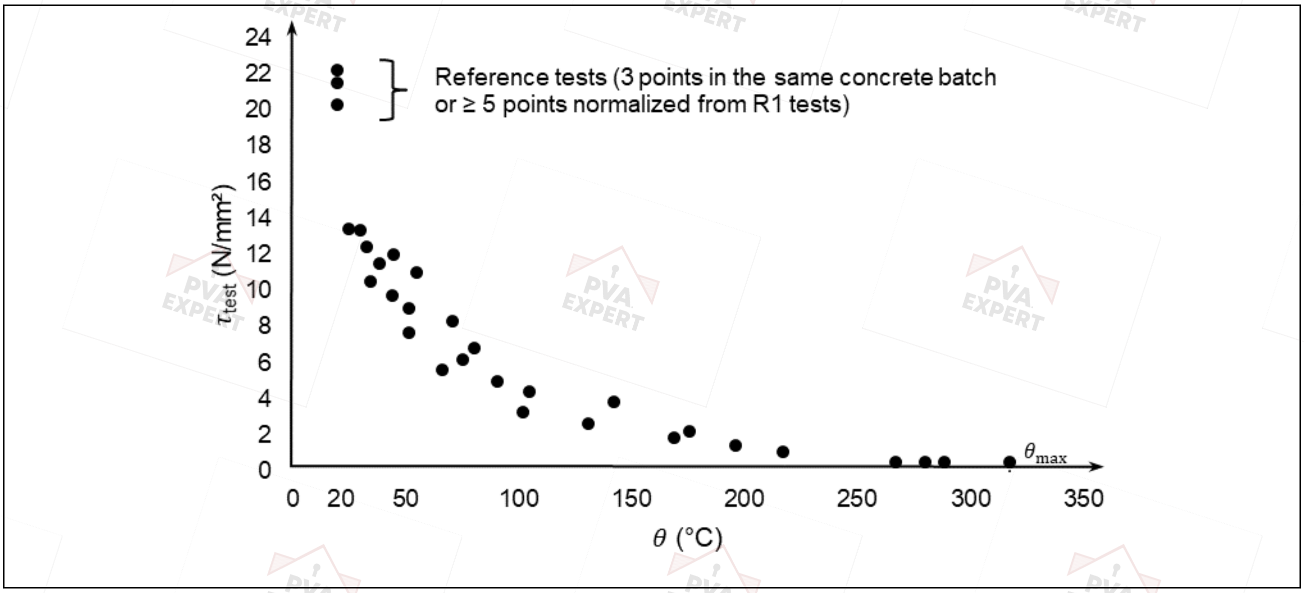

Figure 2.2.18.1 Example of a bond resistance vs. temperature relationship

Assessment of the results

Plot the bond strength $\boldsymbol{\tau_{test}(\theta)}$ as a function of weighted average failure temperature $\boldsymbol{\theta}$ for all the test results (see Figure 2.2.18.1).

<u>Fitting curve and limiting value</u>

Determine the mean bond resistance $\tau_{um}(\theta)$ with the best fitting curve trend function. Exponential, power or linear function shall be used. Choose the trend function that yields the lowest coefficient of variation out of the three possible options. The fitting curve is limited to $\tau_{um,ucr,21}$ and the temperature corresponding to the intersection point of the fitting curve and $\tau_{um,ucr,21}$ is denominated θ_k. (i.e., a horizontal line applies for $\tau_{um}(\theta)$ between normal ambient temperature and θ_k; see Figure 2.2.18.3. No extrapolation of the fitting curve shall be done beyond the maximum temperature θ_{max} measured during the tests. At 20°C, all single values derived from the reference tests shall be considered in the determination of the fitting curve.

The function may be chosen to best fit test results.

Requirements for the chosen trend function:

- The resulting function shall not contain any points of inflection (i.e., reversal of curvature).
- The resulting function shall not produce an increase in capacity for any increment of increasing temperature.

Figure 2.2.18.2 presents an example of $\tau_{um}(\theta)$ exponential curve fitted to the test data.

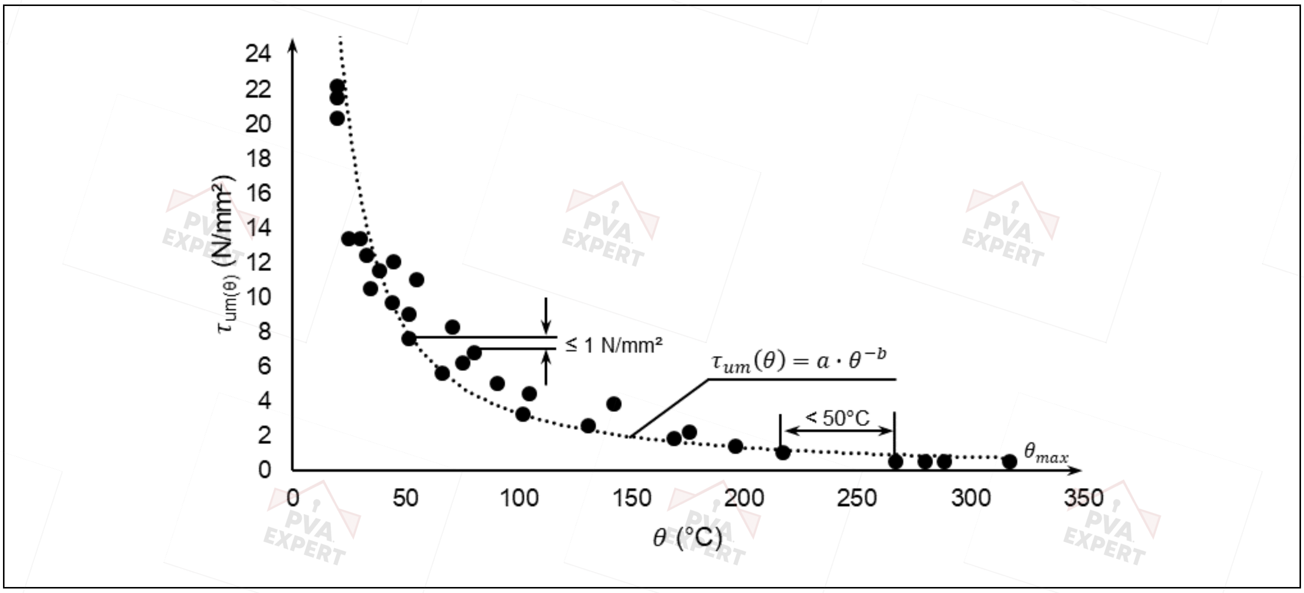

Figure 2.2.18.2 Example for determination of bond resistance τ_{um} as a function of temperature θ using a trend line

The coefficient of variation shall be calculated as the relative deviation from the fitting curve according to Equation (2.2.18.2).

$$cv = \sqrt{\frac{1}{n_{test} - 1} \sum_{i=1}^{n_{test}} \left(\frac{\tau_{test,i}}{\tau_{um}(\theta_i)} - 1 \right)^2} \qquad (2.2.18.2)$$

The coefficient of variation shall be $cv \leq 45\%$. Increase of number of tests is allowed for better representation of the behaviour of the product.

Temperature reduction factor

The temperature reduction factor $k_{fi,p}(\theta)$ shall be determined according to the Equations (2.2.18.3) to (2.2.18.5):

$k_{fi,p}(\theta) = 1{,}0$ for $\theta < \theta_k$ (2.2.18.3)

$k_{fi,p}(\theta) = \tau_{um}(\theta)/\tau_{um,ucr,21} \leq 1{,}0$ for $21°C \leq \theta \leq \theta_{max}$ (2.2.18.4)

$k_{fi,p}(\theta) = 0$ for $\theta > \theta_{max}$ (2.2.18.5)

Where

$\tau_{um,ucr,21}$ = mean value obtained from above mentioned confined tension tests in uncracked concrete at normal ambient temperature.

No extrapolation on test temperatures is allowed. For temperatures higher than the maximal measured temperature during tests θ_{max}, the reduction factor $k_{fi,p}(\theta)$ is equal to zero.

Figure 2.2.18.3 presents an example of the temperature reduction factor $\boldsymbol{k_{fi,p}(\theta)}$.

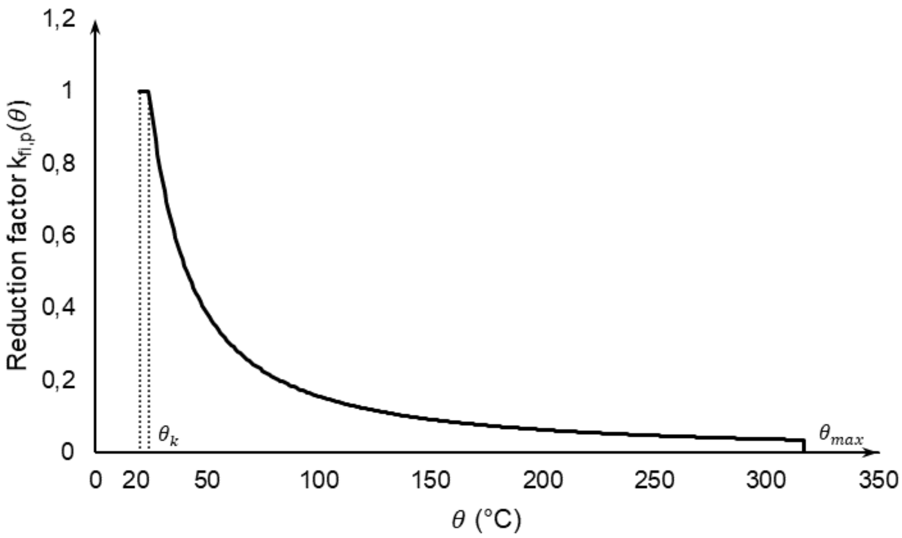

Figure 2.2.18.3 Example of the graph of reduction factor $\boldsymbol{k_{fi,p}(\theta)}$ for concrete strength class C20/25

Case where the mortar has an assessment for PIR application according to EAD 330087-01-0601 [27], clause 2.2.7.

The same fitting curve obtained in the PIR assessment for the same bonding material (mortar) can be used for the assessment of BF under fire (i.e., applied in the determination of the temperature reduction factor $k_{fi,p}(\theta)$ as per Equation (2.2.18.4)) under the condition that additional tests are provided and prove to have equivalent or higher bond stresses at high temperature.

A minimum of 6 additional tests shall be provided using the same type of steel insert used for BF application (i.e., threaded rod, threaded sleeve…).

If the type of steel insert used as fastener element is a rebar (PIR), then no further tests are required and the same fitting curve determined within the PIR assessment can be used. For the purpose of an assessment of the BF using a rebar steel insert, the fitting curve of $f_{bm}(\theta)$ from the PIR assessment (see EAD 330087-01-0601 [27], 2.2.7) can be extended for bond strength values above 10 N/mm² up to the maximum tested bond strength using the PIR product.

Tests on BF elements (threaded rods, threaded sleeves…) shall prove the transferability of the bond stress-temperature relationship from tests on PIRs. The additional selected loads shall be chosen in such a way to ensure that the results are distributed over the entire temperature range.

The fitting curve (bond stress versus temperature) established with tests with the steel insert used for BF application shall provide a bond stress equal to or larger than the fitting curve given in the PIR assessment (see EAD 330087-01-0601 [27], 2.2.7) within the tested range.

If the temperature range between data points with the steel insert used for BF application covers at least 2/3 of the temperature range covered by the fitting curve of the PIR assessment (i.e., between normal ambient temperature and the maximum temperature tested with PIR), then the use of the full PIR fitting curve for the evaluation of the BF application shall be permitted. The determination of $k_{fi,p}(\theta)$ shall be conducted according to Equations (2.2.18.4) and (2.2.18.5).

If these conditions are fulfilled, then the PIR curve may be used for the assessment of the bond strength vs. temperature relationship of the steel insert used for BF application. No extrapolation on test temperatures is allowed beyond θ_{max} (for temperatures higher than the maximum measured temperature during tests on the PIR product, θ_{max}, the reduction factor $k_{p,fi}(\theta)$ shall be taken equal to zero). No extension of the fitting curve is allowed for temperatures higher than θ_{max} using additional data points using the steel insert used for BF application. No increase of the bond resistance vs. temperature relationship is allowed (i.e., the same fitting curve obtained from the PIR assessment shall be used for the BF assessment).

Fire resistance to bond failure under tension loading

The fire resistance to bond failure under tension loading $\tau_{Rk,fi}(\theta)$ shall be determined according to Equation (2.2.18.6):

$$\tau_{Rk,fi}(\theta) = k_{fi\ p}(\theta) \cdot \tau_{Rk,cr} \quad (2.2.18.6)$$

Where:

$\tau_{Rk,cr}$ = characteristic bond resistance for cracked concrete for concrete strength class C20/25 according to 2.2.2.14 for cracked concrete.

The characteristic bond resistance for cracked concrete for concrete class C20/25 shall be used conservatively for concrete classes C20/25 to C50/60.

The factor $k_{fi,p}(\theta)$ according to the Equations (2.2.18.3) to (2.2.18.5) obtained from tests conducted in uncracked concrete can be applied for cracked concrete condition.

Expression of results:

Reduction factor for fire resistance to bond failure: $k_{fi,p}(\theta)$ according to the Equations (2.2.18.3) to (2.2.18.5).

Characteristic bond resistance for cracked concrete under fire condition for a given temperature (θ): $\tau_{Rk,fi}(\theta)$

2.2.19 Fire resistance to steel failure under shear loading (test series F3)

Purpose of the test

The tests are performed to determine the resistance to steel failure of the fasteners under shear load and fire exposure. The determination of the duration of the fire resistance is according to the conditions given in EN 1363-1 [30] using the "Standard Temperature/Time Curve" (STC).

Test conditions

The tests shall be performed according to D.4.3.

Assessment

If testing and assessment given in Table A.1, F3 was not conducted, then it is permitted to transfer tension fire test results obtained from Table A.1, line F1 to shear if the steel element features a constant section throughout its length and that this section is the same subjected to tension and shear load, or the section is larger for shear load than for tension load. Transfer of results shall be conducted as follows for fire resistance classes R30, R60, R90 and R120:

$$V_{Rk,s,fi} = N_{Rk,s,fi} \tag{2.2.19.1}$$

$$M^0_{Rk,s,fi} = 1{,}2 \cdot \sigma_{Rk,s,fi} \cdot W_{el} \tag{2.2.19.2}$$

Where

$\sigma_{Rk,s,fi}$ = characteristic tension strength of a fastener in case of steel failure under tension loading under fire conditions as determined according to 2.2.17.

Note: Some test results in the literature show that the fire resistance of steel to shear load obtained in Table A.1, line F3 may be higher than that of the fire resistance of steel to tension load obtained in Table A.1, line F1. This may be due to several factors such as: higher section subjected to shear load than that in tension, different test conditions leading to higher temperatures at the loaded part of the fastener in tension, different steel failure modes in tension (mix between rod and nut failure) and shear (pure shear failure of the rod), different displacement limits to reach failure. Equation (2.2.19.1) *leads to slightly conservative $V_{Rk,s,fi}$ values than the results obtained from Table A.1, line F3.*

If testing and assessment given in Table A.1, lines F1 and F3 was not conducted, then the characteristic tension strength $\sigma_{Rk,s,fi}$ of a fastener in case of steel failure under fire conditions given in EN 1992-4 [4], Tables D.1 and D.2 for the covered steel materials are valid for the unprotected steel part of the fastener outside the concrete and may be used in the design. These values are conservative against values assessed according to Table A.1 lines F1 and F3.

Determine $V_{Rk,s,fi}$ where EN 1992-4 [4], Equation (D.6) applies.

Determine $M^0_{Rk,s,fi}$ where EN 1992-4 [4], Equation (D.7) applies.

Expression of results:

$V_{Rk,s,fi}$ [kN], $M^0_{Rk,s,fi}$ [Nm]

2.2.20 Content, emission and release of dangerous substances

The performance of the hardened bonding material related to the emissions and release and, where eventually, the content of dangerous substances will be assessed on the basis of the information provided by the manufacturer[4] after identifying the release scenarios taking into account the intended use of the product and the Member States where the manufacturer intends his product to be made available on the market.

The identified intended release scenarios for this product and intended use with respect to dangerous substances are:

IA2: Product with indirect contact to indoor air (e.g., covered products) but possible impact on indoor air.

S/W1: Product with direct contact to soil, ground- and surface water.

S/W2: Product with indirect contact to soil, ground- and surface water.

2.2.20.1 SVOC and VOC

For the intended use covered by the release scenario IA2 semi-volatile organic compounds (SVOC) and volatile organic compounds (VOC) are to be determined in accordance with EN 16516 [7]. The loading factor to be used for emission testing is 0,007 m^2/m^3.

The preparation of the test specimen is performed by use of a concrete member in which the anchor is installed in accordance with the manufacturer's product installation instructions (MPII) or (in absence of such instructions) the usual practice of anchor installation. The anchor with maximum thread size specified by the manufacturer shall be used. The embedment depth shall be at least 4d.

Once the test specimen has been produced, as described above, it should immediately be placed in the emission test chamber. This time is considered the starting time of the emission test.

The test results have to be reported for the relevant parameters (e.g., chamber size, temperature and relative humidity, air exchange rate, loading factor, size of test specimen, conditioning, production date, arrival date, test period, test result) after 3- and 28-days testing.

The relevant test results shall be expressed in [mg/m^3] and stated in the ETA.

2.2.20.2 Leachable substances

For the intended use covered by the release scenario S/W1 the performance of the bonding material concerning leachable substances has to be assessed. A leaching test with subsequent eluate analysis shalltake place, each in duplicate. Leaching tests of the bonding material are conducted according to CEN/TS 16637-2 [8]. The leachant shall be pH-neutral demineralised water and the ratio of liquid volume to surface area shallbe (80 ± 10) l/m^2.

Cubes of the bonding material with dimensions of 100 mm x 100 mm x 100 mm shall be prepared.

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4 The manufacturer may be asked to provide to the TAB the REACH related information which he must accompany the DoP with (cf. Article 6(5) of Regulation (EU) No 305/2011).

The manufacturer is **not** obliged:

- to provide the chemical constitution and composition of the product (or of constituents of the product) to the TAB, or
- to provide a written declaration to the TAB stating whether the product (or constituents of the product) contain(s) substances which are classified as dangerous according to Directive 67/548/EEC and Regulation (EC) No 1272/2008 and listed in the "Indicative list on dangerous substances" of the SGDS.

Any information provided by the manufacturer regarding the chemical composition of the products may not be distributed to EOTA or to TABs.

In eluates of "6 hours" and "64 days", the following biological tests shall be conducted:

- Acute toxicity test with Daphnia magna Straus according to EN ISO 6341 [9]
- Toxicity test with algae according to ISO 15799 [10]
- Luminescent bacteria test according to EN ISO 11348-1 [11], EN ISO 11348-2 [12] or EN ISO 11348-3 [13]

For each biological test, EC20-values shall be determined for dilution ratios 1:2, 1:4, 1:6, 1:8 and 1:16.

If the parameter TOC is higher than 10 mg/l, then the following biological tests shall be conducted with the eluates of "6 hours" and "64 days" eluates:

- Biological degradation according to OECD Test Guideline 301 part A, B or E [31].

Determined toxicity in biological tests shall be expressed as EC20-values for each dilution ratio. Maximum determined biological degradability shall be expressed as "…% within …hours/days". The respective test methods for analysis shall be specified.

3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

3.1 System of assessment and verification of constancy of performance to be applied

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

The system is 1.

3.2 Tasks of the manufacturer

The corner stones of the actions to be undertaken by the manufacturer of BF and BEF for use in concrete in the procedure of assessment and verification of constancy of performance are laid down in Table 3.2.1.

Table 3.2.1 Control plan for the manufacturer; corner stones

No	Subject/type of control	Test or control method	Criteria, if any	Mini-mum number of sam-ples	Minimum frequency of control
Factory production control (FPC) [including testing of samples taken at the factory in accordance with a prescribed test plan]					
Steel elements					
1	Dimensions (outer diameter, inner diameter, thread length, etc.)	Caliper or gauge	Laid down in control plan	3	Every manufact-uring batch or 100.000 elements or when raw material batch has been changed *)
2	Tensile Load or tensile strength	EN ISO 6892-1 [19], EN ISO 898-1 [6], EN ISO 3506-1 [15]		3	
3	Yield strength	EN ISO 6892-1 [19], EN ISO 898-1 [6], EN ISO 3506-1 [15]		3	
4	Zinc plating - where relevant	x-ray measurement according to EN ISO 3497 [16], magnetic method according to EN ISO 2178 [17], Phase-sensitive eddy-current method according to EN ISO 21968 [18]		3	
5	Fracture elongation - where relevant	EN ISO 6892-1 [19], EN ISO 898-1[6]		3	
Bonding material					
6	Batch number and expiry date	visual check	Laid down in control plan	1	each batch
7	Components	check material and the mass of components according to recipe			
8	Specific gravity / Density	Standardized method proposed by the manufacturer			Every shift or 8 hours of production per machine
9	Viscosity				
10	Reactivity (gel time, where relevant: max. reaction temperature, time to max reaction temperature)				Each batch
11	Properties of raw material	(e.g., by infrared analysis)			initial testing and each change of batch
12	Performance of the cured bonding material	(e.g., tension test to failure)		3	Each batch

*) The lower control interval is decisive

3.3 Tasks of the notified body

The corner stones of the actions to be undertaken by the notified body in the procedure of assessment and verification of constancy of performance for BF and BEF for use in concrete are laid down in Table 3.3.1.

Table 3.3.1 Control plan for the notified body; corner stones

No	Subject/type of control (product, raw/constituent material, component - indicating characteristic concerned)	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control ***(for systems 1+, 1 and 2+ only, not related to reaction to fire)***					
1	Notified Body will ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the bonding material and steel elements.	Verification of the complete FPC as described in the control plan agreed between the TAB and the manufacturer	According to Control plan	According to Control plan	When starting the production or a new line
Continuous surveillance, assessment and evaluation of factory production control *(for systems 1+, 1 and 2+ only, not related to reaction to fire)*					
2	The Notified Body will ascertain that the system of factory production control and the specified manufacturing process are maintained taking account of the control plan.	Verification of the controls carried out by the manufacturer as described in the control plan agreed between the TAB and the manufacturer with reference to the raw materials, to the process and to the product as indicated in Table 3.2.1	According to Control plan	According to Control plan	**1**/year

4 REFERENCE DOCUMENTS

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

[2] EN ISO 6988:1994 Metallic and other non-organic coatings – Sulphur dioxide test with general condensation of moisture

[3] EN 1990:2023: Eurocode: Basis of structural design

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

[5] EN ISO/IEC 17025: 2017, General requirements for the competence of testing and calibration laboratories

[6] EN ISO 898-1:2013/AC 2013, Mechanical properties of fasteners made of carbon steel and alloy steel - Part 1: Bolts, screws and studs with specified property classes - Coarse thread and fine pitch thread

[7] EN 16516:2017+A1:2020, Construction products – Assessment of release of dangerous substances – Determination of emissions into indoor air

[8] EN 16637-2:2023, Construction products – Assessment of release of dangerous substances – Part 2: Horizontal dynamic surface leaching test

[9] EN ISO 6341:2012, Water quality - Determination of the inhibition of the mobility of Daphnia magna Straus (Cladocera, Crustacea) - Acute toxicity test

[10] EN ISO 15799:2022, Soil quality - Guidance on the ecotoxicological characterization of soils and soil materials

[11] EN ISO 11348-1:2008/A1:2018, Water quality - Determination of the inhibitory effect of water samples on the light emission of Vibrio fischeri (Luminescent bacteria test) - Part 1: Method using freshly prepared bacteria

[12] EN ISO 11348-2:2008/A1:2018, Water quality - Determination of the inhibitory effect of water samples on the light emission of Vibrio fischeri (Luminescent bacteria test) - Part 2: Method using liquid-dried bacteria

[13] EN ISO 11348-3:2008/A1:2018, Water quality - Determination of the inhibitory effect of water samples on the light emission of Vibrio fischeri (Luminescent bacteria test) - Part 3: Method using freeze-dried bacteria

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

[15] EN ISO 3506-1:2020, Mechanical properties of corrosion-resistant stainless steel fasteners - Part 1: Bolts, screws and studs with specified property classes - Coarse pitch thread and fine pitch thread

[16] EN ISO 3497:2000, Metallic coatings - Measurement of coating thickness - X-ray spectrometric methods (ISO 3497:2000)

[17] EN ISO 2178:2016, Non-magnetic coatings on magnetic substrates - Measurement of coating thickness - Magnetic method (ISO 2178:2016)

[18] EN ISO 21968:2019, Non-magnetic metallic coatings on metallic and non-metallic basis materials - Measurement of coating thickness - Phase-sensitive eddy-current method (ISO 21968:2019)

[19] EN ISO 6892-1:2019, Metallic materials - Tensile testing - Part 1: Method of test at room temperature (ISO 6892-1:2016)

[20] EN 1998-1:2004/A1:2013: Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings

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

[22] EN 14651:2005 + A1:2007: Test method for metallic fibre concrete - Measuring the flexural tensile strength (limit or proportionality (LOP)

[23] EN 14889-1:2006: Fibres for concrete - Part 1: Steel fibres - Definitions, specifications and conformity

[24] EN 14721:2005+A1:2007: Test method for metallic fibre concrete – Measuring the fibre content in fresh and hardened concrete

[25] EN 12390-1:2021: Testing hardened concrete – Part 1: Shape, dimensions and other requirements for specimens and moulds

[26] EAD 330499-01-0601-v01: Bonded fasteners for use in concrete

[27] EAD 330087-01-0601: Systems for post-installed rebar connections with mortar

[28] EAD 330076-01-0604: Metal injection anchors for use in masonry

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

[30] EN 1363-1:2020 Fire resistance tests – Part 1: General requirements

[31] OECD Guideline for testing of chemicals (301), 17.07.1992

Further technical background:

Omar Al-Mansouri [Ph.D thesis]. Behavior of bonded anchors in concrete under fire. Civil Engineering. Ecole nationale supérieure Mines-Télécom Lille Douai, 2020. English. (NNT: 2020MTLD0011).

ANNEX A TEST PROGRAM FOR BF AND GENERAL ASPECTS OF ASSESSMENT

A.1 Test program for BF

The test program for BF is given in Table A.1.1, which covers fasteners for use in cracked and uncracked concrete and fasteners for use in uncracked concrete only. For BF qualified for use in uncracked concrete only, the tests in cracked concrete may be omitted. Detailed information concerning the tests is given in the corresponding clauses referred to in these tables.

A torque shall not be applied to the BF except for torque tests.

The tests shall be performed with the embedment depth requested by the manufacturer (for e.g., capsule type fasteners). If the manufacturer applies for BF with several embedment depths (variable embedment depth), then the robustness test series according to Table A.1.1, lines B6 to B9 shall be done with the maximum embedment depth $h_{ef,max}$ = 20 d or as requested by the manufacturer, while the other test series shall be performed with an embedment depth of h_{ef} = 7 d. To avoid steel failure in the tension tests, either the steel strength of the steel element may be increased or the embedment depth may be modified. Further details are given in clause A.2.

The recommended fastener size as required for tests in Table A.1.1 for medium size "m" is d = 12 mm (1/2 inch).

Tests in concrete strength class C12/15 and in strength classes higher than C50/60 may be omitted, if the intended use is limited to the range of strength classes C20/25 to C50/60.

Table A.1.1 Test program for BF

N°	Purpose of test	concrete	crack width [mm]	Size 2)	h_{ef}	n_{min}	rqd. α	Clause
Resistance to steel failure								
N1	Steel capacity	-	-	All	-	5	-	2.2.1.1
N2	Installation torque	C50/60	0	All	7d 1)	5	-	2.2.1.2
Reference tests (with confined test setup)								
R1	Bond strength with confined test setup	C12/15	0	All	7d 1)	5	-	2.2.2.1
		C20/25				5		
R2		C50/60	0	s/m/l	7d 1)	5	-	
		max 4)				5		
R3		C12/15	0,3	s/m/l	7d 1)	5	-	
		C20/25				5		
R4		C50/60	0,3	s/m/l	7d 1)	5	-	
		max 4)				5		
R5	Reference for robustness test series B6 to B9	C12/15	0	s/m/l	max	5	-	2.2.5
		C20/25				5		
R6	Reference for sustained load a) at normal ambient temperature and b) at maximum long-term temperature	C12/15	0	m	7d 1)	a) 5 b) 5	-	2.2.2.6
		C20/25				a) 5 b) 5		
R7	Reference for freeze/thaw	C50/60	0	m	7d 1)	5	-	2.2.2.7
R8	Reference for slice tests	C20/25	0	m	30 mm	10	-	2.2.2.12
R9	Reference for minimum installation temperature	C12/15	0	m	7d 1)	5	-	2.2.2.13
		C20/25				5		
R10	Reference for series F2	C20/25	0	m	7d 1)	3	-	2.2.2.1 and 2.2.18
Basic tension tests (with unconfined test setup)								
A1	Characteristic resistance for tension loading not influenced by edge and spacing effects	C12/15	0	s/m/l	min	5	-	2.2.2.2
		C20/25				5		
A2		C50/60	0	s/m/l	min	5	-	
A3		C12/15	0,3	s/m/l	min	5	-	
		C20/25				5		
A4		C50/60	0,3	s/m/l	min	5	-	
A5	Edge distance to prevent splitting under load	C12/15	0	s/m/l	min	4	1,00	2.2.4
		C20/25				4		
A6	Minimum embedment depth	C12/15	0	Smallest 4 sizes	min	20	0,90	2.2.3.2
		C20/25				20		
Resistance to shear load								
V1	Characteristic resistance for shear loading not influenced by edge and spacing effects	C12/15	0	All	min	5	-	2.2.7.1
		C20/25				5		
V2	Resistance to pry-out failure	C12/15	0	All	min	5	-	2.2.8
		C20/25				5		

N°	Purpose of test	concrete	crack width [mm]	Size [2)]	h_{ef}	n_{min}	rqd. α	Clause
Resistance to combined pull-out and concrete failure								
B1	Minimum edge distance and spacing	C12/15 C20/25	0	s/m/l	min	5 5	-	2.2.6
B2	Maximum long-term temperature	C12/15 C20/25	0	m	min	5 5	-	2.2.2.9
B3	Maximum short-term temperature	C12/15 C20/25	0	m	min	5 5	-	2.2.2.9
B4	Minimum installation temperature	C12/15 C20/25	0	m	min	5 5	1,00	2.2.2.10
B5	Minimum curing time at normal ambient temperature	C12/15 C20/25	0	m	min	5+5 5+5	0,90 ref to long curing	2.2.2.11
B6	Robustness in dry concrete	C12/15 C20/25	0	s/m/l	max[2)]	5 5	see Table 2.2.5.6.1	2.2.5.2
B7	Robustness in water saturated concrete	C12/15 C20/25	0	s/m/l	max[2)]	5 5		2.2.5.3
B8	Robustness in water filled holes (clean water)	C12/15 C20/25	0	s/m/l	max[2)]	5 5		2.2.5.4
B9	Robustness to mixing technique	C12/15 C20/25	0	m	max[2)]	5 5		2.2.5.5
B10	Increased crack width	C12/15 C20/25	0,5	s/m/l	7d [1)]	5 5	0,80	2.2.2.3
B11	Increased crack width	C50/60 max [4)]	0,5	s/m/l	7d [1)]	5 5	0,80	2.2.2.3
B12	Repeated loads	C12/15 C20/25	0	m	7d [1)]	5 5	1,00	2.2.2.4
B13	Crack cycling under load	C12/15 C20/25	0,1 - 0,3	All	7d [1)]	5 5	0,90	2.2.2.5
B14	Sustained loads (normal ambient temperature)	C12/15 C20/25	0	m	7d [1)]	5 5	0,90	2.2.2.6
B15	Sustained loads (maximum long-term temperature)	C12/15 C20/25	0	m	7d [1)]	5 5	0,90	2.2.2.6
B16	Freeze/thaw conditions	C50/60	0	m	7d [1)]	5	0,90	2.2.2.7
B17	Installation direction	C12/15 C20/25	0	max	7d [1)]	5 5	0,90	2.2.2.8
B18	High alkalinity	C20/25	0	m	30 mm	10	1,00	2.2.2.12
B19	Sulphurous atmosphere	C20/25	0	m	30 mm	10	0,90	2.2.2.12
B20	Installation at freezing condition	C12/15 C20/25	0	m	7d [1)]	5 5	0,90	2.2.2.13

N°	Purpose of test	concrete	crack width [mm]	Size [2)]	h_{ef}	n_{min}	rqd. α	Clause
Resistance to Fire								
F1	Fire resistance to steel failure under tension loading	C20/25	0	2.2.17	2.2.17	5	-	2.2.17
F2	Bond resistance at simulated fire conditions [3)]	C20/25	0	m	120 mm	20	-	2.2.18
F3	Fire resistance to steel failure under shear loading	C20/25	0	2.2.17	2.2.17	5	-	2.2.19

1) This value is valid for injection type and bulk type BF. For capsule type BF, the specified embedment depth associated with the capsule size shall be used. To avoid steel failure, the embedment depth modifications may be necessary (see clause A.2).
2) Pull-out test such that steel failure will be avoided. To avoid steel failure, the embedment depth modifications may be necessary (see clause A.2).
3) Existing test results may be used (details see 2.2.18)
4) Highest concrete strength class (not larger than C90/105) for which the assessment is requested by the manufacturer.

