EUROPEAN ASSESSMENT DOCUMENT

EAD 330499-01-0601

December 2018

BONDED FASTENERS FOR USE IN CONCRETE

www.eota.eu

Contents

1 SCOPE OF THE EAD

1.1 Description of the construction product

This EAD covers bonded fasteners (including bonded expansion fasteners) consisting of a bonding material and an embedded metal part placed in pre-drilled holes perpendicular to the surface (maximum deviation 5°) in concrete and anchored therein primarily by means of bond. Bonded fasteners are often used to connect structural elements and non-structural elements to structural components.

The embedded metal part 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 1 The stated limit for the maximum embedment depth of 20 d is in accordance with EN 1992-4 [5][1]. For deeper embedment a constant distribution of bond stress over the embedment depth cannot be readily assumed.

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

Types and operating principles of fasteners

This EAD covers bonded fasteners with the following mixing and installation techniques:

<u>Mix proportions</u>

Only those bonded 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 fastener, 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

<u>Drilling techniques</u>

- rotary hammer (electric drilling machine or driven by compressed air)
- diamond drilling

---

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

Installation techniques

- Capsule placed in the hole and embedded part driven by machine with simultaneous hammering and/or turning (Figure 1.1).
- Bonding material injected into the hole. Embedded part may be inserted manually or mechanically (Figure 1.2).
- Bonding material poured into the hole and embedded part inserted (Figure 1.3).

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

Operating principles

- Bonded fastener:	placed in cylindrical hole and anchored by bonding the metal parts to the sides of the drilled hole.
- Bonded expansion fastener:	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 bonded fasteners are given in Figure 1.1 to Figure 1.3.

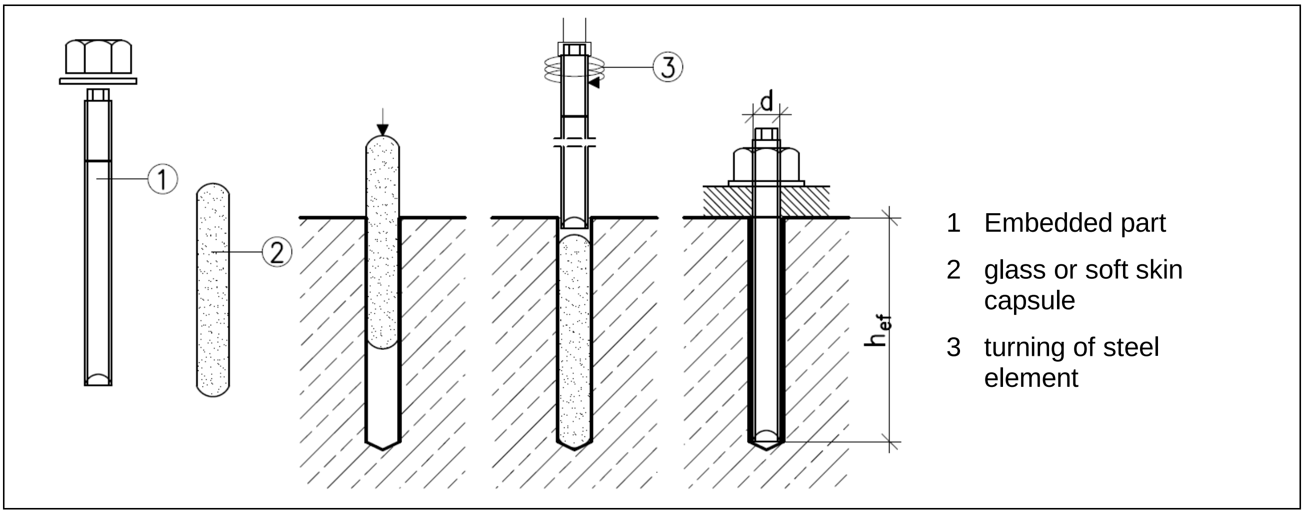


Figure 1.1 Capsule type

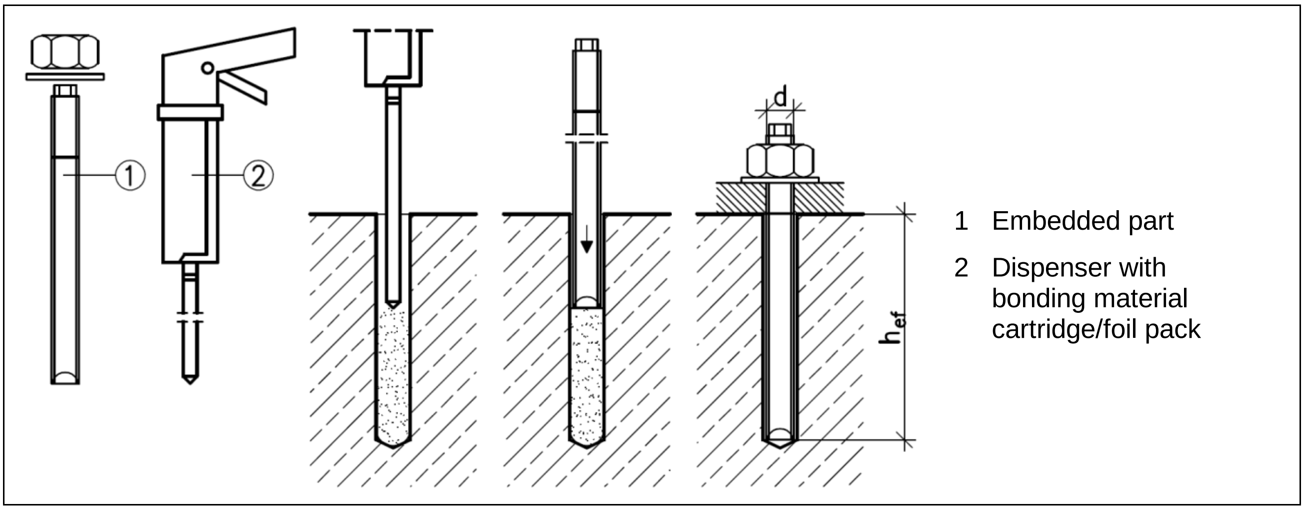


Figure 1.2 Injection type

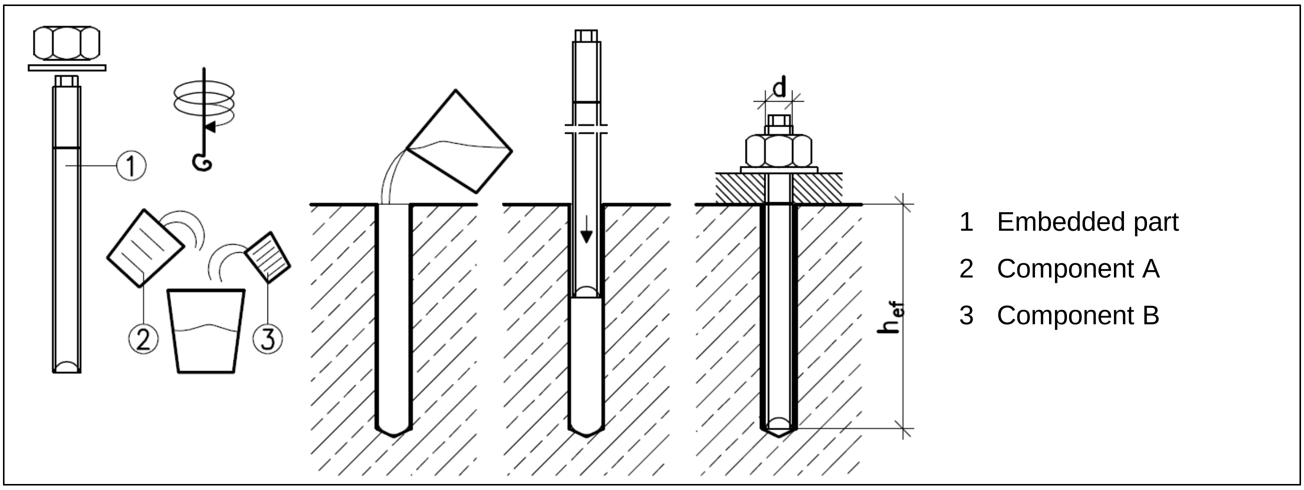


Figure 1.3 Bulk type

In this EAD the assessment is made to determine characteristic values of the bonded fastener for design according to EN 1992-4.

Note 2 For other design provisions 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.).

Note 3 The assessment of post-installed rebar connections with bonding material for design according to EN 1992-1-1:2004 [3] and EN 1992-1-2:2004 [4] is covered by EAD 330087-00-0601. impact

Note 4 The assessment of metal injection fasteners for use in masonry is covered by EAD 330076-00-06.04.

The product is not fully covered by EAD 330499-00-0601.

Additionally to EAD 330499-00-0601 the following new assessments/essential characteristics are added.

- Extension of the intended use for assessment of the fasteners performance for installation under freezing conditions in section 2.2.2.13.
- Intended working life of 100 years and assessment of resistance to combined pull-out and concrete failure (new performances $\tau_{Rk,100}$ and $N_{Rk,100}$) in Annex C.
- Consideration of EN 1993-1-4 [18] for durability of fasteners made of stainless steel.
- Extension of assessment for new performance ψ^0_{sus} (only for working life up to 50 years) in section 2.2.2.6.4.

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

Bonded fastener placed into pre-drilled holes for use in compacted reinforced or unreinforced normal weight concrete without fibres with strength classes in the range C20/25 to C50/60 all in accordance with EN 206 [1].

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

- in uncracked concrete only (Table 1.1, option 7 – 12),
- in cracked and uncracked concrete (Table 1.1, option 1 – 6),
- under static or quasi-static actions,
- under seismic actions (category C1, C2 according to Annex E).

Note 5 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 and/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 suitable for

Concrete condition:

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 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.

Installation direction:

D1 = downward only,

D2 = downward and horizontal installation

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

Installation temperature:

This EAD covers a range of temperature during installation and curing of the bonding material in the concrete base material between minimum installation temperature not lower than -40 °C and the maximum installation temperature not higher than +40°C.

If the manufacturer applies for installation of the fastener under freezing condition he may choose either for standard variation of temperature or rapid variation of temperature (within a 12-hour period from a low of 0 °C or less to a high of +24 °C or more) after installation.

Service temperature:

This EAD covers service temperature ranges of the concrete base material (anchorage base) 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 $+T_{st}$, with a maximum long-term temperature T_{mlt} = 0,6 to 1,0 T_{st}, and a maximum short-term temperature of $T_{mst} \geq 40$°C if applied for by the manufacturer.

Note 6 The maximum short-term temperature T_{st} and the maximum long-term temperature T_{lt} for different temperature range as given in T1 and T2 may be chosen by 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 $h \geq 100$ mm, with $\Delta h \geq 2\, d_0$ and $\Delta h \geq 30$ mm.

The performance characteristics are consistent with the design provisions of EN 1992-4 and are based on a design working life of 50 years and/or 100 years (see 1.2.2).

Note 7 Performance characteristics need to be consistent with the design provisions to achieve the required safety of the fastening application. For other design provisions than given in EN 1992-4 modified or additional performance characteristics may be necessary.

It is assumed that

- the design of an anchorage and the specification of the fastener is under control of an engineer experienced in anchorages and concrete work;
- the fastener installation is executed by trained personnel, ensuring that the MPII and the specifications by the engineer are observed.

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

Fasteners subject to impact loads (e.g. fasteners for the attachment of fall arresting devices) and/or fatigue loads are not covered in this EAD.

Durability of metal parts:

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

(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 EN 1993-1-4 [18], Annex A:

Fasteners made of stainless steel according to Tables A.3 and A.4 in Annex A of EN 1993-1-4 [18] are considered to have sufficient durability for the corresponding Corrosion Resistance Class (CRC).

Options for the intended use

According to the intended use the manufacturer may choose one of the options given in Table 1.1.

Table 1.1 Options for intended use covered by this EAD

<table>
<tr><th>Option</th><th>Cracked concrete</th><th>uncracked concrete</th><th>One value for all concrete strength</th><th>Different values for C20/25 to C50/60</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>Design method [1] DM-x</th></tr>
<tr><td>1</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>×</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] Design method according to EN 1992-4

Use of fastener in fastener groups according to EN 1992-4 [5]:

Use of fastener groups according to EN 1992-4 assumes, that all fasteners of the group show a similar displacement under load. The criteria for load-displacement behaviour are given in sections 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 [5]. This information shall be stated in the ETA.

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 working life of 50 years and/or 100 years[2] when installed in the works (provided that the bonded fastener is subject to appropriate installation (see 1.1). These provisions are based upon the current state of the art and the available knowledge and experience.