For certain test series according to Table A.1.1 and Table B.2.1 a reduced range of tested sizes, indicated by "s/m/l", may be used. The number of diameters to be tested in this case depends on the number of requested sizes and is given in Table A.1.2.

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

Number of requested sizes	Number of diameters to be tested
Up to 5	3
6 to 8	4
9 to 11	5
More than 11	6

A.2 Provisions for all test series

As far as applicable the Annex D shall be followed with respect to the test members, test setup and performance of the tests. Modifications are addressed in the following clauses, which overrule conflicting provisions in the Annex D.

It is recommended that handling of tests and calibration items are performed in accordance with EN ISO/IEC 17025 [5].

The failure mode “combined pull-out and concrete cone failure” is characterized by pulling the steel elements (with or without the surrounding bonding material) out of the concrete. Depending on various influencing factors single fasteners and especially fastener groups may show combined pull-out and concrete cone failures starting from any point along the embedment depth.

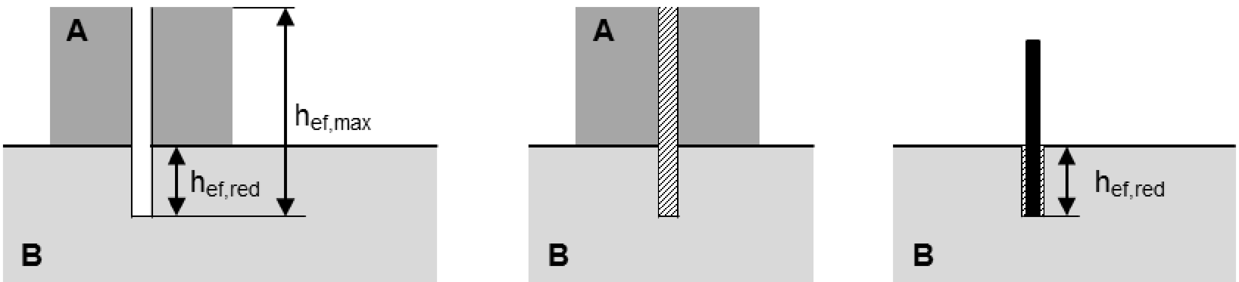
The failure mode “concrete cone failure” is typically characterized by a concrete failure starting from the deepest point of embedment. This failure mode may be observed for single fasteners or fastener groups with or without an influence of edge distances. The concrete cone failure mode shows the highest possible resistance of BF and may be predicted according to current experience as given in EN 1992 4 [4], Equation (7.1) using the default values for factors $k_{ucr,N}$ = 11,0 and $k_{cr,N}$ = 7,7 related to concrete cylinder strength.

“Steel failure” or “splitting failure” may limit the resistance of BF compared to the resistance of “combined pull-out and concrete cone failure” or “concrete cone failure”.

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

In cases where the use of high strength steel elements (steel strength class ≥ 10.9 according to EN ISO 898-1 [6]) is insufficient to prevent “steel failure” of the fastener the embedment depth shall be reduced. This principle may overrule the required embedment depth given in Table A.1.1 except for the test series concerning robustness (B6 to B9). To avoid steel failure, in the tests with maximum embedment depth for injection type systems or nominal embedment depth for capsule type systems the following test procedure may be employed.

Use a test member consisting of two concrete blocks A and B stacked on the top of each other without a permanent connection as shown in Figure A.2.1 a). Drill the hole in accordance with the procedures described in the MPII. Clean the hole as described below for the specific test. Install the bonding material and the steel element (for capsule type systems) or the bonding material only (for injection type systems) in each case in accordance with the MPII with the equipment supplied by the manufacturer as shown in Figure A.2.1 b). Remove the upper block A and for injection type systems install the steel element (Figure A.2.1 c)). After curing perform the confined tension test. In this context $h_{ef,red}$ represents the reduced embedment, for which steel yielding of a high strength steel element is just avoided. For capsule type systems the test setup shall be adapted accordingly.



a) drill & clean b) install bonding material c) insert steel element

Figure A.2.1 Test set up to avoid steel failure

The unconfined tests with minimum specified embedment depth may show “concrete cone failure”. If these results are used for evaluating the characteristic bond resistance, then the approach is conservative. More precise results may be achieved if the corresponding embedment depth is chosen in a way that bond failure (“combined pull-out and concrete cone failure”) is decisive.

BF with a high bond resistance may show only "concrete cone failure" or "steel failure" in unconfined tests. In this case it is recommended to perform all tests as confined tests and to evaluate τ_{Rk} taking the modification factor α_{setup} into account.

For the assessment of a BF the overall test programme has to be carried out including at least the following minimum number of different concrete batches within the programme of testing:

Assessment for C20/25	on at least 3 different batches, if the concrete comes from different concrete suppliers.
	on at least 4 different batches, if the concrete comes from the same concrete suppliers.
Assessment for C50/60	on at least 2 different batches, if the concrete comes from the same or from different concrete suppliers.

Reference tension tests (R) shall be performed because they are needed for the evaluation of the results of the test series for resistance to pull-out failure and to take account of the influence of certain parameters on the resistance of BF to tension load. They shall be made in each batch. All reference tests shall be carried out as follows:

- in dry concrete
- at normal ambient temperature (T = + 21° C ± 3 °C)
- installation in accordance with the MPII
- as confined test;

The reference tests shall be made in the same concrete batch as the tests to which they shall be compared. The reference tests shall be made in uncracked concrete (cracked concrete: Δw = 0,3 mm), if their results shall be compared with results of tests in uncracked concrete (cracked concrete).

If the manufacturer applies for steel elements of BF which are geometrically identical but of different material, then all tests shall be made with one material. For the other material, only the tests according to Table A.1.1, lines N1, N2 and V1 shall be carried out.

If the assessment covers more than one drilling technique, all tests shall be done with all drilling techniques. If different sizes of packages, types of nozzles and dispensers will be used for one system, equal mixing of the bonding material components shall be assessed for all sizes of the packages and with all admissible types of nozzles and dispensers both for coaxial and shuttle cartridges.

If precise instructions for hole cleaning are not provided by the MPII, then the tests are carried out without hole cleaning.

The curing time before commencement of the test in test series according to Table A.1.1, lines B1 to B19 shall be comparable to the curing time in the corresponding reference test series.

A.2.1 General assessment of test results

A.2.1.1 Assessment of the failure mode

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

Tension tests:

- concrete cone failure (cc) – give diameter and depth of concrete cone
- splitting (sp) – test condition for tests in uncracked concrete in case when a first crack of the concrete is observed
- bond failure between steel element and bonding material (be)
- bond failure between bonding material and bore hole (bb) (mixed bond failure between steel element and bonding material as well as between bonding material and bore hole (bbe) may occur)
- combined bond and concrete failure in unconfined tests (bc)
- steel failure (s) – define position of the steel rupture over length of the fastener

Shear tests:

- steel failure (s) – define position of the steel rupture over length of the fastener
- pry-out (pr) – concrete breakout opposite to the load direction (may occur for shallow embedment)
- concrete edge failure (ce) – may occur when testing close to the edge

If initial failure is not clear, then a combination of failure modes may be reported.

A.2.1.2 Conversion of failure loads to nominal strength

The conversion of failure loads shall be done according to Equation (A.2.1.2.1) to (A.2.1.2.8) depending on the failure mode.

The increasing factor $\psi_{c,50}$ may be determined separately for cracked and uncracked concrete.

Concrete failure	$F_{u,c} = F_{u,t} \cdot \left(\frac{f_{ck}}{f_{c,t}}\right)^{0,5}$ with $\frac{f_{ck}}{f_{c,t}} \leq 1,0$	(A.2.1.2.1)
Bond failure	$F_{u,p} = F_{u,t} \cdot \left(\frac{f_{ck}}{f_{c,t}}\right)^{m}$ with $\frac{f_{ck}}{f_{c,t}} \leq 1,0$	(A.2.1.2.2)
confined uncracked	$m = \frac{\log(N_{u,m,R2} / N_{u,m,R1})}{\log(f_{c,R2} / f_{c,R1})} \leq 0,5$	(A.2.1.2.3)
confined cracked	$m = \frac{\log(N_{u,m,R4} / N_{u,m,R3})}{\log(f_{c,R4} / f_{c,R3})} \leq 0,5$	(A.2.1.2.4)
unconfined uncracked	$m = \frac{\log(N_{u,m,A2} / N_{u,m,A1})}{\log(f_{c,A2} / f_{c,A1})} \leq 0,5$	(A.2.1.2.5)
unconfined cracked	$m = \frac{\log(N_{u,m,A4} / N_{u,m,A3})}{\log(f_{c,A4} / f_{c,A3})} \leq 0,5$	(A.2.1.2.6)
	$\psi_{c,xx} = \left(\frac{f_{ck,xx}}{f_{ck,20}}\right)^{m} > 1,0$ 1)	(A.2.1.2.7)
Steel failure	$F_{u,s} = F_{u,t} \frac{f_{uk}}{f_{u,t}}$	(A.2.1.2.8)

1) If no distinction is made for cracked and uncracked conditions, then the factor m shall be determined as the minimum of Equation (A.2.1.2.3) to (A.2.1.2.6).

A.2.1.3 Conversion of failure load to bond strength

Mean failure loads and 5 % fractile of failure loads shall be converted to bond strength related to the nominal diameter of the steel element according to Equation (A.2.1.3.1).

$$\tau_u = \frac{N_u}{\pi \cdot d \cdot h_{ef}} \quad \text{(A.2.1.3.1)}$$

A.2.1.4 Conversion of failure load to account for concrete batch influence

When bond failure is observed, the conversion of failure loads for all the tests carried out in the i-batch $F_{u,t,i}$ shall be done according to Equation (A.2.1.4.1).

$$F_{u,p} = F_{u,t,i} \cdot \alpha_{ref,i} \quad \text{(A.2.1.4.1)}$$

The factor $\alpha_{ref,i}$ takes into account the sensitivity of each specific concrete batch using the results of reference tests and it shall be calculated according to Equation (A.2.1.4.2).

$$\alpha_{ref,i} = \frac{\min \tau_{Ru,m,r,12}}{\tau_{Ru,m,i,12}} \leq 1,0 \quad \text{(A.2.1.4.2)}$$

If the coefficient of variation of the ultimate bond resistance of all results in the reference test series with medium diameter is cv ≤ 15 %, then the assessment according to Equation (A.2.1.4.2) may be omitted and α_{ref} = 1,0. In this case the characteristic value of the bond resistance in the reference test series and basic tension tests has to be determined with a coefficient of variation of 15 %.

A.2.1.5 Criteria regarding scatter of failure loads

If the coefficient of variation of the failure load in any test series according to Table A.1.1, lines R1 to R9 and A1 to A6 and V1 exceeds 15 % and is not larger than 30 %, then the following reduction shall be taken into account:

$$\beta_{cv} = \frac{1}{1 + 0{,}03(cv - 15)} \leq 1{,}0 \tag{A.2.1.5.1}$$

If the coefficient of variation of the failure load in any test series according to Table A.1.1, lines B1 to B19 exceeds 20 % and is not larger than 30 %, then the following reduction shall be taken into account:

$$\beta_{cv} = \frac{1}{1 + 0{,}03(cv - 20)} \leq 1{,}0 \tag{A.2.1.5.2}$$

If the maximum limit for the coefficient of variation of the failure loads of 30 % is exceeded, then the number of tests shall be increased to meet this limit.

The smallest result min $ß_{cv}$ in any test shall be taken for assessment.

A.2.1.6 Establishing fractile values from test data

The fractile value of the quantity measured in a test series (e.g., the ultimate failure loads F) is to be calculated according to statistical procedures for a confidence level of 90 %. A normal distribution and an unknown standard deviation of the population shall be assumed.
For a single test series (e.g., representing failure loads for one diameter) the 5 %- and 95 % fractile shall be calculated as follows:

$$F_{5\%} = F_m \cdot (1 - k_s \cdot cv_F) \tag{A.2.1.6.1}$$

$$F_{95\%} = F_m \cdot (1 + k_s \cdot cv_F) \tag{A.2.1.6.2}$$

where

k_s = tolerance factor corresponding to a 5 percent probability of non-exceedance with a confidence of 90 percent according to Table A.2.1.6.1

cv_F = coefficient of variation of quantity F measured in a test series

F_m = mean value of quantity F of a test series

Table A.2.1.6.1 Factor k_s depending on number of tests n

n	5	6	7	8	9	10	15	20	25	30	40	50	∞
k_s [1)]	3,401	3,093	2,893	2,754	2,650	2,568	2,329	2,208	2,132	2,080	2,010	1,965	1,645

[1)] see e.g., Owen, D.: Handbook of Statistical Tables. Addison/ Wesley Publishing Company Inc., 1968.

For BF with bond strength that varies with the diameter of the fastener in a non-random manner, the mean and characteristic value of bond strength may be determined using trend lines developed from regression analysis of the calculated bond strength as a function of diameter $\tau_{u,m}(d)$ and $\tau_{5\%}(d)$ as described below. If no trend line can or will be established, then an assessment of the single test series is required.

The trend line shall fulfil the following requirements:

(1) The trend line shall be selected such, that it represents actual fastener system behaviour (of e.g., chemical, or physical nature, including size effects).

(2) The value of the slope of the trend line is only allowed to change the sign once. The trend line should be either a linear, an exponential or a power function (see Figure A.2.1.6.1). A combination of 2 trend lines for two ranges of diameters may be used (see Figure A.2.1.6.2). As an exception a polynomial function (degree ≥ 2) may be used (see Figure A.2.1.6.3), if this can be justified with fastener system behaviour and is specifically documented in the assessment report.

(3) The number of diameter sizes for a trend line shall be equal to or larger than the number of fitting parameters + 1. The diameters shall be evenly distributed in the considered interval represented by the trend line.

(4) Results of tests of all diameters within an interval shall be considered in the determination of the trend line.
(5) If a test series at the lower or upper end of the considered interval does not follow the trend line, then this test series shall be evaluated as single test series (see Figure A.2.1.6.4). Such a test series can be identified by outlier tests.
(6) An extrapolation of the trend line to non-tested diameters is not allowed. The interval of the trend line therefore is always limited to the minimum and maximum tested diameters.
(7) No maximum value (peak) of a fitting curve shall be assigned to non-tested diameters.
(8) Different steel elements (materials and types of steel elements) can be assessed using one trend line if equivalence is shown for each test series or for the corresponding trend lines.
(9) If additional diameters are tested outside an established interval, then a new assessment of all tested diameters is required, or the new test series shall be assessed as single test series.
(10) The coefficient of variation cv_F for the data represented by the trend line shall meet the same requirements as given for the corresponding test series (15% in reference test series and 20% in sensitivity test series including $ß_{cv}$, where relevant). The best fit of the trend line leads to the lowest coefficient of variation.
(11) If all test data for a specific diameter are below the mean trend line, then the TAB shall justify the use of these data for trendline assessment. All test parameter shall be checked (e.g., size of steel element, embedment depth, size of drill hole, cleaning tools, curing time etc.). Validation of the test data by repeating the test in a different concrete member is recommended.

The trend lines established for reference and sensitivity test series are used to determine the reduction factor for each diameter. See Figure A.2.1.6.5.

The 5% fractile of the trend line for the bond strength as a function of the diameter d is determined as follows:

$$\tau_{5\%}(d) = \tau_{u,m}(d) \cdot (1 - k_s \cdot cv_\tau) \qquad \text{(A.2.1.6.3)}$$

where

$$cv_\tau = \sqrt{\frac{1}{n_{tot}-1} \cdot \sum_{i=1}^{n_i} \left[\sum_{j=1}^{n_j} \left(\frac{\tau_{u,i,j}}{\tau_{u,m}(d_i)} - 1 \right)^2 \right]} \qquad \text{(A.2.1.6.4)}$$

n_{tot} = number of tests considered for determination of the trend line

n_i = number of tested diameter sizes

n_j = number of tests with diameter size i

$\tau_{u,d,i}$ = ultimate bond strength for test j with diameter d

$\tau_{u,m}(d)$ = mean bond strength for the diameter d as given by the (mean) trend line

k_s = tolerance factor for the trend line corresponding to a 5 percent probability of non-exceedance with a confidence of 90 percent according to Table A.2.1.6.2

for the trend line, the value for k_s depends on the total number of tests n_{tot} and on the number of constants n_c in the Equation for the trendline; the value of k_s is given in Table A.2.1.6.2 for $n_{tl} = n_{tot} + 1 - n_c$.

Note As an example the number of constants for a few trend line Equations are shown here:

$\tau_{u,m}(x) = a$	$n_c = 1$
$\tau_{u,m}(x) = a + b \cdot x$	$n_c = 2$ *(also valid in case of a = 0)*
$\tau_{u,m}(x) = a + b \cdot x + c \cdot x^2$	$n_c = 3$
$\tau_{u,m}(x) = a \cdot e^{-b \cdot x}$	$n_c = 2$

For a large number of test data n_{tot} and a small number of constants n_c in the Equation (not larger than 3), the influence of the number of constants may be neglected ($n_{tot} \sim n_{tl}$).

Table A.2.1.6.2 Factor k_s for the trend line

n_{tl}		5	6	7	8	9	10	15	20	25	30	40	50	∞
k_s		3,401	3,093	2,893	2,754	2,650	2,568	2,329	2,208	2,132	2,080	2,010	1,965	1,645

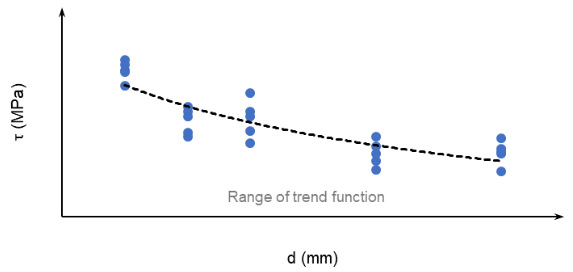


Figure A.2.1.6.1 Example for trend line

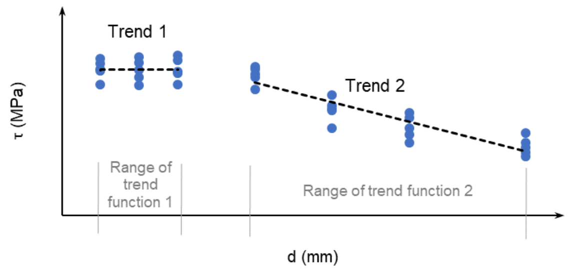


Figure A.2.1.6.2 Example for 2 ranges of trends

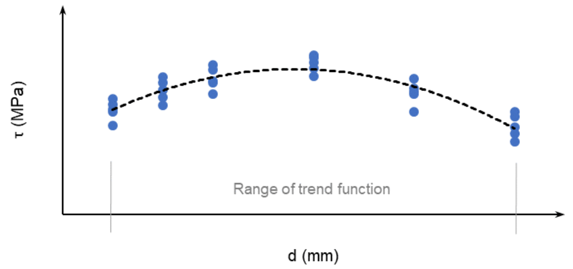


Figure A.2.1.6.3 Example for trend line with one peak

The sign of the slope of the trend line is only allowed to change once.

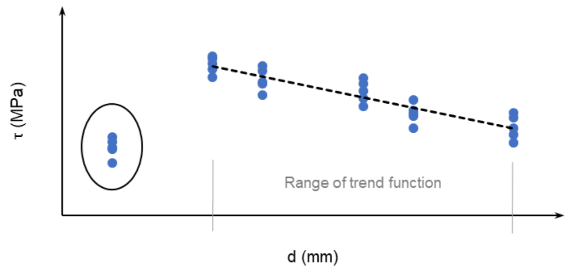


Figure A.2.1.6.4 Example for trend line with a separate assessment for single test series

If diameters at the lower or upper end of the range do not fulfil the trend, then these diameters are assessed separately.

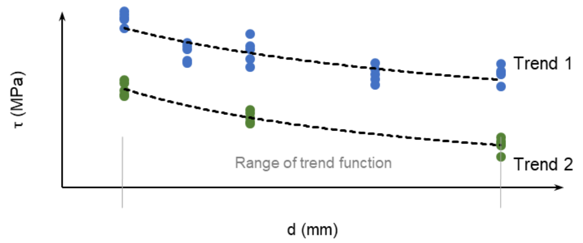


Figure A.2.1.6.5 Example for comparison with a reference test series

A.2.1.7 Failure loads (reduction factors α)

For test series B4 to B19 the mean failure loads and 5 % - fractile of failure loads shall be compared with the corresponding reference test series according to Table A.1.1:

$$\alpha = \min \{N_{u,m,t} / N_{u,m,r}; N_{5\%,t} / N_{5\%,r}\} \leq 1{,}0 \quad \text{(A.2.1.7.1)}$$

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

With the exception of tests series B6 to B9 (Table A.1.1), also the characteristic loads as given in the ETA can be used as reference loads.

For tests for sensitivity to installation the reduction factor α is used to determine the factor γ_{inst} accounting for the sensitivity to installation.

If the criteria for the required value of α given in Equation (A.2.1.7.1) are not met in one test series, then the characteristic resistance shall be reduced by α / rqd. α.

A.2.2 Analysis of displacements

A.2.2.1 Loss of adhesion

With BF uncontrolled slip occurs when the bonding material with the steel element is pulled out of the drilled hole (because then the load displacement behaviour depends significantly on irregularities of the drilled hole). The corresponding load when uncontrolled slip starts is called load at loss of adhesion $N_{u,adh}$.

$N_{u,adh}$ shall be evaluated for every test from the measured load displacement curve. The load at loss of adhesion is characterised by a significant change of stiffness, see Figure A.2.2.1.1. If the change in stiffness at a defined load is not so obvious, e.g., the stiffness is smoothly decreasing, then the load at loss of adhesion shall be evaluated as follows:

1) Compute the tangent to the load-displacement curve at a load 0,3 N_u (N_u = peak load in test). The tangent stiffness can be taken as the secant stiffness between the points 0/0 and 0,3 $N_u/\delta_{0,3}$ ($\delta_{0,3}$: displacement at N = 0,3 N_u).
2) Divide the tangent stiffness with a factor of 1,5.
3) Draw a line through the point 0/0 with the stiffness as calculated in 2).
4) The point of intersection between this line and the measured load-displacement curve gives the load $N_{u,adh}$ where the adhesion fails, see Figure A.2.2.1.2.
5) If there is a peak in the load-displacement curve, to the left side of this line, which is higher than the load at intersection, then $N_{u,adh}$ is taken as the peak load, see Figure A.2.2.1.3.
6) If there is a very stiff load-displacement curve at the beginning ($\delta_{0,3} \leq 0{,}05$ mm), then the drawing of the line for the calculation can be shifted to the point (0,3 N_u / $\delta_{0,3}$), see Figure A.2.2.1.4.

For tension tests the factor α_1 shall be calculated according to Equation (A.2.2.1.1):

$$\alpha_1 = \frac{N_{u,adh}}{N_{Rk,p}} \cdot \frac{1{,}5}{1{,}3} \cdot \gamma_{inst} \leq 1{,}0 \quad \text{(A.2.2.1.1)}$$

where

$N_{Rk,p}$ = $\tau_{Rk} \cdot \pi \cdot d \cdot h_{ef}$; characteristic resistance for pull-out failure given in the ETA for concrete strength class and state of concrete (cracked, uncracked) corresponding to the evaluated tension test.

The evaluation of the load at loss of adhesion is not required when failure occurs between bonding material and steel elements along the entire embedment depth. In this case the factor α_1 shall be taken as 1,0.

Examples of load-displacement curves

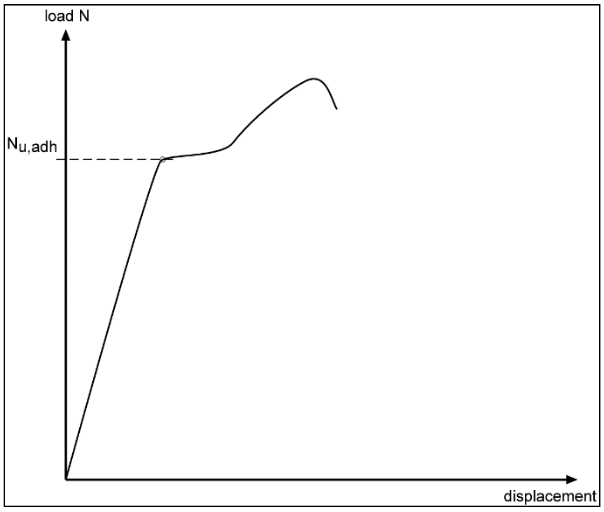


Figure A.2.2.1.1 Load at loss of adhesion by a significant change of stiffness

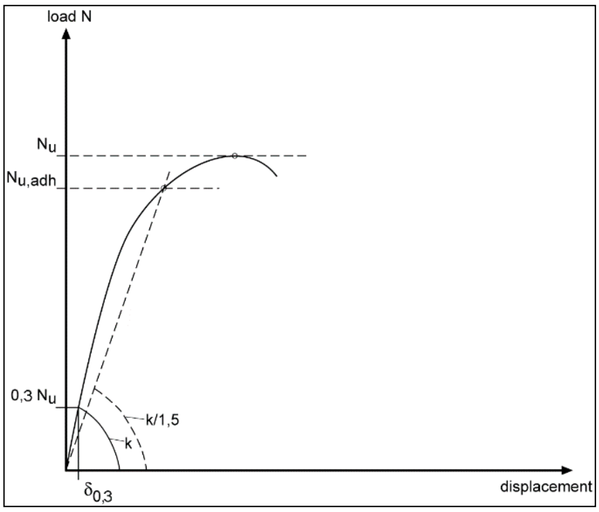


Figure A.2.2.1.2 Evaluation of load at loss of adhesion

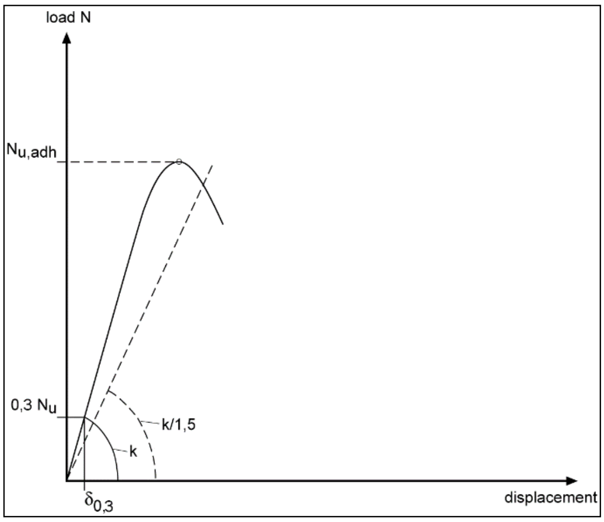


Figure A.2.2.1.3 Evaluation of load at loss of adhesion

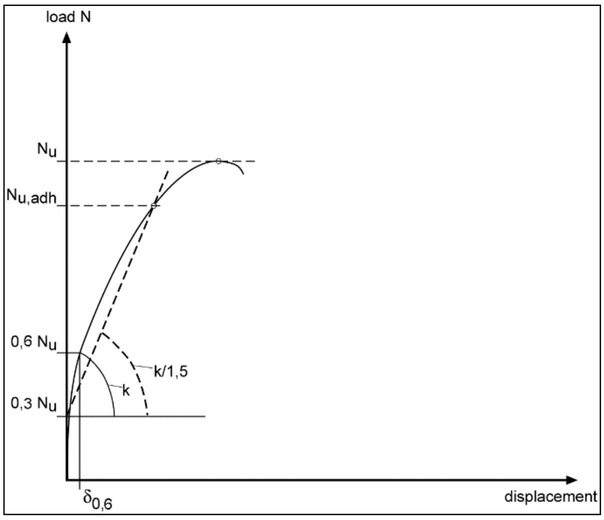


Figure A.2.2.1.4 Evaluation of load at loss of adhesion

A.2.2.2 Limitation of the scatter of displacements

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

The coefficient of variation of the mean displacement at the load level of 0,5 $N_{Ru,m}$ shall fulfil the criteria given in Equation (A.2.2.2.1) and Equation (A.2.2.2.2).

$cv_{\delta} \leq 0,25$ (test series R1 to R9, A1 to A5, B1 to B5) (A.2.2.2.1)

$cv_{\delta} \leq 0,40$ (test series B6 to B17 and B20) (A.2.2.2.2)

The load displacement curves may be shifted according to Figure A.2.2.2.1 for determination of the displacement at 0,5 $N_{Ru,m}$.

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

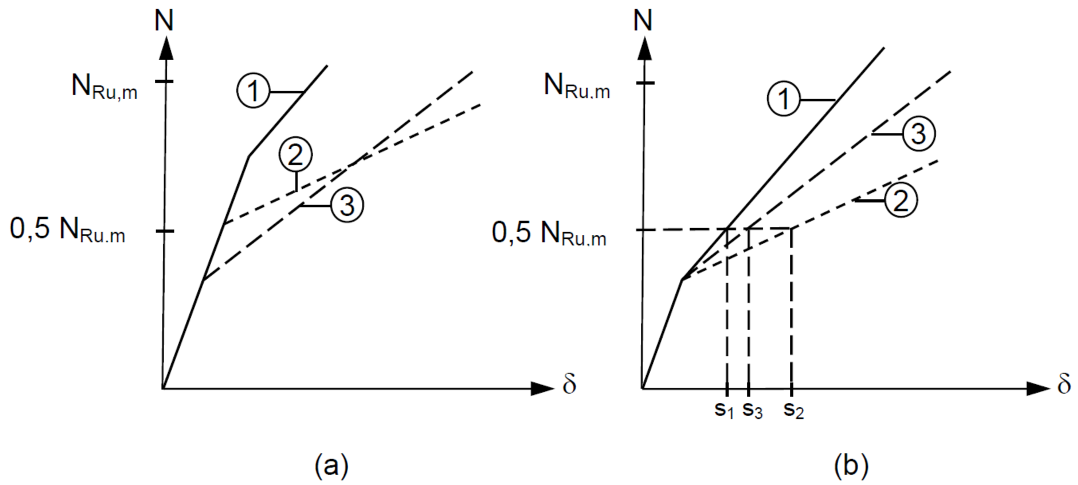


Figure A.2.2.2.1 Influence of pre-stressing on load/displacement curves

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

ANNEX B BONDED EXPANSION FASTENERS

B.1 General

Bonded expansion fasteners (BEF) are installed in cylindrical holes, the load transfer is realised e.g., by mechanical interlock of a cone or several cones in the bonding material and then via a combination of bonding- and friction forces in the anchorage ground (concrete).

When a tension force of a certain magnitude is acting in the fastener rod the adhesion between bonding material and fastener rod is destroyed.

After this bonding has been destroyed the expansion areas, due to their geometry, cause expansion forces as in the case of expansion fasteners, which press the bonding material to the wall of the drilled hole; thus the bonding material is expanded or bursts, i.e., it takes over the function of an expansion sleeve of torque-controlled expansions.

In uncracked concrete the loadbearing effect of the bonding by friction is increased due to the expansion forces. In cracked concrete an extensive loss of adhesion between bonding material and concrete is likely to occur.

The function of the fasteners is ensured, if during loading the adhesion between fastener rod and bonding material is destroyed at a level which is lower than the holding capacity of the bond between bonding material and drill hole wall.

The influences of temperature and durability on the bonding material shall be determined according to 2.2.

The test program is intended for application of BEF in cracked concrete.

B.2 Test program for BEF

B.2.1 Test Program

The following test series shall be carried out and assessed in the same way as for BF according to 2.2 and test program for BF given in Table A.1.1:

- Resistance to steel failure (N1 to N2)
- Reference tests with confined test setup (R1 to R9)
- Basic tension tests with unconfined test setup (A1 to A6)
- Resistance to shear load (V1 to V2)
- Minimum edge distance and spacing (B1)
- Temperature tests (B2 to B5, B20)
- High alkalinity and sulphurous atmosphere (B18 and B19): rest results with threaded rods (BF) may be used for assessment of α_4, see 2.2.2.12)

For the test series given in Table B.2.1 clause 2.2 applies, as far as it is not overruled by Annex B for BEF.

Tests in concrete strength class C12/15 and in strength classes higher than C50/60 may be omitted, if the intended use is limited to the range of strength classes C20/25 to C50/60.

Table B.2.1 Test program for BEF

N°	Purpose of test	concrete	crack width [mm]	T/T_{inst}	size 1) 2)	n_{min}	rqd. α	Test conditions clause
E1	Reduced installation torque in dry concrete	C12/15	0,3	0,5	all	10	see Table 2.2.5.6.1	B.2.3
		C20/25				10		
E2	Robustness in dry concrete	C12/15	0,3	1/0,5	all	10		
		C20/25				10		
E3	Robustness in water saturated concrete	C12/15	0,3	1/0,5	all	10		
		C20/25				10		
E4	Robustness in water filled holes (clean water)	C12/15	0,3	1/0,5	all	10		
		C20/25				10		
E5	Robustness to mixing technique	C12/15	0,3	1/0,5	m	10		
		C20/25				10		
E6	Increased crack width	C12/15	0,5	1/0,5	s/m/l	10	0,80	2.2.2.3
		C20/25				10		
E7	Increased crack width	C50/60	0,5	1/0,5	s/m/l	10	0,80	2.2.2.3
		maximum				10		
E8	Crack cycling under load	C12/15	0,1–0,3	1/0,5	s/m/l	10	0,90	2.2.2.5
		C20/25				10		
		C12/15			intermediate	5		
		C20/25				5		
E9	Sustained loads (normal ambient temperature)	C12/15	0	1/0,5	m	5	0,90	2.2.2.6
		C20/25				5		
E10	Sustained loads (maximum long-term temperature)	C12/15	0	1/0,5	m	5	0,90	2.2.2.6
		C20/25				5		
E11	Freeze/thaw conditions	C50/60	0	1/0,5	m	5	0,90	2.2.2.7
E12	Installation direction	C12/15	0,3	1/0,5	max	5	0,90	2.2.2.8
		C20/25				5		
E13	Slip force test	C12/15	0,3	0	All	5	-	B.2.5
		C20/25				5		
E14	Bond force test	C12/15	0,3	0	All	5	-	B.2.6
		C20/25				5		

1) See Table A.1.2; m: size 12 mm or smallest size which is larger than 12 mm;
2) The reduced range of tested sizes s/m/l depends on the number of requested sizes and is given in Table A.1.2.

B.2.2 General

If the slip and bond force tests are carried out and the requirements according to B.2.7 are fulfilled, then the tests given in Table B.2.1 lines E1 to E8 may be performed with reduced number of tests n_{min} = 5. If the conditions according to clause B.2.7 are not fulfilled or the slip and bond force tests are not carried out, then the number of tests given in Table B.2.1 applies. Therefore, it is recommended that first the tests are carried out according to Table B.2.1, line E13 and E14 with checking of the requirements to clause B.2.7.

The test procedures given in Table B.2.1, line E1 to E12 correspond in principle to the required tests for BF according to Table A.1.1, the necessary modifications and adaptations (including the number of tests) are given in the following.

In contrast to the assessment of BF, all tests in lines E1 to E8 and line E12 shall be carried out as unconfined tests in cracked concrete. The results of these tests shall be compared with the results of tests according to Table A.1.1, line A3 (tests in C20/25) or line A4 (tests in C50/60).

The tests according to line E9, E10 and E11 shall be carried out as confined tests, and the results shall be compared with confined reference tests (Table A.1.1, lines R6 and R7) performed in the same concrete batch.

In the tests the installation torque T_{inst} specified by the manufacturer in the MPII shall be applied with the exception of the tests according to Table B.2.1, lines E1 and Table A.1.1, line N2.

Ten minutes after applying the installation torque it shall be reduced to 0,5 T_{inst}. If no torque is given by the manufacturer, then the tests shall be carried out without installation torque.

B.2.3 Robustness (test series E1 – E5)

The robustness tests shall be carried out according to Annex D and 2.2.5, however, they shall be performed in cracked concrete (Δw = 0,3 mm) as unconfined tests.

In the tests according to line E1 the installation torque of 50 % of T_{inst} recommended by the manufacturer shall be applied. The hole shall be cleaned according to the MPII.

B.2.4 Installation direction (test series E12)

These tests shall be carried out in cracked concrete Δw = 0,3 mm as unconfined tests.

B.2.5 Slip force tests (test series E13)

The tests according to Table B.2.1, line E13 are carried out to determine the slip force.

The slip force is that force, at which the adhesion between fastener rod and bonding material is destroyed.

The slip force may be determined by a significant change in the stiffness of the load-displacement curve or a clear increase of the splitting force.

At least 5 tests per fastener size shall be carried out.

The mean slip force ($F_{slip,m}$) and the 95 %-fractile of the slip force ($F_{slip95\%}$) shall be determined for each size with a confidence level of 90 % and by assuming an unknown standard deviation.

The fastener is installed into concrete C20/25 with hole cleaning according to MPII.

No installation torque shall be applied.

After opening of the cracks up to Δw = 0,3 mm the fastener is loaded until failure occurs.

The relative displacement of the fastener rod related to the concrete is measured by means of an inductive displacement transducer on the fastener side opposite to the load (unloaded end of the rod).

B.2.6 Bond force tests (test series E14)

The tests according to Table B.2.1, line E14, are carried out to determine the bond forces by taking account of the most unfavourable anchorage ground conditions.

The bond force is defined as load at loss of adhesion between bonding material and wall of the drill hole.

The tests are carried out in cracked concrete C20/25 Δw = 0,3 mm using a fastener rod which generates no expansion forces (e.g., normal threaded rod with a comparable diameter and length) instead of the fastener rod which is intended for the BEF.

No installation torque is applied.

The hole cleaning is carried out according to robustness test series for BF, see (2.2.5).

At least 5 tests per fastener size are required. The most unfavourable condition of robustness tests (E2 to E4) applies.

The determination of the loads at loss of adhesion shall be done according A.2.2.1.

The loads shall be converted to nominal concrete strength value of C20/25 according to clause A.2.1.2.

The mean bond force (min $F_{bond,m}$) and the 5 %-fractile of the bond force ($F_{bond5\%}$) shall be determined for each fastener size with a confidence level of 90 % by assuming an unknown standard deviation.

B.2.7 Assessment of slip and bond force tests

One of the following criteria shall be fulfilled:

$$F_{bond,m} / F_{slip,m} \geq 3{,}0 \quad \text{(B.2.7.1)}$$

$$F_{bond5\%} / F_{slip95\%} \geq 1{,}3 \quad \text{(B.2.7.2)}$$

where

$F_{bond,m}$ = mean bond force;

$F_{slip,m}$ = mean slip force;

$F_{slip95\%}$ = 95 %-fractile of the slip force;

$F_{bond5\%}$ = 5 %-fractile of the bond force.

Under the assumption of a normal distribution of the bond forces and slip forces and unknown standard deviation the two conditions ensure that the slip forces will not exceed the bond forces with a probability in the order of 10^{-3}.

The two conditions given above are considered as being equivalent, if the coefficient of variation of the tests is ≤ 15 % (tests according to Table B.2.1, line E13) and ≤ 10 % (tests according to Table B.2.1, line E14).

If the coefficient of variation is larger in a test series with a particular fastener sizes, then the number of tests in this series may be increased.

B.2.8 Load displacement behaviour

Load displacement curves of BEF in cracked concrete may show a short plateau (max length about 0,5 mm) and also in some cases a very small decrease of the load.

This behaviour indicates the point when the adhesion between bonding material and fastener rod is destroyed. This small plateau in the load displacement curve is acceptable for this kind of fastener in cracked concrete and is not interpreted as uncontrolled slip.

ANNEX C ADDITIONAL PROVISIONS FOR WORKING LIFE OF 100 YEARS

C.1 General

The assessment of fasteners shall be done in accordance with clause 2.2 with the modifications as given in this chapter. For BEF, replace bond strength τ by forces N.

C.2 Repeated loads (test series B12)

The methods for testing and assessment are the same as given in clause 2.2.2.4 with the following exceptions:

- Perform 200.000 load cycles instead of 100.000 load cycles
- Replace $\tau_{Rk,ucr}$ in Equations (2.2.2.4.1) and (2.2.2.4.2) by $\tau_{Rk,100,ucr}$ (= characteristic bond strength as calculated in Equation (2.2.2.14.1) or (2.2.2.15.1) for use in uncracked concrete for 100 years working life)

C.3 Crack cycling under load (test series B13, E8)

The methods for testing and assessment are the same as given in clause 2.2.2.5 with the following exceptions:

- Perform 2.000 crack cycles instead of 1.000 crack cycles
- Replace $\tau_{Rk,cr}$ in Equations (2.2.2.5.1) by $\tau_{Rk,100,cr}$
- Assessment of displacements during crack cycles after 20 (δ_{20}) and 2000 (δ_{2000}) cycles
- If all diameters are already tested for 50 years working life, then only the three smallest diameters shall be tested for 100 years.

C.4 Sustained loads (test series R6, B14, B15, E9, E10)

The methods for testing and assessment are the same as given in clause 2.2.2.6 with the following exceptions:

- Replace $\tau_{Rk,ucr,21}$ in Equation (2.2.2.6.1) by $\tau_{Rk,100,ucr,21}$ (= characteristic bond strength as calculated in Equation (2.2.2.14.1) or (2.2.2.15.1) for use in uncracked concrete for 100 years working life for normal ambient temperature)
- Replace $\tau_{Rk,ucr,mlt}$ in Equation (2.2.2.6.2) by $\tau_{Rk,100,ucr,mlt}$ (= characteristic bond strength as as calculated in Equation (2.2.2.14.1) or (2.2.2.15.1) for use in uncracked concrete for 100 years working life for maximum long-term temperature)
- Maintain the load at tests N_{sust} (the applied load shall not decrease to less than N_{sust} and shall vary by no more than 5 % from the initially applied load) and maintain temperature at normal ambient temperature (and maximum long-term temperature respectively) and measure the displacements until they appear to have stabilised, but at least for six months. Measure the applied sustained load and displacements at a frequency of no less than once per working day.

  The displacements have to be stabilized as defined by the following steps:
  1. At least the final three months of displacement data have to be viewed in a plot with the logarithm of the time of sustained loading on the x-axis and the logarithm of the displacement on the y-axis.
  2. The data plotted as described in step 1 shall show concave or approximately linear behaviour.
  3. If step 2 is not satisfied, then continue to apply the sustained load until this criterion is met.

- If the product has previously been tested for working life of 50 years with a sample size n ≥ 5, then n_{min} may be reduced to 3 provided that the following are true of the previous data:
  1. A coefficient of variation $cv_F \leq 10$ % shall have been achieved for ultimate loads in both reference tests and residual load tests;
  2. If the mean value of displacements at 50 % of the failure load were larger than 0,4 mm, then cv_δ shall not have exceeded 20 % ($cv_\delta \leq 20$ %); and
  3. The creep displacements in all of the sustained load tests shall have shown a clear stabilizing behaviour with the coefficient of variation of the displacements at the end of testing and the estimated displacements for 50 years (ambient temperature) and 10 years (maximum long-term temperature) applying the Findley approach shall not have exceeded 10 % ($cv_\delta \leq 10$ %).

Assessment:

The displacements measured in the tests have to be extrapolated in accordance with Equation (2.2.2.6.4.2) to 100 years for tests at normal ambient temperature and 20 years for tests at maximum long-term temperature. A least-squares regression of the data against Equation (2.2.2.6.4.2) have to be performed using, at minimum, daily displacement readings covering approximately the final 70 % of the time under sustained loading. Extrapolated displacements have to be less than the mean value of the displacements $\delta_{u,adh}$ in the corresponding reference tests at normal ambient temperature or maximum long-term temperature respectively. $\delta_{u,adh}$ is the displacement at $N_{u,adh}$ (loss of adhesion).

Determine α_p after successful test according to clause 2.2.2.6.1.

The factor $\psi^0_{sus,100}$ shall be determined in accordance with clause 2.2.2.6.4 using the data of a successful sustained load test according to C.4.

The justification given in the end of clause 2.2.2.6.4 also applies for intended working life of 100 years, i.e., the factor 1,15 in Equation (2.2.2.6.4.4) stays the same.

C.5 Determination of the characteristic bond resistance

The determination of the characteristic bond resistance to combined pull-out and concrete cone failure shall be done in accordance with clause 2.2.2.14 or 2.2.2.15 taking into account the smallest reduction factors derived in clause 2.2.2 or Annex C.

If the fastener is intended to be used for 100 years working life, then the characteristic resistance to combined pull-out and concrete cone failure for 100 years working life is given for BF as $\tau_{Rk,100}$ [N/mm²] and as $N_{Rk,100}$ [kN] for BEF.

All other essential characteristics are valid both for 50 and 100 years working life.

Expression of results:

Factor: $\psi^0_{sus,100}$

ANNEX D DETAILS OF TESTS FOR BF AND BEF IN CONCRETE

D.1 Scope

This Annex provides details for the tests with post-installed fasteners in concrete.

D.2 Abbreviation and Notation

The specific terms are listed in clause 1.3.

D.3 Details of Tests

D.3.1 Test samples, test members, test setup, installation and test equipment

D.3.1.1 Test samples

Fasteners with inner threads may be supplied without the fixing steel elements such as screws or nuts, but the manufacturer of the fastener shall specify the screws or nuts to be used. If according to the chosen design method the characteristic resistance for concrete failure is needed, then it may be necessary to use screws or bolts of higher strength than those specified, in order to achieve a concrete failure in tests. If higher strength screws or bolts are used, then the functioning of the fasteners shall not be influenced in any way. The use of such test specimens shall be clearly stated in the test report.

D.3.1.2 Test members

D.3.1.2.1 General

This Annex is valid for fasteners tested in concrete members using compacted normal weight concrete with strength classes in the range of C12/15 to C90/105 in accordance with EN 206 [1]. The fastener performance is only valid for the range of tested concrete.

The test members shall comply with the following:

D.3.1.2.2 Aggregates

Aggregates shall be of natural occurrence (i.e., non-artificial) and with a grading curve falling within the boundaries given in Figure D.3.1.2.2.1. The maximum aggregate size shall be 16 mm or 20 mm. The aggregate density shall be between 2.0 and 3.0 t/m^3 (see EN 206 [1]).

The boundaries reported in Figure D.3.1.2.2.1 are valid for aggregate with a maximum size of 16 mm. For different values of maximum aggregate sizes, different boundaries may be adopted, if previously agreed with the responsible TAB.

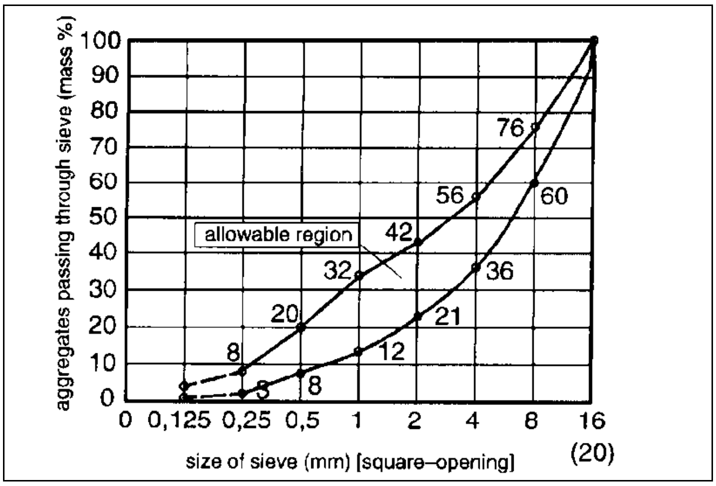


Figure D.3.1.2.2.1 Admissible region for the grading curve

D.3.1.2.3 Cement

The concrete shall be produced using Portland cement Type CEM I or Portland-Composite cement Type CEM II/A-LL, CEM II/B-LL (see EN 197-1 [29])

D.3.1.2.4 Water/cement ratio and cement content

The water/cement ratio shall not exceed 0,75 and the cement content shall be at least 240 kg/m^3.

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

D.3.1.2.5 Concrete strength

The following mean compressive strengths at the time of testing fasteners shall not exceed the nominal concrete strength + 10 N/mm².

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

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

$$f_c = \frac{f_{ck,cyl}}{f_{ck,cube}} f_{c,t,cube} \quad \text{(D.3.1.2.5.1)}$$

Where

$f_{ck,cube}$ = characteristic minimum cube strength according to EN 206 Table 12 [1]

$f_{ck,cyl}$ = characteristic minimum cylinder strength according to EN 206 Table 12 [1]

$f_{c,t,cube}$ = mean strength of concrete strength of the test member measured on cubes

For cube sizes, the concrete compressive strength may be converted as follows:

$$f_{cube100} = \frac{1}{0{,}95} f_{cube} \quad \text{(D.3.1.2.5.2)}$$

$$f_{cube} = \frac{1}{0{,}95} f_{cube200} \quad \text{(D.3.1.2.5.3)}$$

Note: Additional literature for conversion is given by R. Lewandowski, Beurteilung von Bauwerksfestigkeiten an Hand von Betongütewürfeln und –bohrproben, Schriftenreihe der Institute für Konstruktiven Ingenieurbau der Technischen Universität Braunschweig, Heft 3, Werner Verlag, Düsseldorf, 1971

For determination of the concrete compression strength with test of cores see EN 13791, clause 6 [21].

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

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

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

If, when evaluating the test results, there should be doubts whether the strength of the control specimens represents the concrete strength of the test members, then at least three cores of 100 mm diameter shall be taken from the test members outside the zones where the concrete has been damaged in the tests, and tested in compression. The cores shall be cut to a height equal to their diameter, and the surfaces to which the compression loads are applied shall be ground or capped. The compressive strength measured on these cores may be converted into the strength of cubes by Equation (D.3.1.2.5.2).

D.3.1.2.6 Test members for tests in cracked concrete

The tests are carried out on test members with unidirectional cracks. The crack width shall be approximately constant throughout the member thickness. To control cracking, so-called ‘crack-inducers may be built into the member, provided they are not situated near the anchorage zone. An example for a test member is given in Figure D.3.1.2.6.1.

In the test with variable crack width the reinforcement ratio (top and bottom reinforcement) shall be $\mu = A_s / (b \cdot h) \sim 0{,}01$ and the spacing of the bars ≤ 400 mm.

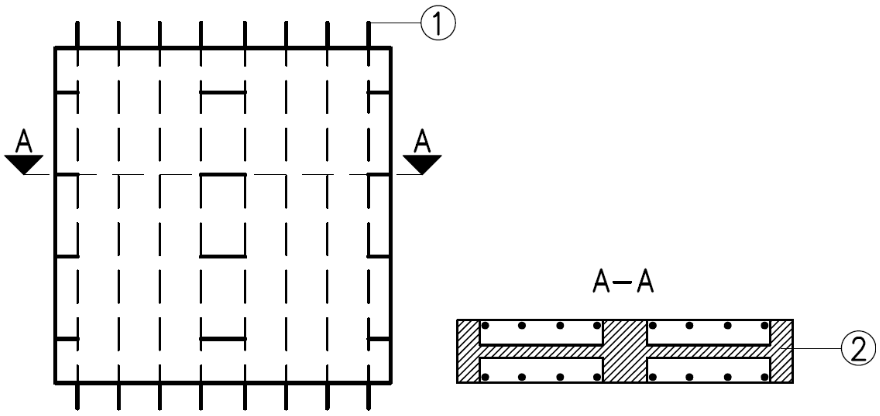


Figure D.3.1.2.6.1 Example of a test member for fasteners tested in cracked concrete

Test members for crack cycling and seismic tests

The thickness of the test member shall be at least the maximum of 1,5 h_{ef} and the minimum member thickness as specified in the MPII. The width of the test member shall be large enough to avoid any influence of the edges on the fastener behaviour. The test member shall be designed such that the crack width is approximately constant throughout the thickness of the test member during the test (including crack cycling, load cycling and peak load). This requirement is considered to be fulfilled if

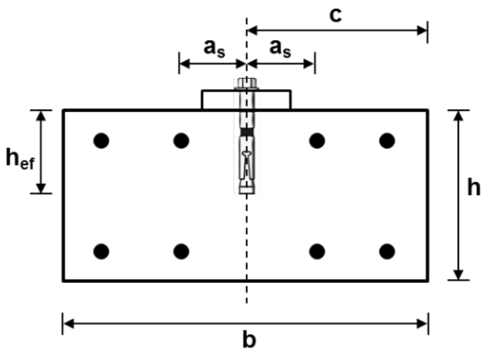
a) the crack width Δw_{hef} at the level of the embedment depth h_{ef} is equal to or greater than the required value, and

b) the crack width Δw_{top} at the top side of the test member (i.e., the side in which the fastener is installed) is equal to or larger than Δw_{hef} for $\Delta w_{hef} \geq 0{,}3$ mm.

The reinforcement shall be of equal size and placed symmetrically (see Figure D.3.1.2.6.2). The spacing of the reinforcement in the test member shall be 2 $a_s \leq 400$ mm with $a_s = \max(75\text{ mm}; 0{,}6\ h_{ef})$. The capacity of the fastener shall not be affected by the reinforcement. The reinforcement shall allow the development of an unrestricted concrete breakout cone. If required, then the spacing shall be increased.

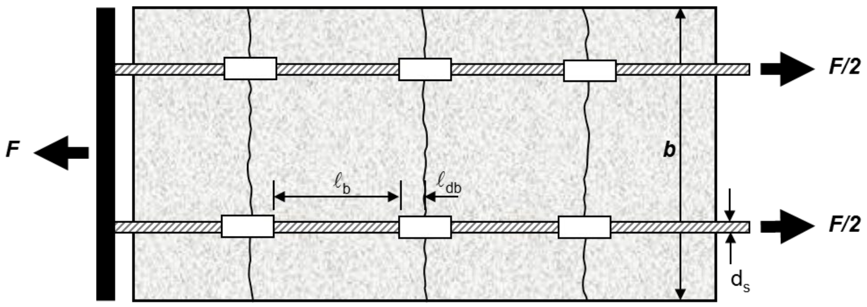
The reinforcement shall remain well in the elastic range during each test. Buckling of the reinforcement shall be avoided. The bond length ℓ_b between possible crack planes and at both ends of the specimen (see Figure D.3.1.2.6.3) shall be large enough to introduce the tension force into the concrete.

To facilitate the opening of the crack by Δw = 0,8 mm a bond breaker may be applied at both sides of the crack (see Figure D.3.1.2.6.3). A plastic pipe with an inner diameter of ≈ 1,2 d_s may be used for this purpose, where d_s denotes the diameter of the reinforcing bar. When using bond breakers the de-bonding length ℓ_{db} is recommended to be ≤ 5 d_s.



a_s … distance between fastener and reinforcement bar
b … width of test member
c … edge distance
h … height of test member
h_{ef} … embedment depth of fastener

Figure D.3.1.2.6.2 Example cross section of test member



▭ … bond breaker
ℓ_b … bond length
ℓ_{db} … de-bonding length
d_s … diameter of rebar
b … width of test member
F … force on test member

Figure D.3.1.2.6.3 Example for test member with bond breaking pipes on rebar (plan view)

The requirement that the fastener behaviour is not influenced by the edges of the test member is considered to be fulfilled if for unconfined testing the concrete breakout body does not intersect with an edge or the edge distance of the fastener in all directions is $c \geq 2{,}0\ h_{ef}$.

For confined tests the distance requirements between fastener and nearest reinforcement as stated in the previous paragraph do not apply.

Note: The above requirement for a_s is based on the consideration that the reinforcement does not intersect the portion of the concrete breakout cone that has developed at peak load and the following two assumptions:

1. *The crack length at ultimate load is approximately 0,4 times the side length of the final cone. The slope of the cone as measured from the horizontal is on the average about 35°.*
2. *The spacing of the reinforcement used to create and control the crack width is typically not less than 150 mm.*

The fulfilment of the requirements regarding the constant crack width shall be demonstrated for each test member design for the fastener with the highest ultimate load to be tested in this test member for the crack width required for the specific test (see Table E.3.3.1.1 and Table E.3.4.1.1) and for crack width Δw = 0,3 mm to 0,8 mm for test series C2.5. At least 3 test members shall be tested for each test member design and in each test the conditions given above shall be fulfilled. The results of this assessment shall be reported in the test report. There are two options for the assessment shown in Figure D.3.1.2.6.4 a) and b).

According to Figure D.3.1.2.6.4 a) the crack widths are measured at the top and bottom of the test member either at the fastener location (locations 1 and 2 in Figure D.3.1.2.6.4 a)) or at a distance of approximately h_{ef} on both sides of the fastener (locations 3 & 4 and 5 & 6 in Figure D.3.1.2.6.4 a)). The mean value of the crack width measurements at locations 3 and 4 represents Δw_{top} and the mean value of the crack width measurements at locations 5 and 6 represents Δw_{bot}. The crack width Δw_{hef} is obtained by linear interpolation of the top and bottom crack widths, i.e., Δw_{top} and Δw_{bot}, respectively.

Alternatively, the approach shown in Figure D.3.1.2.6.4 b) may be pursued if it is shown that the width of the crack remains approximately constant across the width of the test member. This condition is considered to be fulfilled if the ratio of the mean value of the crack width measurements at locations 7 and 8 to the mean value of the measurements at locations 3 and 4 is ≤ 1,05. The mean value of the crack width measurements at locations 3 and 4 represents Δw_{top} and the mean value of the crack width measurements at locations 9 and 10 represents Δw_{hef}.

Only one fastener shall be located in a crack at the time of testing.

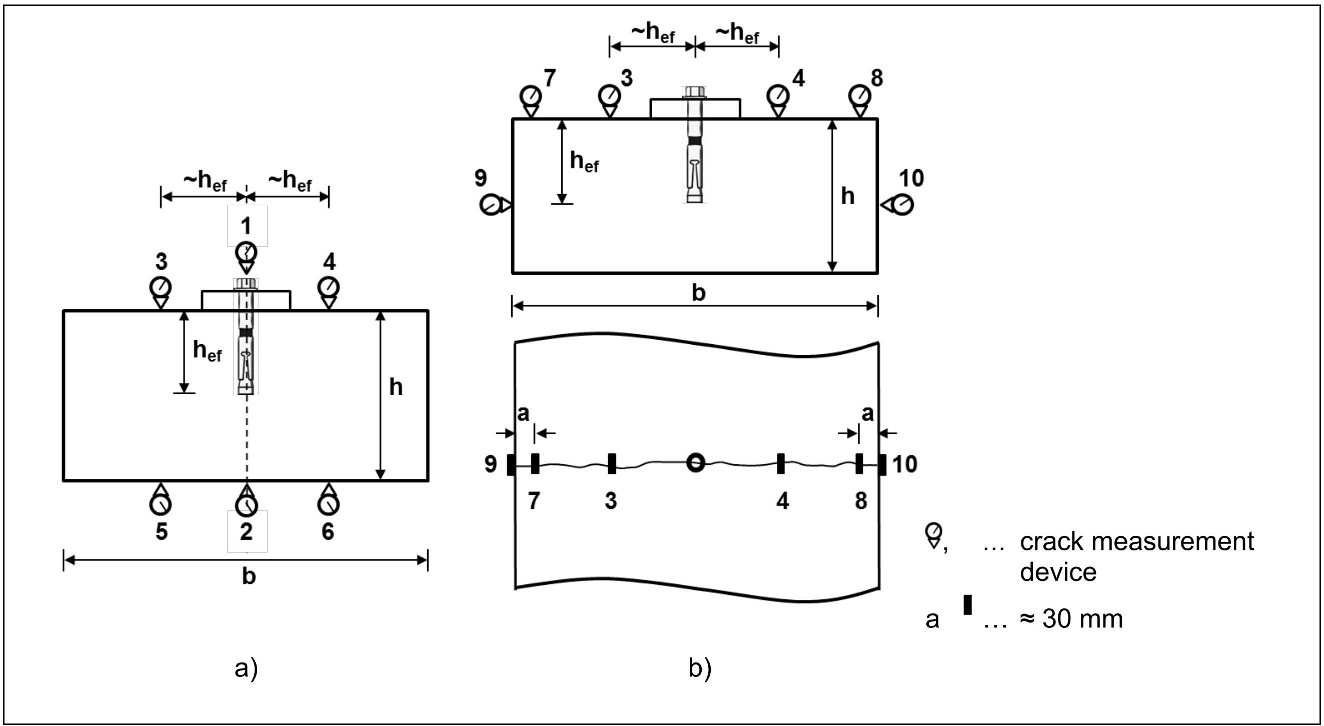


Figure D.3.1.2.6.4 Measurements to show fulfilment of the constant crack width requirement

<u>Crack measurement and tolerance on crack width</u>

The crack width shall be measured continuously during the test with a measuring error not greater than 0,02 mm.

In tension tests the crack width Δw_{hef} shall be determined by either one of the following two approaches:

a) Linear interpolation of crack measurements at the top Δw_{top} and bottom Δw_{bot} of the test member (see Figure D.3.1.2.6.4 a). In this case the crack width shall be measured either at the location of the fastener (i.e. locations 1 (Δw_{top}) and 2 (Δw_{bot}) in Figure D.3.1.2.6.4 a) or on both sides of the fastener (i.e. locations 3 & 4 (for Δw_{top}) and 5 & 6 (for Δw_{bot}) in Figure D.3.1.2.6.4 a) with the two mean values of the measurements at the top and bottom representing Δw_{top} and Δw_{bot}, respectively.

b) Measuring the crack width at the side of the test member at the embedment depth level h_{ef} (i.e. locations 9 & 10 in Figure D.3.1.2.6.4 b). In this case the mean value of the measurements at the side of the test member shall be determined to represent Δw_{hef}.

For both approaches in unconfined tension tests the measurement devices shall be placed as shown in Figure D.3.1.2.6.4 In confined tension tests the measuring devices 3, 4, 5 and 6 in Figure D.3.1.2.6.4 a) and 3 & 4 in Figure D.3.1.2.6.4 b) shall be placed as close as possible to the fastener but not further away than 150 mm from the fastener.

In shear tests the crack width shall be measured within a distance of approximately 1,0 h_{ef} in front of and behind the fastener (and the mean value is determined) or directly at the fastener location where possible.

The mean of the measured crack widths Δw_{hef} for each test series determined for each fastener shall be equal to or greater than the specified crack width for the test series. Individual crack widths shall be within the following tolerance:

Table D.3.1.2.6.1 Tolerances for crack widths

Nominal value Δw [mm]	Maximum allowed deviation [%]	[mm]
0,1	20%	± 0,02
0,2	20%	± 0,04
0,3	20%	± 0,06
0,35	20%	± 0,07
0,4	10%	± 0,04
0,5	10%	± 0,05
0,6	10%	± 0,06
0,7	10%	± 0,07
0,8	10%	± 0,08

D.3.1.2.7 Test members for tests in uncracked concrete

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

D.3.1.2.8 Casting and curing of test members

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

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

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

D.3.1.3 Unconfined test setup

Unconfined tests allow an unrestricted formation of the rupture concrete cone. An example for an unconfined test setup is shown in Figure D.3.1.3.1.

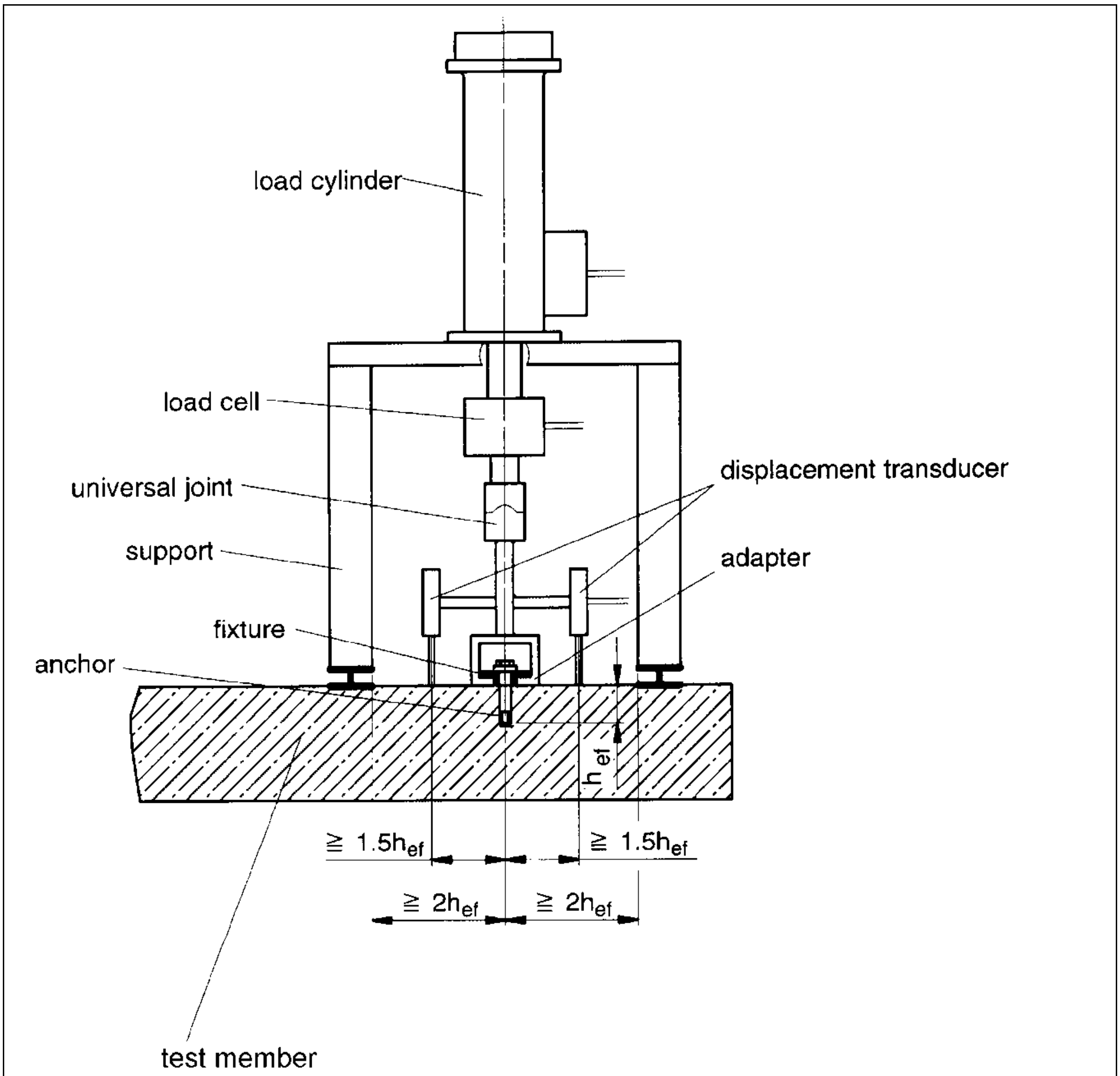


Figure D.3.1.3.1 Example of a tension test rig for unconfined tests

D.3.1.4 Confined test setup

Confined tests are performed when concrete cone failure shall be excluded (e.g., for bond resistance of BF). In confined tests concrete cone failure is eliminated by transferring the reaction force close to the fastener into the concrete.