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

1.3 Specific terms used in this EAD

1.3.1 Abbreviations

BEF	=	bonded expansion fastener (torque-controlled bonded fastener)
BF	=	bonded fastener
C1	=	seismic performance category C1 (use in design according to EN 1992-4 [5])
C2	=	seismic performance category C2 (use in design according to EN 1992-4 [5])
cv	=	coefficient of variation
DLS	=	Damage limit state (see EN 1998-1 [24])
DM-A	=	design method A according to EN 1992-4
DM-B	=	design method B according to EN 1992-4
DM-C	=	design method C according to EN 1992-4
F	=	Force
MPII	=	manufacturer's product installation instructions
N	=	Normal force
ULS	=	Ultimate limit state (see EN 1998-1 [24])
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 E.1)

---

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

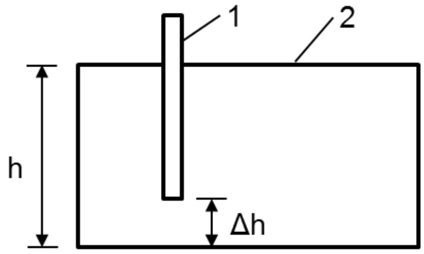
A_5	=	percentage elongation after fracture (measured over a length of 5d)"
A_g	=	cross section area of the concrete member used in a test
A_s	=	relevant stressed cross section of the embedded metal part
A_{sp}	=	Projecting area according to Figure 2.3
c_{cr}	=	characteristic edge distance
$c_{cr,N}$	=	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 embedded part
d_0	=	nominal drill hole diameter
d_{cut}	=	drill bit diameter
d_f	=	diameter of the clearance hole of the fixture
d_{nom}	=	effective diameter of fastener for calculation of concrete edge failure
ds	=	diameter of the reinforcing bar (see Figure E.1)
$f_{c,i}$	=	mean compressive strength of concrete in test series i
f_u	=	mean ultimate steel strength
f_c	=	concrete compressive strength measured on cylinders
$f_{c,cube}$	=	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_{uk}	=	characteristic ultimate strength of the metal part [N/mm²]
f_{yk}	=	characteristic yield strength of the metal part [N/mm²]
h	=	thickness of the concrete member
hiz	=	interaction zone between fastener and concrete
$hltz$	=	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.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 (2.21)

k_{cr}	=	factor for resistance to concrete failure cracked concrete
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 E.2)
ℓ_{db}	=	de-bonding length (see Figure E.2)
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	=	normalisation exponent taking into account the effect of concrete strength on the resistance
n	=	number of tests in a test series
N_{eq}	=	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 metal part at 1,3 T_{inst}
$N_{1,3Tinst,95\%}$	=	95% fractile of pre-stressing force of the embedded metal part 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
$N_{Rk,p,Cx}$	=	characteristic tension pull-out resistance under seismic action reported in the ETA for seismic performance category C1, C2
$N_{Rk,s,Cx}$	=	characteristic steel tension resistance under seismic action reported in the ETA for seismic performance category C1, C2
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 (Figure A.2)
$N_{u,m}$ ($N_{5\%}$)	=	mean (5% fractile of) failure loads 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 bonded fasteners (BF) for fixing the attachment
T_{inst}	=	Installation torque specified by the manufacturer for a bonded expansion fastener (BEF)
t_{fix}	=	thickness of fixture
T_{mlt}	=	maximum long-term temperature
T_{mst}	=	maximum short-term temperature
V_{eq}	=	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
$V_{Rk,s,Cx}$	=	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 metal part
α	=	reduction factor, see equation (A.18)
α_{ref}	=	factor taking into account sensitivity to different concrete batches according to equation (A.11)
α_{setup}	=	factor taking into account the influence of confined test setup
α_1	=	criteria for loss of adhesion, see equation (A.19)
α_2	=	ratio according to equation (2.14), tests at maximum long-term temperature
α_3	=	ratio according to equation (2.15), tests at maximum short-term temperature
α_4	=	ratio according to equation (2.16), 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
$\beta_{cv,C2.x}$	=	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
$\delta(N)$	=	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
rqd. α	=	required value for reduction factor α in the assessment
β_{cv}	=	Reduction factor for large scatter of failure loads
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
δ_{m1}	=	mean fastener displacement after 10^3 crack movements
δ_{m2}	=	mean displacement of fastener determined from the repeated load tests after 10^5 load cycles or the sustained load tests after terminating the tests.
$\delta_{u,adh}$	=	mean displacement in tests at loss of adhesion.
Δh	=	distance from the embedded end of the fastener (1) to the opposite end of the concrete member (2)



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
$\tau_{5\%}$	=	initial characteristic bond strength for equation (2.19)
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
$\tau_{Rk,ucr}$	=	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
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 normalized to minimum concrete strength, according to equation (A.11)

$\tau_{Ru,r,i}$ ($\tau_{5\%,r,i}$)	=	mean (5% fractile) of bond resistance of the corresponding reference test carried out in the same slab i or same batch
$\tau_{Ru,t,i}$ ($\tau_{5\%,t,i}$)	=	mean (5% fractile) of bond strength in test series t in slab i
$\tau_{Ru,m,i,12}$	=	mean bond resistance of reference test with diameter d = 12 mm carried out in the same slab 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
γ_{inst}	=	factor accounting for the sensitivity to installation (used in design according to EN 1992-4)
γ_{Mc}	=	partial factor for concrete failure (to be given in the ETA)
ψ_c	=	increasing factor accounting for concrete strength
$\tau_{Rk,Cx}$	=	characteristic seismic bond resistance reported in the ETA for seismic performance category C1, C2

1.3.3 Indices

21	=	at normal ambient temperature
c	=	concrete
cr	=	cracked concrete
ucr	=	uncracked concrete
LT	=	long-term with respect to assessment of bond strength
mlt	=	maximum long-term temperature of the concrete
conf	=	confined test setup
unconf	=	unconfined test setup
r	=	reference
s	=	steel
mst	=	maximum short-term temperature of the concrete
sust	=	sustained (permanent)
t	=	test
100	=	working life of 100 years according to Annex C.

1.3.4 Definitions

anchor	=	historically synonymous to fastener
component installation temperature range	=	temperature range of the bonding material and embedded part immediately prior to installation.
confined test setup	=	close spacing of the support according to Annex D, Figure D.4
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	=	metal element made of steel or malleable iron post-installed into hardened concrete and used to transmit applied load; as defined in EN 1992-4 [5]
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 metal element into the bonding material (for bulk type fasteners);
	=	maximum time from start of injection to end of insertion of the metal element into the bonding material (for injection type fasteners);
	=	maximum time for setting (insertion of the metal element) (for capsule type fasteners);
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, slab
unconfined test setup	=	wide spacing of the support according to Annex D, Figure D.3
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 shows how the performance of bonded fasteners for use in concrete is assessed in relation to the essential characteristics.

Table 2.1. Essential characteristics of the product and methods and criteria for assessing the performance of the product in relation to those essential characteristics

No	Essential characteristic		Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability				
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	τ_{Rk} and/or $\tau_{Rk,100}$ [N/mm²], ψ^0_{sus} [-] (BF)
			C.5	$N_{Rk,p}$ and/or $N_{Rk,p,100}$ [kN] (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 and spacing		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	Displacements under short-term and long-term loading		2.2.10	δ_0, δ_∞ [mm or mm/(N/mm²)]
Characteristic resistance and displacements for seismic performance categories C1 and C2				
12	Resistance to tension load, displacements	C1	2.2.11	$N_{Rk,s,C1}$ [kN] (all) $\tau_{Rk,C1}$ [N/mm²] (BF) $N_{Rk,p,C1}$ [kN] (BEF)
		C2	2.2.12	$N_{Rk,s,C2}$ [kN] (all) $\tau_{Rk,C2}$ [N/mm²] (BF) $N_{Rk,p,C2}$ [kN] (BEF) $\delta_{N,C2}$ [mm] (all)
13	Resistance to shear load, displacements	C1	2.2.13	$V_{Rk,s,C1}$ [kN] (all)
		C2	2.2.14	$V_{Rk,s,C2}$ [kN] (all) $\delta_{V,C2}$ [mm] (all)
14	Factor for annular gap		2.2.15	α_{gap} [-]
Basic Works Requirement 3: Hygiene, health and the environment				
15	Content, emission and/or release of dangerous substances		2.2.16	Description

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 section 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 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 bonded expansion fasteners 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 test

The characteristic resistance to steel failure may be calculated for steel elements with constant strength over the length of the element as given in equation (2.1). The smallest cross section in the area of load transfer applies.

$$N_{Rk,s} = A_s \cdot f_{uk} \quad [N] \qquad (2.1)$$

If the steel strength differs along the length of the element, calculate the design steel capacity for the specified steel strengths and the corresponding nominal stressed cross sections according to equation (2.1) taking into account the recommended partial factor for steel resistance $\gamma_{M,s}$ according to EN 1992-4, Table 4.1. Take the minimum of these design steel capacities and determine the characteristic resistance to steel failure. The characteristic resistance and the corresponding partial factor $\gamma_{M,s}$ shall be stated in the ETA.

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.

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.8).

2.2.1.2 Installation torque (test series N2)

Purpose of the test

The tests are performed in order to verify that steel failure (yielding) of the steel element may not occur by application of a torque, accounting for corresponding tolerances.

Test conditions

The tests shall be performed according to Annex D, D.3.5.

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

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Annex D, Figure D.5. The diameter of the clearance hole in the fixture shall correspond to the values given in Table 2.5.

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 ~~moment~~ 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 metal part.
2. The 95% of tension force generated in the torque tests at T = 1,3 T_{inst} (1,3 max T_{inst}, respectively) shall not be larger than the characteristic resistance for pull-out failure for minimum embedment depth.

$$N_{Rk,p} = \pi \cdot d \cdot \min h_{ef} \cdot \tau_{Rk,ucr} \quad (2.2)$$

3. The tension force generated in the torque test shall be smaller than the concrete cone capacity for uncracked concrete C20/25 according to EN 1992-4 for minimum embedment depth.
4. At the end of the test, the connection shall be capable of being unscrewed.

2.2.2 Resistance to combined pull-out and concrete failure

2.2.2.1 Reference (test series R1 to R4)

Purpose of test

These tests are performed to establish a reference for the assessment of the test series for resistance to pull-out failure. These tests may also be used to determine the normalization factor for the normalization to nominal concrete strength. Furthermore, for Options 8, 10 and 12 according to Table 1.1 the test series R2 is used to assess the functioning in high strength concrete.

Test conditions

The reference tests shall be carried out with the same diameter of the fastener and in the same slab or same concrete batch as in the corresponding tests for resistance to pull-out failure.

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

In addition, reference tension tests (R1) on medium size (M12) as described in Annex AA.2 have to be performed to take into account the possible influence of different concrete parameters (in various batches) on the failure load.

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 1.1).

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 paragraphs A2.3.2 and A2.3.4, respectively.
- If the basic tension tests with unconfined test setup (2.2.2.2) are not performed, determine the increasing factor $\psi_{c,50}$ according to equation (A.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 paragraphs A2.3.2 and A2.3.4, respectively to be used in 2.2.2.14 / 2.2.2.15.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 15% (cv_F > 15%), determine the reduction factor for large scatter $ß_{cv}$ according to A2.3.5.
- The test results in high strength concrete R2 or R4 may not be smaller than the corresponding test series in low strength concrete R1 or R3 (equation (A.7): $\psi_{c,xx} \geq 1,0$).

Load displacement behaviour

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 25 %.

The assessment for Options 8, 10 and 12 according to Table 1.1 regarding the functioning in high strength concrete is performed as follows:

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.
- Determine the 5% fractile of the failure loads $N_{5\%}$ [kN] and bond strength $\tau_{5\%}$ [N/mm²], converted to the nominal concrete strength to be used in 2.2.2.14 / 2.2.2.15.
- 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 A2.3.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A1.1, line R1.
- Use the reduction factor α together with rqd. α = 1,0 in equation (2.19).

Load displacement behaviour

- Determine the reduction factor α_1 according to Annex A.
- Determine the mean value of the failure loads $N_{u,m}$ [kN] of the test 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

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

Purpose of the test

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

- basic characteristic bond strength $\tau_{5\%}$
- the increasing factors accounting for concrete strength ψ_c
- short-term displacement δ_{NO}

This test series may be omitted if the characteristics given above are determined by confined test series R1 to R4 and using the default reduction factors α_{setup} as follows:

- α_{setup} = 0,75 for confined basic tension tests in uncracked concrete (test series R1 and R2)
- α_{setup} = 0,70 for confined basic tension tests in cracked concrete (test series R3 and R4)

Test conditions

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

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 A2.3.2 and A2.3.4, respectively.
- Determine the increasing factor $\psi_{c,50}$ according to equation (A.7).
- 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 A2.3.2 and A2.3.4, respectively.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 15 % (cv_F > 15 %), determine the reduction factor for large scatter $ß_{cv}$ according to A2.3.5.

Load displacement behaviour

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50 % of the failure load are larger than 0,4 mm, cv_δ shall not exceed 25 %.

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

Purpose of test

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 an assessment in uncracked concrete only (option 7-12).

Test conditions

The tests are carried out in low strength cracked concrete C20/25 (test series B10) and high strength cracked concrete C50/60 (test series B11), with a crack width of Δw = 0,5 mm. The tests shall be carried out with confined test setup according to Annex D.

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 A2.3.2 and A2.3.4, 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 A2.3.2 and A2.3.4, respectively.
- 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 A2.3.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1 line R3 for tests in C20/25 and according to Table A.1 line R4 for tests in C50/60.
- Use the reduction factor α together with rqd. α = 0,8 in equation (2.19).