An example of the test setup is shown in Figure D.3.1.4.1. The rig / steel plate shall be stiff and the area of support large to avoid high compression of the concrete. Recommendation: compression strength under the steel plate < 0,7 of the concrete compression strength.

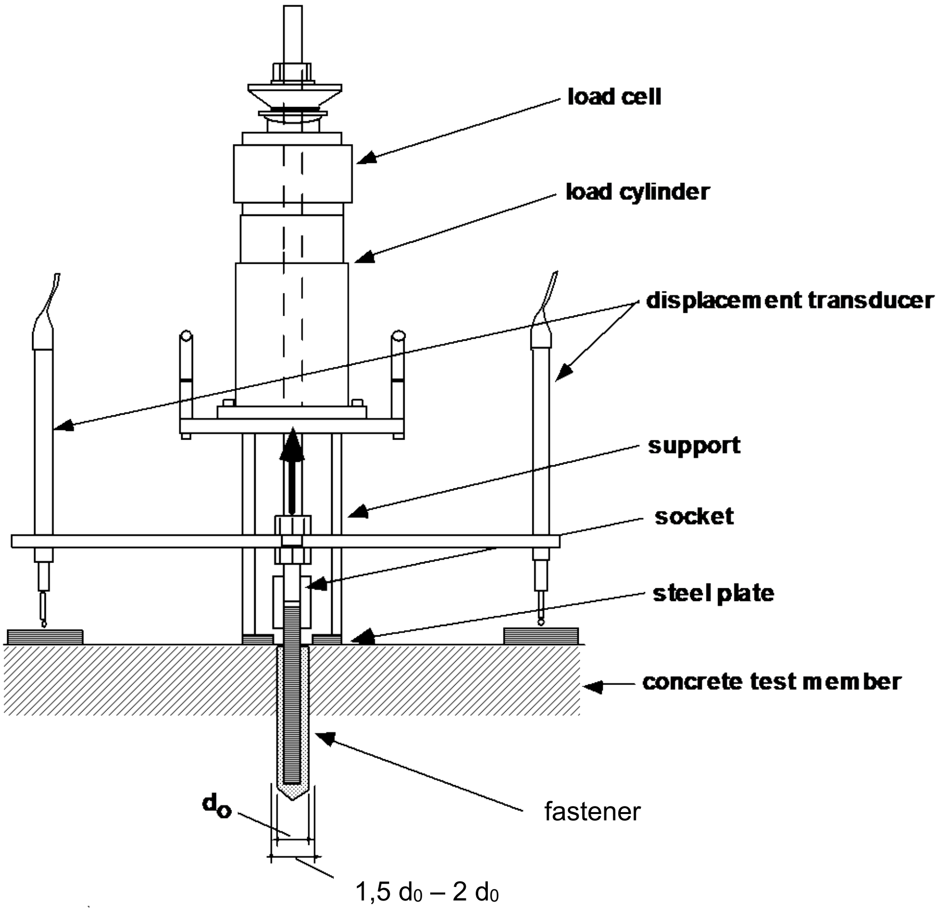


Figure D.3.1.4.1 Example of a tension test rig for <u>confined</u> tests

D.3.1.5 Installation of fasteners

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

The fasteners shall be installed in accordance with the manufacturer's product installation instructions (MPII), except where special conditions are specified in the EAD for the test series.

The installation torque T_{inst} required by the manufacturer shall be applied to the fastener by a torque wrench which has a documented calibration.

The measuring error shall not exceed 5 % of the applied torque throughout the whole measurement range. After about 10 minutes of applying Tinst to the fastener, the installation torque shall be reduced to 0,5 Tinst to account for relaxation of the pre-stressing force with time. If no torque is specified by the manufacturer's product installation instructions, then finger-tighten the fastener prior to testing. Test internally threaded fasteners with the bolt specified by the manufacturer and report the bolt type in the test report.

For tests in cracked concrete, install the fastener in a hairline crack according to D.3.1.2.6, and the manufacturer's product installation instructions (MPII) except for tests described in E.3.4.5, where a compression load is applied to the test member before installation of the fastener.

For torque controlled BEF, about 10 minutes after torquing the fasteners with the installation torque T_{inst} required by the manufacturer, the installation torque shall be reduced to 0,5 T_{inst} to account for relaxation of the pre-stressing force with time.

Fasteners not needing the application of a defined installation torque shall be finger-torqued before testing.

With fasteners which need to be torqued, the test results can be influenced by the roughness of the fixture. Therefore, the washer shall not turn relative to the fixture. To ensure defined test conditions, e.g., double-sided abrasive material may be inserted between washer and fixture (see Figure D.3.1.6.3).

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

> *Note: In the test with variable crack width the crack may be opened for the verification of the crack in the hole. This can be documented by a picture in the test report. After drilling the hole, before opening the crack, the crack measurement must be started (Δw=0). Before installation of the fastener, the crack must be closed back to Δw=0.*

The holes for fasteners shall be perpendicular (± 5° deviation) to the surface of the concrete member.

In the tests the drilling tools specified by the manufacturer for the fasteners shall be used. If hard metal hammer-drill bits are required, then these bits shall meet the requirements laid down in ISO 5468:2006 with regard to dimensional accuracy, symmetry, symmetry of insert tip, height of tip and tolerance on concentricity.

D.3.1.6 Test equipment

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

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

For unconfined tests the test rigs shall allow the formation of an unrestricted rupture cone. For this reason, the distance between the support reaction and a fastener (single fastener) or an outer fastener (fastener group) respectively shall be at least 2 h_{ef} (tension test) as shown in Figure D.3.1.3.1 or 2 c_1 (shear test at the edge with load applied towards the edge, with c_1 = edge distance in load direction) as shown in Figure D.3.1.6.2. Only in shear tests without edge influence where steel failure is expected this distance may be less than 2 c_1.

The capacity of the test equipment shall prevent yielding or failure of its components during all tests.
The stiffness of the test equipment shall ensure that the applied tension load remains parallel to the axis of the fastener and the applied shear load remains parallel to the surface of the test member.

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

During tension tests the load shall be applied concentrically to the fastener. To achieve this, hinges shall be incorporated between the loading device and the fastener. Requirements for the diameter of the clearance hole of the fixture may be given in the EADs. An example of a tension test rig is illustrated in Figure D.3.1.3.1.

In shear tests (see D.3.6), the load shall be applied parallel to the concrete surface. A plate with interchangeable sleeves may be used for testing the different sizes of fasteners (see Figure D.3.1.6.1). The sleeves shall be made of quenched steel and have radiused edges (0,4 mm) where in contact with the fastener. The height of the sleeves shall be approximately equal to the outside diameter of the fastener. To reduce friction, smooth sheets (e.g., PTFE) with a maximum thickness of 2 mm shall be placed between the plate with sleeve and the test member.

An example of a shear test rig is illustrated in Figure D.3.1.6.2. As there is a lever arm between the applied load and the support reaction, the test member is stressed by a torsion moment. This shall be taken up by additional reaction forces placed sufficiently far away from the fastener.

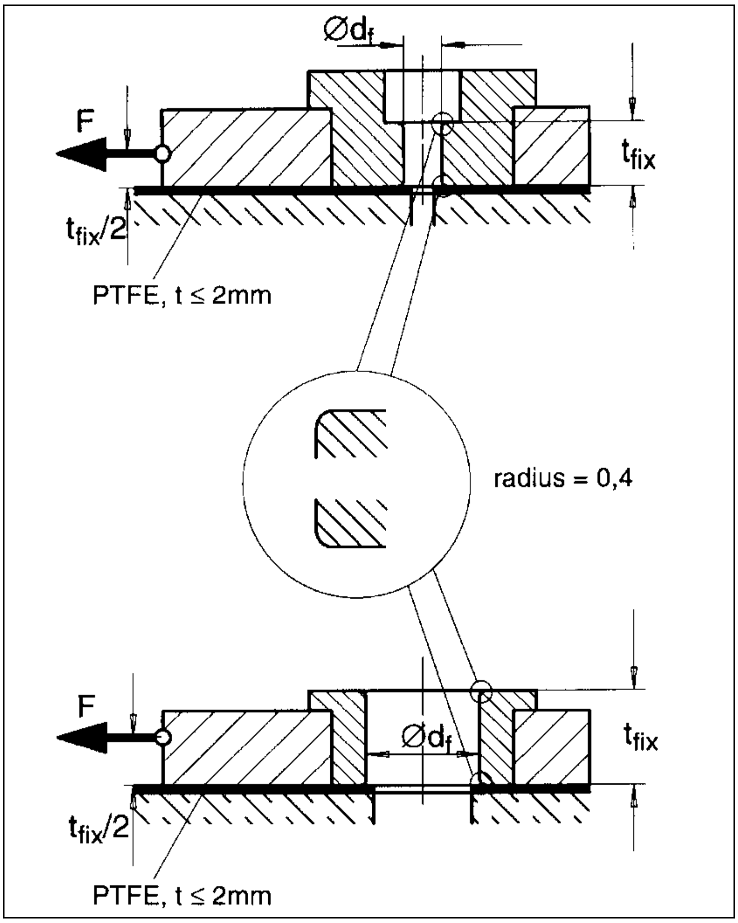
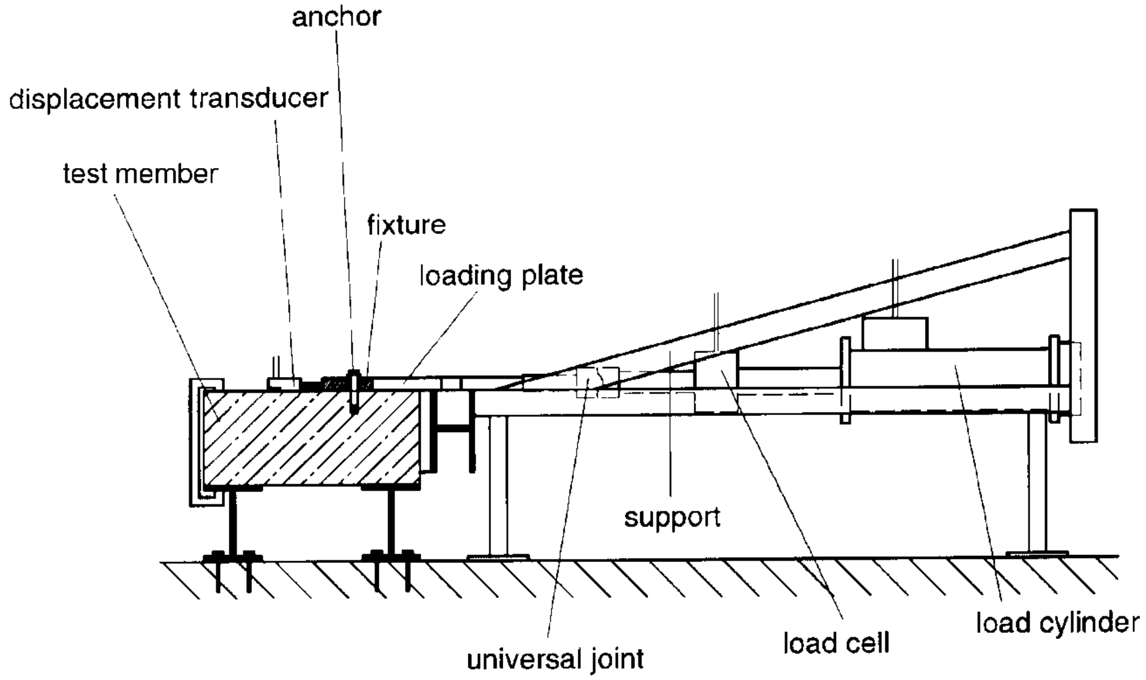


Figure D.3.1.6.1 Examples of shear test sleeves

Side view:



Top view:

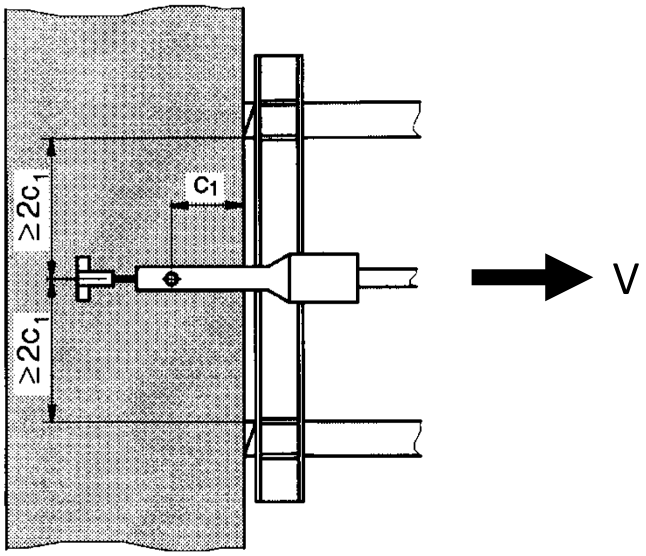


Figure D.3.1.6.2 Example of a shear test rig

In torque tests (see D.3.5) the relation between the applied installation torque and the tension force in the bolt is measured. For this, a calibrated load cell with a measuring error ≤ 3,0 % throughout the whole measuring range is used as a fixture (see Figure D.3.1.6.3).

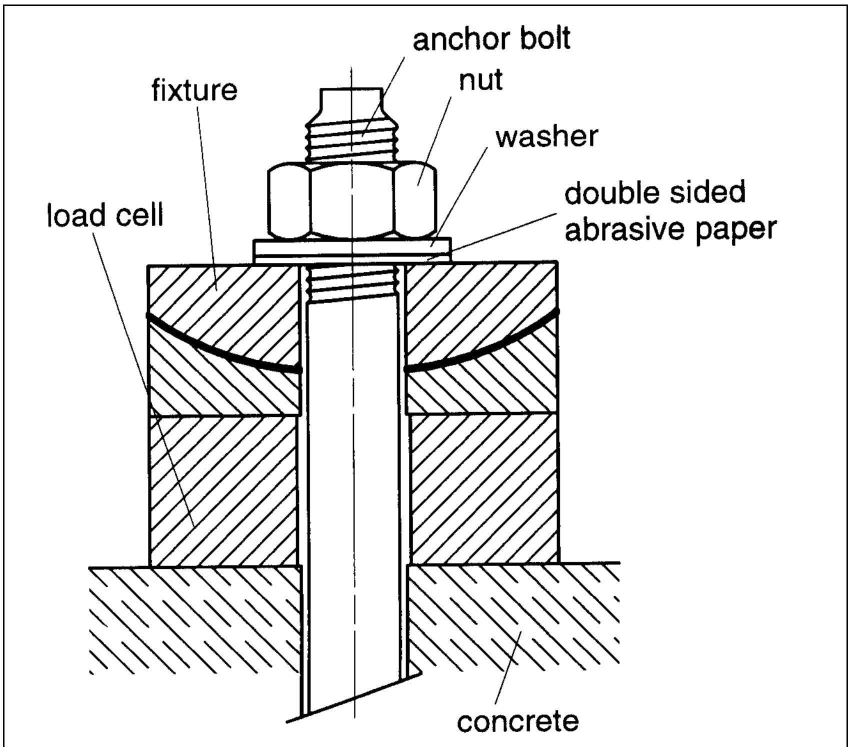


Figure D.3.1.6.3 Example for torque test (schematic)
Any rotation of the spherical part of the fixture shall be prevented.

D.3.2 Test procedure – general aspects

The fasteners shall be installed in accordance with the MPII, except where special conditions are specified in clause 2.2 for the test series.

The tests in cracked concrete are undertaken in unidirectional cracks. Δw is the difference between the crack width when loading the fastener and the crack width at fastener installation. After installation of the fastener the crack is widened to the required crack width while the fastener is unloaded. The initial crack width shall be set to within +10 % of the specified value.

Use one-sided tolerance for crack width.

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

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

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

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

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

D.3.3 Tension tests

D.3.3.1 Single fastener under tension load

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

When testing fasteners at the corner of a uncracked test member, the test rig shall be placed such that an unrestricted concrete failure towards the corner is possible (see Figure D.3.3.1.1). It may be necessary to support the test rig outside the test member.

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

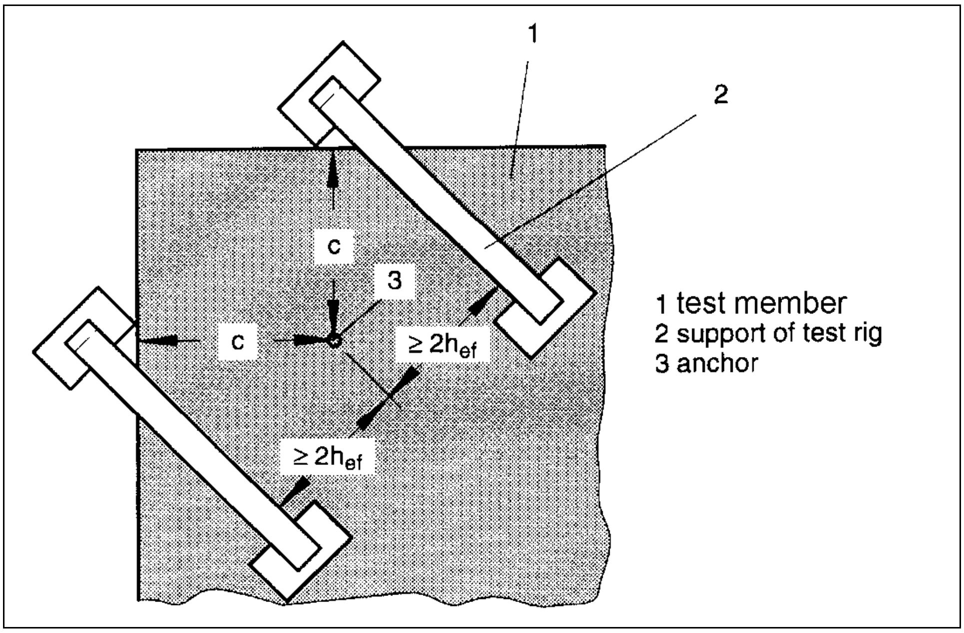


Figure D.3.3.1.1 Example of the test rig for tension tests on fasteners at a corner

D.3.3.2 Crack cycling under load

After installation of the fastener the maximum ($F = N_{s,max}$) and minimum ($F = N_{s,min}$) forces applied to the test member (see Figure D.3.1.2.6.3) shall be determined such that the crack width under $N_{s,max}$ is Δw_1 = 0,3 mm and under $N_{s,min}$ is Δw_2 = 0,1 mm at start of the test. To stabilize crack formation, up to 10 load changes varying between $N_{s,max}$ and $N_{s,min}$ shall be applied. Then a tensile load N_p as specified in 2.2.2.5 is applied to the fastener after opening the crack to Δw_1 = 0,3 mm.

N_p shall remain constant during the test (variation ± 5 %). Then the crack is opened and closed 1000 times (frequency approximately 0,2 Hz).

During opening of the cracks, the upper crack width Δw_1 is kept constant with minimum 0,3 mm and the lower crack width Δw_2 must comply with limits in Table D.3.3.2.1. If the lower crack width exceeds the values of table xy, the test can be continued under the condition that upper crack width must be increased, in such case, the crack width difference (Δw1 - Δw2) according to Table D.3.3.2.1 must be kept.

Table D.3.3.2.1 Tolerances for crack width in crack cycling tests

Cycle	Lower crack width Δw_2 [mm]	Minimum crack cycling width $\Delta w_1 - \Delta w_2$ [mm]
20	0,10 - 0,14	0,16
50	0,10 - 0,16	0,14
100	0,10 - 0,17	0,13
200	0,10 - 0,18	0,12
500	0,10 - 0,19	0,11
750	0,10 - 0,20	0,10
1000	0,10 - 0,20	0,10

The load/displacement behaviour shall be measured up to the load N_p. Afterwards under N_p, the displacements of the anchor and the crack widths Δw_1 and Δw_2 shall be recorded either continuously or at least after 1, 2, 5, 10, 20, 50, 100, 200, 500, 750 and 1000 crack movements.

After completion of the crack movements the anchor shall be unloaded, the displacement measured and a tension test to failure performed with $\Delta w = 0,3$ mm.

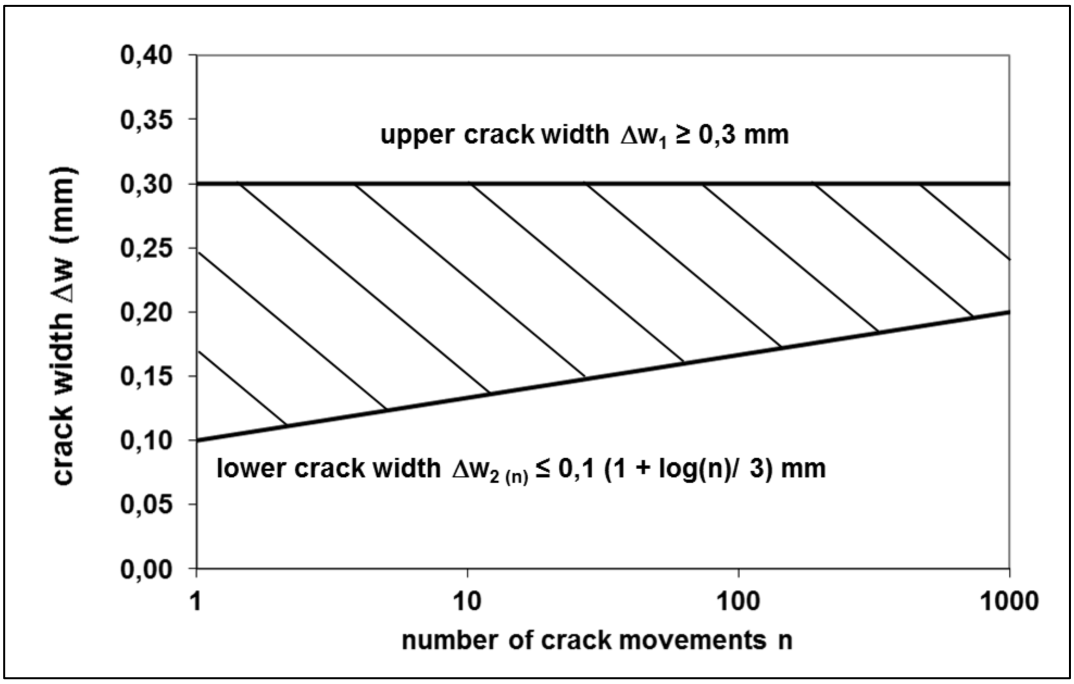


Figure D.3.3.2.1 Allowable crack opening variations during the crack cycling test

D.3.3.3 Repeated loads

The test is performed in uncracked concrete. The 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 maximum and minimum value, i.e., N_{max} and N_{min}, respectively, given in 2.2.2.4. The displacements shall be measured during the first loading up to max N and then either continuously or at least after 1, 10, 10^2, 10^3, 10^4 and 10^5 load cycles.

After completion of the load cycles the fastener shall be unloaded, the displacement measured and a tension test to failure performed using confined test setup.

D.3.3.4 Freeze/thaw condition test

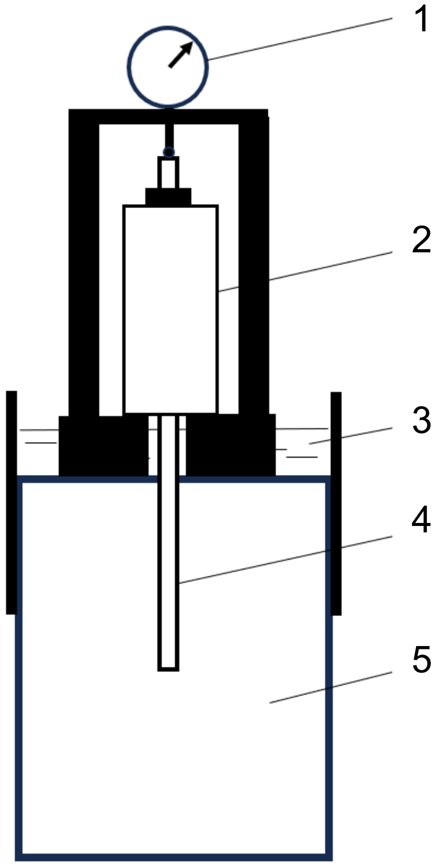
The anchors are installed into cylindrical specimens at normal ambient temperature. After the curing of the mortar the anchors are loaded up to the sustained loads (N_{sust}). The test members are placed into a calibrated climate chamber and the concrete surface was covered with tap water. Subsequently 50 freeze/thaw cycles are carried out as follows:

- Raise the temperature to 20°C within 1 hour and keep constant for 7 hours
- Lower the temperature to -20°C within 1 hour and keep constant for 14 hours.

The sustained load is actuated with pre-stressed soft disc springs.

A principle test set-up for the test series B16 according to Table A.1.1 for BF and test series E1 according to Table B.2.1 for BEF is shown in Figure D.3.3.4.1.

The displacement is measured by means of dial gauges and periodically noted in displacement protocols. After 50 cycles, the anchors are unloaded and a confined tension tests is performed in order to check the residual capacity.



1 Displacement measurement

2 Load application

3 Water

4 Fastener

5 Concrete cube or steel encased concrete cylinder

Figure D.3.3.4.1 Principle test set-up for freeze/thaw condition tests

D.3.4 Test for minimum edge distance and spacing

The tests shall be performed in uncracked concrete of strength class C20/25 (minimum concrete strength class according to Table A.1.1) or C12/15 (minimum concrete strength class according to Table A.1.1).

The tests are carried out with double fasteners with a spacing $s = s_{min}$ and an edge distance $c = c_{min}$. The double fasteners are placed with a distance $s > 3\ h_{ef}$ between neighbouring groups. The dimensions of the fixture shall be width = 3 d_f, length = s_{min} + 3 d_f and thickness ≅ d_f (d_f according to Table 2.2.7.1.1).

The fasteners shall be torqued alternately in steps of 0,2 T_{inst}. After each load step the concrete surface shall be inspected for cracks. The test is stopped when the installation torque cannot be increased further.

The number of revolutions per load step shall be measured for both fasteners. Furthermore, the torque moment at the formation of the first hairline crack at one or both fasteners and the maximum installation torque that can be applied to the two fasteners shall be recorded.

D.3.5 Maximum installation torque

The installation torque is applied with a calibrated torque wrench until it cannot be increased further or at least to 1,3 T_{inst}.

The tension force in the bolt or screw shall be measured as a function of the applied installation torque.

D.3.6 Tests under shear load

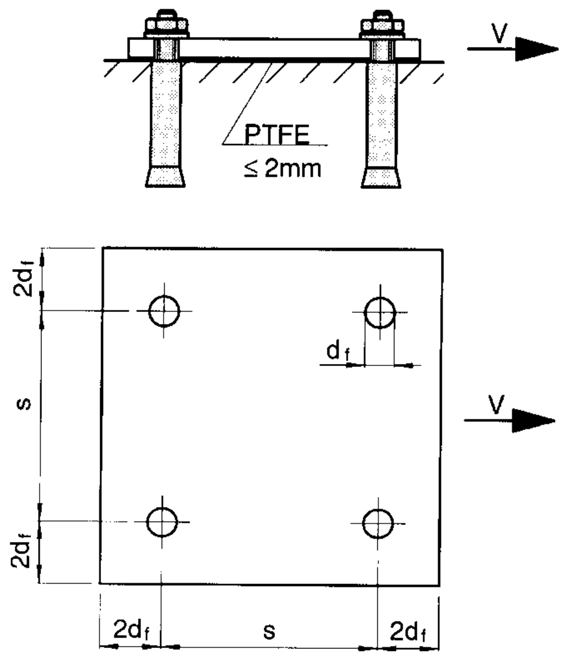
D.3.6.1 Single fastener

After installation, the fastener is connected to the test rig without gap between the fastener and the interchangeable sleeve in the loading plate and is then loaded to failure. The displacements of the fastener relative to the concrete shall be measured in the direction of the load application, e.g., by use of a displacement transducer fixed behind the fastener (seen from the direction of load application) on the concrete (see Figure D.3.1.6.2).

If the fastener is requested to be assessed for different embedment depths for a specific diameter, then the most unfavourable condition shall be tested. If the most unfavourable condition cannot be determined, then all embedment depths have to be tested.

D.3.6.2 Quadruple fastener group

After installation, the 4 fasteners shall be connected by a rigid fixture with the dimension given in Figure D.3.6.2.1.



d_f diameter of clearance hole in the fixture

s spacing of fasteners

V shear load

Figure D.3.6.2.1 Dimensions of fixture

Below the fixture, a sheet of PTFE (sliding layer) with a maximum thickness of 2 mm shall be placed. The test arrangement shall simulate a hinged connection so that the 4 fasteners are loaded equally. The shear force may be applied to the front or back side of the fixture.

The load on the fastener group and the shear mean displacement of the fixture relative to the concrete outside the rupture cone shall be measured.

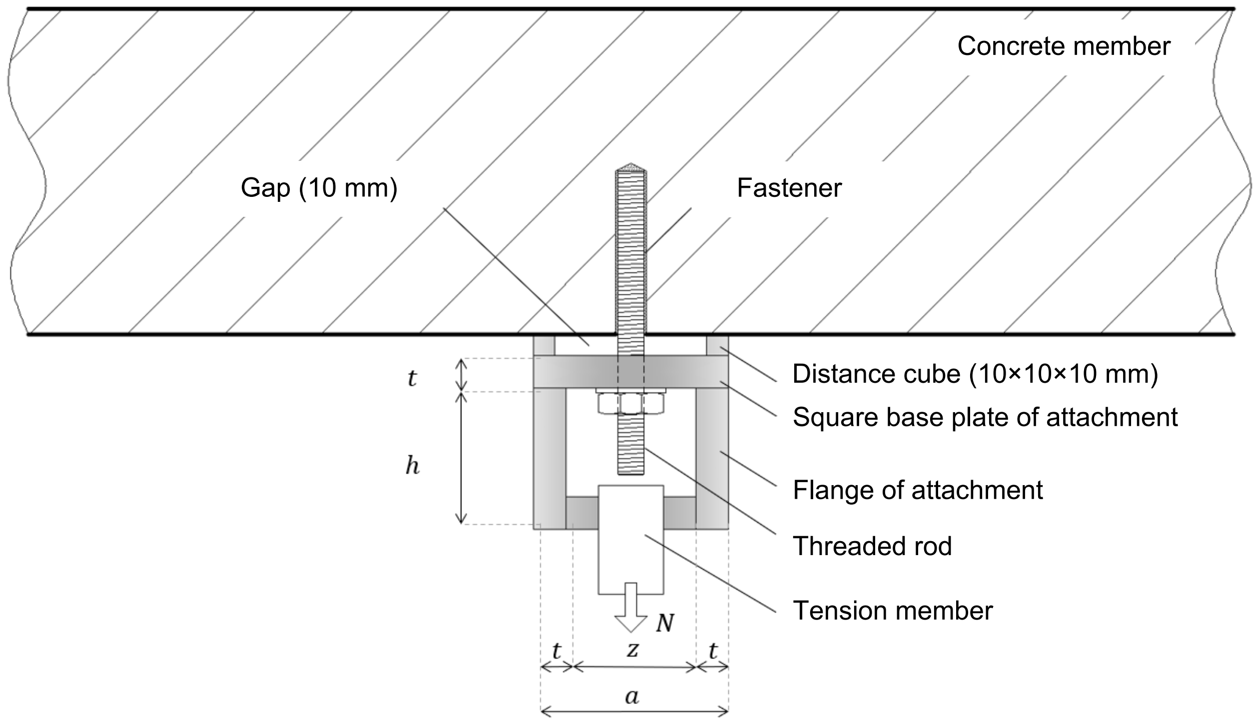
D.4 Tests for fire resistance

D.4.1 Fire resistance to steel failure under tension loading

Test set-up:

The tests for the determination of the carrying capacity under steel failure shall be carried out in uncracked concrete using an unloaded concrete member. The principal test set-up can be seen in Figure D.4.1.1. It is allowed to test more than one fastener in a test.

In order to ensure the "Standard Temperature/Time Curve" (STC) according to EN 1363-1 [30], the temperature shall be measured close (less than 150 mm distance) to the fastener. If more than one fastener are tested, the temperature shall be measured close to each fastener separately.



t: thickness of the square base plate / flange of attachment

h: height of the flange of attachment

z: clear width of the attachment

a: total width of attachment

N: applied constant load during the test

Figure D.4.1.1 Test setup for the determination of the steel failure under fire exposure

The dimensions of fixture have to be chosen depending on the load categories according to Table D.4.1.1.

For fasteners with an internal threaded sleeve:

Fastening screws of the minimum strength according to the specifications given in the ETA should be used. It is proven by experience that failure of nuts on threaded rods is decisive and should be used for the tests. If commercial standard screws or rods are allowed in the ETA, then they should not be delivered by the manufacturer.

Table D.4.1.1 Dimensions of the fixture during the test under fire exposure

Type of adapter	Load categories	Length of the square base plate	flange height/ width	profile thickness	distance between the flanges
	$N_{Rk,s,fi}$ [kN]	a [mm]	h/b [mm]	t [mm]	z [mm]
I	> 1 - ≤ 3	90	100 / 90	15	60
	> 3 - ≤ 5	90	100 / 90	15	60
II	> 5 - ≤ 7	110	120 / 110	20	70
	> 7 - ≤ 9	110	120 / 110	20	70
III	> 9 - ≤ 11	120	120 / 120	25	70
	> 11 - ≤ 13	120	120 / 120	25	70

Test procedure:

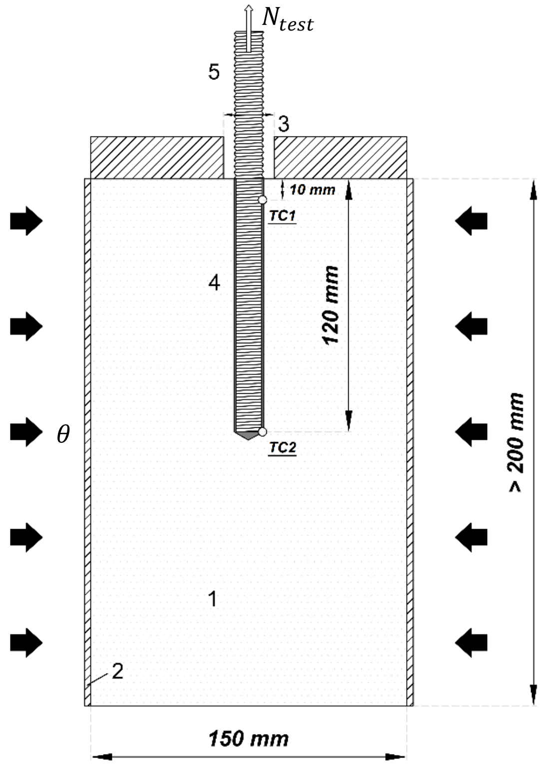
The fastener has to be loaded in tension during the test under fire exposure via the fixture which is defined in Table D.4.1.1. The fire tests have to be carried out according to EN 1363-1 [30] – tests in electric ovens are not permitted.

At least 5 tests each using the smallest size d_1 and the medium size d_2 (≤ 12 mm) of the fastener have to be carried out. The duration of fire resistance shallbe more than 60 min in at least 4 tests per fastener size.

For each test record the test load and the corresponding duration to failure.

D.4.2 Fire resistance to bond failure under tension loading

The test set-up is shown in Figure D.4.2.1 in principle. Further details are given in 2.2.18.



Designation:

1	Concrete
2	Steel jacket, thickness ≥ 3 mm
3	Confinement $1{,}5d_0$ to $2d_0$
4	Bond surface
5	Steel insert
θ	Thermal loading
N_{test}	Constant load during the test
TC1	Thermocouple 1 in the mortar layer
TC2	Thermocouple 2 in the mortar layer

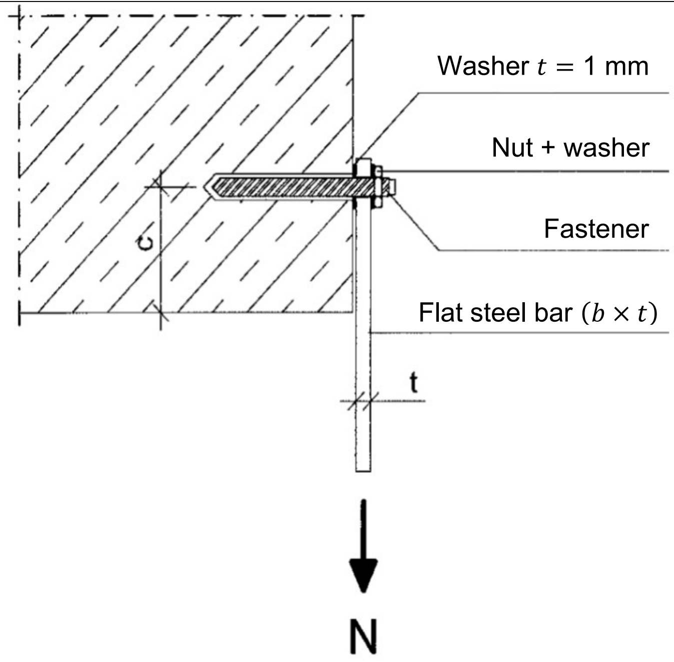
Figure D.4.2.1 Test member during thermal and mechanical loading

D.4.3 Tests for steel failure under shear load

The test set-up can be seen in principle in Figure D.4.3.1.

The test procedure shall be done according to clause D.4.1. The shear load shall be applied via flat-bar steel, which is adequate for a steel stress of 2 to 4 N/mm^2.

For each test record the test load and the corresponding duration to failure.



<u>Designations:</u>

$c =$ edge distance

$t =$ thickness of the flat-bar steel
10 mm $\leq t \leq$ 20 mm

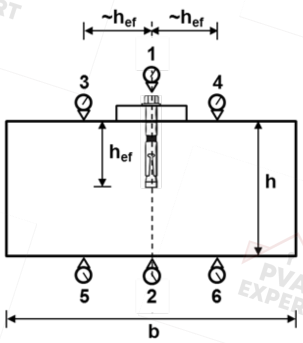
$b =$ width of the flat steel bar
$b = N/(t \times \sigma_{Rk,s,fi})$ with
2 N/mm² $\leq \sigma_{Rk,s,fi} \leq$ 4 N/mm²

Figure D.4.3.1 Test setup for the determination of the characteristic resistance under fire exposure to steel failure due to shear load

D.5 Test Report

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

1. Description test specimen		
Fastener type		Manufacturer, trade name, dimensions, material
status of specimen		serial product / prototype
production lot / batch		
Steel parts	Mechanical properties (tensile strength, yield limit, fracture elongation), type of coating,	e.g., (f_{uk} = 970 N/mm², R_{p02} = 890 N/mm², A_5 = 18%, galvanized 5 µm, functional coating)
Mortar	Designation, size of package, type of cartridge	xy injection mortar – fast curing version, side by side cartridge xxx ml
	Mass of components, density, viscosity, reactivity, infrared analysis	
	Type of dispenser and other tools, if any	e.g., Manual dispenser xy, piston plug size xx
2. Test member		
element type / drawing no.		sketch according to "examples cross section" and "example for test member with bond breaking pipes"
dimensions		(l / w / h)
concrete mix		e.g., cement, aggregate type and content, w/c-ratio
curing conditions		
age of concrete member at time of testing		
type and grade of reinforcement		
longitudinal reinforcement quantity.		
longitudinal reinforcement size		
type of bond breaker sheets		e.g., wood/ plastic/ metal/ none
reinforcement spacing		e.g., 254 mm horizontal, 50 mm from edges
distribution of reinforcement over depth of member		e.g., two rows, 100 mm from top and bottom
reinforcement is distributed double symmetrically		
3. Setting/ Installation information		
ratio member thickness / h_{nom}		e.g., 2,2
place of fastener installation		formwork side
type/ diameter of support		confined / unconfined d = 450 mm
spacing between rebar and fastener		200 mm
drilling in hairline crack		yes / no
drill hole prepared separately before each test		yes / no
Drilling method		
Type of drilling machine		
Type and cutting diameter of drill bit		
For stop drills: length of drill bit		
Tools for cleaning of drill holes (if relevant)		
borehole depth h_1 [mm]		

borehole cleaning procedure (if any)	
nominal / effective embedment depth h_{nom}/h_{ef}	
thickness of fixture (t_{fix}) [mm]	
clearance hole d_f [mm]	
installation torque T_{Inst} [Nm]	
position of the fastener over load transfer zone in the crack	sketch
verification method of fastener position in crack	e.g., borescope (sketch of crack formation over load transfer zone)
BF only	
type and diameter of cleaning brush	
setting tool/ dispenser	e.g., torque wrench / dispenser xy
curing time	
min / max temperature of concrete over curing time	
height of over-drilled borehole [mm]	e.g., no over-drilling
4. Test parameter	
crack opening mechanism	Describe how the crack width in the area of the load transfer zone is ensured
loading/ unloading rates [sec.]	e.g., 2,5 / 2,5
nominal sustained load	e.g., 10 kN
min. sustained load	10,1 kN
max. sustained load	10,9 kN
mean sustained load	10,3 kN
no. of replicates tested simultaneously	e.g., one
measuring of fastener displacement	e.g., continuously / at the fastener
no. of replicates tested in one specimen/ crack	e.g., 6 per specimen / 2 per crack
amount / type of crack width measurement	e.g., 4 / capacitive sensor
position of the crack width sensors	sketch with distances e.g.: 
determination of crack width at fastener	e.g., (linear interpolation)
Diagram containing: - crack width at the fastener position for the top and bottom of the load transfer zone - plot the cycles in normal logarithmic scale - plot the upper and the lower crack width	
measuring uncertainty for crack width transducers	e.g., ±0,005 mm.
minimal frequency during the test	

maximal frequency during the test	
5. Test results	
Load at failure	
Load at loss of adhesion	
Displacement at failure	
Displacement at 50 % of failure load	
Diagram with load displacement curve	
Failure mode (If initial failure is not clear, then a combination of failure modes may be reported.)	- See Annex A.2.1.1
Torque at failure (torque tests only)	
Diagram with displacement over time of testing (long term tests only)	

ANNEX E BF AND BEF IN CONCRETE UNDER SEISMIC ACTION

E.1 Scope

This Annex covers BF and BEF for use in concrete under seismic actions. The Annex deals with the preconditions, assumptions, required tests and assessment under seismic actions.

E.1.1 General

The tests in this Annex are intended to evaluate the performance of fasteners under simulated seismic tension and shear loading, including the effects of cracks, and under simulated seismic crack cycling conditions. The behaviour of fasteners in regions of reinforced concrete structures, where plastic steel strains are expected (e.g., in plastic hinge zones) is not covered in the requirements of this annex; fasteners shall be placed outside of these regions.

Note: The assessment of the fasteners for seismic performance categories C1 and C2 is based on the full assessment of the fastener for cracked concrete.

The compressive strength of concrete $f_{c,test}$ used in the various Equations in this document shall consistently represent the value measured with standard cylinders or standard cubes, unless specifically required otherwise.

E.1.2 Categories

For the evaluation of the performance of fasteners subjected to seismic loading two seismic performance categories, i.e., C1 and C2, with C2 being more stringent than C1, are distinguished. The recommended use of the performance categories C1 and C2 as they relate to the design of fastenings in concrete is given in EN1992-4 [4].

Performance category C1 provides fastener capacities in terms of strength (forces), while performance category C2 provides fastener capacities in terms of both strength (forces) and displacements. In both cases, the effect of concrete cracking is taken into account. The maximum crack width considered in C1 is Δw = 0,5 mm and in C2 it is Δw = 0,8 mm, where Δw is additive to the hairline crack width in the concrete member after fastener installation but before fastener loading.

The assessment of fasteners for category C1 comprises tests under pulsating tension load (clause E.3.3.2) and tests under alternating shear load (clause E.3.3.3). The assessment of fasteners for category C2 includes reference tests up to failure (clause E.3.4.2), tests under pulsating tension load (clause E.3.4.3), tests under alternating shear load (clause E.3.4.4) as well as tests under crack cycling (clause E.3.4.5). In these tests forces and displacements are measured either continuously or at certain intervals. The assessment of fasteners for category C2 places higher demands on the performance of fasteners under seismic action as compared to category C1.

Based on the respective load histories and crack widths, which are different for the two categories C1 and C2, the performance for C1 contains values of tension and shear resistance of the fastener, while for C2 it contains values of tension and shear resistance as well as fastener displacement.

If the manufacturer does not apply for tests for category C1, then the results of tests of C2 may be assigned for C1.

E.2 Abbreviation and Notation

The specific terms for assessment under seismic action are listed in clause 1.3.

E.3 Test Methods

E.3.1 General testing requirements

As far as applicable the Annex D shall be followed for test members, test setup and details of tests. Modifications addressed here overrule conflicting provisions in the Annex D.

E.3.1.1 Test setup

The fastener shall be located in the crack over the entire effective load transfer zone, h_{ltz}, of the fastener (meaning, e.g., over the entire embedment depth for a BF, over 1,5 times the length of the interaction zone h_{iz} of a BEF, see Figure E.3.1.1.1). See also test set-up in D.3.1.2.6 and Figure D.3.1.2.6.4.

Note: One way to achieve this, at least for larger fastener diameters, is to drill the fastener hole at the desired position prior to initiating the cracking.

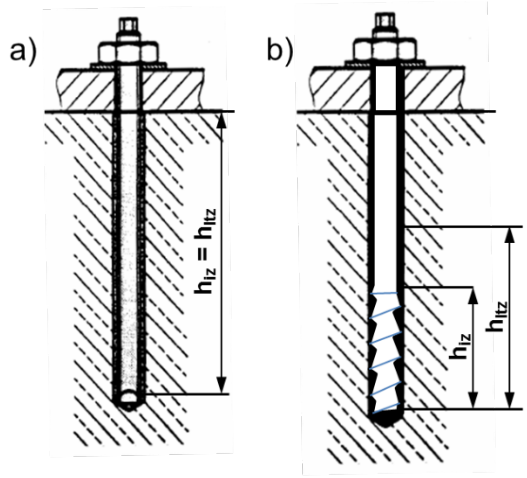
It shall be verified that the fastener is located in the crack over the length defined above, e.g., by use of a borescope.

All tension tests shall be performed as unconfined tests according to D.3.1.3 unless specified otherwise in the specific test clause below.

In shear tests uplift of the fixture (steel plate) shall be restrained such that no significant friction forces are induced. Such friction forces are avoided if for example a setup as shown in Figure E.3.1.1.2 is used, which prevents the uplift, limits friction by roller bearing and does not actively apply a compression force. Furthermore, the maximum allowed annular gap of the clearance hole (see Table 2.2.7.1.1) shall be selected in the shear tests. For fasteners with a specified smaller gap or without an annular gap, both of which have to be stated in the ETA, the specific fastener system may be tested in addition.

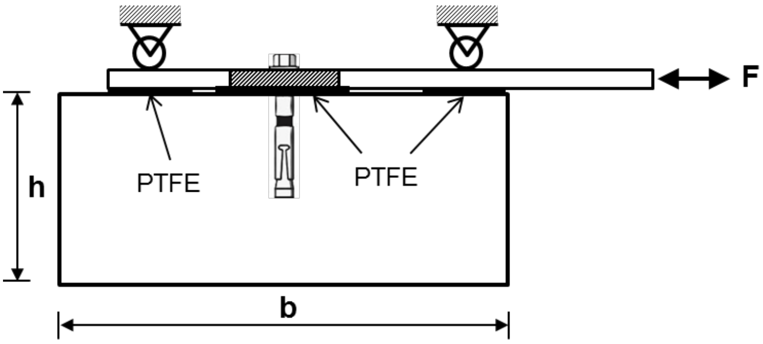
All tests with BF shall be performed at normal ambient temperature (21°C ± 3°C).

Note: The effect of high loading rates on the fastener behaviour is conservatively neglected.



a) bonded fastener (BF)
b) bonded expansion fastener (BEF)

Figure E.3.1.1.1 Effective load transfer zone



… roller bearing
PTFE … Teflon layer
F … shear force

Figure E.3.1.1.2 Sketch of example for shear test setup with no significant friction forces

E.3.1.2 Control of crack width

In the tests to failure (monotonic tests and residual capacity tests) the fastener is subjected to load while the crack width is controlled in accordance with clause D.3.1.2.6, either

a) at a constant width taking into account the requirements given in clause D.3.1.2.6, for example, by means of a servo system, or
b) limited to a width close to the specified value by means of the reinforcement and test member dimensions (see D.3.1.2.6).

E.3.2 Fastener types to be tested

In general, the tests described in E.3.3 and E.3.4 shall be performed with all fastener diameters, embedment depths, steel types (galvanised steel, stainless steel, high corrosion resistant steel) and grades (strength classes and lowest rupture elongation), production methods, types of steel elements (threaded rod, threaded sleeve or rebar for BF), different mortar versions of BF as well as drilling methods to be assessed for use in seismic applications. The number of variants to be tested may be reduced as described below. It shall be allowed to perform additional tests beyond the minimum number of tests described below to verify fastener characteristics for additional parameters (e.g., tests at different embedment depths).

If certain reference tension tests, which are required in the context of this assessment, have not been performed in the non-seismic part of the assessment, then these tests shall be performed. Equally, it shall be permitted that the corresponding resistance under ultimate load is calculated from the data obtained in the non-seismic assessment for cracked concrete.

E.3.2.1 Bonded fasteners

E.3.2.1.1 Type of steel element

E.3.2.1.1.1 Tension tests:

If the bond strength is equal for BF with different types of steel elements (threaded rod, rebar, internal threaded sleeve etc.) tests can be performed with the most adverse type of steel element and the results shall be applied to all other types of steel elements. If the bond strength is different, then all types of steel elements shall be tested.

E.3.2.1.1.2 Shear tests:

For fasteners under category C1 shear tests (test series C1.2) need to be performed for the smallest, medium and largest diameters only. For intermediate sizes the smaller performance $\alpha_{V,C1}$ (see Equation (E.4.1.2.1) of the neighbouring tested sizes shall be used.

E.3.2.1.2 Steel type, steel grade and production method

E.3.2.1.2.1 Tension tests

For BF only one steel type needs to be tested. The steel type with the highest strength shall be selected.

E.3.2.1.2.2 Shear tests

If the manufacturer applies for more than one steel grade, only fasteners of the highest steel grade according to EN ISO 898-1 [6] or EN ISO 3506-1 [15] need to be tested if the reduction of the characteristic steel shear resistance due to simulated seismic shear testing (see E.4.3.1.2 for category C1 and E.4.3.2.2 for category C2) is accepted for all steel types and steel grades. The rupture elongation (percentage of elongation after fracture, A, see EN ISO 898-1 [6] or EN ISO 3506-1 [15]) of the steel element, which is used in the test, shall be close to the nominal rupture elongation specified for the corresponding steel strength class.

Otherwise, all steel types and steel grades shall be tested.

E.3.2.1.3 Embedment depth

E.3.2.1.3.1 Tension tests:

a) Fasteners under category C1 (test series C1.1):
If multiple embedment depths are specified, then only the minimum and maximum embedment depths need to be tested.

b) Fasteners under category C2:
If multiple embedment depths are specified, then test series C2.1, C2.3 and C2.5 may only be performed with an embedment depth of h_{ef} = 7*d* as confined test in accordance with Annex D to ensure bond failure. In this case the reduction factors $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ according to Equation (E.4.2.7.1.1) and Equation (E.4.2.7.1.2), respectively, at this embedment depth shall be applied to all embedment depths and the displacements measured at this embedment depth shall be applied to all embedment depths. If for h_{ef} = 7*d* steel failure occurs, then the test shall be performed with a steel element having the same geometry but a higher steel strength than specified. In case steel failure does also occur in this situation the embedment depth shall be reduced such that bond failure is observed.

In addition, the steel behaviour under pulsating tension load shall be captured. The corresponding tests may be carried out in uncracked concrete. Perform test series C2.3 in uncracked concrete (i.e., Δw = 0,0 mm) with the highest steel strength for use in seismic applications and an embedment depth ensuring steel failure. Determine the mean failure load of the steel element $N_{s,C2.3}$ used for the definition of N_{max} and for the assessment of this C2.3 test series as given in Equation (E.3.2.1.3.1.1).

$$N_{s,C2.3} = A_s \cdot f_{u,C2.3} \qquad \text{(E.3.2.1.3.1.1)}$$

with

A_s = [mm²] - effective stressed cross-section area of steel element

$f_{u,C2.3}$ = [N/mm²] ultimate mean steel strength of fasteners used in the test series C2.3

An assessment of the displacements for this C2.3 test series may be omitted as the displacements in case of combined pull-out and concrete cone failure are considered decisive and are to be reported as the displacement behaviour of the fastener.

The resulting reduction factors $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ according to Equation (E.4.2.7.1.1) and Equation (E.4.2.7.1.2), respectively, for this steel strength shall be applied to all lower steel strengths. When calculating $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ it shall be assumed that the reduction factors associated with the test series C2.5, which is not required in this case, are set equal to 1,0, i.e., $\alpha_{C2.5}$ = 1,0 and $\beta_{cv,C2.5}$ = 1,0.

Testing to capture the steel failure for a given steel class may be omitted if it is demonstrated that the maximum force corresponding to the combined pull-out and concrete failure mode at maximum embedment depth is lower than 80 % of the force corresponding to yielding of the steel element.

E.3.2.1.3.2 Shear tests:

a) Fasteners under category C1 (test series C1.2):

If there is more than one embedment depth specified for a fastener diameter, then tests need to be performed for the minimum and maximum embedment depth only. If in the tests with minimum embedment depth steel failure occurs, then tests at the maximum embedment depth may be omitted if the reduction factor $\alpha_{V,C1}$ according to Equation (E.4.1.2.1) is applied to all embedment depths.

b) Fasteners under category C2 (test series C2.2, C2.4):
Only the minimum embedment depth needs to be tested if the reduction factor for seismic loading $\alpha_{V,C2}$ according to Equation (E.4.2.7.2.1) is accepted for all embedment depths. If at the minimum embedment depth pry-out failure is encountered, then select a larger embedment depth avoiding pry-out failure. The displacements measured in the tests with the minimum embedment depth shall be applied to fasteners with a larger embedment depth.

E.3.2.1.4 Drilling method

A reduction of number of drilling methods to be tested is only allowed for shear tests. In this case the hole shall be drilled with the most adverse drilling method, which in many cases will be diamond coring.

E.3.2.2 Bonded expansion fasteners

E.3.2.2.1 Steel type, steel grade and production method

E.3.2.2.1.1 Tension tests

If all of the following conditions are fulfilled, and the eventual reduction factor is accepted for all fastener types, then only fasteners of one steel type, the highest steel grade and one production method need to be tested. Otherwise, fasteners of all steel types, steel grades and production methods shall be tested. Meaning, if all following conditions are fulfilled for all steel types and steel grades but not for different production methods, fasteners of different production methods shall be tested.

a) The geometry of the fastener is identical.

b) The pre-stressing forces at torque T = 0,5 T_{inst} as well as at T = 1,0 T_{inst} are statistically equivalent for the different steel types, steel grades and production methods. The installation torque T_{inst} may be different for different steel types and grades.

c) Both the slip force as well as the bond force, as defined in Annex B, is statistically equivalent for the different steel types, steel grades and production methods. This condition shall be considered to be fulfilled if the fasteners are made out of the same material, any coatings are the same, and the surface roughness of the fastener in the load transfer zone is comparable. For fasteners made out of different materials (e.g., galvanized and corrosion resistant steel) this condition shall be considered to be fulfilled if the coating is identical, and the slip force depends mainly on the coating, and the surface roughness of the fastener in the load transfer zone is comparable.

The measured displacements shall be applied to the fasteners made from other steel types, steel grades or by other production methods.

E.3.2.2.1.2 Shear tests

See E.3.2.1.2.2.

E.3.2.2.2 Embedment depth

E.3.2.2.2.1 Tension tests

a) Fasteners under category C1 (test series C1.1):
If multiple embedment depths are specified, then in general, minimum and maximum embedment depths shall be tested. However, only the maximum embedment depth needs to be tested if the reduction factor for seismic loading $\alpha_{N,C1}$ according to Equation (E.4.1.1.1) is accepted for all embedment depths.

b) Fasteners under category C2 (test series C2.1, C2.3 and C2.5):
If multiple embedment depths are specified, then it is allowed to only perform tests at the maximum embedment depth. If only the maximum embedment depth is tested, then the reduction factors $\alpha_{N,C2}$ according to Equation (E.4.2.7.1.1) and $\beta_{cv,N,C2}$ according to Equation (E.4.2.7.1.2), respectively, for the maximum embedment depth shall be applied to fasteners with shallower embedment depths and the displacements measured for fasteners with the maximum embedment shall be applied to fasteners with shallower embedment depths.

E.3.2.2.2.2 Shear tests

c) Fasteners under category C1 (test series C1.2):
If there is more than one embedment depth specified for a fastener diameter, then tests need to be performed for the minimum and maximum embedment depth only. If in the tests with minimum embedment depth steel failure occurs, then tests at the maximum embedment depth may be omitted if the reduction factor $\alpha_{V,C1}$ according to Equation (E.4.1.2.1) is applied to all embedment depths.

d) Fasteners under category C2 (test series C2.2, 2.4):
Only the minimum embedment depth needs to be tested if the reduction factor for seismic loading $\alpha_{V,C2}$ is accepted for all embedment depths. If at the minimum embedment depth pry-out failure is encountered, then select a larger embedment depth to avoid pry-out failure. The displacements measured in the tests with the minimum embedment depth shall be applied to fasteners with a larger embedment depth.

All fastener versions made of hot-dip galvanized steel (HDG) shall be tested under shear load.

If for a specified embedment depth deeper setting is allowed, then the embedment depth for the tests shall be selected such, that the most unfavourable position with regard to the shear plane is accounted for. For example, fasteners may consist of a smooth shaft and a threaded part. Depending on the thickness of the fixture the shear plane may pass through the smooth portion or the threaded part (see Figure E.3.2.2.2.2.1).

Note: For BEF a single embedment depth h_{ef} is frequently specified for each diameter (e.g., diameter 12 mm, h_{ef} = 70 mm). Different lengths of the fastener for the same diameter may account for different thicknesses of the fixture t_{fix}. It may therefore be allowed to set the fastener deeper than the specified value (as long as all other requirements such as for example h_{min} are met) for ease of use to avoid extensive projection of the fastener above the fixture. This may result in an unfavourable position with regards to shear loading.

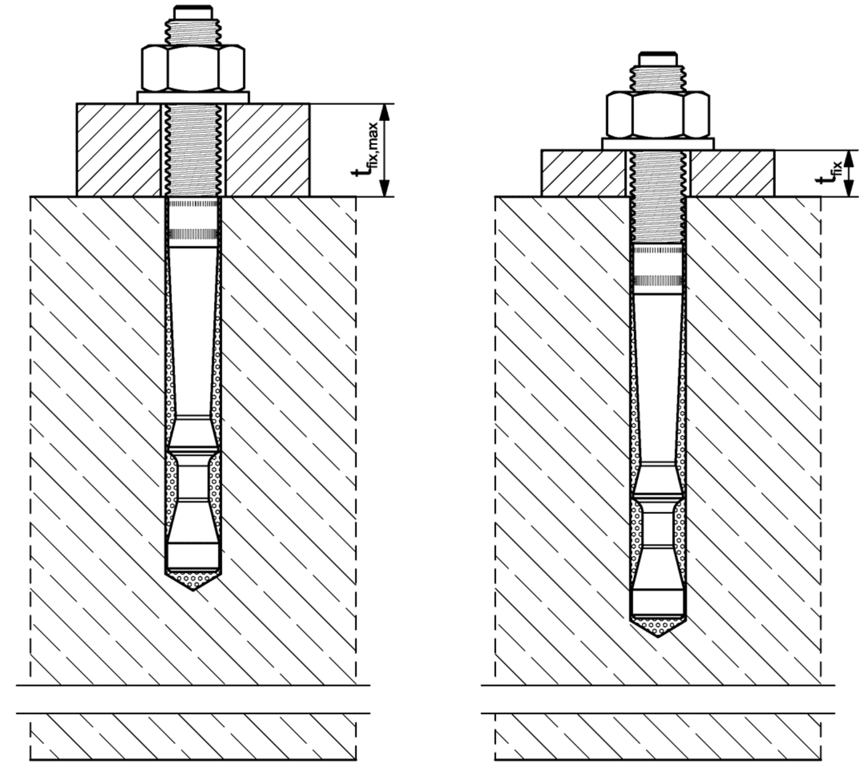


Figure E.3.2.2.2.2.1 Shear test with unfavourable position with regard to shear plane

E.3.2.2.3 Drilling method

See E.3.2.1.4.

E.3.3 Tests for category C1

E.3.3.1 Tests program

The additional tests for category C1 are shown in Table E.3.3.1.1.

Table E.3.3.1.1 Additional tests for fasteners under category C1

	Purpose of test	**Concrete**	**Crack width Δw 1) [mm]**	**Minimum number of tests 2)**	**Test procedure** see Clause	**Assessment criteria** see Clause
C1.1	Functioning under pulsating tension load 3)	C20/25	0,5	5	E.3.3.2	E.4.1.1
C1.2	Functioning under alternating shear load 4)	C20/25	0,5	5	E.3.3.3	E.4.1.2

1) Crack width added to the hairline crack width after fastener installation but before loading of fastener.
2) Test all fastener diameters to be assessed for use in seismic applications. For different fastener types to be tested see E.3.2.
3) For BF: for each type of steel element with the same mechanical properties the number of tested sizes can be reduced in accordance with Table A.1.2.
4) For BF: test smallest, medium and largest diameter

E.3.3.2 Tests under pulsating tension load (test series C1.1)

Purpose:

These tests are intended to evaluate the performance of fasteners under simulated seismic tension loading, including the effects of cracks, and without edge effects.

General test conditions for BEF:

The test shall be performed with an unconfined test setup according to Annex D.

General test conditions for BF:

The test shall be performed with a confined or an unconfined test setup according to Annex D. If a confined test setup is used and if multiple embedment depths are specified, then an embedment depth of h_{ef} = 7d is recommended for tests with the minimum embedment depth. If an unconfined test setup is used, then the minimum embedment depth shall be selected such that pull-out failure is ensured. Both test conditions are equivalent. In case of dispute, a confined test setup shall be used.

Note: In order to select the proper embedment dept h for pull-out failure for BF it shall be demonstrated that Equation (E.3.3.2.1) is fulfilled for the embedment depth h_{ef} used. If Equation (E.3.3.2.1) is not fulfilled with the chosen embedment depth, then the embedment depth shall be increased until Equation (E.3.3.2.1) is fulfilled, where steel failure is avoided. If Equation (E.3.3.2.1) cannot be fulfilled in unconfined tests, then confined tests shall be conducted (see above).

$$7 \cdot h_{ef,test}^{1,5} \cdot \sqrt{f_{c,C1.1}} \leq N_{u,m} \cdot \left(\frac{f_{c,C1.1}}{f_{c,3}}\right)^m \leq 10 \cdot h_{ef,test}^{1,5} \cdot \sqrt{f_{c,C1.1}} \qquad \text{(E.3.3.2.1)}$$

where

$N_{u,m}$ = [N] - mean failure load from basic tension tests for calculation of the "characteristic resistance for tension loading not influenced by edge and spacing effects" in cracked concrete C20/25 performed with an unconfined test set-up according to clause 2.2.2.2 (Table A.1.1, lines A1 to A4);

$h_{ef,test}$ = [mm] - effective embedment depth;

$f_{c,C1.1}$ = [N/mm^2] - mean compressive strength of concrete measured with cubes used for the test series C1.1 at the time of testing;

$f_{c,3}$ = [N/mm^2] - mean compressive strength of concrete measured with cubes used for the basic tension test series "characteristic resistance for tension loading not influenced by edge and spacing effects" in concrete C20/25 according to clause 2.2.2.2; at the time of testing;

m = normalization exponent.

In addition, tests with the maximum embedment depth are required.