Load displacement behaviour

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

2.2.2.4 Repeated loads (test series B12)

Purpose of the test

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

The tests may be omitted for fasteners qualified for cracked concrete (option 1-6 according to Table 1.1).

Test conditions

The tests shall be carried out in uncracked concrete C20/25 according to Annex D. The tests are performed as confined tests with medium diameter size M12 or smallest size if that is larger than M12.

The maximum load N_{max} on the fastener shall be calculated as given in equation (2.3) and the minimum load N_{min} is calculated according to equation (2.4).

$$N_{max} = \frac{1{,}1 \cdot \tau_{Rk,ucr} \cdot \pi \cdot d \cdot h_{ef}}{1{,}5 \cdot \gamma_{inst}} \cdot \frac{1}{\alpha_2} \cdot \frac{1}{\alpha_3} \cdot \frac{1}{\alpha_4} \quad (2.3)$$

$$N_{min} = \max (0{,}25\ \tau_{Rk,ucr} \bullet \pi \cdot \bullet \cdot d \bullet h_{ef};\ N_{max} - A_s \bullet \Delta\sigma_s) \quad (2.4)$$

where

$\Delta\sigma_s$ = 120 N/mm²

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

Assessment

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, repeat the test with load values N_{max} and N_{min} determined based on a reduced value $N_{max,red}$ until the requirements are met. In this case determine $\alpha_p = N_{max,red} / N_{max}$. Calculate the reduction factor according α_p to A2.3.7.

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 paragraphs A2.3.2 and A2.3.4, 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 A2.3.2 and A2.3.4, respectively.
- 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 A2.3.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1 line R1.
- Use the reduction factor α together with rqd. α = 1,0 in equation (2.19).

Load displacement behaviour in the residual load test

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

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

Purpose of test

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 in the range covered by this EAD. The test series may be omitted for an assessment in uncracked concrete only (option 7-12).

Test conditions

The tests shall be carried out according to Annex D in concrete C20/25. The constant tension load N_p shall be calculated from equation (2.5). The sustained load N_p shall be applied with unconfined test setup.

$$N_p = \frac{0{,}75 \cdot \tau_{Rk,cr} \cdot \pi \cdot d \cdot h_{ef}}{1{,}5 \cdot \gamma_{inst}} \cdot \frac{1}{\alpha_2} \cdot \frac{1}{\alpha_3} \cdot \frac{1}{\alpha_4} \qquad (2.5)$$

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

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

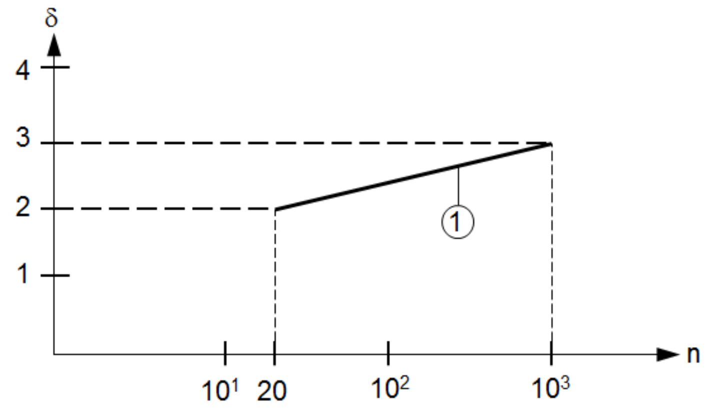
Assessment

Displacements during crack cycles

In each test the rate of increase of fastener displacements, plotted in a half-logarithmic scale (see Figure 2.1), 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 to 20 tests:	$\delta_{20} \leq 2$ mm; one tests is allowed to 3 mm
	$\delta_{1000} \leq 3$ mm; one tests is allowed to 4 mm
> 20 tests:	$\delta_{20} \leq 2$ mm; 5% of tests are allowed to 3 mm
	$\delta_{1000} \leq 3$ mm; 5% of tests are allowed to 4 mm

Note 8 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 2.1 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, the test series shall be repeated with a reduced tension load $N_{p,red}$ until the requirements are fulfilled. Calculate the reduction factor α_p according to A2.3.7.

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 A2.3.2 and A2.3.4, 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 A2.3.2 and A2.3.4, respectively.
- 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 A2.3.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1 line R3.
- Use the reduction factor α together with rqd. α = 0,9 in equation (2.19).

Load displacement behaviour in the residual load tests

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

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

Purpose of the test

The tests are performed to check the creep behaviour of the loaded fastener at normal ambient temperature (Test series B14) and at maximum long-term temperature (test series B15). Based on these tests for each temperature range the factor $\psi_0$sus 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 in uncracked concrete C20/25, both at normal ambient temperature and maximum long-term temperature with medium diameter size M12 or smallest size if that is larger than M12 as specified by the manufacturer.

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

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

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

Load fastener to $N_{sus,21}$ according to equation (2.6):

$$N_{sust,21} \geq \frac{1{,}1 \cdot \tau_{Rk,ucr,21} \cdot \pi \cdot d \cdot h_{ef}}{1{,}5 \cdot \gamma_{inst}} \cdot \frac{1}{\alpha_2} \cdot \frac{1}{\alpha_3} \cdot \frac{1}{\alpha_4} \qquad (2.6)$$

where

$\tau_{Rk,ucr,21}$ = characteristic bond strength as given in the ETA for use in uncracked concrete for normal ambient temperature

For BEF replace the term ($\tau_{Rk,ucr,21} \bullet \pi \bullet d \bullet h_{ef}$) by $N_{Rk,ucr,21}$.

Maintain the load at N_{sust} (maximum variation: -5 %) and maintain temperature at normal ambient temperature and measure the displacements until they appear to have stabilised, but at least for three months (in special justified cases the TAB may allow a shorter duration for the sustained load test). 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 at normal ambient temperature.

b) Test at maximum long-term temperature (test series B15)

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.

Load fastener to $N_{sust,mlt}$ according to equation (2.7):

$$N_{sust,mlt} \geq \frac{1{,}1 \cdot \tau_{Rk,ucr,mlt} \cdot \pi \cdot d \cdot h_{ef}}{1{,}5 \cdot \gamma_{inst}} \cdot \frac{1}{\alpha_3} \cdot \frac{1}{\alpha_4} \qquad (2.7)$$

where

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

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

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) applies.

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 at maximum long-term temperature.

Assessment

2.2.2.6.1 Displacements in sustained load tests

The displacements measured in the tests have to be extrapolated according to equation (2.8) (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 (2.8) 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 $\delta_{u,adh}$ 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).

$$\delta(t) = \delta_o + a \bullet t^b \qquad (2.8)$$

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, the test may be repeated with modified parameters (e.g. reduced load $N_{sust,red}$ or reduced temperature). If the test is repeated with a reduced load calculate the reduction factor α_p according to A2.3.7.

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

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 A2.3.2 and A2.3.4, 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 A2.3.2 and A2.3.4, respectively.
- 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 A2.3.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1 line R6 having the same curing time.
- Use the reduction factor α together with rqd. α = 0,9 in equation (2.19).

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 α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

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

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 assessed for working life of 50 years 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 every temperature range requested by the manufacturer according to 1.2.1 for the maximum long-term temperature. Please note that normal ambient temperature corresponds to maximum long-term temperature of temperature range T1.

If the displacement criteria for the extrapolated displacements (2.2.2.6.1) and residual load test requirements (2.2.2.6.2 and 2.2.2.6.3) are fulfilled, determine the factor ψ^0_{sus} with the applied constant tension load normalized to C20/25 using equation (2.9) to (2.12). The conversion of failure loads to the nominal concrete strength shall be done according to paragraph A2.3.2.

The bond stress τ_{sus} applied in the sustained load tests, normalized to the nominal concrete strength, is obtained as given in equation (2.9):

$$\tau_{sus} = \frac{N_{sus}}{\pi \cdot d \cdot h_{ef}} \cdot \min\left(1; \frac{\alpha}{0{,}9}\right) \qquad (2.9)$$

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

N_{sus} = sustained load applied in sustained load tests at maximum long-term temperature, which meet the criteria, normalized to C20/25 concrete strength (according to section A2.3.2)

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 meet the criteria.

$$\tau^0_{Rk,LT} = \tau_{sus} \tag{2.10}$$

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:

$$\tau_{Rk,LT} = \tau^0_{Rk,LT} \bullet \alpha_3 \bullet \alpha_4 \bullet k_{sus} \bullet \alpha_{setup} \bullet min\, \beta_{CV} \tag{2.11}$$

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 section 2.2.2.9, equation (2.15)

α_4 = reduction factor according to section 2.2.2.12, equation (2.16)

α_{setup} = 0,75, reduction factor for uncracked concrete according to section 2.2.2.2.

k_{sus} = 1,135

min β_{CV} = minimum of reduction factors β_{CV} according to section A2.3.5, equation (A.13)

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 (2.12).

$$\psi^0_{sus} = \frac{\tau_{Rk,LT}}{\tau_{Rk,ucr}} \bullet 1{,}15 \leq 1{,}0 \tag{2.12}$$

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 9 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.

Note 10 The bond strength is determined at the end of the provided service life. Therefore, the partial factor can be determined assuming a reduced reliability index β = 3,2 with $\gamma_{c,LT}$ = 1,3 compared to the normal value for RC 2, 50 years of service life, β = 3,8 with γ_c = 1,5. The factor 1,15 = 1,5/1,3 = $\gamma_c/\gamma_{c,LT}$ accounts for this reduction.

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

Purpose of the test

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 medium diameter size M12 or smallest size if that is larger than M12. 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 180 mm to 300 mm (15d to 25d) or a steel encased concrete cylinder shall be used and splitting of concrete shall be prevented.

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.

Load fastener to N_{sust} according to equation (2.13):

$$N_{sust} = \frac{\tau_{Rk,ucr,60} \cdot d \cdot \pi \cdot h_{ef}}{1{,}5 \cdot 1{,}4 \cdot \gamma_{inst}} \tag{2.13}$$

where

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

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

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).

If the test is interrupted, 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.

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

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, the test may be repeated with a reduced load $N_{sust,red}$. In this case calculate the reduction factor α_p according to A2.3.7.

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 A2.3.2 and A2.3.4, 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 A2.3.2 and A2.3.4, respectively.
- 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 A2.3.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1 line R7 having the same curing time.
- Use the reduction factor α together with rqd. α = 0,9 in equation (2.19).

Load displacement behaviour

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

2.2.2.8 Installation directions (test series B17, E12)

Purpose of the test

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 manufacturer allows in the MPII all installation directions (D3), tension tests are needed with metal parts installed vertically upwards only. If the manufacturer allows horizontal and vertical downward only (D2), tension tests have to be done with metal parts 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.

Perform the tests with confined test setup. The tests are performed in low strength concrete C20/25 with largest diameter size applied for by the manufacturer. The tension tests are performed according to Annex D.

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 A2.3.2 and A2.3.4, 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 A2.3.2 and A2.3.4, respectively.
- 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 A2.3.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1 line R1.
- Use the reduction factor α together with rqd. α = 0,9 in equation (2.19).

Load displacement

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

2.2.2.9 Increased temperature (test series B2 and B3)

Purpose of the test

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 requested temperature ranges) 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 C20/25 at maximum long-term temperature and maximum short-term temperature a for each temperature range applied for.

They may be carried out in slabs 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 M12 (or smallest in range if smallest size is larger than M12).

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.

While maintaining the temperature of the test member in the area of the embedded part at a distance of 1 d from the concrete surface at ± 2 K of the required value, carry out confined tension test.

Note 11 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:

The influence of increased temperature is determined based on a comparison of mean failure loads as well as 5%-fractile of failure loads.

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 (2.14):

$$\alpha_2 = \min\left(\frac{N_{Ru,m,mlt}}{N_{Ru,m,r}};\frac{N_{u,5\%,mlt}}{N_{u,5\%,r}}\right) \le 1{,}0 \qquad (2.14)$$

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 (2.15):

$$\alpha_3 = \min\left(\frac{N_{Ru,m,mst}}{0{,}8 \cdot N_{Ru,m,mlt}}; \frac{N_{u,5\%,mst}}{0{,}8 \cdot N_{u,5\%,mlt}}\right) \leq 1{,}0 \qquad (2.15)$$

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

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 %.

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 A2.3.2 and A2.3.4, 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 A2.3.2 and A2.3.4, respectively.
- 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 A2.3.5.

Load displacement

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 25%.

2.2.2.10 Minimum installation temperature (test series B4)

Purpose of the test

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.

Test conditions

The tests are performed in uncracked concrete C20/25. For test member dimensions, see "Increased temperature" section 2.2.2.9.

Perform the test with medium size M12 (or smallest in range if smallest size is larger than M12).

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 embedded part 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, 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 embedded parts shall be conditioned to the minimum installation temperature.

Note 12 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, 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 embedded part at a distance of 1d from the concrete surface at the specified lowest installation temperature ± 2K.

Note 13 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.

Note 14 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

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 shall be at least equal to the corresponding values measured in tests 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.

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 %.

<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 paragraphs A2.3.2 and A2.3.4, 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 A2.3.2 and A2.3.4, respectively.
- 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 A2.3.5.