For all types of fasteners, the pulsating tension load tests shall be executed as described in the following:

Open the crack by Δw = 0,5 mm. Subject the fasteners to sinusoidal tension loads with the levels and cycle counts specified in

Table E.3.3.2.1 and Figure E.3.3.2.1, where N_{C1} is given in Equation (E.3.3.2.2) in case of concrete or bond failure and in Equation (E.3.3.2.3) in case of steel failure, N_i is given in Equation (E.3.3.2.4), and N_m is given in Equation (E.3.3.2.5). The cycling frequency shall be between 0,1 and 2 Hz. The bottom of the tension load pulses may be taken to be slightly greater than zero to avoid servo control problems but shall not exceed N_{min}, with N_{min} being the maximum of 3% of N_{C1} and 200 N.

$$N_{C1} = 0{,}5 \cdot N_{Ru,m} \cdot \left(\frac{f_{c,C1.1}}{f_{c,3}}\right)^m$$ [N] (concrete, pull-out or bond failure) (E.3.3.2.2)

where

$N_{Ru,m}$ = [N] - BEF:
mean failure load from "basic tension tests" in cracked concrete C20/25 for the considered embedment depth;

[N] - BF with unconfined test setup in test series C1.1:
mean failure load from basic tension tests "characteristic resistance for tension loading not influenced by edge and spacing effects" according to *clause 2.2.2.2 (*Table A.1.1*, lines A1 to A4)* for the considered embedment depth

[N] - BF with confined test setup in test series C1.1:
mean failure load from reference tension tests "characteristic resistance for tension loading not influenced by edge and spacing effects" for the considered embedment depth;

$f_{c,C1.1}$ = [N/mm²] - mean compressive strength of concrete used for the test series C1.1 at the time of testing;

$f_{c,3}$ = [N/mm²] - mean compressive strength of concrete used for the "characteristic resistance for tension loading not influenced by edge and spacing effects" according to *clause 2.2.2.2 (*Table A.1.1*, lines A1 to A4)* or (as applicable) at the time of testing;

m = normalization exponent.

$$N_{C1} = 0{,}5 \cdot N_{Ru,m} \cdot \left(\frac{f_{u,C1.1}}{f_{u,3}}\right)$$ [N] (steel failure) (E.3.3.2.3)

where

$N_{Ru,m}$ = [N] - mean steel failure load from tests for "characteristic resistance for tension loading not influenced by edge and spacing effects".

$f_{u,C1.1}$ = [N/mm²] - ultimate mean steel strength of fasteners used for test series C1.1;

$f_{u,3}$ = [N/mm²] - ultimate mean steel strength of fasteners used for "characteristic resistance for tension loading not influenced by edge and spacing effects.

Adjustment for different steel strengths in Equation (E.3.3.2.3) is not required if the fasteners used in test series C1.1 and tests for "characteristic resistance for tension loading not influenced by edge and spacing effects" according to Table A.1.1 for BF and Table B.1 for BEF are taken from the same production lot.

If mixed failure modes occur in the tests for "characteristic resistance for tension loading not influenced by edge and spacing effects" according to Table A.1.1, then the load N_{C1} shall be determined assuming that the failure mode, which was observed in the majority of tests in the test series, occurred in all tests.

$$N_i = 0{,}75 \cdot N_{C1}$$ [N] (E.3.3.2.4)

$$N_m = 0{,}5 \cdot N_{C1}$$ [N] (E.3.3.2.5)

Table E.3.3.2.1 Required loading history for test series C1.1

Load level	N_{C1}	N_i	N_m
Number of cycles (n_{cyc})	10	30	100

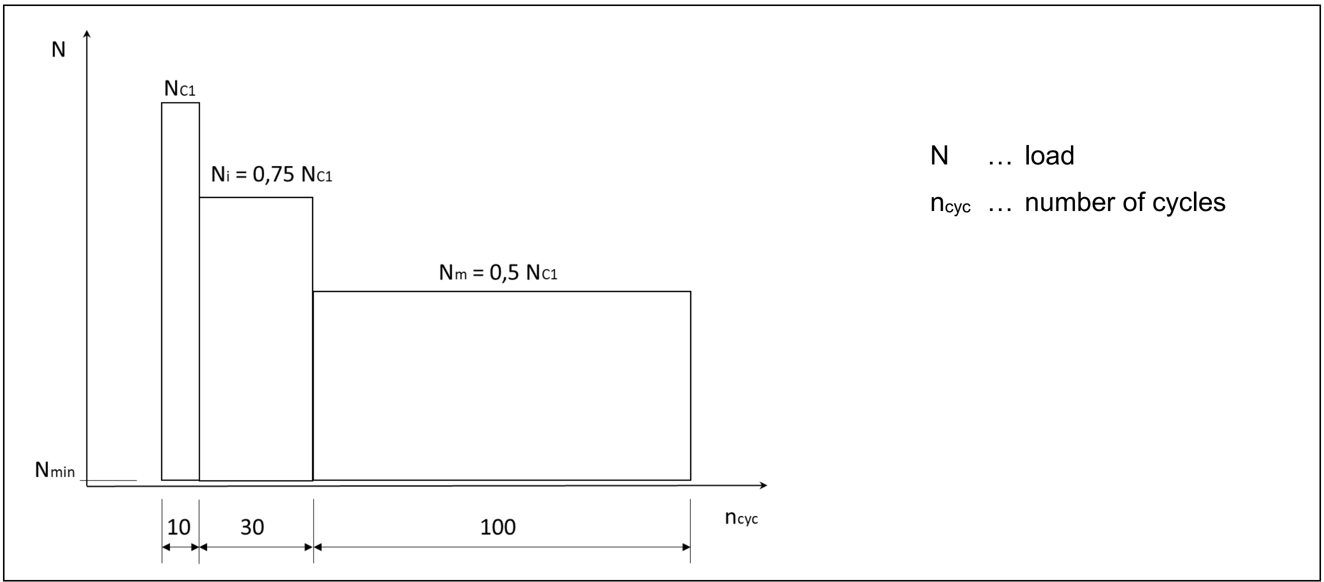


Figure E.3.3.2.1 Required loading history for test series C1.1

Record the crack width, fastener displacement and applied tension load. Following completion of the simulated seismic tension cycles, open the crack by Δw = 0,5 mm, but not less than the crack opening width as measured at the end of the cyclic test and load the fastener in tension to failure. Record the maximum tension load (residual tension capacity), the corresponding displacement, the crack width, and plot the load-displacement response.

The tests may be performed with a reduced load level ($N_{C1,red}$ instead of N_{C1}, N_i = 0,75 $N_{C1,red}$; N_m = 0,5 $N_{C1,red}$).

E.3.3.3 Tests under alternating shear load cycling (test series C1.2)

Purpose:

These tests are intended to evaluate the performance of fasteners under simulated seismic shear loading, including the effects of concrete cracking.

General test conditions:

The test shall be performed according to Annex D with the following modifications.

Open the crack by Δw = 0,5 mm. Subject the fasteners to sinusoidal shear loads in the direction of the crack with the levels and cycle counts specified in Table E.3.3.1.1 and Figure E.3.3.3.1, where V_{C1} is given in Equation (E.3.3.3.1), or Equation (E.3.3.3.2) as applicable, V_i is given in Equation (E.3.3.3.3) and V_m is given in Equation (E.3.3.3.4). The cycling frequency shall be between 0,1 and 2 Hz.

$$V_{C1} = 0{,}5 \cdot V_{Ru,m} \cdot \left(\frac{f_{u,C1.2}}{f_{u,5}}\right) \qquad [N] \qquad (E.3.3.3.1)$$

where

$V_{Ru,m}$ = [N] - mean shear capacity as determined in 2.2.7.

$f_{u,C1.2}$ = [N/mm^2] - mean ultimate tensile strength of steel elements used in test series C1.2;

$f_{u,5}$ = [N/mm^2] - mean ultimate tensile strength of steel elements used in tests for “characteristic resistance to steel failure under shear load” in uncracked concrete C20/25

Adjustment for different steel strengths in Equations (E.3.3.3.1) is not required if the fasteners tested in C1.2 and in in tests for “characteristic resistance to steel failure under shear load” in uncracked concrete C20/25, are taken from the same production lot.

If tests for “characteristic resistance to steel failure under shear load” have not been performed, then V_{C1} shall be permitted to be calculated in accordance with Equation (E.3.3.3.2).

$V_{C1} = 0{,}35 \cdot A_s \cdot f_{uk}$ [N] (E.3.3.3.2)

where

A_s = [mm²] - effective stressed cross section area of steel element in the shear plane;

f_{uk} = [N/mm²] - nominal characteristic steel ultimate tensile strength as specified in the technical specification of the manufacturer for the fastener;

$V_i = 0{,}75 \cdot V_{C1}$ [N] (E.3.3.3.3)

$V_m = 0{,}5 \cdot V_{C1}$ [N] (E.3.3.3.4)

Table E.3.3.3.1 Required loading history for test series C1.2

Load level	$\pm V_{C1}$	$\pm V_i$	$\pm V_m$
Number of cycles (n_{cyc})	10	30	100

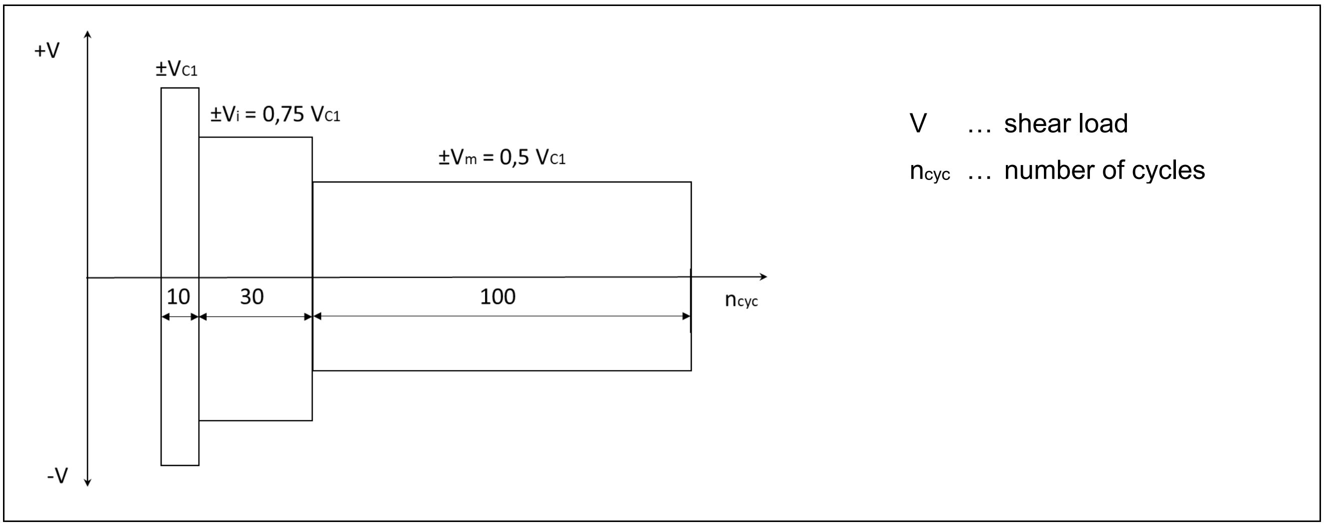


Figure E.3.3.3.1 Required load history for test series C1.2

To reduce the potential for uncontrolled slip during load reversal, the alternating shear loading (Figure E.3.3.3.2 a)) is permitted to be approximated by two half-sinusoidal load cycles at the required frequency connected by a reduced speed, ramped load as shown in Figure E.3.3.3.2 b), or by simply triangular loading cycles as shown in Figure E.3.3.3.2 c).

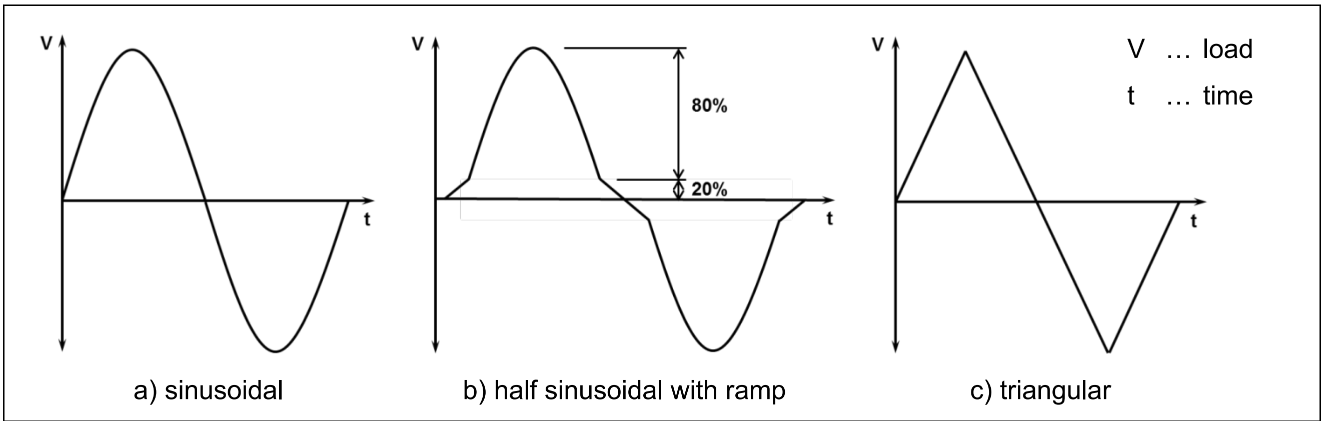


Figure E.3.3.3.2 Permitted seismic shear cycle C1.2

Record the crack width, fastener displacement and applied shear load. Plot the load-displacement history in the form of hysteresis loops.

Following completion of the simulated seismic shear cycles, open the crack by Δw = 0,5 mm, but not less than the crack opening width as measured at the end of the cyclic shear test and load the fastener in shear to failure. Record the maximum shear load (residual shear capacity), the corresponding displacement, the crack width, and plot the load-displacement response.

The tests may be performed with a reduced load level ($V_{C1,red}$ instead of V_{C1}, V_i = 0,75 $V_{C1,red}$; V_m = 0,5 $V_{C1,red}$).

E.3.4 Tests for category C2

E.3.4.1 Test program

The required additional tests for fasteners of category C2 are given in Table E.3.4.1.1.

Table E.3.4.1.1 Additional tests for fasteners under category C2

Test no.	Purpose of test	Concrete	Crack width Δw [1) [mm]	Minimum number of tests [2)	Test procedure see Clause	Assessment criteria see Clause
C2.1a	Reference tension tests in low strength concrete	C20/25	0,8	5	E.3.4.2	E.4.2.1 E.4.2.2
C2.1b	Reference tension tests in high strength concrete	C50/60	0,8	5	E.3.4.2	E.4.2.1 E.4.2.2
C2.2 [3)	Reference shear tests	C20/25	0,8	5	E.3.4.2	E.4.2.1 E.4.2.3
C2.3	Functioning under pulsating tension load	C20/25	see Figure E.3.4.3.1 [4)	5	E.3.4.3	E.4.2.1 E.4.2.4
C2.4	Functioning under alternating shear load	C20/25	0,8	5	E.3.4.4	E.4.2.1 E.4.2.5
C2.5	Functioning with tension load under varying crack width	C20/25	See Figure E.3.4.5.1 [5)	5	E.3.4.5	E.4.2.1 E.4.2.6

1) Crack width Δw added to the width of hairline crack after fastener installation but before loading of fastener.
2) Test all fastener diameters for which the fastener is to be assessed for use in seismic applications. For fasteners with different steel types, steel grades, production methods, types of steel elements (BF), multiple embedment depths and drilling methods see E.3.2.
3) See E.3.4.2
4) The tests may also be conducted in Δw = 0,8 mm at all load levels (N/N_{max}).
5) Δw_1 = 0,0 mm is defined in E.3.4.5.

Test series C2.1, C2.3 and C2.5 shall be performed with the same embedment depths and test set-up (confinement conditions). This requirement is also valid for test series C2.2 and C2.4.

Test series C2.1, C2.3 and C2.5:

BF shall be tested with a confined test setup in accordance with D.3.1.4 with an embedment depth and steel strength as defined in E.3.2.1.1. BEF shall be tested with an unconfined test setup.

All tests shall be performed with fasteners with a steel strength not smaller than the nominal characteristic steel ultimate tensile strength f_{uk}.

E.3.4.2 Reference tension and shear tests (test series C2.1 and C2.2)

The tension test series C2.1 and shear test series C2.2 shall be with a crack width as specified in Table E.3.4.1.1.

The test series C2.2 may be omitted if the results of the basic shear tests "characteristic under shear load (V1)" in uncracked concrete C20/25 (Δw = 0,0 mm) are accepted as $V_{u,m,C2.2}$. In this case the steel properties of the samples in the tests for "characteristic resistance to steel failure under shear load" in uncracked concrete C20/25, have to be used for the normalization in the context of the C2.4 test series.

If in the test series C2.2 failure is caused by pull-out of the fastener, then the test may be repeated with a larger embedment depth avoiding these failure modes (compare E.4.2.3).

E.3.4.3 Tests under pulsating tension load (test series C2.3)

The tests shall be performed according to D.3.1.2.6 with the following modifications:

Open the crack by Δw = 0,5 mm (see exception in Footnote 4 of Table E.3.4.1.1). Subject the fastener to the sinusoidal tension loads specified in Table E.3.4.3.1 and Figure E.3.4.3.1 with a cycling frequency no greater than 0,5 Hz, where N_{max} is given by Equation (E.3.4.3.1) to Equation (E.3.4.3.3). Triangular loading cycles may be used in place of sinusoidal cycles. The bottom of the tension load pulses may be taken to be slightly greater than zero to avoid servo control problems but shall not exceed N_{min}, with N_{min} being the maximum of 2% of N_{max} and 200 N. Crack width shall be controlled during load cycling. The crack shall be opened to Δw = 0,8 mm after the load cycles at 0,5 N/N_{max} have been completed.

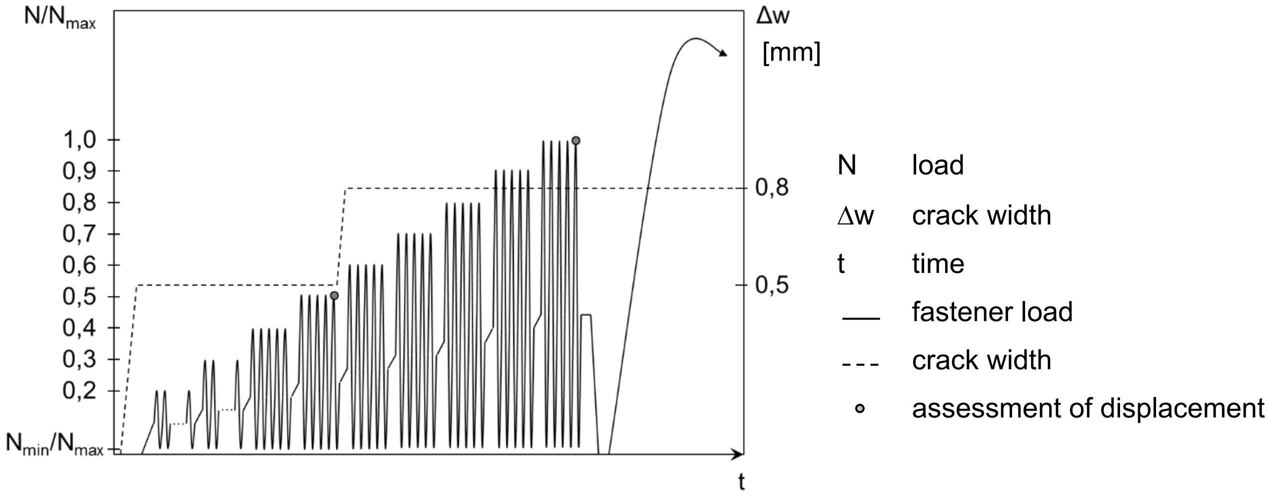


Figure E.3.4.3.1 Schematic test procedure C2.3

Table E.3.4.3.1 Required load amplitudes for test series C2.3

N/N_{max}	Number of cycles	Crack width Δw [mm]
0,2	25	0,5
0,3	15	0,5
0,4	5	0,5
0,5	5	0,5
0,6	5	0,8
0,7	5	0,8
0,8	5	0,8
0,9	5	0,8
1	5	0,8
SUM	75	

Depending on the failure mode observed in test C2.1a, N_{max} is determined as follows:

Steel failure

$$N_{max} = 0{,}75 \cdot N_{s,C2.3} \cdot \left(\frac{f_{u,C2.3}}{f_{u,C2.1a}}\right) \text{ [N]} \qquad \text{(E.3.4.3.1)}$$

Bond failure of BF

$$N_{max} = 0{,}75 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{c,C2.3}}{f_{c,C2.1a}}\right)^{m} \text{ [N]} \qquad \text{(E.3.4.3.2)}$$

All other failure modes

$$N_{\max} = 0{,}75 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{c,C2.3}}{f_{c,C2.1a}}\right)^{0,5} \text{ [N]} \qquad \text{(E.3.4.3.3)}$$

where

$N_{u,m,C2.1a}$ = [N] - mean failure load from the reference test series C2.1a ;

$N_{s,C2.3}$ = [N] – resistance to steel failure of fasteners used in test series C2.3;

$f_{u,C2.3}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.3;

$f_{u,C2.1a}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.1a

$f_{c,C2.3}$ = [N/mm²] - mean compressive strength of concrete at the time of testing of the test series C2.3;

$f_{c,C2.1a}$ = [N/mm²] - mean compressive strength of concrete at the time of testing of the test series C2.1a;

m = normalization factor to account for concrete strength according to clause A.2.1.2.

If mixed failure modes occur in test series C2.1a, then the largest value resulting from Equation (E.3.4.3.1) or (E.3.4.3.3) shall be applied.

Adjustment for different steel strengths in Equation (E.3.4.3.1) is not required if the fasteners tested in C2.1a and C2.3 are taken from the same production lot.

Record the crack width, fastener displacement and applied tension load continuously during the simulated seismic tension cycles. Report the displacements at minimum and maximum load and the crack width as a function of the number of load cycles.

Following completion of the simulated seismic tension cycles unload the fastener. During the unloading of the fastener the crack width may get smaller. For the residual capacity test open the crack to Δw = 0,8 mm, maintain crack width as obtained after unloading and load the fastener in tension to failure. Record the maximum tension load (residual tension capacity), the corresponding displacement, the crack width, and plot the load-displacement response.

The tests may be performed with a reduced load level ($N_{max,red,1}$ instead of N_{max}).

E.3.4.4 Tests under alternating shear load (test series C2.4)

The tests shall be performed according to D.3.1.2.6 with the following modifications:

Open the crack by Δw = 0,8 mm. Subject the fastener to the sinusoidal shear loads specified in Table E.3.4.4.1 and Figure E.3.4.4.1 with a cycling frequency no greater than 0,5 Hz, where V_{max} is given by Equation (E.3.4.4.1).

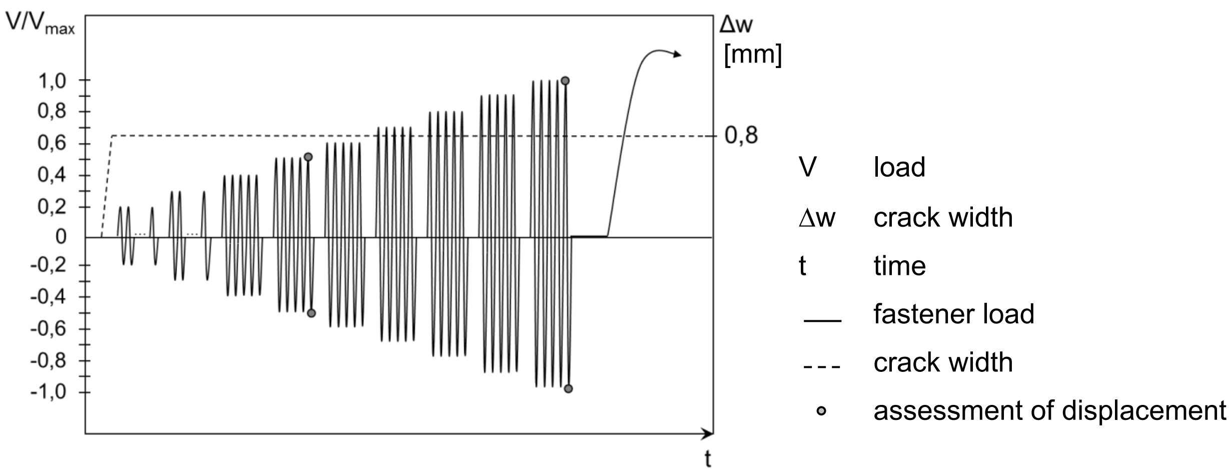


Figure E.3.4.4.1 Schematic test procedure C2.4

Table E.3.4.4.1 Required load amplitudes for test series C2.4

$\pm V/V_{max}$	Number of cycles	Crack width Δw [mm]
0,2	25	0,8
0,3	15	0,8
0,4	5	0,8
0,5	5	0,8
0,6	5	0,8
0,7	5	0,8
0,8	5	0,8
0,9	5	0,8
1	5	0,8
SUM	75	

$$V_{\max} = 0{,}85 \cdot V_{u,m,C2.2} \left(\frac{f_{u,C2.4}}{f_{u,C2.2}} \right) \quad [\mathrm{N}] \qquad \text{(E.3.4.4.1)}$$

where

$V_{u,m,C2.2}$ = [N] - mean shear capacity from the reference test series C2.2;

$f_{u,C2.4}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.4;

$f_{u,C2.2}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.2.

Adjustment for different steel strengths in Equations (E.3.4.4.1) is not required if the fasteners tested in C2.2 and C2.4 are taken from the same production lot.

The load shall be applied parallel to the direction of the crack. To reduce the potential for uncontrolled slip during load reversal, an approximation by two half-sinusoidal load cycles at the required frequency connected by a reduced speed, ramped load (see Figure E.3.4.4.2 b)) or simply triangular loading cycles (see Figure E.3.4.4.2 c)) may be used in place of sinusoidal cycles (see Figure E.3.4.4.2 a)). The crack width shall be controlled during load cycling.

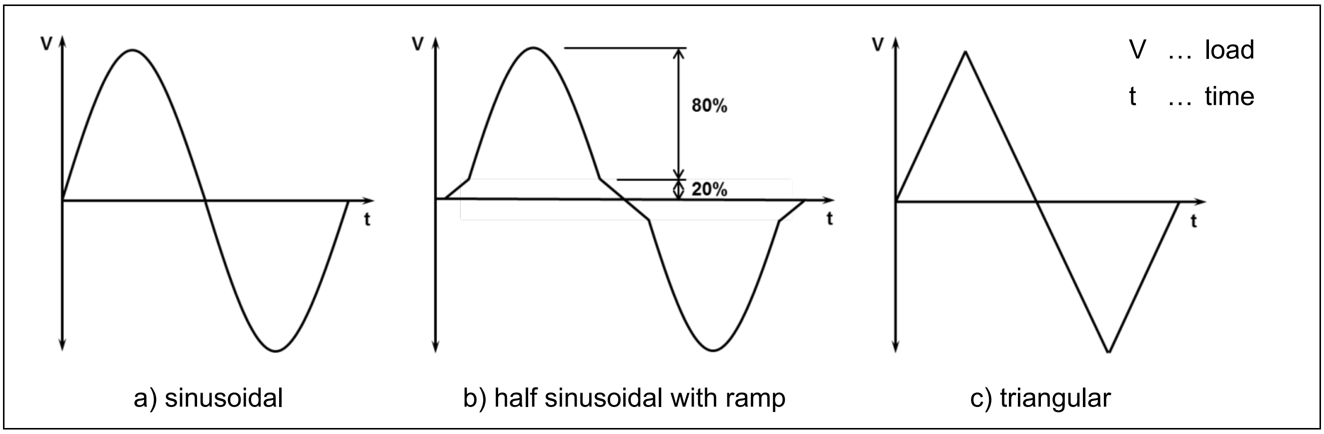


Figure E.3.4.4.2 Permitted seismic shear cycle C2.4

Record the crack width, fastener displacement and applied shear load continuously during the simulated seismic shear cycles. Report the displacements at minimum and maximum load and the crack width as a function of the number of load cycles.

Following completion of the simulated seismic shear cycles unload the fastener. During the unloading of the fastener the crack width may get smaller. For the residual capacity test open the crack to Δw = 0,8 mm, but not less than the crack opening width as measured at the end of the cyclic test, and load the fastener in shear to failure. Record the maximum shear load (residual shear capacity), the corresponding displacement, the crack width, and plot the load-displacement response.

The tests may be performed with a reduced load level ($V_{max,red,1}$ instead of V_{max}).

If in the test series C2.4 failure is caused by pull-out, then the test may be repeated with a larger embedment depth avoiding these failure modes (compare E.4.2.5).

Note: During the shear load cycling test failure may occur in the embedded portion of the fastener. If such a failure occurs close to the embedded end of the fastener, then the residual capacity may not be significantly affected. Hence, in this case failure of the fastener during cycling may easily be overlooked. Attention should be paid to this aspect.

E.3.4.5 Tests with tension load and varying crack width (test series C2.5)

The tests shall be performed according to D.3.3.2 and D.3.1.2.6 with the following modifications:

Tests shall be carried out on one fastener at a time with no other fasteners installed in the same crack.

Prior to installing fasteners in the test member, loading cycles as required to initiate cracking and to stabilise the relationship between crack width and applied load may be applied to the test member. This loading shall not exceed the elastic limit of the test member.

In order to create similar starting conditions when using a test member with one crack plane and a test member with multiple crack planes the initiated hairline crack may be closed by applying a centric compression force. Before installation of the fastener, it shall be ensured that the compression force is not larger than C_{ini} according to Equation (E.3.4.5.1).

$$C_{ini} = 0{,}01 \cdot f_{c,C2.5} \cdot A_g \quad [N] \qquad (E.3.4.5.1)$$

where

A_g = [mm²] - cross section area of the test member;
= $b \cdot h$, with b and h being the width and thickness of the test member, respectively;

$f_{c,C2.5}$ = [N/mm²] - mean compressive strength of concrete measured on cubes at the time of testing of the test series C2.5.

Install the fastener in the hairline crack according to D.3.1.5. When C_{ini} is applied for testing BF and BEF the following procedure may be applied: remove the compression force C_{ini}, install the fastener according D.3.1.2.6 and after curing again apply C_{ini} on the concrete test member.

Place crack measurement displacement transducers according to D.3.1.2.6 and zero the devices. Following application of load to the fastener sufficient to remove any slack in the loading mechanism, begin recording the fastener displacement and increase the tension load on the fastener to N_{w1} as given by Equation (E.3.4.5.3) to Equation (E.3.4.5.5). With the fastener load N_{w1} held constant, begin the crack cycling program specified in Table E.3.4.5.1 and Figure E.3.4.5.1 with a cycling frequency no greater than 0,5 Hz. The first crack movement is in the direction of crack closure by applying a compression load on the test member.

Note: The initial crack width w_{ini} after applying N_{w1} may exceed Δw = 0,1 mm. In this case the first crack movement in the direction of crack closure will close the crack and the crack cycling program is performed starting with Δw = 0,1 mm (see Figure E.3.4.5.1).

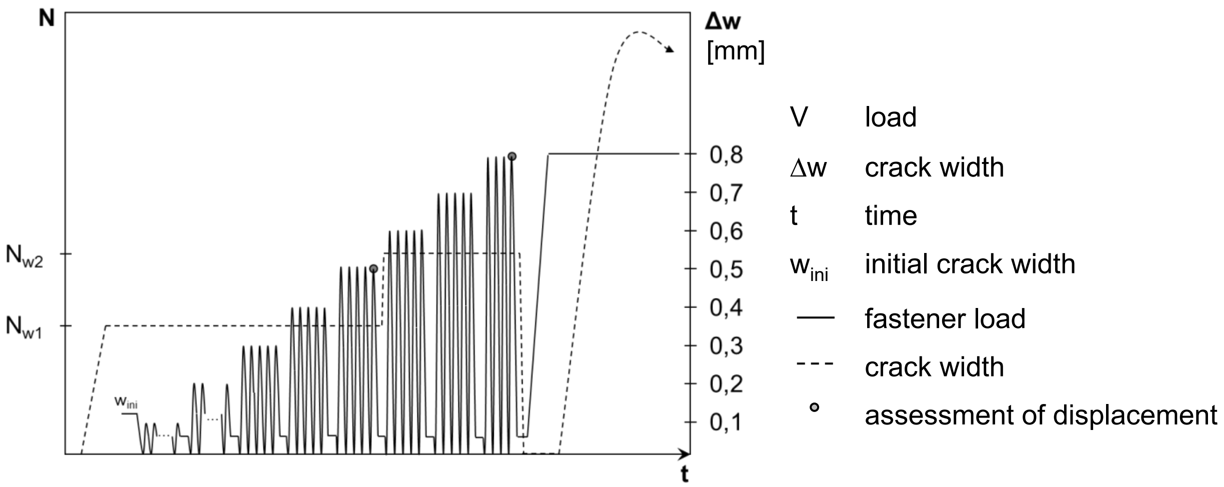


Figure E.3.4.5.1 Schematic test procedure C2.5

Table E.3.4.5.1 Required crack widths for test series C2.5

Fastener load	Number of cycles	Crack width Δw [mm]
N_{w1}	20	0,1
N_{w1}	10	0,2
N_{w1}	5	0,3
N_{w1}	5	0,4
N_{w1}	5	0,5
N_{w2}	5	0,6
N_{w2}	5	0,7
N_{w2}	4	0,8
	59	SUM

In each cycle the crack shall be closed by applying a centric compression force C_{test} according to Equation (E.3.4.5.2).

$$C_{test} = 0{,}1 \cdot f_{c,C2.5} \cdot A_g \quad \text{[N]} \tag{E.3.4.5.2}$$

where

A_g = [mm²] - cross section area of the test member;
 = $b \cdot h$, with b and h being the width and thickness of the test member, respectively;

$f_{c,C2.5}$ = [N/mm²] - mean compressive strength of concrete measured on cubes at the time of testing of the test series C2.5

If the crack is not closed to $\Delta w \leq 0{,}1$ mm when applying C_{test} according to Equation (E.3.4.5.2), then the compression force shall be increased until either $\Delta w \leq 0{,}1$ mm is achieved or the compression force reaches the maximum value of $C_{test,max} = 0{,}15 \cdot f_{c,C2.5} \cdot A_g$. This procedure fulfils the requirement of $\Delta w_1 = 0$ mm (see Table E.3.4.1.1).