<u>Load displacement</u>

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 25%.

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 test

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

Test conditions

Perform confined tension tests in uncracked concrete C20/25 at normal ambient temperature at the corresponding minimum curing time specified by the manufacturers. Test with medium diameter size M12 or smallest size if that is larger than M12.

Note 15 One series of reference tests R1 may be performed at minimum curing time.

Number of tests: n ≥ 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 and basic tension tests according to Table A.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 paragraphs A2.3.2 and A2.3.4, 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 A2.3.2 and A2.3.4, respectively.
- 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 A2.3.5.

Load displacement

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 25 %.

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 test

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

Test conditions

Perform the test with medium diameter size M12 or smallest size if that is larger than M12.

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

One fastener (medium size M12 or smallest size if the smallest size is larger than M12) shall be installed per cylinder or cube on the central axis in dry concrete according to the MPII. The embedded part shall be made out 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 $\pm$ 3 °C / relative humidity 50 $\pm$ 5%) for 2000 hours are necessary.

High Alkalinity (test series B18)

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.

Sulphurous atmosphere (test series B19)

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 the theoretical sulphur dioxide concentration shall be 0,67 % at beginning of a cycle. 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.

Slice tests

After removal from storage the thickness of the slices is measured and the metal segments of the bonded fasteners 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.

Reference test series (tests series R8)

The reference test series R8 shall be performed under the same test conditions but the fasteners shall be kept unloaded and stored under normal ambient conditions.

Assessment

It shall be shown that the bond strength of the slices stored in an alkaline liquid is at least as high as that of the bond strength of the comparison tests on slices stored under normal conditions.

Determine α_4 according to equation (2.16).

$$\alpha_4 = \min\left(\frac{\tau_{Ru,m,B18}}{\tau_{Rum,r}};\frac{\tau_{Ru,m,B19}}{0,9 \cdot \tau_{Rum,r}}\right) \leq 1,0 \qquad (2.16)$$

The reference bond strength $\tau_{um,r}$ is gained in the test series Table A.1, line R8.

The bond strength in the slice tests shall be calculated according to equation (2.17).

$$\tau_u = \frac{N_u}{\pi \cdot d \cdot h_{sl}} \qquad (2.17)$$

2.2.2.13 Installation at freezing condition (test series B20)

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

Purpose of the test

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 declared in the ETA together with the corresponding curing time (test series B4).

Test conditions – standard test (96 hours test)

Perform the tests in uncracked concrete C20/25 with medium diameter of the steel element d = 12 mm or smallest diameter, if that is larger than 12 mm, as specified by the manufacturer. A thermocouple inserted into the test member may be used to confirm temperature of the 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} (maximum variation: -5 %) as given by Equation (2.6) with confined test setup. Raise the temperature of the test chamber at a constant rate to normal ambient temperature over a period of 72 to 96 hours while monitoring the displacement response for each fastener.

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, 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 calculate the reduction factor α_p according to A2.3.7.

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."*

Test conditions – 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, perform the following test.

Perform the tests in uncracked concrete C20/25 with medium diameter of the steel element d = 12 mm or smallest diameter, if that is larger than 12 mm, as specified by the manufacturer. The concrete test member shall have maximum dimensions of 750 mm by 450 mm by 300 mm. Alternatively, a 300 mm high cylinder with maximum diameter of 330 mm may be used. A thermocouple inserted into the test member may be used to confirm the temperature at the time of testing.

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 (2.6) or 1,5 kN to the fastener prior to zeroing displacement readings. Then increase the load on the fastener to a constant load N_{sust} as given by Equation (2.6)[4], 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. 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, the test shall be discontinued and the test may be repeated with modified parameters (e.g. reduced load $N_{sust,red}$ or increase the minimum installation temperature). If the test is repeated with a reduced load, calculate the reduction factor α_p according to A2.3.7.

4 If the sustained load in test series B14 is reduced to $N_{sust,red}$ (see 2.2.2.6), perform the test series with the same load as successfully performed

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

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 A2.3.2 and A2.3.4, 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 A2.3.2 and A2.3.4, respectively.
- 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 A2.3.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1, line R6 c) having the same curing time and the same temperature history.
- Use the reduction factor α together with rqd. α = 0,9 in equation (2.19).

Load displacement behaviour in the residual load tests

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

Displacement under sustained load for rapid variation of temperature:

- The condition given in equation (2.18) shall be satisfied.

$$\delta_{N\infty,m} \le \delta_{u,adh,m} - \left(\delta_{dt,42d,m} - \delta_{sust,42d,m}\right) \quad (2.18)$$

where

$\delta_{N,\infty,m}$ mean value of the extrapolated displacements in the sustained load test at normal ambient temperature (test series B14)

$\delta_{u,adh,m}$ mean displacement in the tension tests at loss of adhesion according to A.2.4.1.

$\delta_{dt,42d,m}$ 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).

Text proposal to be given in the ETA for the case of assessment of both, standard and 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 bonded fasteners

The characteristic bond resistance τ_{Rk} shall be determined according to equation (2.19).

$$\tau_{Rk} = \tau_{5\%} \bullet \alpha_{setup} \bullet \min ß_{cv} \bullet \min \alpha_p \bullet \min \{1; \min \frac{\alpha}{rqd.\alpha}; \min \alpha_1\} \bullet \alpha_2 \bullet \alpha_3 \bullet \alpha_4 \quad (2.19)$$

For cracked concrete apply min α_p of sustained load tests, freeze thaw tests and crack cycling tests.

For uncracked concrete apply min α_p of sustained load tests, repeated load tests and freeze thaw tests.

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.

Also, a function with no more than one extremum is possible if all test results show this product behaviour; e.g. it does not come from the influence of the different concrete batches.

The characteristic bond resistance shall be rounded according to Table 2.2.

The factor ψ_c can be used as an increasing factor to express the bond strength for different concrete strength classes.

Table 2.2 Rounding steps for characteristic bond resistance

τ_{Rk} [N/mm²]	step $\Delta\tau_{Rk}$ [N/mm²]	example
≤ 10	0,5	4 / 4,5 / 5 / 5,5 …
> 10 ≤ 20	1,0	12 / 13 / 14 / 15…
> 20	2,0	26 / 28 / 30 / 32 …

2.2.2.15 Determination of the characteristic resistances for bonded expansion fasteners

The determination of the characteristic resistance shall be given in forces instead of bond strength as for bonded fasteners (τ_{Rk}, in N/mm²) as given in equation (2.20).

$$N_{Rk,p} = N_{5\%} \bullet \min ß_{cv} \bullet \min \alpha_p \bullet \min \{1; \min \frac{\alpha}{rqd.\alpha}; \min \alpha_1\} \bullet \alpha_2 \bullet \alpha_3 \bullet \alpha_4 \text{ [kN]} \quad (2.20)$$

2.2.3 Resistance to concrete cone failure

2.2.3.1 Single Fasteners

The design according to EN 1992-4 needs the factors $k_{ucr,N}$ and $k_{cr,N}$. The following factors can be taken without further testing. They are related to concrete cylinder strength.

$k_{ucr,N}$ = 11

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

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

2.2.3.2 Minimum embedment depth (test series A6)

Purpose of the test

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.

Note 16 Groups of fasteners with short embedment depth may not create the calculated resistance of concrete cone capacity according to EN 1992-4 with the factors given in 2.2.3.1 which was derived for larger embedment depth.

The test series may be omitted if the default minimum embedment depth according to Table 2.3 is kept. If the manufacturer applies for smaller embedment depth but still larger or equal to $h_{ef,min}$ = 4d, the test series according to Table A.1 line A6 are required.

Table 2.3 Default minimum embedment depth

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

Note 17 In cases of such lower 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 minimum embedment depth $h_{ef,min}$ as a quadruple group with a spacing $s_{cr,N}$ = 2 $c_{cr,N}$. The tension test until failure shall be carried out as unconfined test setup in uncracked concrete C20/25 in accordance with Annex D. At least 20 tests with quadruple fastener groups shall be performed with each 5 tests with the smallest 4 sizes.

Assessment

Determine the mean failure load of the quadruple fasteners group in the test series. Determine the theoretical concrete cone capacity $N_{Rk,c}$ according to EN 1992-4 equation (7.1) for the group of fasteners as the reference. For assessment according to section A2.3.7 replace in equation (A.18) $F_{u.5\%,r}$ by $N_{Rk,c}$.

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 2.3 without further testing)

where

$N_{Rk,c} / 0,75$ = calculated mean value of concrete cone failure according to EN 1992-4 with cv = 15%, k = 1,645: (1-0,15 • 1,1645) = 0,75

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

Purpose of the test

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 C20/25 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 Annex D, section D.3.3.1.

If not requested otherwise by the manufacturer test with

- Edge distance $c = c_{min} = 1,5\ h_{ef}$.
- Thickness of concrete member $h = h_{min}$ = max {100 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, line A1) for the same concrete strength. If this condition is not fulfilled, the edge distance shall be increased accordingly.

The characteristic resistance to splitting $N^0_{Rk,sp}$ shall be determined in the design provisions as the minimum of the basic characteristic resistance to pull-out failure $N^0_{Rk,p}$ and the basic characteristic resistance to concrete failure $N^0_{Rk,c}$, i.e. min {$N^0_{Rk,p}$; $N^0_{Rk,c}$}.

In the ETA the value for $N^0_{Rk,sp}$ shall be given as the text “min {$N^0_{Rk,p}$; $N^0_{Rk,c}$} according to EN 1992-4”. For bonded expansion fastener the text should read “min {$N_{Rk,p}$; $N^0_{Rk,c}$} according to EN 1992-4”.

2.2.5 Robustness

Purpose of the test

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 in uncracked concrete C20/25. The fasteners are installed with the maximum embedment depth $h_{ef,max}$ defined by the manufacturer. To avoid steel failure, but still account properly for the installation aspects for $h_{ef,max}$ the procedure given in section Annex AA.2 shall be applied.

Additional test conditions for the specific test series B6 to B9 are given in the following subsections. 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. The conditions are also valid for other drilling techniques, which require different methods of bore hole cleaning (e.g. flushing for diamond drilled holes).

Assessment

The assessment for the test series B6 to B9 is carried out according to A2.3.2 accounting for the normalization to the nominal concrete strength. 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.

2.2.5.1 Reference test series (test series R5)

Purpose of the test

The test series is needed as reference for comparison of test results in test series B6 to B9.

Test conditions

The tests shall be performed with fastener sizes s/m/l (see Table A1.2) with maximum embedment depth in uncracked concrete C20/25. To avoid steel failure, see Figure A2.1. 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 defined by the manufacturer. Clean the drill hole according to the MPII. Place the bonding material and insert the metal part in accordance with the MPII.

Perform a confined tension test according to Annex D.

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 A2.3.5.

Load displacement behaviour

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 25 %.

2.2.5.2 Robustness in dry substrate (test series B6)

Purpose of the test

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.2) with maximum embedment depth in uncracked concrete C20/25. To avoid steel failure, see Figure A.1. The tests shall be performed in dry concrete (equilibrium moisture content).

Drill downwards to the maximum embedment depth defined by the manufacturer.

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, 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, the same procedure (including requirements and corresponding reduced operations) applies. If the vacuum cleaning is part of the drilling process, 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 metal part 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 A2.3.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1 line R5.
- Determine the robustness factor γ_{inst} according to Table 2.4.
- If $\alpha < 0,70$ use the reduction factor α together with rqd. $\alpha = 0,70$ in equation (2.19) and $\gamma_{inst} = 1,4$.

Load displacement behaviour

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

2.2.5.3 Robustness in water saturated (wet) substrate (test series B7)

Purpose of the test

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.2) with maximum embedment depth in uncracked concrete C20/25. To avoid steel failure, see Figure A.1.

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

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

1. A pilot hole is drilled in the concrete substrate to the recommended depth.
2. The pilot hole is filled with water and remains flooded 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 18 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.

If methods other than those described above are used it shall be shown by methods that the concrete in the area of the anchorage is water saturated (e.g. concrete is stored under water immediately after stripping 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, 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, the same procedure (including requirements and corresponding reduced operations) applies. If the vacuum cleaning is part of the drilling process, 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.

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 A2.3.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1 line R5.
- Determine the robustness factor γ_{inst} according to Table 2.4.
- If α < 0,65 use the reduction factor α together with rqd. α = 0,65 in equation (2.19) and γ_{inst} = 1,4.

Load displacement behaviour

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

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

Purpose of the test

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.2) with maximum embedment depth in uncracked concrete C20/25. To avoid steel failure, see Figure A.1.

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, 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, the same procedure (including requirements and corresponding reduced operations) applies. If the vacuum cleaning is part of the drilling process, 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 embedded metal part as described in 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 A2.3.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1 line R5.
- Determine the robustness factor γ_{inst} according to Table 2.4.
- If α < 0,65 use the reduction factor α together with rqd. α = 0,65 in equation (2.19) and γ_{inst} = 1,4.

Load displacement behaviour

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

2.2.5.5 Robustness of mixing technique (test series B9)

Purpose of the test

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 or static mixers of injection type systems according to Figure 1.2.

Test conditions

Perform the test with medium diameter size M12 or smallest size if that is larger than M12 with maximum embedment depth in uncracked concrete C20/25. To avoid steel failure, see Figure A.1.

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%), determine the reduction factor for large scatter $ß_{cv}$ according to A2.3.5.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1 line R5.
- Determine the robustness factor γ_{inst} according to Table 2.4.
- If α < 0,70 use the reduction factor α together with rqd. α = 0,70 in equation (2.19) and γ_{inst} = 1,4.

Load displacement behaviour

- Determine the reduction factor α_1 according to Annex A.
- 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 displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

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 each test series B6 to B9 as applied by the manufacturer the factor γ_{inst} shall be determined according to Table 2.4 by comparing the factor α with the value of rqd α for the specific test. The largest resulting factor γ_{inst} applies.

Table 2.4 Values of rqd. α in the sensitivity to robustness tests for bonded fasteners

factor γ_{inst}	rqd. α for tests according to Table A.1, respectively	
	lines B6, B9, E1, E2	lines B7, B8, E3, E4
1,0	≥ 0,95	≥ 0,90
1,2	≥ 0,80	≥ 0,75
1,4	≥ 0,70	≥ 0,65

2.2.6 Minimum edge distance and spacing (test series B1)

Purpose of the test

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, 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 Annex D, section D.3.3.1 in uncracked concrete C20/25 with the embedment depth requested by the manufacturer. For bonded fasteners with several embedment depths (variable embedment depth) 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}:

$c_{min} \geq \max\{35\text{ mm}; 4\ d_0\}$

$s_{min} \geq \max\{35\text{ mm}; 4\ d_0\}$

$h_{min} \geq h_{ef} + \max\{30\text{ mm}; 2\ d_0\}$

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

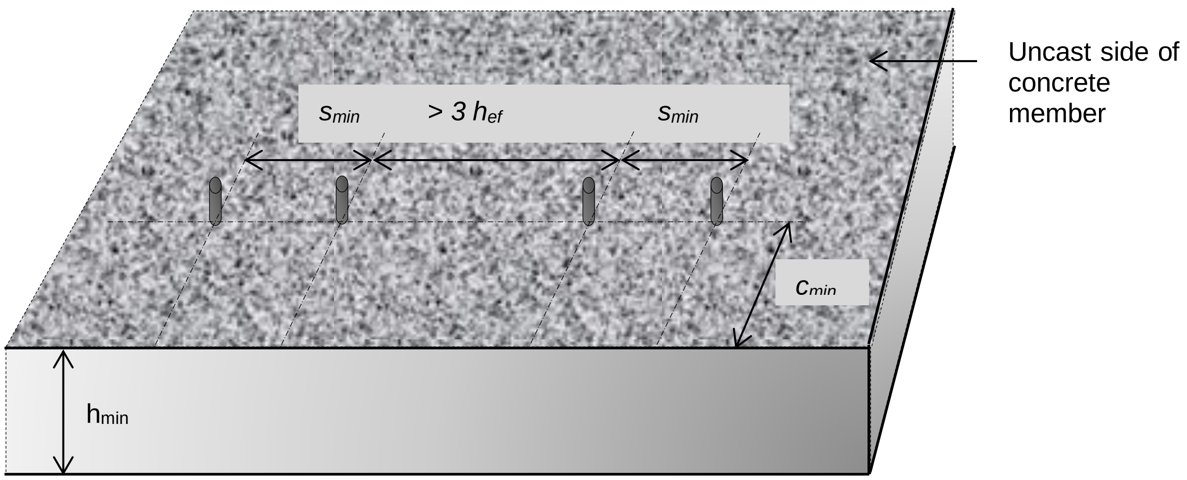


Figure 2.2 Installation of fasteners at the edge of concrete member

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 section A2.3.5) at which a hairline crack has been observed at one fastener of the double fastener group, shall fulfil equation (2.21).

$$T_{5\%} \geq k \cdot \max T_{inst} \, (f_c / f_{c,t})^{0,5} \quad \text{(for concrete failure)} \qquad (2.21)$$

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

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

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 torqueing and the ratio splitting force to pre-stressing force. Pre-stressing force and splitting force may be measured in the tests (see Annex D).

Note 19 If steel failure occurs in this test series, 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, the minimum edge distance and 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.
- Calculate k from equation (2.21) as tested
- Calculate A_{sp} with enlarged c_{min} and/or s_{min} and verify A_{sp} > rqd. k / k $A_{sp,t}$.

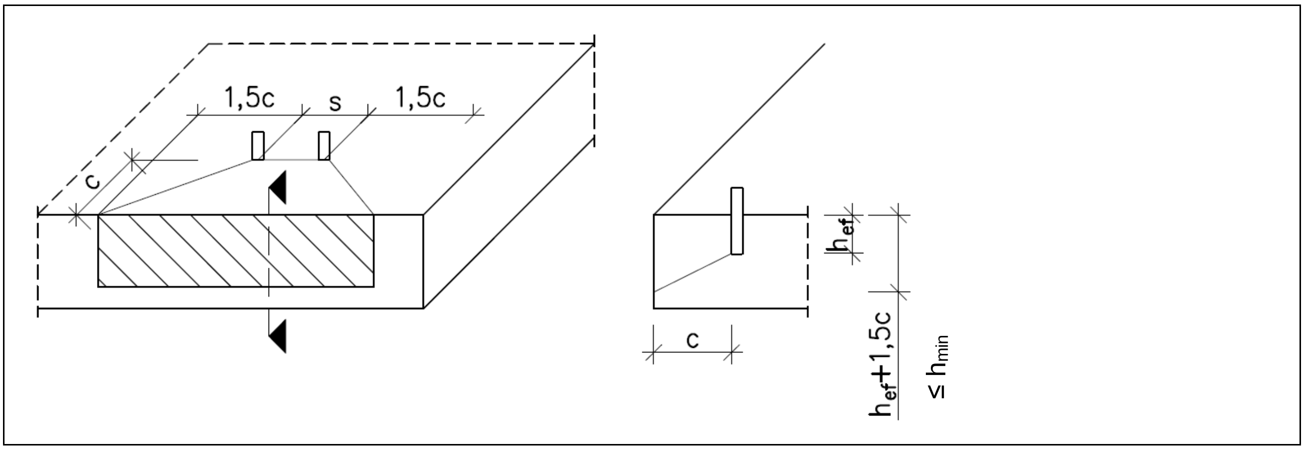


Figure 2.3 Projecting Area A_{sp}

2.2.7 Resistance to steel failure under shear load (test series V1 and V2)

2.2.7.1 Single fastener (test series V1)

In accordance with EN 1992-4 [5] section 7.2.2.3.1 the characteristic resistance to steel failure may be calculated for steel elements with constant strength over the length of the element as given below. The smallest cross section of the fastener in the area of load transfer applies.

$$V^0_{Rk,s} = k_6 \cdot A_s \cdot f_{uk} \text{ [N]} \quad (2.22)$$

$$M^0_{Rk,s} = 1,2 \cdot W_{el} \cdot f_{uk} \text{ [Nm]} \quad (2.23)$$

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 (2.22) is not applicable, the characteristic resistance to steel failure $V^0_{Rk,S}$ shall be determined by tests.

Purpose of the test

These tests are performed to determine the shear capacity of a single fastener without edge influence and thereby establishing the performance characteristics $V_{Rk,s}$ as well as for the determination of the displacement under shear load.

The tests are required only 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. For all other fasteners the shear capacity may be determined according to equations (2.22) and (2.23).

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

Test conditions

The tests shall be performed in uncracked concrete C20/25 according to Annex D, section 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 2.5.

Table 2.5 Diameter of clearance hole in the fixture

external diameter1) 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:

<u>Failure loads</u>

- 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.8).

2.2.7.2 Group of fasteners (ductility factor k_7)

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.

The factor k_7 may be assumed as follows:

k_7 = 1,0 for ductile steel characterized by a rupture elongation $A_5 > 8\%$;

k_7 = 0,8 for steel characterized by a rupture elongation $A_5 \leq 8\%$.

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

Purpose of the test

The test series is performed to determine the k_8 factor for design according to EN 1992-4 for pry-out failure. The test series may be omitted if the default values for k_8 according to Table 2.6 apply.

Table 2.6 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 C20/25 according to Annex D, section 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, the spacing may be reduced.

Assessment

The 5% fractile of failure loads in the test series $V_{5\%}$ are compared to the characteristic resistance of the fastener group to tension load in uncracked concrete $N_{Rk,ucr}$ according to equations (2.24) and (2.25).

$$k_8 = \frac{V_{u,5\%}}{N_{Rk,ucr}} \tag{2.24}$$

$$N_{Rk,ucr} = k_{ucr} \cdot h_{ef}^{1.5} \cdot \sqrt{f_{c,t}} \cdot \frac{(s+3h_{ef})^2}{9h_{ef}^2} \tag{2.25}$$

2.2.9 Resistance to concrete edge failure

Geometrical data d_{nom} and ℓ_f used for design are given as follows:

d_{nom} outside diameter of the fastener relevant for shear loading.

ℓ_f = h_{ef} in case of a uniform diameter of the steel element

≤ 12 d_{nom} in case of $d_{nom} \leq 24$ mm

≤ max {8 d_{nom}; 300 mm} in case of $d_{nom} > 24$ mm

2.2.10 Displacements under short-term and long-term loading

Assessment

As a minimum the displacements under short-term loading and long-term loading shall be determined for the maximum service load. They may be given as absolute values given in [mm] or relative values either per unit bond stress given in [mm/(N/mm^2)] or per unit load given in [mm/kN].

The displacements under short-term tension and shear loading (δ_{N0} and δ_{V0}) are evaluated from the tests on single fasteners without edge or spacing effects (test series according to Table A.1, lines R1 to R4, V1) The value derived shall correspond approximately to the 95 %-fractile for a confidence level of 90 %.

The short-term tension and shear displacements δ_{N0} and δ_{V0} 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 cracked concrete the long-term displacements under tension loading, $\delta_{N\infty}$, shall be calculated from the results of tests with crack cycling under load (see Table A.1, line B13) according to equation (2.26).

$$\delta_{N\infty} = \frac{\delta_{m1}}{1{,}5} \tag{2.26}$$

For fasteners to be used in uncracked concrete only, the long-term displacements under tension loading, $\delta_{N\infty}$, shall be calculated from the results of sustained load tests (see Table A.1, line B14 and B15) according to equation (2.27).

$$\delta_{N\infty} = \frac{\delta_{m2}}{2{,}0} \tag{2.27}$$

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

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

Purpose of the test

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

Assessment

The assessment of tests is given in section E.4.1.1. The characteristic resistance to tension load for seismic performance category C1 shall be calculated according to section E.4.3.1.1.

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

Purpose of the test

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 section E.3.1. Explanations for fastener types to be tested are given in section E.3.2. Specific test conditions are given in section E.3.4.1 for reference test series E.2.1, in section E.2.4.2 for tests under pulsating tension loading (test series C2.3) and in section E.3.4.4 for tests with tension load and varying crack width (test series C2.5).

Assessment

The assessment of test series is given in section E.4.2. The characteristic resistance to tension load for seismic performance category C2 shall be determined according to section E.4.3.2.1. The displacements shall be assessed according to section E.4.3.2.3.

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

Purpose of the test

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

Assessment

The assessment of test series is given in section E.4.2. The characteristic resistance to shear load for seismic performance category C1 shall be determined according to section E.4.3.1.2.

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

Purpose of the test

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 section E.3.1. Explanations for fastener types to be tested are given in section E.3.2. Specific test conditions are given in section E.3.4.1 for the reference test series C2.2 and in section E.2.4.3 for test series under alternating shear load (series C2.4).

Assessment

The assessment of test series is given in section E.4.2. The characteristic resistance to shear load for seismic performance category C2 shall be determined according to section E.4.3.2.2. The displacements shall be assessed according to section E.4.3.2.3.

2.2.15 Factor for annular gap for seismic performance categories C1 and C2

The factor for annular gap for seismic performance categories C1 and C2 shall be determined according to section E.4.3.4.

2.2.16 Content, emission and/or release of dangerous substances

The performance of the hardened bonding material related to the emissions and/or release and, where eventually, the content of dangerous substances will be assessed on the basis of the information provided by the manufacturer[5] after identifying the release scenarios (in accordance with EOTA TR 034 [10]) 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.

2.2.16.1 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 [11]. 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

5 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.

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/m³] and stated in the ETA.

2.2.16.2 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 must take place, each in duplicate. Leaching tests of the bonding material are conducted according to CEN/TS 16637-2:2014 [12]. The leachant shall be pH-neutral demineralised water and the ratio of liquid volume to surface area must be (80 ± 10) l/m².

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

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 [13]
- Toxicity test with algae according to ISO 15799 [14]
- Luminescent bacteria test according to EN ISO 11348-1 [15], EN ISO 11348-2 [16] or EN ISO 11348-3 [17]

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, 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.

Determined toxicity in biological tests must be expressed as EC20-values for each dilution ratio. Maximum determined biological degradability must be expressed as "…% within …hours/days". The respective test methods for analysis must 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: Decision 1996/582/EC.