Depending on the failure mode observed in the test series C2.1a, N_{w1} is determined as follows:

Steel Failure

$$N_{w1} = 0{,}4 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{u,C2.5}}{f_{u,C2.1a}} \right) \text{ [N]} \tag{E.3.4.5.3}$$

Bond Failure of BF

$$N_{w1} = 0{,}4 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{c,C2.5}}{f_{c,C2.1a}} \right)^{m} \text{ [N]} \tag{E.3.4.5.4}$$

All other failure modes

$$N_{w1} = 0{,}4 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{c,C2.5}}{f_{c,C2.1a}} \right)^{0{,}5} \text{ [N]} \tag{E.3.4.5.5}$$

where

$N_{u,m,C2.1a}$ = [N] - mean failure load from the test series C2.1a [N];

$f_{u,C2.5}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.5;

$f_{u,C2.1a}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.1a;

$f_{c,C2.5}$ = [N/mm²] - mean compressive strength of concrete used at the time of testing in the test series C2.5;

$f_{c,C2.1a}$ = [N/mm²] - mean compressive strength of concrete used at the time of testing in the test series C2.1a;

m = normalization factor to account for concrete strength.

If mixed failure modes occur in the test series C2.1a, then the largest value resulting from Equation (E.3.4.5.3) or (E.3.4.5.5) shall be applied.

After completion of the crack cycles at crack width Δw = 0,5 mm, increase the tension load on the fastener to N_{w2} as given by Equation (E.3.4.5.6) to Equation (E.3.4.5.8) and then continue the crack cycling sequence to completion.

Depending on the failure mode observed in the test series C2.1a, N_{w2} is determined as follows:

Steel Failure:

$$N_{w2} = 0{,}5 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{u,C2.5}}{f_{u,C2.1a}} \right) \text{ [N]} \quad \text{(E.3.4.5.6)}$$

Bond Failure of BF:

$$N_{w2} = 0{,}5 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{c,C2.5}}{f_{c,C2.1a}} \right)^{m} \text{ [N]} \quad \text{(E.3.4.5.7)}$$

All other failure modes:

$$N_{w2} = 0{,}5 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{c,C2.5}}{f_{c,C2.1a}} \right)^{0{,}5} \text{ [N]} \quad \text{(E.3.4.5.8)}$$

with $N_{u,m,C2.1a}$, $f_{u,C2.5}$, $f_{u,C2.1a}$, $f_{c,C2.5}$, $f_{c,C2.1a}$, and n as defined in Equation (E.3.4.5.3) to Equation (E.3.4.5.5).

If mixed failure modes occur in the test series C2.1a, then the largest value resulting from Equation (E.3.4.5.6) or (E.3.4.5.8) shall be applied.

Adjustment for different steel strengths in Equation (E.3.4.5.3) and Equation (E.3.4.5.6) is not required if the fasteners tested in C2.1 and C2.5 are taken from the same production lot.

Record the crack width, fastener displacement and applied tension load continuously during the simulated seismic crack cycles. Report the displacements at minimum and maximum crack width and the applied tension load as a function of the number of crack cycles.

Following completion of the simulated seismic crack cycles unload the fastener. During the unloading of the fastener the crack width may get smaller. For the residual capacity test open the crack to Δw = 0,8 mm, but not less than the crack opening width as measured at the end of the cyclic test, and load the fastener in tension to failure. Record the maximum tension load (residual tension capacity), the corresponding displacement, the crack width, and plot the load-displacement response.

The tests may be performed with a reduced load level ($N_{w2,red,1}$ instead of N_{w2}).

E.4 Assessment of test results

E.4.1 Assessment for category C1

E.4.1.1 Assessment of tests under pulsating tension load (test series C1.1)

All fasteners in a test series shall complete the simulated seismic tension load history specified in Table E.3.3.2.1 and Figure E.3.3.2.1. Failure of a fastener to develop the required resistance in any cycle prior to completing the load history specified in Table E.3.3.2.1 and Figure E.3.3.2.1 shall be recorded as an unsuccessful test. The mean-residual capacity of the fasteners in the test series shall be equal to or greater than 160 % of N_{C1} as given by Equation (E.3.3.2.2) or Equation (E.3.3.2.3), as applicable.

Successful completion of the cyclic loading history and fulfilment of the residual tension capacity requirement of this clause shall be reported. In this case the seismic reduction factor for tension loading according to Equation (E.4.1.1.1) is $\alpha_{N,C1}$ = 1,0.

If the fastener fails to fulfil one of the above requirements at N_{C1}, then it shall be permitted to conduct the test with reduced cyclic loads $N_{C1,red}$ until the requirements are met. The loading history specified in Table E.3.3.2.1 and Figure E.3.3.2.1 shall be applied, where $N_{C1,red}$, $N_{i,red}$ and $N_{m,red}$ are substituted for N_{C1}, N_i and N_m, respectively. All fasteners in a test series shall complete the simulated seismic tension load history. Failure of a fastener to develop the required tension resistance in any cycle prior to completing the loading history given in Table E.3.3.2.1 and Figure E.3.3.2.1 shall be recorded as an unsuccessful test. The mean residual capacity of the fasteners in the test series shall be at least 160 % of the reduced load $N_{C1,red}$. Successful completion of the cyclic loading history with reduced load values and fulfilment of the residual tension capacity requirement of this clause shall be recorded together with the type of failure mode caused by the reduced load values and the reduction factor $\alpha_{N,C1}$, which is calculated as given in Equation (E.4.1.1.1).

$$\alpha_{N,C1} = \frac{N_{C1,red}}{N_{C1}} \tag{E.4.1.1.1}$$

If the fastener successfully completes the cyclic loading history but does not fulfil the residual capacity requirement, then a linear reduction (in the extent of actual residual capacity divided by required residual capacity) may be applied in terms of $\alpha_{N,C1}$ without repeating the test series.

The reduction factor $\alpha_{N,C1}$ is then valid for fasteners with the tested embedment depth and all smaller embedment depths.

If fasteners with more than one embedment depth have been tested and different failures are observed in these tests, then different reduction factors for steel and pull-out (bond) failure may be obtained.

The reduction factor $\alpha_{N,C1}$ shall be used to determine the characteristic resistances under seismic loading according to E.4.3.1.

E.4.1.2 Assessment of tests under alternating shear load (test series C1.2)

All fasteners in a test series shall complete the simulated seismic shear load history specified in Table E.3.3.3.1 and Figure E.3.3.3.1. Failure of a fastener to develop the required resistance in any cycle prior to completing the loading history specified Table E.3.3.1.1 and Figure E.3.3.3.1 shall be recorded as an unsuccessful test. The mean residual capacity of the fasteners in the test series shall be at least 160 % of V_{C1} given by Equation (E.3.3.3.1), or Equation (E.3.3.3.2), as applicable.

Successful completion of the cyclic loading history and fulfilment of the residual shear capacity requirement of this clause shall be reported. In this case the seismic reduction factor for shear loading according to Equation (E.4.1.1.1) is $\alpha_{V,C1}$ = 1,0.

If the fastener fails to fulfil one of the above requirements at V_{C1}, then it shall be permitted to conduct the test with reduced cyclic loads $V_{C1,red}$ until the requirements are met. The loading history specified in Table E.3.3.3.1 and Figure E.3.3.3.1 shall be applied, where $V_{C1,red}$, $V_{i,red}$ and $V_{m,red}$ are substituted for V_{C1}, V_i and V_m, respectively. All fasteners in a test series shall complete the simulated seismic shear load history. Failure of a fastener to develop the required shear resistance in any cycle prior to completing the loading history given in Table E.3.3.3.1 and Figure E.3.3.3.1 shall be recorded as an unsuccessful test. The mean residual capacity of the fasteners in the test series shall be at least 160 % of the reduced load $V_{C1,red.}$ Successful completion of the cyclic history with reduced load values and fulfilment of the residual capacity requirement of this clause shall be recorded together with a corresponding reduction factor $\alpha_{V,C1}$, which is calculated as given in Equation (E.4.1.2.1).

$$\alpha_{V,C1} = \frac{V_{C1,red}}{V_{C1}} \tag{E.4.1.2.1}$$

If the fastener successfully completes the cyclic loading history but does not fulfil the residual capacity requirement, then a linear reduction (in the extent of actual residual capacity divided by required residual capacity) may be applied in terms of $\alpha_{V,C1}$ without repeating the test series.

The reduction factor $\alpha_{V,C1}$ shall not exceed the value $\alpha_{V,C1}$ = 0,7 for commercial standard rods or standard reinforcing bars which are not produced and subjected to factory production control by the manufacturer of the BF system.

The reduction factor $\alpha_{V,C1}$ shall be used to determine the characteristic resistance for seismic loading according to E.4.3.1.

The reduction factor $\alpha_{V,C1}$ according to Equation (E.4.1.2.1) is valid for all embedment depths greater than the tested embedment depth. If more than one embedment depth has been tested, then the reduction factor $\alpha_{V,C1}$ for an intermediate embedment depth may be determined by linear interpolation.

E.4.2 Assessment for category C2

E.4.2.1 General Requirements

E.4.2.1.1 Normalization of test results

The test results shall be normalised as follows:
Steel Failure

$$N_{u,m}(f_u) = N_{u,m,test} \cdot \left(\frac{f_u}{f_{u,test}}\right) \quad [N] \qquad (E.4.2.1.1.1)$$

$$V_{u,m}(f_u) = V_{u,m,test} \cdot \left(\frac{f_u}{f_{u,test}}\right) \quad [N] \qquad (E.4.2.1.1.2)$$

For fasteners with a sleeve in the shear plane the normalization shall be calculated as follows:

$$V_{u,m}(f_u) = V_{u,m,test} \cdot \left(\frac{f_u}{f_{u,test}} \cdot \frac{A_{s,bol}}{A_{s,fas}} + \frac{f_{u,sle}}{f_{u,sle,test}} \cdot \frac{A_{s,sle}}{A_{s,fas}}\right) [N] \qquad (E.4.2.1.1.3)$$

Bond Failure of BF

$$N_{u,m}(f_c) = N_{u,m,test} \cdot \left(\frac{\boldsymbol{f_c}}{\boldsymbol{f_{c,test}}}\right)^{\boldsymbol{m}} \qquad (E.4.2.1.1.4)$$

All other failure modes

$$N_{u,m}(f_c) = N_{u,m,test} \cdot \left(\frac{f_c}{f_{c,test}}\right)^{0.5} \quad [N] \qquad (E.4.2.1.1.5)$$

where

$A_{s,bol}$	=	[mm²] - effective cross section of bolt;
$A_{s,sle}$	=	[mm²] - effective cross section of sleeve;
$A_{s,fas}$	=	[mm²] - $A_{s,bol}$ + $A_{s,sle}$.
$N_{u,m}$	=	[N] - normalized mean failure load;
$N_{u,m,test}$	=	[N] - mean failure load from the test series;
$V_{u,m}$	=	[N] - normalized mean shear load;
$V_{u,m,test}$	=	[N] - mean shear load from the test series;
f_c	=	[N/mm²] - mean compressive strength of concrete to which the capacity is to be normalized;
$f_{c,test}$	=	[N/mm²] - mean compressive strength of concrete used at the time of testing;
f_u	=	[N/mm²] - mean ultimate steel strength of bolt, threaded rod or steel element to which the capacity is to be normalized;
$f_{u,sle}$	=	[N/mm²] - mean ultimate steel strength of the sleeve to which the capacity is to be normalized;
$f_{u,sle,test}$	=	[N/mm²] - ultimate steel strength of the sleeve of fasteners used in the tests ;
$f_{u,test}$	=	[N/mm²] - ultimate mean steel strength of bolt, threaded rod or steel element of fasteners used in the tests;
m	=	normalization factor to account for concrete strength according to clause A.2.1.2.

Adjustment for different steel strengths in Equation (E.4.2.1.1.1) to Equation (E.4.2.1.1.3) is not required if the fasteners in all tests are taken from the same production lot.

If mixed failure modes occur in the test series C2.1, C2.3 and C2.5, then the normalization shall be performed assuming that the failure mode, which was observed in the majority of tests in the test series, occurred in all tests.

E.4.2.1.2 Load/displacement behaviour

In the load/displacement curve for each fastener tested, a load plateau with a corresponding slip greater than 10 % of the displacement at ultimate load, or a temporary drop in load of more than 5 % of the ultimate load is not acceptable up to a load of 70 % of the ultimate load in the single test.

This requirement shall be fulfilled in the test series C2.1a and C2.1b, and in the initial loading as well as in the residual capacity tests of test series C2.3 and C2.5. If this requirement is not fulfilled, then the fastener is not suitable for use in category C2.

E.4.2.2 Assessment of reference tension tests (test series C2.1)

The following conditions apply:

1. Scatter of displacements:

$$cv\left(\delta\left(0{,}5 \cdot N_{u,m,C2.1}\right)\right) \le 40\% \qquad \text{(E.4.2.2.1)}$$

with

cv = [%] - coefficient of variation;

$\delta(0{,}5 \cdot N_{u,m,C2.1})$ = [mm] - displacement of the fastener at 50 % of mean ultimate load of test series C2.1a and b, i.e., $N_{u,m,C2.1a}$ and $N_{u,m,C2.1b}$, respectively .

If this condition is not fulfilled for one of the test series, then the fastener is not suitable for use in category C2. It is allowed to increase the number of tests to fulfil this requirement. Note that if in a test series displacements of all fasteners at the load 0,5 $N_{u,m}$ are smaller than or equal to 0,4 mm the above condition on the scatter of the displacement does not apply.

2. Ultimate load:

   a. Test series C2.1a in low strength concrete C20/25:

$$N_{u,m,C2.1a} \ge 0{,}8 \cdot N_{u,m,3} \qquad \text{(E.4.2.2.2)}$$

with

$N_{u,m,C2.1a}$ = [N] - mean ultimate tension load from test series C2.1a;

$N_{u,m,3}$ = [N] - mean failure load from the tests for “sensitivity to increased crack width (B10)” in concrete C20/25 according to 2.2.2.3.

If this condition is fulfilled, then $\alpha_{C2.1a}$ = 1,0. If the condition is not fulfilled, then the reduction factor $\alpha_{C2.1a}$ is determined for the test series C2.1a according to Equation (E.4.2.1.1.5).

$$\alpha_{C2.1a} = \frac{N_{u,m,C2.1a}}{0{,}8 \cdot N_{u,m,3}} \qquad \text{(E.4.2.2.3)}$$

In Equations (E.4.2.1.1.4) and (E.4.2.1.1.5) the resistances from the tests for suitability tests “sensitivity to increased crack width (B10)” in concrete C20/25 according to 2.2.2.3 shall be normalized according to Equation (E.4.2.1.1.1), Equation (E.4.2.1.1.4) or Equation (E.4.2.1.1.5), as applicable, to the strength in test series C2.1a.

   b. Test series C2.1b in high strength concrete C50/60:

$$N_{u,m,C2.1b} \ge 0{,}8 \cdot N_{u,m,4} \qquad \text{(E.4.2.2.4)}$$

with

$N_{u,m,C2.1b}$ = [N] - mean failure load from test series C2.1b;

$N_{u,m,4}$ = [N] - mean failure load from the tests for “maximum crack width and small hole diameter” in suitability tests “sensitivity to increased crack width (~~F7~~ B11)” in concrete C50/60 according to Table 2.2.7.1.1.

If this condition is fulfilled, then $\alpha_{C2.1b}$ = 1,0. If the condition is not fulfilled, then the reduction factor $\alpha_{C2.1b}$ is determined for the test series C2.1b according to Equation (E.4.2.2.5).

$$\alpha_{C2.1b} = \frac{N_{u,m,C2.1b}}{0{,}8 \cdot N_{u,m,4}} \qquad \text{(E.4.2.2.5)}$$

In Equations (E.4.2.2.1) and (E.4.2.2.2) the resistances from the tests suitability tests “sensitivity to increased crack width (B11)” in concrete C50/60 according to 2.2.2.3 shall be normalized according to Equation (E.4.2.1.1.1), Equation (E.4.2.1.1.4) or Equation (E.4.2.1.1.5), as applicable, to the strength in test series C2.1b.

The reduction factor $\alpha_{C2.1}$ is determined according to Equation (E.4.2.2.6).

$$\alpha_{C2.1} = \min\left(\alpha_{C2.1a};\alpha_{C2.1b}\right) \tag{E.4.2.2.6}$$

3. Scatter of ultimate loads:

$$cv\left(N_u\right) \leq 20\% \tag{E.4.2.2.7}$$

If this condition is fulfilled for both test series C2.1a and C2.1b, then $\beta_{cv,C2.1a} = \beta_{cv,C2.1b} = 1{,}0$. If this condition is not fulfilled in a test series, then the factors $\beta_{cv,C2.1a}$ or $\beta_{cv,C2.1b}$ shall be calculated according to Equation (E.4.2.2.8) and Equation (E.4.2.2.9), respectively.

$$\beta_{cv,C2.1a} = \frac{1}{1+\left(cv\left(N_{u,C2.1a}\right)-20\right)\cdot 0{,}03} \tag{E.4.2.2.8}$$

$$\beta_{cv,C2.1b} = \frac{1}{1+\left(cv\left(N_{u,C2.1b}\right)-20\right)\cdot 0{,}03} \tag{E.4.2.2.9}$$

where $cv(N_{u,C2.1a})$ and $cv(N_{u,C2.1b})$ are the coefficients of variation of the ultimate loads in test series C2.1a and C2.1b, respectively.

The factor $\beta_{cv,C2.1}$ is determined as given in Equation (E.4.2.2.10):

$$\beta_{cv,C2.1} = \min\left(\beta_{cv,C2.1a};\beta_{cv,C2.1b}\right) \tag{E.4.2.2.10}$$

If $cv(N_u)$ is larger than 30 % in one test series, then the fastener is not suitable for use in category C2. It shall be allowed to increase the number of tests in a test series to possibly fulfil this requirement.

E.4.2.3 Assessment of reference shear tests (test series C2.2)

If calculated values or results of tests for “characteristic resistance to steel failure under shear load” are taken as reference tests, then this clause does not apply. If test series C2.2 are performed for reference shear values, then the following conditions apply:

1. Failure mode:

   If failure is caused by pull-out, then the fastener is not suitable for use in category C2. The test may be repeated with a larger embedment depth avoiding pull-out failure.

2. Ultimate load:

$$V_{u,m,C2.2} \geq 0{,}8 \cdot V_{u,m,5} \tag{E.4.2.3.1}$$

with

$V_{u,m,C2.2}$ = [N] - mean ultimate shear load from test series C2.2;

$V_{u,m,5}$ = [N] - mean shear capacity from the tests for “characteristic resistance to steel failure under shear load".

If this condition is fulfilled, then $\alpha_{C2.2} = 1{,}0$. If this condition is not fulfilled, then the factor $\alpha_{C2.2}$ shall be determined according to Equation (E.4.2.3.2).

$$\alpha_{C2.2} = \frac{V_{u,m,C2.2}}{0{,}8 \cdot V_{u,m,5}} \tag{E.4.2.3.2}$$

In Equations (E.4.2.3.1) and (E.4.2.3.2) the resistances from the tests for “characteristic resistance to steel failure under shear load” shall be normalized according to Equation (E.4.2.1.1.2) or Equation (E.4.2.1.1.3), as applicable, to the strength in test series C2.2.

3. Scatter of ultimate loads:

$$cv\left(V_u\right) \leq 15\% \tag{E.4.2.3.3}$$

If this condition is fulfilled, then $\beta_{cv,C2.2}$ = 1,0. If this condition is not fulfilled, then the factor $\beta_{cv,C2.2}$ shall be determined according to Equation (E.4.2.3.4).

$$\beta_{cv,C2.2} = \frac{1}{1+(cv(V_u)-15)\cdot 0{,}03} \qquad \text{(E.4.2.3.4)}$$

where $cv(V_u)$ is the coefficient of variation of the ultimate loads in test series C2.2.

If $cv(V_u)$ is larger than 30 %, then the fastener is not suitable for use in category C2.

E.4.2.4 Assessment of tests under pulsating tension load (test series C2.3)

The following conditions apply:

1. All fasteners in a test series shall complete the pulsating tension load history specified in Figure E.3.4.3.1 and Table E.3.4.3.1. Failure of a fastener to develop the required resistance in any cycle prior to completing the loading history specified in Table E.3.4.3.1 shall be recorded as an unsuccessful test. In case of an unsuccessful test, the test series shall be repeated with a reduced value $N_{max,red,1}$ until the requirement is fulfilled. In this case the reduction factor $\alpha_{C2.3a}$ shall be calculated according to Equation (E.4.2.4.1).

$$\alpha_{C2.3a} = \frac{N_{max,red,1}}{N_{max}} \qquad \text{(E.4.2.4.1)}$$

with

N_{max} = [N] - maximum tension load according to Equation (E.3.4.3.1) to Equation (E.3.4.3.3).

$N_{max,red,1}$ = [N] - reduced tension load to fulfil the requirement.

2. Displacements are assessed during the last cycle at $0{,}5\cdot N/N_{max}$ and at $1{,}0\cdot N/N_{max}$ or at $0{,}5\cdot N/N_{max,red,1}$ and at $1{,}0\cdot N/N_{max,red,1}$, respectively, (refer to Figure E.3.4.3.1). Displacements shall be reported in terms of the mean value.

   To avoid excessive displacement of the fastener a displacement limit at the end of load cycling at $0{,}5\cdot N/N_{max}$ or $0{,}5\cdot N/N_{max,red,1}$ (i.e., after 50 load cycles (see Figure E.3.4.3.1 and Table E.3.4.3.1) is introduced for the assessment of fasteners. Due to lack of sufficient test data this limit is assumed as $\delta_{N,lim}$ = 7 mm. The following condition shall be fulfilled:

$$\delta_m(0{,}5\cdot N/N_{\max}) \le \delta_{N,\lim} \qquad \text{(E.4.2.4.2)}$$

with

$\delta_m(0{,}5\cdot N/N_{max})$ = [mm] - mean value of displacements of the fastener after load cycling at $0{,}5\cdot N/N_{max}$ or $0{,}5\cdot N/N_{max,red,1}$ of test series C2.3;

$\delta_{N,lim}$ = 7 mm.

If this condition is not fulfilled, then repeat the tests with a reduced value $N_{max,red,2}$ until the requirement is fulfilled and calculate the reduction factor $\alpha_{C2.3b}$ according to Equation (E.4.2.4.3).

$$\alpha_{C2.3b} = \frac{N_{max,red,2}}{N_{max}} \qquad \text{(E.4.2.4.3)}$$

with

N_{max} = [N] - maximum tension load according to Equation (E.3.4.3.1) to Equation (E.3.4.3.3);

$N_{max,red,2}$ = [N] - reduced tension load to fulfil the requirement.

If the condition according to Equation (E.4.2.4.2) is fulfilled but a smaller displacement is intended, then it shall be permitted to repeat the tests with a reduced value $N_{max,red,2}$.

3. Residual capacity tests (all three conditions apply):

   a. Scatter of displacement:

$$cv\left(\delta(0{,}5\cdot N_{u,m,C2.3})\right) \le 40\% \qquad \text{(E.4.2.4.4)}$$

with

$\delta(0{,}5 \cdot N_{u,m,C2.3})$ = [mm] - displacement of the fastener at 50 % of the mean ultimate tension load from the residual capacity tests of test series C2.3. Only the displacement in the residual capacity test is taken, i.e., the displacement that occurred during the cyclic loading is neglected.

$N_{u,m,C2.3}$ = [N] - mean ultimate tension load from residual capacity tests of test series C2.3.

If this condition is not fulfilled, then the fastener is not suitable for use in category C2.

b. Ultimate load:

$$N_{u,m,C2.3} \geq 0{,}9 \cdot N_{u,m,C2.1a} \quad \text{(E.4.2.4.5)}$$

with

$N_{u,m,C2.1a}$ = [N] - mean ultimate tension load from test series C2.1a;

$N_{u,m,C2.3}$ = [N] - mean ultimate tension load from residual capacity tests of test series C2.3.

If this condition is fulfilled, then $\alpha_{C2.3c}$ = 1,0. If this condition is not fulfilled, then the factor $\alpha_{C2.3c}$ shall be determined according to Equation (E.4.2.4.6) or the test series C2.3 shall be repeated with a reduced value of N_{max} until the condition given in Equation (E.4.2.4.5) is fulfilled. Both methods are equivalent. In case of dispute, the factor $\alpha_{C2.3c}$ shall be determined according to Equation (E.4.2.4.6).

$$\alpha_{C2.3c} = \frac{N_{u,m,C2.3}}{0{,}9 \cdot N_{u,m,C2.1a}} \quad \text{(E.4.2.4.6)}$$

In Equations (E.4.2.4.5) and (E.4.2.4.6) the resistances from test series C2.1a shall be normalized according to Equation (E.4.2.1.1.1), Equation (E.4.2.1.1.4) or Equation (E.4.2.1.1.5), as applicable, to the strength in test series C2.3.

c. Scatter of ultimate loads:

$$cv(N_u) \leq 20\% \quad \text{(E.4.2.4.7)}$$

If this condition is fulfilled, then $\beta_{cv,C2.3}$ = 1,0. If this condition is not fulfilled, then $\beta_{cv,C2.3}$ shall be determined according to Equation (E.4.2.4.8).

$$\beta_{cv,C2.3} = \frac{1}{1 + (cv(N_u) - 20) \cdot 0{,}03} \quad \text{(E.4.2.4.8)}$$

where $cv(N_u)$ is the coefficient of variation of the ultimate loads in the residual capacity tests in test series C2.3.

If $cv(N_u)$ is larger than 30 %, then the fastener is not suitable for use in category C2

The reduction factor $\alpha_{C2.3}$ resulting from the pulsating tension test series C2.3 is determined according to Equation (E.4.2.4.9).

$$\alpha_{C2.3} = \min(\alpha_{C2.3a}; \alpha_{C2.3b}) \cdot \alpha_{C2.3c} \quad \text{(E.4.2.4.9)}$$

Report the displacements after successful completion at $0{,}5 \cdot N/N_{max}$ and $1{,}0 \cdot N/N_{max}$ or at $0{,}5 \cdot N/N_{max,red}$ and $1{,}0 \cdot N/N_{max,red}$ in case the tests are repeated with a reduced load value, as applicable.

E.4.2.5 Assessment of tests under alternating shear load (test series C2.4)

The following conditions apply:

1. All fasteners in a test series shall complete the alternating shear load history specified in Figure E.3.4.4.1 and Table E.3.4.4.1. Failure of a fastener to develop the required resistance in any cycle prior to completing the loading history specified in Table E.3.4.4.1 shall be recorded as an unsuccessful test. In case of an unsuccessful test, the test series shall be repeated with a reduced value $V_{max,red,1}$ until the requirement is fulfilled. In this case the reduction factor $\alpha_{C2.4a}$ shall be calculated according to Equation (E.4.2.5.1).

$$\alpha_{C2.4a} = \frac{V_{max,red,1}}{V_{max}} \quad \text{(E.4.2.5.1)}$$

with

V_{max} = [N] - maximum shear load according to Equation (E.3.4.4.1);

$V_{max,red,1}$ = [N] - reduced shear load to fulfil the requirement.

2. Displacements are assessed during the last cycle at $\pm 0{,}5 \cdot V/V_{max}$ and $\pm 1{,}0 \cdot V/V_{max}$ or $\pm 0{,}5 \cdot V/V_{max,red,1}$ and $\pm 1{,}0 \cdot V/V_{max,red,1}$ (refer to Figure E.3.4.4.1). Displacements shall be reported as the maximum of the mean of the absolute values in the positive loading direction and the mean of the absolute values in the negative loading direction.

   To avoid excessive displacement of the fastener a displacement limit at the end of load cycling at $\pm 0{,}5 \cdot V/V_{max}$ (i.e., at load cycle 50 (see Figure E.3.4.4.1 and Table E.3.4.4.1) is introduced for the assessment of fasteners. Due to lack of sufficient test data this limit is assumed as $\delta_{V,lim}$ = 7 mm. The following condition shall be fulfilled:

$$\delta_m(0{,}5 \cdot V/V_{\max}) \leq \delta_{V,\lim} \qquad \text{(E.4.2.5.2)}$$

   with

   $\delta_m (0{,}5 \cdot V/V_{max})$ = [mm] - max ($|\delta_m (+0{,}5 \cdot V/V_{max})|$; $|\delta_m (-0{,}5 \cdot V/V_{max})|$); maximum of the mean value of displacements of the fastener after load cycling at $+0{,}5 \cdot V/V_{max}$ and the mean value of displacements of the fastener after load cycling at $-0{,}5 \cdot V/V_{max}$ of test series C2.4; if the tests have been performed with $V_{max,red,1}$ replace V_{max} by $V_{max,red,1}$;

   $\delta_{V,lim}$ = 7 mm.

   If the condition is not fulfilled, then repeat the tests with a reduced value $V_{max,red,2}$ until the requirement is fulfilled. Determine the corresponding reduction factor $\alpha_{C2.4b}$ in accordance with Equation (E.4.2.5.3).

$$\alpha_{C2.4b} = \frac{V_{max,red,2}}{V_{max}} \qquad \text{(E.4.2.5.3)}$$

   with

   V_{max} = [N] - maximum shear load according to Equation (E.3.4.4.1);

   $V_{max,red,2}$ = [N] - reduced shear load to fulfil the requirement.

   If the condition according to Equation (E.4.2.5.2) is fulfilled but a smaller displacement is intended, then it shall be permitted to repeat the tests with a reduced value $V_{max,reE.}$

3. Residual capacity tests (both conditions apply):

   a. Failure mode:

      If failure is caused by pull-out, then the fastener is not suitable for use in category C2. The tests may be repeated with a larger embedment depth avoiding these failure modes.

   b. Ultimate load:

$$V_{u,m,C2.4} \geq 0{,}95 \cdot V_{u,m,C2.2} \qquad \text{(E.4.2.5.4)}$$

      with

      $V_{u,m,C2.4}$ = [N] - mean ultimate shear load from residual capacity tests of test series C2.4.

      $V_{u,m,C2.2}$ = [N] - mean ultimate shear load from residual capacity tests of test series C2.2.

      If this condition is fulfilled, then $\alpha_{C2.4c}$ = 1,0. If this condition is not fulfilled, then the factor $\alpha_{C2.4c}$ shall be determined according to Equation (E.4.2.5.5) or the test series C2.4 shall be repeated with a reduced value of V_{max} until the requirement given in Equation (E.4.2.5.4) is fulfilled. Both methods are equivalent. In case of dispute, the factor $\alpha_{C2.4c}$ shall be determined according to Equation (E.4.2.5.5).

$$\alpha_{C2.4c} = \frac{V_{u,m,C2.4}}{0{,}95 \cdot V_{u,m,C2.2}} \qquad \text{(E.4.2.5.5)}$$

      In Equations (E.4.2.5.4) and (E.4.2.5.5) the resistances from test series C2.2 shall be normalized according to Equation (E.4.2.1.1.2) or Equation (E.4.2.1.1.3), as applicable, to the strength in test series C2.4.

c. Scatter of ultimate loads:

$$cv(V_u) \leq 15\% \quad \text{(E.4.2.5.6)}$$

If this condition is fulfilled, then $\beta_{cv,C2.4}$ = 1,0. If this condition is not fulfilled, then $\beta_{cv,C2.4}$ shall be determined according to Equation (E.4.2.5.7).

$$\beta_{cv,C2.4} = \frac{1}{1+(cv(V_u)-15)\cdot 0{,}03} \quad \text{(E.4.2.5.7)}$$

where $cv(V_u)$ is the coefficient of variation of the ultimate loads in the residual capacity tests in test series C2.4.

If $cv(V_u)$ is larger than 30 %, then the fastener is not suitable for use in category C2.

The reduction factor $\alpha_{C2.4}$ resulting from the alternating shear load test series C2.4 is determined according to Equation (E.4.2.5.8).

$$\alpha_{C2.4} = \min(\alpha_{C2.4a}; \alpha_{C2.4b}) \cdot \alpha_{C2.4c} \quad \text{(E.4.2.5.8)}$$

Report the displacements after successful completion at ±0,5·V/V_{max} and ±1,0·V/V_{max} or at ±0,5·$V/V_{max,red}$ and ±1,0·$V/V_{max,red}$ in case the tests are repeated with a reduced shear load, as applicable.

E.4.2.6 Assessment of tests under tension load with varying crack width (test series C2.5)

The following conditions apply:

1. All fasteners in the test series shall complete the varying crack width history under tension load specified in Figure E.3.4.5.1 and Table E.3.4.5.1. Failure of a fastener to develop the required resistance in any cycle prior to completing the crack cycling history specified in Table E.3.4.5.1 shall be recorded as an unsuccessful test. In case of an unsuccessful test, the test series shall be repeated with proportionally reduced values of N_{w1} and N_{w2}, i.e., $N_{w1,red,1}$ and $N_{w2,red,1}$, respectively, until the requirement is fulfilled. The corresponding reduction factor $\alpha_{C2.5a}$ shall be calculated according to Equation (E.4.2.6.1).

$$\alpha_{C2.5a} = \frac{N_{w2,red,1}}{N_{w2}} \quad \text{(E.4.2.6.1)}$$

with

N_{w2} = [N] - tension load according to Equation (E.3.4.5.6) to Equation (E.3.4.5.8) as applicable;

$N_{w2,red,1}$ = [N] - reduced tension load to fulfil the requirement.

2. Displacements are assessed during the last cycle at Δw = 0,5 mm and Δw = 0,8 mm (see Figure E.3.4.5.1). Displacements shall be reported in terms of the mean value.

   To avoid excessive displacement of the fastener a displacement limit at the end of cycling at Δw = 0,5 mm (i.e., at the end of cycle 45 (see Figure E.3.4.5.1 and Table E.3.4.5.1) is introduced for the assessment of fasteners. Due to lack of sufficient test data this limit is assumed as $\delta_{N,lim}$ = 7 mm. The following condition shall be fulfilled:

$$\delta_m(\Delta w = 0{,}5) \leq \delta_{N,\lim} \quad \text{(E.4.2.6.2)}$$

with

δ_m (Δw = 0,5) = [mm] - mean value of displacements of the fastener at the end of cycling at Δw = 0,5 mm of test series C2.5;

$\delta_{N,lim}$ = 7 mm.

If this condition is not fulfilled, then repeat the tests with proportionally reduced values of N_{w1} and N_{w2}, i.e., $N_{w1,red,2}$ and $N_{w2,red,2}$, respectively, until the requirement is fulfilled and calculate the reduction factor $\alpha_{C2.5b}$ according to Equation (E.4.2.6.3).

$$\alpha_{C2.5b} = \frac{N_{w2,red,2}}{N_{w2}} \quad \text{(E.4.2.6.3)}$$

with

N_{w2} = [N] - tension load according to Equation (E.3.4.5.6) to Equation (E.3.4.5.8);

$N_{w2,red,2}$ = [N] - reduced tension load to fulfil the requirement.

If the condition according to Equation (E.4.2.6.2) is fulfilled but a smaller displacement is intended, then it shall be permitted to repeat the tests with proportionally reduced values $N_{w1,red,2}$ and $N_{w2,red,2}$.

3. Residual capacity tests (all three conditions apply):

a. Scatter of displacement:

$$cv(\delta(0{,}5 \cdot N_{u,m,C2.5})) \leq 40\% \tag{E.4.2.6.4}$$

with

$\delta(0{,}5 \cdot N_{u,m,C2.5})$ = [mm] - displacement of the fastener at 50 % of the mean ultimate tension load from the residual capacity tests of test series C2.5; displacement in the residual capacity test only, i.e., neglecting the displacement that occurred during the crack cyclic.

$N_{u,m,C2.5}$ = [N] - mean ultimate tension load from residual capacity tests of test series C2.5.

The condition of Equations (E.4.2.6.4) may be neglected for displacemensts < 0,4 mm. If this condition is not fulfilled, then the fastener is not suitable for use in category C2.

b. Ultimate load:

$$N_{u,m,C2.5} \geq 0{,}9 \cdot N_{u,m,C2.1a} \tag{E.4.2.6.5}$$

with

$N_{u,m,C2.1a}$ = [N] - mean ultimate tension load from test series C2.1a

$N_{u,m,C2.5}$ = [N] - mean ultimate tension load from residual capacity tests of test series C2.5.

If this condition is fulfilled, then $\alpha_{C2.5c}$ = 1,0. If this condition is not fulfilled, then the factor $\alpha_{C2.5c}$ shall be determined according to Equation (E.4.2.6.6) or the test series C2.5 shall be repeated with a reduced value of N_{max} until the condition given in Equation (E.4.2.6.5) is fulfilled. Both methods are equivalent. In case of dispute, the factor $\alpha_{C2.5c}$ shall be determined according to Equation (E.4.2.6.6).

$$\alpha_{C2.5c} = \frac{N_{u,m,C2.5}}{0{,}9 \cdot N_{u,m,C2.1a}} \tag{E.4.2.6.6}$$

In Equations(E.4.2.6.5) and (E.4.2.6.6) the resistances from test series C2.1a shall be normalized according to Equation (E.4.2.1.1.1), Equation (E.4.2.1.1.4) or Equation (E.4.2.1.1.5), as applicable, to the strength in test series C2.5.

c. Scatter of ultimate loads:

$$cv(N_u) \leq 20\% \tag{E.4.2.6.7}$$

If this condition is fulfilled, then $\beta_{cv,C2.5}$ = 1,0. If this condition is not fulfilled, then $\beta_{cv,C2.5}$ shall be determined according to Equation (E.4.2.6.8).

$$\beta_{cv,C2.5} = \frac{1}{1 + (cv(N_u) - 20) \cdot 0{,}03} \tag{E.4.2.6.8}$$

If $cv(N_u)$ is larger than 30 %, then the fastener is not suitable for use in category C2.

The reduction factor $\alpha_{C2.5}$ resulting from the varying crack width test series C2.3 is determined according to Equation (E.4.2.6.9).

$$\alpha_{C2.5} = \min(\alpha_{C2.5a}; \alpha_{C2.5b}) \cdot \alpha_{C2.5c} \tag{E.4.2.6.9}$$

Report the displacements after successful completion at the end of crack cycling at Δw = 0,5 mm and Δw = 0,8 mm.

E.4.2.7 Determination of decisive reduction factors for seismic category C2

E.4.2.7.1 Tension

The reduction factors $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ are determined according to Equations (E.4.2.7.1.1) and (E.4.2.7.1.2), respectively.

$$\alpha_{N,C2} = \alpha_{C2.1} \cdot \min(\alpha_{C2.3}; \alpha_{C2.5}) \quad \text{(E.4.2.7.1.1)}$$

where

$\alpha_{C2.1}$ = reduction factor α according to E.4.2.2;

$\alpha_{C2.3}$ = reduction factor α according to E.4.2.4;

$\alpha_{C2.5}$ = reduction factor α according to E.4.2.6.

$$\beta_{cv,N,C2} = \min(\beta_{cv,C2.1}; \beta_{cv,C2.3}; \beta_{cv,C2.5}) \quad \text{(E.4.2.7.1.2)}$$

where

$\beta_{cv,C2.1}$ = reduction factor β_{cv} accounting for large scatter according to E.4.2.2;

$\beta_{cv,C2.3}$ = reduction factor β_{cv} accounting for large scatter according to E.4.2.4;

$\beta_{cv,C2.5}$ = reduction factor β_{cv} accounting for large scatter according to E.4.2.6.

The reduction factors according to Equation (E.4.2.7.1.1) and Equation (E.4.2.7.1.2) are valid for fasteners with the tested embedment depth and all other embedment depths.

If fasteners with more than one embedment depth have been tested and different failure modes are observed in these tests, then different reduction factors for steel and pull-out (bond) failure may be obtained.

The reduction factors $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ shall be used to determine the characteristic resistances under seismic loading according to E.4.3.2.1.

E.4.2.7.2 Shear

The reduction factors $\alpha_{V,C2}$ and $\beta_{cv,V,C2}$ are determined according to Equations (E.4.2.7.2.1) and (E.4.2.7.2.2), respectively.

$$\alpha_{V,C2} = \alpha_{C2.2} \cdot \alpha_{C2.4} \quad \text{(E.4.2.7.2.1)}$$

where

$\alpha_{C2.2}$ = reduction factor α according to E.4.2.3;

$\alpha_{C2.4}$ = reduction factor α according to E.4.2.5.

$$\beta_{cv,V,C2} = \min(\beta_{cv,C2.2}; \beta_{cv,C2.4}) \quad \text{(E.4.2.7.2.2)}$$

where

$\beta_{cv,C2.2}$ = reduction factor β_{cv} accounting for large scatter according to E.4.2.3;

$\beta_{cv,C2.4}$ = reduction factor β_{cv} accounting for large scatter according to E.4.2.5;

The reduction factors according to Equation (E.4.2.7.2.1) and Equation (E.4.2.7.2.2) are valid for fasteners with the tested embedment depth and all larger embedment depths. If more than one embedment depth has been tested, then the reduction factors $\alpha_{V,C2}$ and $\beta_{cv,V,C2}$ for an intermediate embedment depth may be determined by linear interpolation.

The reduction factors $\alpha_{V,C2}$ and $\beta_{cv,V,C2}$ shall be used to determine the characteristic resistances under seismic loading according to E.4.3.2.2.

E.4.3 Characteristic values for seismic design

In this assessment it is assumed that the characteristic resistances under seismic action for concrete failure modes (concrete cone breakout in tension and concrete edge breakout and pry-out failure in shear) are covered in the design method by applying reduction factors to the corresponding characteristic resistances under non-seismic loading conditions.

E.4.3.1 Seismic performance category C1

E.4.3.1.1 Tension

The characteristic resistances as determined below are valid for fasteners with the tested embedment depth and all smaller embedment depths.

E.4.3.1.1.1 Bonded expansion fasteners

a. Steel failure caused reduction:

The characteristic resistances for steel tension and pull-out under seismic loading, i.e., $N_{Rk,s,C1}$ and $N_{Rk,p,C1}$, respectively, to be reported in the ETA are determined as follows:

$$N_{Rk,s,C1} = \alpha_{N,C1} \cdot N_{Rk,s} \text{ [N]} \qquad \text{(E.4.3.1.1.1.1)}$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,p} \text{ [N]} \qquad \text{(E.4.3.1.1.1.2)}$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,c} \text{ [N]} \quad \text{(if no pull-out failure occurs for static loading)} \qquad \text{(E.4.3.1.1.1.3)}$$

where

$N_{Rk,s}$ = [N] - characteristic steel tension resistance as reported in the ETA for static loading;

$N_{Rk,p}$ = [N] - characteristic pull-out resistance in cracked concrete as reported in the ETA for static loading;

$N_{Rk,c}$ = [N] - characteristic concrete cone resistance in cracked concrete for static loading;

$\alpha_{N,C1}$ = reduction factor α according to E.4.1.1.

b. Pull-out failure caused reduction:

The characteristic resistances for steel tension and pull-out under seismic loading, i.e., $N_{Rk,s,C1}$ and $N_{Rk,p,C1}$, respectively, to be reported in the ETA are determined as follows:

$$N_{Rk,s,C1} = N_{Rk,s} \text{ [N]} \qquad \text{(E.4.3.1.1.1.4)}$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,p} \text{ [N]} \qquad \text{(E.4.3.1.1.1.5)}$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,c} \text{ [N]} \quad \text{(if no pull-out failure occurs for static loading)} \qquad \text{(E.4.3.1.1.1.6)}$$

For $N_{Rk,s}$, $N_{Rk,p}$, $N_{Rk,c}$, and $\alpha_{N,C1}$ see a.

E.4.3.1.1.2 Bonded fasteners:

a. Steel failure caused reduction:

The characteristic resistances for steel tension and pull-out (bond) under seismic loading, i.e., $N_{Rk,s,C1}$ and $\tau_{Rk,C1}$, respectively, to be reported in the ETA are determined as follows:

$$N_{Rk,s,C1} = \alpha_{N,C1} \cdot N_{Rk,s} \text{ [N]} \qquad \text{(E.4.3.1.1.2.1)}$$

$$\tau_{Rk,C1} = \alpha_{N,C1} \cdot \tau_{Rk,cr} \text{ [N]} \qquad \text{(E.4.3.1.1.2.2)}$$

where

$N_{Rk,s}$ = [N] - characteristic steel tension resistance as reported in the ETA for static loading;

$\tau_{Rk,cr}$ = [N/mm²] - characteristic bond resistance for cracked concrete as reported in the ETA for static loading;

$\alpha_{N,C1}$ = reduction factor α according to E.4.1.1.

b. Pullout failure caused reduction:

The characteristic resistances for steel tension and pull-out (bond) under seismic loading, i.e., $N_{Rk,s,C1}$ and $\tau_{Rk,C1}$, respectively, to be reported in the ETA are determined as follows:

$$N_{Rk,s,C1} = N_{Rk,s} \text{ [N]} \qquad \text{(E.4.3.1.1.2.3)}$$

$$\tau_{Rk,C1} = \alpha_{N,C1} \cdot \tau_{Rk,cr} \text{ [N]} \qquad \text{(E.4.3.1.1.2.4)}$$

with $N_{Rk,s}$, $\tau_{Rk,cr}$ and $\alpha_{N,C1}$ as defined in Equation (E.4.3.1.1.2.1) and Equation (E.4.3.1.1.2.2).

E.4.3.1.2 Shear

The characteristic shear resistance for steel under seismic loading, $V_{Rk,s,C1}$, to be reported in the ETA is determined as follows:

$$V_{Rk,s,C1} = \alpha_{V,C1} \cdot V^0_{Rk,s} \cdot k_7 \text{ [N]} \qquad \text{(E.4.3.1.2.1)}$$

where

$V^0_{Rk,s}$ = [N] - characteristic shear resistance as reported in the ETA for static loading;

k_7 = factor for ductility according to 2.2.7.2

$\alpha_{V,C1}$ = reduction factor α according to E.4.1.2.

The value $V_{Rk,s,C1}$ according to Equation (E.4.3.1.2.1) is valid for all embedment depths greater than the tested embedment depth. If more than one embedment depth has been tested, then the value $V_{Rk,s,C1}$ for an intermediate embedment depth may be determined by linear interpolation.

E.4.3.2 Seismic performance category C2

E.4.3.2.1 Tension loading

The characteristic resistances as determined below are valid for fasteners with the tested embedment depth and all smaller embedment depths.

The characteristic resistance for seismic actions as given in the following shall be limited by the values for static and quasi-static loading.

E.4.3.2.1.1 Bonded expansion fasteners

a) Steel failure:
The characteristic resistances for steel tension and pull-out under seismic loading, i.e., $N_{Rk,s,C2}$ and $N_{Rk,p,C2}$, to be reported in the ETA are determined as follows:

$$N_{Rk,s,C2} = \alpha_{N,C2} \cdot \beta_{cv,N,C2} \cdot N_{Rk,s} \quad [N] \qquad (E.4.3.2.1.1.1)$$

$$N_{Rk,p,C2} = \alpha_{N,C2} \cdot \beta_{cv,N,C2} \cdot N_{Rk,0} \quad [N] \qquad (E.4.3.2.1.1.2)$$

where

$N_{Rk,0}$ = [N] - characteristic value of tests for “maximum crack width and large hole diameter (E6)”-and “maximum crack width and small hole diameter (E7)” according to Table B.2.1, (normalized to the compressive strength of concrete (measured on cylinders) of f_c = 20 N/mm²);

Note E.1: The characteristic value $N_{Rk,0}$ may be determined as follows:

(1) determine the characteristic value of the test series E6 and E7 separately and take the minimum of the two;
(2) determine the characteristic value of the combined test data of the test series E6 and E7;
(3) take the maximum of (1) and (2), i.e.,
$N_{Rk,0}$ = max (min (E6; E7); (E6 U E7)).

$N_{Rk,s}$ = [N] - characteristic steel tension resistance as reported in the ETA for static loading;

$\alpha_{N,C2}$ = reduction factor α as determined in Equation (E.4.2.7.1.1);

$\beta_{cv,N,C2}$ = reduction factor β_{cv} accounting for large scatter as determined in Equation (E.4.2.7.1.2)

b) Pull-out failure:

The characteristic resistances for pull-out under seismic loading, i.e., $N_{Rk,s,C2}$ and $N_{Rk,p,C2}$, respectively, to be reported in the ETA are determined as follows:

$$N_{Rk,s,C2} = N_{Rk,s} \quad [N] \qquad (E.4.3.2.1.1.3)$$

$$N_{Rk,p,C2} = \alpha_{N,C2} \cdot \beta_{cv,N,C2} \cdot N_{Rk,0} \quad [N] \qquad (E.4.3.2.1.1.4)$$

with $N_{Rk,0}$, $N_{Rk,s}$, $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ as given in Equation (E.4.3.2.1.1.2), (E.4.2.7.1.1), (E.4.2.7.1.2).

E.4.3.2.1.2 Bonded fasteners

a) Steel failure:

The characteristic resistance for steel tension $N_{Rk,s,C2}$ to be reported in the ETA is determined as follows:

$$N_{Rk,s,C2} = \alpha_{N,C2} \cdot \beta_{cv,N,C2} \cdot N_{Rk,s} \quad [N] \qquad (E.4.3.2.1.2.1)$$

where

$N_{Rk,s}$ = [N] - characteristic steel tension resistance as reported in the ETA for static loading;

$\alpha_{N,C2}$ = reduction factor α as determined in Equation (E.4.2.7.1.1) for tests in which steel failure occurred;

$\beta_{cv,N,C2}$ = reduction factor β_{cv} accounting for large scatter as determined in Equation (E.4.2.7.1.2) for tests in which steel failure occurred.

b) Pullout (bond) failure:

If pullout (bond) failure for BF is given in terms of a characteristic bond resistance, then the corresponding resistance under seismic loading $\tau_{Rk,C2}$ is determined as follows:

$$\tau_{Rk,C2} = \alpha_{N,C2} \cdot \beta_{cv,N,C2} \cdot \tau_{Rk,base} \quad [N/mm^2] \qquad (E.4.3.2.1.2.2)$$

with

$\tau_{Rk,base}$ = [N/mm²] - basic bond strength τ^0_{Rk} from tests “sensitivity to increased crack width (B10)” in concrete C20/25 applying α_1 to α_4 and α_{setup} (i.e., reduction factors regarding “uncontrolled slip”, maximum long term temperature, maximum short term temperature, and durability) as defined in clause 2.2.2 and the reduction resulting from tests “sensitivity to sustained loads” (i.e., reduction resulting from sustained load); however, the reduction resulting from tests “sensitivity to crack movements (B13)” (i.e., reduction resulting from functioning in crack movement) may not be applied.

$\alpha_{N,C2}$ = reduction factor α as determined in Equation (E.4.2.7.1.1) for tests in which pull-out (bond) failure occurred;

$\beta_{cv,N,C2}$ = reduction factor β_{cv} accounting for large scatter as determined in Equation (E.4.2.7.1.2) for tests in which pull-out (bond) failure occurred.

E.4.3.2.2 Shear loading

Under shear loading only steel failure is considered in the evaluation. Pry-out and concrete edge failure are taken into account in the design provisions.

The characteristic steel shear resistance under seismic shear loading, $V_{Rk,s,C2}$, is determined as follows:

$$V_{Rk,s,C2} = \alpha_{V,C2} \cdot \beta_{cv,V,C2} \cdot V^0_{Rk,s} \cdot k_7 \quad [N] \qquad (E.4.3.2.2.1)$$

where

$V^0_{Rk,s}$ = [N] - characteristic resistance for steel failure given in the ETA for static loading;

$\alpha_{V,C2}$ = reduction factor α according to Equation (E.4.2.7.2.1);

$\beta_{cv,V,C2}$ = reduction factor β_{cv} accounting for large scatter according to Equation (E.4.2.7.2.2);

k_7 = factor for ductility according to 2.2.7.2.

The characteristic resistance according to Equation (E.4.3.2.1.1.3) is valid for fasteners with the tested embedment depth and all larger embedment depths. If more than one embedment depth has been tested, then the characteristic resistance for an intermediate embedment depth may be determined by linear interpolation.

E.4.3.2.3 Displacements

Determine the displacements und tension load $\delta_{N,C2}$ and for shear load $\delta_{V,C2}$ according to Table E.4.3.2.3.1 each for 50% and 100% of N/N_{max} (tension) and V/V_{max} (shear).

Table E.4.3.2.3.1 Displacement information

Displacement	**Obtained from**
$\delta_{N,C2(50\%)}$	Maximum of the mean value of displacements reported at $0{,}5 \cdot N/N_{max}$ or $0{,}5 \cdot N/N_{max,red}$ (as applicable) of C2.3 tests and the mean value of displacements reported at Δw = 0,5 mm of C2.5 tests.
$\delta_{V,C2(50\%)}$	Mean value of displacements reported at $0{,}5 \cdot V/V_{max}$ or $0{,}5 \cdot V/V_{max,red}$ (as applicable) of C2.4 tests.
$\delta_{N,C2(100\%)}$	Maximum of the mean value of displacements reported at $1{,}0 \cdot N/N_{max}$ or $1{,}0 \cdot N/N_{max,red}$ (as applicable) of C2.3 tests and the mean value of displacements reported at Δw = 0,8 mm of C2.5 tests.
$\delta_{V,C2(100\%)}$	Mean value of displacements reported at $1{,}0 \cdot V/V_{max}$ or $1{,}0 \cdot V/V_{max,red}$ (as applicable) of C2.4 tests.

E.5 Test Report

In addition to the minimum requirements listed in D.5, the report shall include at least the following information regarding the seismic tests:

Test member
- Reinforcement ratio
- Drawing of test member (including dimensions and position of reinforcement)

Test setup
- Loading device
- Type and positioning of crack measurement device(s)
- Particulars concerning restraining uplift in shear tests (where applicable)
- Test method for fastener being located in crack over required length
- Method of crack creation
- Verification of approximately constant crack width throughout thickness of test member (where applicable)

Measured values
- Frequency of load cycling (where applicable)
- (hairline) crack width before and after fastener installation
- Minimum and maximum loads in each cycling sequence of load cycling tests
- Annular gap of clearance hole for shear tests
- Crack width for residual capacity tests
- Alternating shear load cycling procedure
- Reduced load levels and reason for reduction (where applicable)
- Location of failure (e.g., in shaft portion, threaded part, neck of fastener)
- Particulars of tests for category C1
  - Crack width Δw
  - Fastener displacement as a function of number of load cycles
  - Constant load levels N_{C1}, N_i and N_m on fastener and method of applying the load in test series C1.1
  - Constant load levels V_{C1}, V_i and V_m on fastener and method of applying the load in test series C1.2
- Particulars of tests for category C2
  - Maximum loads N_{max} and V_{max} in test series C2.3 and C2.4, respectively
  - Type of loading cycles (sinusoidal or triangular) in test series C2.3
  - Fastener displacements at minimum and maximum load and crack width as a function of number of load cycles in test series C2.3 and C2.4
  - Fastener displacements at 0,5 N/N_{max} and 1,0 N/N_{max} in test series C2.3
  - Fastener displacements at 0,5 V/V_{max} and 1,0 V/V_{max} in test series C2.4
  - Constant load levels N_{w1} and N_{w2} on fastener and method of applying the load in test series C2.5
  - Frequency of crack cycling in test series C2.5
  - Initial compression force C_{ini} in test series C2.5
  - Compression force C_{test} in test series C2.5
  - Fastener displacements at minimum and maximum crack width and applied tension load as a function of number of crack cycles in test series C2.5
  - Fastener displacements at the end of crack cycling at level Δw = 0,5 mm and Δw = 0,8 mm in test series C2.5.

ANNEX F ASSESSMENT FOR BF AND BEF IN STEEL FIBRE REINFORCED CONCRETE

F.1 Scope

This Annex provides a reduced test program for the assessment of BF and BEF for use in steel fibre reinforced concrete (SFRC) according to EN 206 [1], to which steel fibres in accordance with EN 14889-1 [23] are included into the concrete matrix. The intention of this Annex is to show equivalent performance of the fastener in SFRC and in plain concrete without fibres. If equivalent performance according to this annex cannot be proven, then

- The use in SFRC shall be excluded or
- The full test program for BF for resistance to combined pull-out and concrete failure (See Table A.1.1, lines B1 to B20) and the full test program for BEF according to Table B.2.1, lines E1 to E14 and Annex E shall be performed in steel fibre reinforced concrete with a steel fibre content of 20 kg/m³ in C20/25 and a steel fibre content of 80 kg/m³ in C50/60.

The maximum content of steel fibres is 80 kg/m³. The volume of steel fibres shall be determined according to EN 14721 [24].

Note: The content of steel fibres up to 80 kg/m³ represents common practice for steel fibre reinforced concrete.

F.2 Test program and details of tests

Test conditions

The test program for use in SFRC is given in Table F.2.1 for BF or in Table F.2.2 for BEF.

Concrete mix:

For steel fibre reinforced concrete, the maximum aggregate size can be reduced to 8 mm. Figure F.2.1 may be used as guidance.

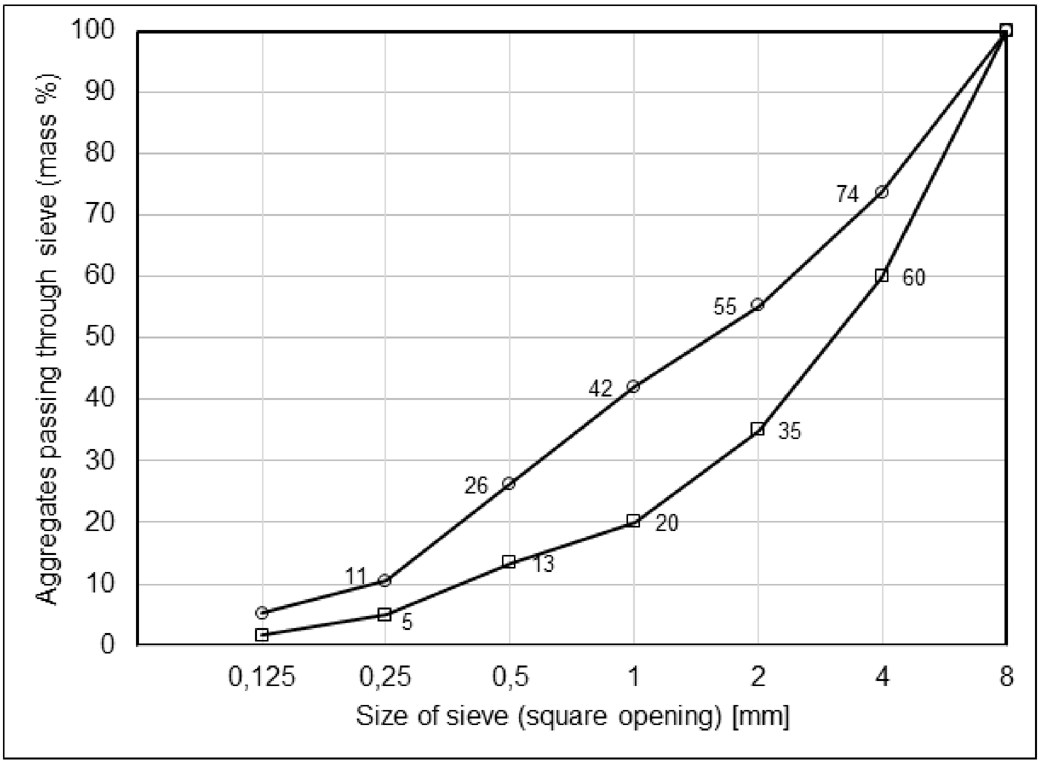


Figure F.2.1 Grading curve for SFRC

Steel fibres according to EN 14889-1 [23] clause 5 group I, with a length of 50-60 mm and a diameter between 0,75 and 1,05 mm shall be used (if not specified otherwise by the manufacturer of the fastener). If other steel fibres are intended to be used, these steel fibres shall be used for the tests and assessment.

The amount of fibres for each test series is given in Table F.2.1 and Table F.2.2.

The steel fibre group and the amount of fibres used in tests shall be stated in the ETA (see clause 2.2.11).

Test program

The test program for use in fibre reinforced concrete is given in Table F.2.1 for BF or in Table F.2.2 for BEF.

For all concrete batches used in this assessment, the following tests procedure shall be carried out:

- Before addition of steel fibres, determine f_c or f_{cube} in concrete without fibres of the same concrete mix for comparison with the assessment in plain concrete without fibres at the time of performing the test series (see D.3.1.2.5). This concrete strength shall be used for the normalization in the assessment.

Table F.2.1 Test program for BF in steel fibre reinforced concrete

N°	Purpose of test	Concrete Steel fibre content	crack width [mm]	Size 2)	h_{ef}	n_{min}	Test conditions Clause
R1F	Bond strength with confined test setup	C20/25 20 kg/m³	0	All	7d 1)	5	2.2.2.1
R2F		C50/60 80 kg/m³	0	s/m/l	7d 1)	5	
B6F	Robustness in dry concrete	C20/25 20 kg/m³	0	s/m/l	max	5	2.2.5.2
B7F	Robustness in water saturated concrete	C20/25 20 kg/m³	0	s/m/l	max	5	2.2.5.3
B8F	Robustness in water filled holes (clean water)	C20/25 20 kg/m³	0	s/m/l	max	5	2.2.5.4
B10F	Increased crack width	C20/25 20 kg/m³	0,5	s/m/l	7d 1)	5	2.2.2.3
B11F	Increased crack width	C50/60 80 kg/m³	0,5	s/m/l	7d 1)	5	2.2.2.3

1) This value is valid for injection type and bulk type BF. For capsule type BF, the specified embedment depth associated with the capsule size shall be used. To avoid steel failure, the embedment depth modifications may be necessary (see clause A.2).

3) The reduced range of tested sizes s/m/l depends on the number of requested sizes and is given in Table A.1.2.

Table F.2.2 Test program for BEF in steel fibre reinforced concrete

N°	Purpose of test	concrete	crack width [mm]	T/T_{inst}	size 1) 2)	n_{min}	Test conditions clause
E1F	Reduced installation torque in dry concrete	C20/25 20 kg/m³	0,3	0,5	all	10	B.2.3
E3F	Robustness in water saturated concrete	C20/25 20 kg/m³	0,3	1/0,5	all	10	
E4F	Robustness in water filled holes (clean water)	C20/25 20 kg/m³	0,3	1/0,5	all	10	
E6F	Increased crack width	C20/25 20 kg/m³	0,5	1/0,5	s/m/l	10	2.2.2.3
E7F	Increased crack width	C50/60 80 kg/m³	0,5	1/0,5	s/m/l	10	2.2.2.3

1) See Table A.1.2; m: medium size (12 mm) or smallest size which is larger than 12 mm;
2) The reduced range of tested sizes s/m/l depends on the number of requested sizes and is given in Table A.1.2.

Assessment test series R1F, R2F

Equivalence of bond strength accounting for the sensitivity of fibres in the concrete is assessed with comparison of the results of the test series R1F and R2F of Table F.2.1 for BF with test series in concrete without steel fibres.

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN] and / or bond strength $\tau_{u,m}$ [N/mm²], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2 respectively using the exponent m according to A.2.1.2 determined for the reference tests R1 and R2 according to Table A.1.1.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN] and / or bond strength $\tau_{5\%}$ [N/mm²], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.
- Verify the coefficient of variation of failure loads. The coefficient of variation shall not exceed 15 % ($cv_F \leq 15$ %) to show equivalence.
- Verify that the $N_{u,m}$ [kN] and / or bond strength $\tau_{u,m}$ [N/mm²] and the 5 % fractile of the failure loads $N_{5\%}$ [kN] and / or bond strength $\tau_{5\%}$ [N/mm²] of test series R1F and R2F are at least 95% of the corresponding parameters of the reference tests R1 and R2 according to Table A.1.1.

Load displacement behaviour

- Determine the reduction factor α_1 according to Annex A. Verify that the reduction factor α_1 is equal to or larger than for the reference tests R1 and R2 according to Table A.1.1.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Assessment test series B6F, B7F, B8F, B10F, B11F, E1F, E3F, E4F, E6F and E7F

Equivalence of bond strength accounting for the sensitivity of fibres in the concrete is evaluated with comparison of the results of the test series B6F, B7F, B8F, B10F and B11F of Table F.2.1 for BF and the test series according to Table F.2.2 with test series in concrete without steel fibres.

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN] and / or bond strength $\tau_{u,m}$ [N/mm²], converted to the nominal concrete strength and accounting for concrete batch influence according to paragraphs A.2 respectively using the exponent m according to A.2.1.2 determined for the reference tests R1 and R2 according to Table A.1.1.
- Determine the 5 % fractile of the failure loads $N_{5\%}$ [kN] and / or bond strength $\tau_{5\%}$ [N/mm²], converted to the nominal concrete strength and accounting for concrete batch influence according to A.2.

- Verify the coefficient of variation of failure loads. The coefficient of variation shall not exceed 20 % ($cv_F \leq 20$ %) to show equivalence.
- Verify that the $N_{u,m}$ [kN] and / or bond strength $\tau_{u,m}$ [N/mm²] and the 5 % fractile of the failure loads $N_{5\%}$ [kN] and / or bond strength $\tau_{5\%}$ [N/mm²] of test series B6F, B7F, B8F, B10F and, B11F for BF and E1F, E3F, E4F, E6F and E7F for BEF are at least 95% of the corresponding parameters of the reference tests B6, B7, B8, B10 and, B11 according to Table A.1.1 for BF and E1, E3, E4, E6 and E7 according to Table B.2.1 for BEF.

<u>Load displacement behaviour</u>

- Determine the reduction factor α_1 according to Annex A. Verify that the reduction factor α_1 is equal to or larger than for the reference tests series.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%]. If the mean value of displacements at 50 % of the failure load are larger than 0,4 mm, then cv_δ shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."