The system is: 1.

3.2 Tasks of the manufacturer

The corner stones of the actions to be undertaken by the manufacturer of bonded fasteners for use in concrete in the procedure of assessment and verification of constancy of performance are laid down in Table 3.1.

Table 3.1 Control plan for the manufacturer; corner stones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC) [**including testing of samples taken at the factory in accordance with a prescribed test plan**]					
Metal Parts					
1	Dimensions (outer diameter, inner diameter, thread length, etc.)	Caliper and/or gauge	Laid down in control plan	3	Every manufacturing batch or 100.000 elements or when raw material batch has been changed *)
2	Tensile Load or tensile strength	EN ISO 6892-1 [23], EN ISO 898-1 [9], EN ISO 3506-1 [19]		3	
3	Yield strength	EN ISO 6892-1 [23], EN ISO 898-1 [9], EN ISO 3506-1 [19]		3	
4	Zinc plating - where relevant	x-ray measurement according to EN ISO 3497 [20], magnetic method according to EN ISO 2178 [21], Phase-sensitive eddy-current method according to EN ISO 21968 [22]		3	
5	Fracture elongation - where relevant	EN ISO 6892-1 [23], EN ISO 898-1[9]		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 acc. 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 fasteners are laid down in Table 3.2.

Table 3.2 Control plan for the notified body; corner stones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control					
1	Ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the bonding material and metal parts. In particular it shall be checked if all tasks in Table 3.1. were performed.	Laid down in control plan		Laid down in control plan	1
Continuous surveillance, assessment and evaluation of factory production control					
2	Verifying that the system of factory production control and the specified automated manufacturing process are maintained taking account of the control plan.	Laid down in control plan		Laid down in control plan	1/year

4 REFERENCE DOCUMENTS

[1] EN 206:2013 + A1 2016, 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 1992-1-1:2004 + AC:2010: Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings

[4] EN 1992-1-2:2004 + AC:2008, Eurocode 2: Design of concrete structures - Part 1-2: General rules – Structural fire design

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

[6] EN 10088-1: 2014, Stainless steels – Part 1: List of stainless steels, and Part 3: Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes

[7] EN 10204: 2004, Metallic products – Types of inspection documents

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

[9] EN ISO 898-1: 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

[10] EOTA Technical Report TR 034, General checklist for EADs/ETAs – Content and/or release of dangerous substances in construction products

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

[12] CEN/TS 16637-2:2014, Construction products – Assessment of release of dangerous substances – Part 2: Horizontal dynamic surface leaching test

[13] EN ISO 6341:2013-01, Water quality - Determination of the inhibition of the mobility of Daphnia magna Straus (Cladocera, Crustacea) - Acute toxicity test

[14] ISO 15799:2003-11, Soil quality - Guidance on the ecotoxicological characterization of soils and soil materials

[15] EN ISO 11348-1:2009-05, 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

[16] EN ISO 11348-2:2009-05, 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

[17] EN ISO 11348-3:2009-05, 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

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

[19] EN ISO 3506-1:2017, 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

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

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

[22] ÊN ISO 21968:2018, Non-magnetic metallic coatings on metallic and non-metallic basis materials - Measurement of coating thickness - Phase-sensitive eddy-current method (ISO/DIS 21968:2018)

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

[24] EN 1998-1:2004 + A1:2009: Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings

ANNEX A TEST PROGRAM FOR BONDED FASTENERS AND GENERAL ASPECTS OF ASSESSMENT

A.1 TEST PROGRAM FOR BONDED FASTENERS

The test program for bonded fasteners is given in Table A.1, which covers fasteners for use in cracked and uncracked concrete and fasteners for use in uncracked concrete only. For bonded fasteners 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 sections referred to in these tables.

For bonded fasteners used in cracked and uncracked concrete for which no increase of the performance in high strength concrete is sought (tests according to Table 1.1 option 2, 4, 6 the tests series R2, R4, A2 and A4 may be omitted.

A torque shall not be applied to the bonded fastener 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 bonded fasteners with several embedment depths (variable embedment depth), the robustness test series according to Table A.1, lines B6 to B9 shall be done with the maximum embedment depth 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 element may be increased or the embedment depth may be modified. Further details are given in A.2.

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

Table A.1 Test program for bonded fasteners

N°	Purpose of test	concrete	crack width [mm]	size 2)	h_{ef}	n_{min}	rqd. α	Section
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 (confined test setup)								
R1	Bond strength with confined test setup	C20/25	0	All	7d 1)	5	-	2.2.2.1
R2		C50/60	0	s/m/l	7d 1)	5	-	
R3		C20/25	0,3	s/m/l	7d 1)	5	-	
R4		C50/60	0,3	s/m/l	7d 1)	5	-	
R5	Reference for sensitivity to reduced cleaning effort	C20/25	0	s/m/l	max	5	-	2.2.5
R6	Reference for sustained load a) at normal ambient temperature and b) at maximum long-term temperature c) at minimum installation temperature < 0°°C	C20/25	0	m	7d 1)	a) 5 b) 5	-	2.2.2.6
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
Basic tension tests with unconfined test setup								
A1	Characteristic resistance for tension loading not influenced by edge and spacing effects	C20/25	0	s/m/l	min	5	-	2.2.2.2
A2		C50/60	0	s/m/l	min	5	-	
A3		C20/25	0,3	s/m/l	min	5	-	
A4		C50/60	0,3	s/m/l	min	5	-	
A5	Edge distance to prevent splitting under load	C20/25	0	s/m/l	min	4	1,00	2.2.4

N°	Purpose of test	concrete	crack width [mm]	size [2)]	h_{ef}	n_{min}	rqd. α	Section
A6	Minimum embedment depth	C20/25	0	small	min	20	0,90	2.2.3.2
Resistance to shear load								
V1	Characteristic resistance for shear loading not influenced by edge and spacing effects	C20/25	0	All	min	5	-	2.2.7.1
V2	Resistance to pry-out failure	C20/25	0	All	min	5	-	2.2.8
Resistance to pull-out failure								
B1	Minimum edge distance and spacing	C20/25	0	s/m/l	min	5	-	2.2.6
B2	Maximum long-term temperature	C20/25	0	m	min	5	-	2.2.2.9
B3	Maximum short-term temperature	C20/25	0	m	min	5	-	2.2.2.9
B4	Minimum installation temperature	C20/25	0	m	min	5	1,00	2.2.2.10
B5	Minimum curing time at normal ambient temperature	C20/25	0	m	min	5 + 5	0,90 ref to long curing	2.2.2.11
B6	Robustness in dry concrete	C20/25	0	s/m/l	max[2)]	5	see Table 2.4	2.2.5.2
B7	Robustness in water saturated concrete	C20/25	0	s/m/l	max[2)]	5		2.2.5.3
B8	Robustness in water filled holes (clean water)	C20/25	0	s/m/l	max[2)]	5		2.2.5.4
B9	Robustness to mixing technique	C20/25	0	m	max[2)]	5		2.2.5.5
B10	Increased crack width	C20/25	0,5	s/m/l	7d [1)]	5	0,80	2.2.2.3
B11	Increased crack width	C50/60	0,5	s/m/l	7d [1)]	5	0,80	2.2.2.3
B12	Repeated loads	C20/25	0	m	7d [1)]	5	1,00	2.2.2.4
B13	Crack cycling under load	C20/25	0,1 - 0,3	All	7d [1)]	5	0,90	2.2.2.5
B14	Sustained loads (normal ambient temperature)	C20/25	0	m	7d [1)]	5	0,90	2.2.2.6
B15	Sustained loads (maximum long-term temperature)	C20/25	0	m	7d [1)]	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	C20/25	0	max	7d [1)]	5	0,90	2.2.2.8
B18	High alkalinity	C20/25	0	m	30 mm	10	1,00 (R8)	2.2.2.12
B19	Sulphurous atmosphere	C20/25	0	m	30 mm	10	0,90 (R8)	2.2.2.12
B20	Installation at freezing condition	C20/25	0	12	7d [1)]	5	0,90	2.2.2.13

1) This value is valid for injection type and bulk type bonded fasteners. For capsule type bonded fasteners the specified embedment depth associated with the capsule size shall be used. To avoid steel failure, the embedment depth modifications may be necessary (see 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 A.2).

For certain test series according to Table A.1 and Table B.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.2.

Table A.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 sections, 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 [8].

The failure mode “combined pull-out and concrete cone failure” is characterized by pulling the embedded part (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 bonded fasteners and may be predicted according to current experience as given in EN 1992-4 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 bonded fasteners compared to the resistance of “combined pull-out and concrete cone failure” or “concrete cone failure”.

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

In cases where the use of high strength fastener elements (steel strength class ≥ 10.9 according to EN ISO 898-1 [9]) is insufficient to prevent “steel failure” of the fastener the embedment depth shall be reduced. This principle may overrule the required embedment depth given in Table A.1 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.1a). 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 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.1 b). Remove the upper block A and for injection type systems install the metal part (Figure A.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 metal part is just avoided. For capsule type systems the test setup shall be adapted accordingly.

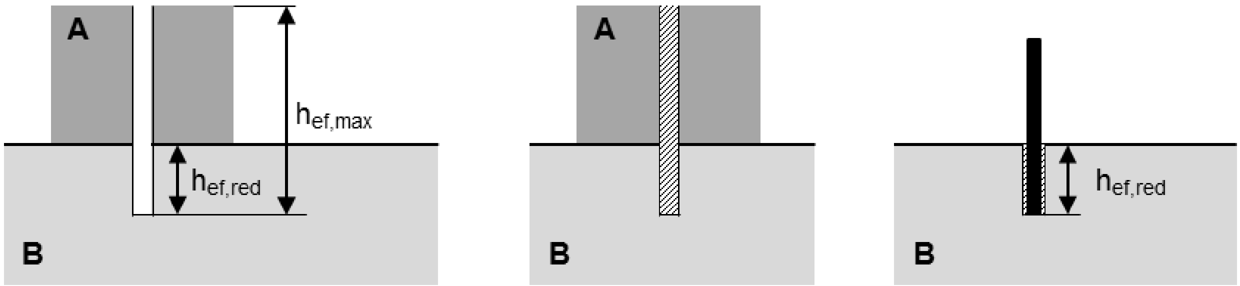


Figure A.1 Test set up to avoid steel failure

The unconfined tests with minimum specified embedment depth may show "concrete cone failure". If these results are used for evaluating the characteristic bond resistance, 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.

Bonded fasteners 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 bonded fastener 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.

If concrete batches come from the same concrete supplier, it shall be ensured that each batch is made from a different delivery of either cement or aggregates.

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 bonded fasteners 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 should 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).

It is necessary to carry out at least 5 reference tests on size M12 in each test series for each concrete batch. The coefficient of variation of the failure loads in one (each) test series of reference tests shall be $cv_F \leq 15$ %. Hence, the number of reference tests may need to be increased until the coefficient of variation meets the requirement.

If the manufacturer applies for embedded parts of bonded fasteners which are geometrically identical but of different material, all tests shall be made with one material. For the other material, only the torque tests according to Table A.1, line N2 shall be carried out and if the embedded part has a reduced section along the length, shear tests according to Table A.1, line V1 for the evaluation of the characteristic shear resistance are required.

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 must be proven 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, the tests are carried out without hole cleaning.

The curing time before commencement of the test in test series according to Table A.1 lines B1 to B19 shall be comparable to the curing time in the corresponding reference test series.

A.2.1 Installation

The fastener shall be installed in accordance with the MPII except for tests according to Table A.1, lines B6 to B9.

A.2.2 Concrete strength and concrete age

The tests are performed for the assessment in "low strength concrete C20/25" and "high strength concrete C50/60". Therefore, the concrete strength at the time of testing the fasteners shall be within the following limits:

C20/25: $25 \le f_{c,cube} \le 35$ [N/mm²]

C50/60: $60 \le f_{c,cube} \le 70$ [N/mm²]

The concrete test member shall be at least 21 days old at the time of installation of the fastener and testing.

A.2.3 Analysis of ultimate loads

A.2.3.1 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 element and bonding material (be)
- bond failure between bonding material and bore hole (bb) (mixed bond failure between 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, a combination of failure modes may be reported.

A.2.3.2 Conversion of failure loads to nominal strength

The conversion of failure loads shall be done according to Equation (A.1) to (A.8) depending on the failure mode.

The increasing factor $\psi_{c,50}$ may be determined separately for cracked and uncracked concrete.

Concrete failure	$F_{u,c} = F_{u,t} \cdot \left(\frac{f_c}{f_{c,t}} \right)^{0,5}$ with $\frac{f_c}{f_{c,t}} \leq 1,0$	(A.1)
Bond failure	$F_{u,p} = F_{u,t} \cdot \left(\frac{f_c}{f_{c,t}} \right)^{m}$ with $\frac{f_c}{f_{c,t}} \leq 1,0$	(A.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.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.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.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.6)
	$\psi_{c,xx} = \left(\frac{f_{ck,xx}}{f_{ck,20}} \right)^{m} > 1,0$ 1)	(A.7)
Steel failure	$F_{u,s} = F_{u,t} \frac{f_u}{f_{u,t}}$	(A.8)

1) If no distinction is made for cracked and uncracked conditions, the factor m shall be determined as the minimum of equations (A2.3) to (A2.6).

A.2.3.3 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 metal part according to equation (A.9).

$$\tau_u = \frac{N_u}{\pi \cdot d \cdot h_{ef}} \qquad \text{(A.9)}$$

A.2.3.4 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.10).

$$F_{u,p} = F_{u,t,i} \cdot \alpha_{ref,i} \qquad \text{(A.10)}$$

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.11).

$$\alpha_{ref,i} = \frac{\min \tau_{Ru,m,r,12}}{\tau_{Ru,m,i,12}} \leq 1,0 \qquad \text{(A.11)}$$

If the coefficient of variation of the ultimate bond resistance of all results in the reference test series with medium diameter is cv ≤ 15 %, the assessment according to equation (A.11) may be omitted and $\alpha_{ref} = 1,0$. 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.2.3.5 Criteria regarding scatter of failure loads

If the coefficient of variation of the failure load in any test series according to Table A.1, lines R1 to R8 and A1 to V1 exceeds 15 % and is not larger than 30 %, the following reduction shall be taken into account:

$$\beta_{cv} = \frac{1}{1 + 0{,}03(cv - 15)} \leq 1{,}0 \qquad \text{(A.12)}$$

If the coefficient of variation of the failure load in any test series according to Table A.1, lines B1 to B19 exceeds 20% and is not larger than 30%, the following reduction shall be taken into account:

$$\beta_{cv} = \frac{1}{1 + 0{,}03(cv - 20)} \leq 1{,}0 \qquad \text{(A.13)}$$

If the maximum limit for the coefficient of variation of the failure loads of 30% is exceeded the number of tests shall be increased to meet this limit.

The smallest result min $ß_{cv}$ in any test shall be taken for assessment.

A.2.3.6 Establishing 5 % fractile of bond strength

The 5 %-fractile value of the ultimate bond resistance measured in a test series is to be calculated according to statistical procedures for a confidence level of 90 %. In the case of bonded fasteners, a test series can consist of more than one diameter of the fastener tested under the same conditions. A normal distribution and an unknown standard deviation of the population shall be assumed.

$$\tau_{5\%} = \tau_{u,m} (1 - k_s \bullet cv_F) \qquad \text{(A.14)}$$

$$F_{5\%} = F_{u,m} (1 - k_s \bullet cv_F) \qquad \text{(A.15)}$$

$$F_{u,95\%} = F_{u,m} (1 + k_s \bullet cv_F) \qquad \text{(A.16)}$$

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

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

Note 20 The confidence level of 90% is defined for characteristic resistance of fasteners in EN 1992-4 and is therefore used for the assessment in this EAD.

A.2.3.7 Reduction factor α_p

If the load $N_{t,act}$ applied on the fastener during a test series according to Table A.1, lines B12 to B16 or B20 is smaller than the required load for the test series, the reduction factor α_p shall be taken into account in the assessment. The smallest value α_p in any of these test series applies for assessment according to equation (2.19).

$$\alpha_p = \frac{N_{t,act}}{N_{t,rqd}} \leq 1{,}0 \qquad \text{(A.17)}$$

with

$N_{t,act}$ actual load applied on the fastener in the respective test series

$N_{t,rqd}$ load required for the respective test series

A.2.3.8 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 of basic tension test series according to Table A.1:

$$\alpha = \min \{F_{u,m,t} / F_{u,m,r}; F_{5\%,t} / F_{5\%,r}\} \leq 1{,}0 \qquad \text{(A.18)}$$

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), 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.18) are not met in one test series, the characteristic resistance shall be reduced by α / rqd. α.

A.2.4 Analysis of displacements

A.2.4.1 Loss of adhesion

With bonded fasteners uncontrolled slip occurs when the bonding material with the embedded part 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. If the change in stiffness at a defined load is not so obvious, e.g. the stiffness is smoothly decreasing, 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.3.
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, $N_{u,adh}$ is taken as the peak load, see Figure A.4.
6) If there is a very stiff load-displacement curve at the beginning ($\delta_{0,3} \leq$ 0,05 mm) the drawing of the line for the calculation can be shifted to the point (0,3 N_u / $\delta_{0,3}$), see Figure A.5.

For tension tests the factor α_1 shall be calculated according to equation (A.19):

$$\alpha_1 = \frac{N_{u,adh}}{N_{Rk,p}} \cdot \frac{1{,}5}{1{,}3} \cdot \gamma_{inst} \leq 1{,}0 \qquad \text{(A.19)}$$

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 embedded part along the entire embedment depth. In this case the factor α_1 shall be taken as 1,0.

Examples of load-displacement curves

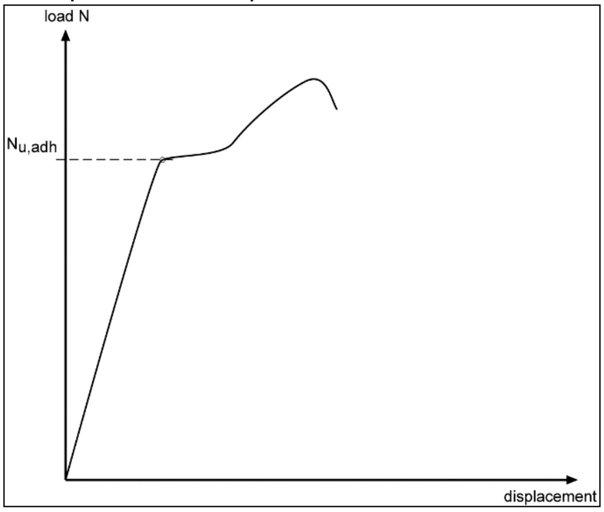


Figure A.2 Load at loss of adhesion by a significant change of stiffness

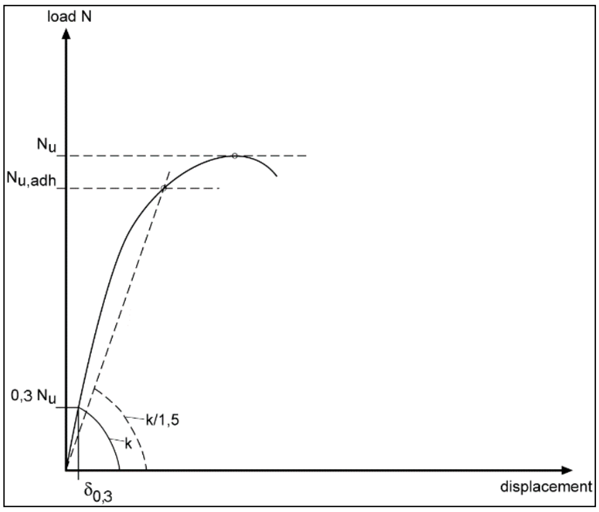


Figure A.3 Evaluation of load at loss of adhesion

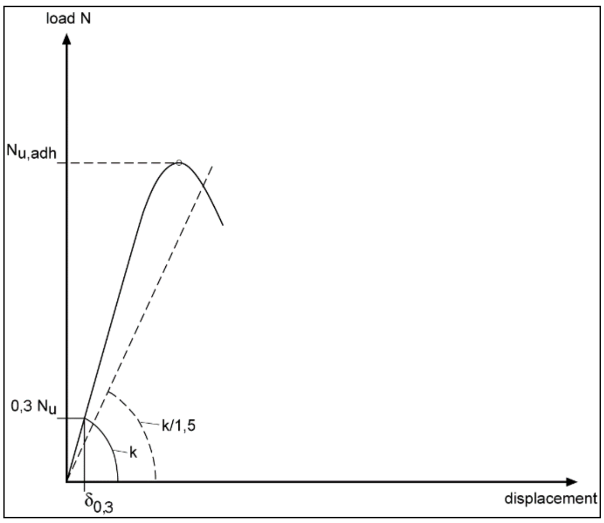


Figure A.4 Evaluation of load at loss of adhesion

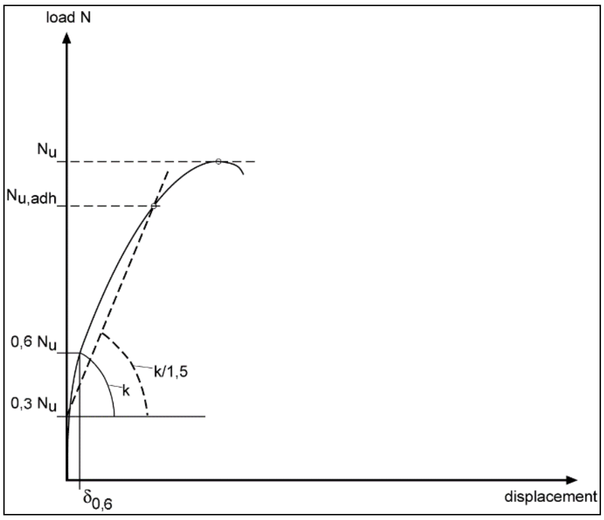


Figure A.5 Evaluation of load at loss of adhesion

A2.4.2 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.20) and equation (A.21).

$$cv_{\delta} \leq 0{,}25 \text{ (test series R1 to R8, A1 to A5, B1 to B5)} \quad \text{(A.20)}$$

$$cv_{\delta} \leq 0{,}40 \text{ (test series B6 to B17)} \quad \text{(A.21)}$$

The load displacement curves may be shifted according to Figure A.6 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.

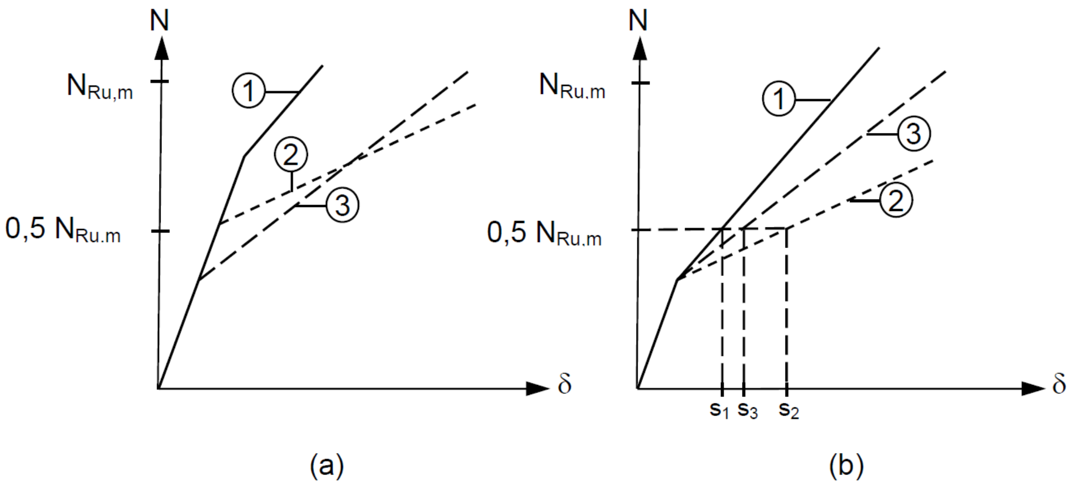


Figure A.6 Influence of pre-stressing on load/displacement curves
a) original curves
b) shifted curves for evaluation of scatter at N = 0,5 $N_{u,m}$

Annex B Bonded Expansion Fasteners

B.1 General

Bonded expansion fasteners 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.

B.2 Test program for bonded expansion fasteners

B.2.1 Test Program

The following test series shall be carried out and assessed as bonded fasteners according to 2.2 and Test program for bonded fasteners given in Table A.1:

- To steel failure (N1 to N2)
- Reference tests (R1 to R8)
- 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 (R6; B2 to B5, B20)
- High alkalinity and sulphurous atmosphere (R8, B18 and B19)

For the test series given in Table B.1 section 2.2 applies with respect to

- purpose of the test,
- test conditions
- assessment

as far as it is not overruled by Annex B for bonded expansion fasteners.

Table B.1 Test program for bonded expansion fasteners

N°	Purpose of test	concrete	crack width [mm]	T/T_{inst}	size 1) 2)	n_{min}	rqd. α	section
E1	Reduced installation torque in dry concrete	C20/25	0,3	0,5	all	10	see Table 2.4	2.2.5
E2	Robustness in dry concrete	C20/25	0,3	1/0,5	all	10		
E3	Robustness in wet concrete	C20/25	0,3	1/0,5	all	10		
E4	Robustness in flooded holes (clean water)	C20/25	0,3	1/0,5	all	10		
E5	Robustness to mixing technique	C20/25	0,3	1/0,5	m	10		
E6	Increased crack width	C20/25	0,5	1/0,5	s/m/l	10	0,80	2.2.2.3
E7	Increased crack width	C50/60	0,5	1/0,5	s/m/l	10	0,80	2.2.2.3
E8	Crack cycling under load	C20/25	0,1–0,3	1/0,5	s/m/l	10	0,90	2.2.2.5
					intermediate	5		
E9	Sustained loads (normal ambient temperature)	C20/25	0	1/0,5	m	5	0,90	2.2.2.6
E10	Sustained loads (maximum long-term temperature)	C20/25	0	1/0,5	m	5	0,90	2.2.2.6
E11	Freeze/thaw conditions	C50/60	0	1/0,5	m	5	0,90	2.2.2.7
E12	Installation direction	C20/25	0,3	1/0,5	max	5	0,90	2.2.2.8
E13	Slip force test	C20/25	0,3	0	All	5	-	B2.5
E14	Bond force test	C20/25	0,3	0	All	5	-	B2.6

1) See Table A.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.2.

B.2.2 General

The required tests for torque-controlled bonded fasteners are given in Table B.1. In addition the test series according to Table A.1, lines A1 to A4 are required.

If the slip and bond force tests are carried out and the requirements according to B2.7 are fulfilled, the number of tests given in Table B.1 lines E1 to E8 may be performed with reduced number of tests n_{min} = 5. If the conditions according to section B2.7 are not fulfilled or the slip and bond force tests are not carried out, the number of tests given in Table B.1 applies. Therefore, it is recommended that first the tests are carried out according to Table B.1, line E13 and E14 with checking of the requirements to section B2.7.

The test procedures given in Table B.1 line E1 to E12 correspond in principle to the required tests for bonded fasteners according to Table A.1, the necessary modifications and adaptations (including the number of tests) are given in the following.

In contrast to the assessment of bonded fasteners, 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, line A3 (tests in C20/25) or line A4 (tests in C50/60).

The results of tests according to line E9, E10 and E11 shall be compared with confined reference tests 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.1 E1 and N2. Different requirements on installation torque in test series for robustness E1 and sensitivity to torque in test series N2 apply.

Ten minutes after applying the installation torque it shall be reduced to 0,5 T_{inst}. If no torque is given by the manufacturer, the tests shall be carried out without installation torque.

B.2.3 Robustness

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

These tests shall be carried out in cracked concrete Δw = 0,3 mm as unconfined tests.

B.2.5 Slip force tests

The tests according to Table B.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 and/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

The tests according to Table B.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 torque-controlled bonded fastener.

No installation torque is applied.

The hole cleaning is carried out according to robustness test series for bonded fasteners, 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 A2.4.1.

The loads shall be converted to nominal concrete strength value of C20/25 according to section A2.3.2.

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:

$$F_{bond,m} / F_{slip,m} \geq 3,0 \quad \text{(B.1)}$$

$$F_{bond5\%} / F_{slip95\%} \geq 1,3 \quad \text{(B.2)}$$

$F_{bond,m}$ = 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.1, line E13) and ≤ 10% (tests according to Table B.1, line E14).

If the coefficient of variation is larger in a test series with a particular fastener sizes, the number of tests in this series may be increased or the ratios in equations (B2.1) or (B2.2) may be increased.

B.2.8 Load displacement behaviour

Load displacement curves of torque-controlled bonded fasteners 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 section 2.2 with the modifications as given in this chapter. Please note, that the determination of the parameter ψ^0_{sus} for 100 years is not covered in this EAD.

C.2 Repeated loads (test series B12)

The methods for testing and assessment are the same as given in section 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 (2.3) and (2.4) by $\tau_{Rk,100,ucr}$ (= characteristic bond strength as calculated in equation (2.19) 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 section 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 (2.5) 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, only the three smallest diameters must 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 section 2.2.2.6 with the following exceptions:

- Replace $\tau_{Rk,ucr,21}$ in equation (2.6) by $\tau_{Rk,100,ucr,21}$ (= characteristic bond strength as calculated in equation (2.19) for use in uncracked concrete for 100 years working life for normal ambient temperature)
- Replace $\tau_{Rk,ucr,mlt}$ in equation (2.7) by $\tau_{Rk,100,ucr,mlt}$ (= characteristic bond strength as as calculated in equation (2.19) 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, continue to apply the sustained load until this criterion is met.
- If the product has previously been tested with a sample size $n \geq 5$, 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 displacements at 50% of the failure load were larger than 0,4 mm, 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 (2.8) 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 (2.8) 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).

C.5 Determination of the characteristic bond resistance

The characteristic bond resistance to combined pull-out and concrete cone failure shall be done in accordance with section 2.2.2.14 or 2.2.2.15 taking into account the smallest reduction factors derived in section 2.2.2 or Annex C.

In consistency with issued ETA based on EAD 330499-00 the resistance to combined pull-out and concrete cone failure for 50 years working life is given for bonded fasteners as τ_{Rk} [N/mm²] and as N_{Rk} [kN] for bonded Expansion fasteners.

If the manufacturer wishes to establish the characteristic resistance to combined pull-out and concrete cone failure for 100 years working life is given for bonded fasteners as $\tau_{Rk,100}$ [N/mm²] and as $N_{Rk,100}$ [kN] for bonded expansion fasteners.

All other essential characteristics are valid both for 50 and 100 years working life.

ANNEX D - DETAILS OF TESTS FOR BONDED FASTENERS 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 section 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 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, 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, the functioning of the fasteners must 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 without fibres with strength classes in the range of C20/25 - C50/60 in accordance with EN 206:2013 + A1:2016. 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.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 206:2013 + A1:2016).

The boundaries reported in Figure D.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 TAD.

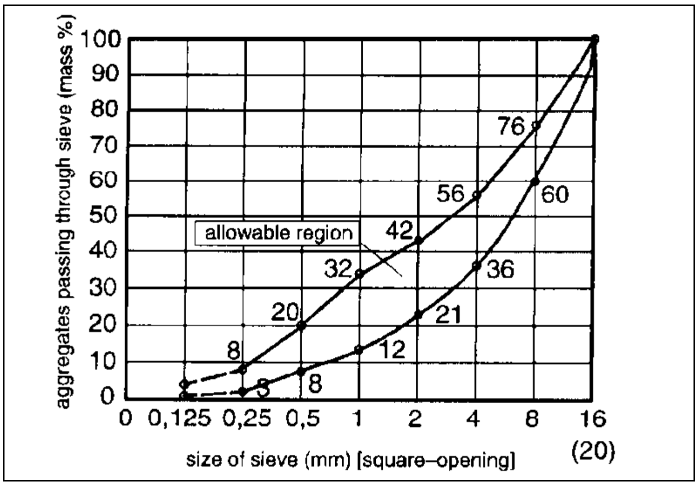


Figure D.1 Admissible region for the grading curve

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 197-1:2014)

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

For the tests carried out in low strength concrete (strength class C20/25) and high strength concrete (strength class C50/60) the following mean compressive strengths at the time of testing fasteners shall be obtained for the two classes:

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

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

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

C20/25 $$f_c = \frac{1}{1{,}25} f_{cube} \quad \text{(D.1)}$$

C50/60 $$f_c = \frac{1}{1{,}20} f_{cube} \quad \text{(D.2)}$$

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

$$f_{cube100} = \frac{1}{0{,}95} f_{cube} \quad \text{(D.3)}$$

$$f_{cube} = \frac{1}{0{,}95} f_{cube200} \quad \text{(D.4)}$$

$f_{cube} = f_{core100}$ (acc. to EN 13791:2007, section 7.1) (D.5)

Note D.1 *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 every concreting operation, specimens (cylinder, cube) shall be prepared having the dimensions conventionally employed in the member country. The specimens shall be made, cured and conditioned in the same way as the test members.

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

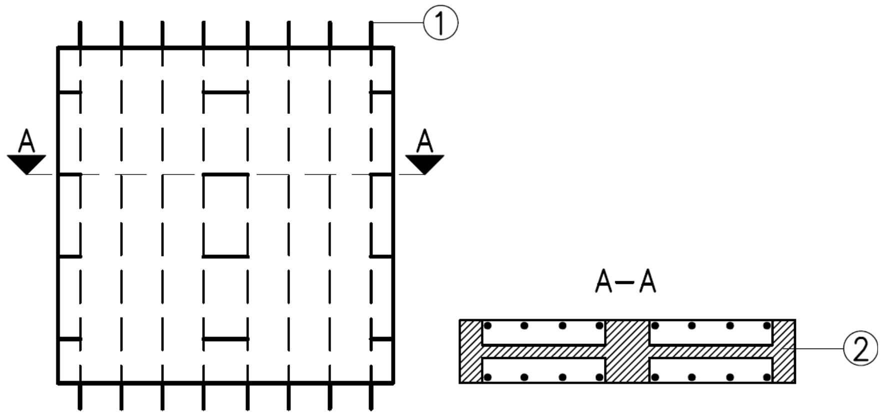
The concrete strength at a certain age shall be measured on at least 3 specimens. The mean value of the measurements governs.

If, when evaluating the test results, there should be doubts whether the strength of the control specimens represents the concrete strength of the test members, at least three cores of 100 mm diameter shall be taken from the test members outside the zones where the concrete has been damaged in the tests, and tested in compression. The cores shall be cut to a height equal to their diameter, and the surfaces to which the compression loads are applied shall be ground or capped. The compressive strength measured on these cores may be converted into the strength of cubes by equation (D.5).

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. The thickness of the test member shall be $h \geq 2\ h_{ef}$ but at least 100 mm. To control cracking, so-called ‘crack-formers’ 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.2.

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



1 reinforcement
2 crack inducers

Figure D.2 Example of a test member for fasteners tested in cracked concrete

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.

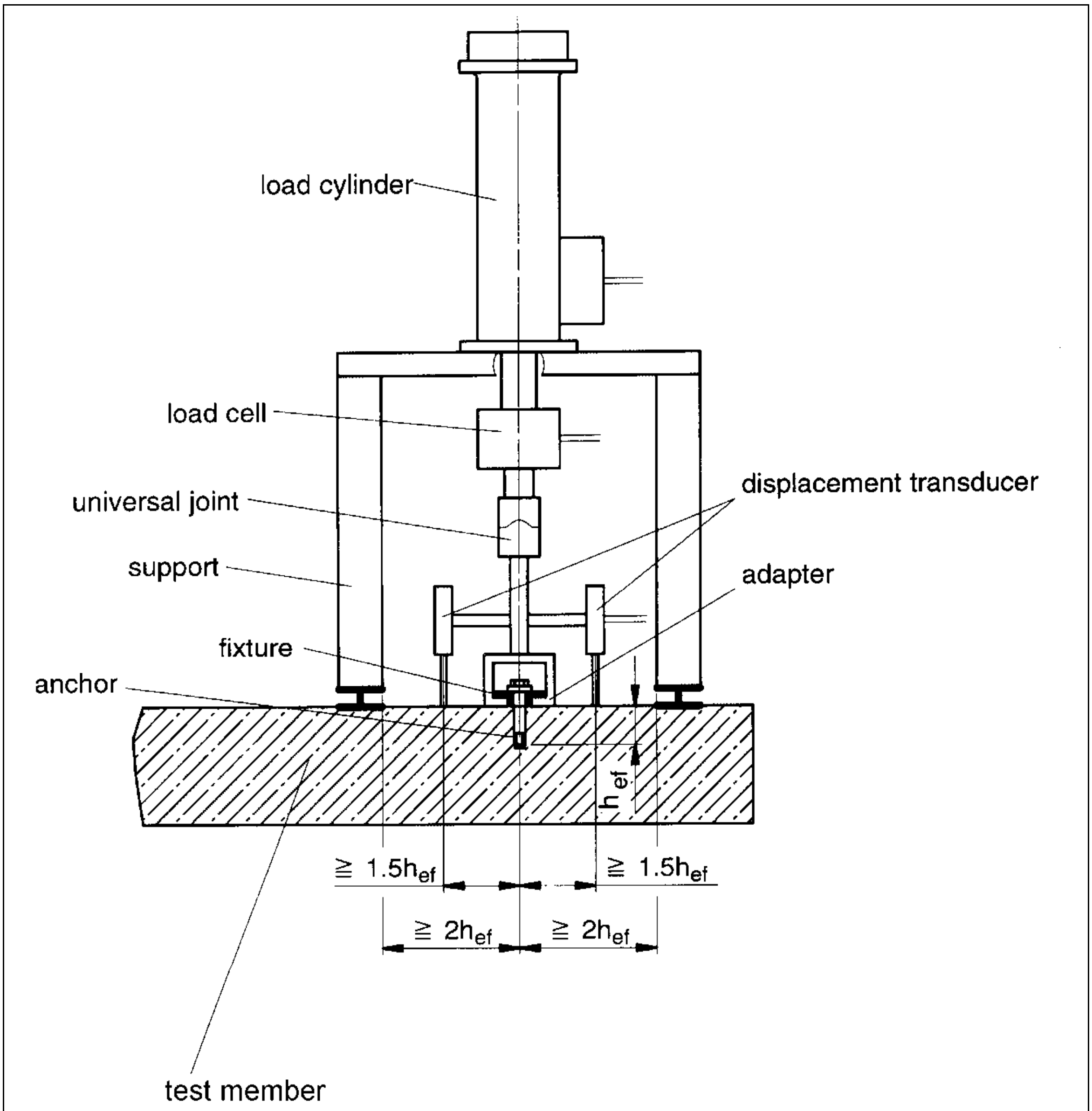


Figure D.3 Example of a tension test rig for unconfined tests

D.3.1.4 Confined test setup

Confined tests are performed when concrete cone failure shall be excluded (e.g. for bond resistance of bonded fasteners). 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.4. 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.

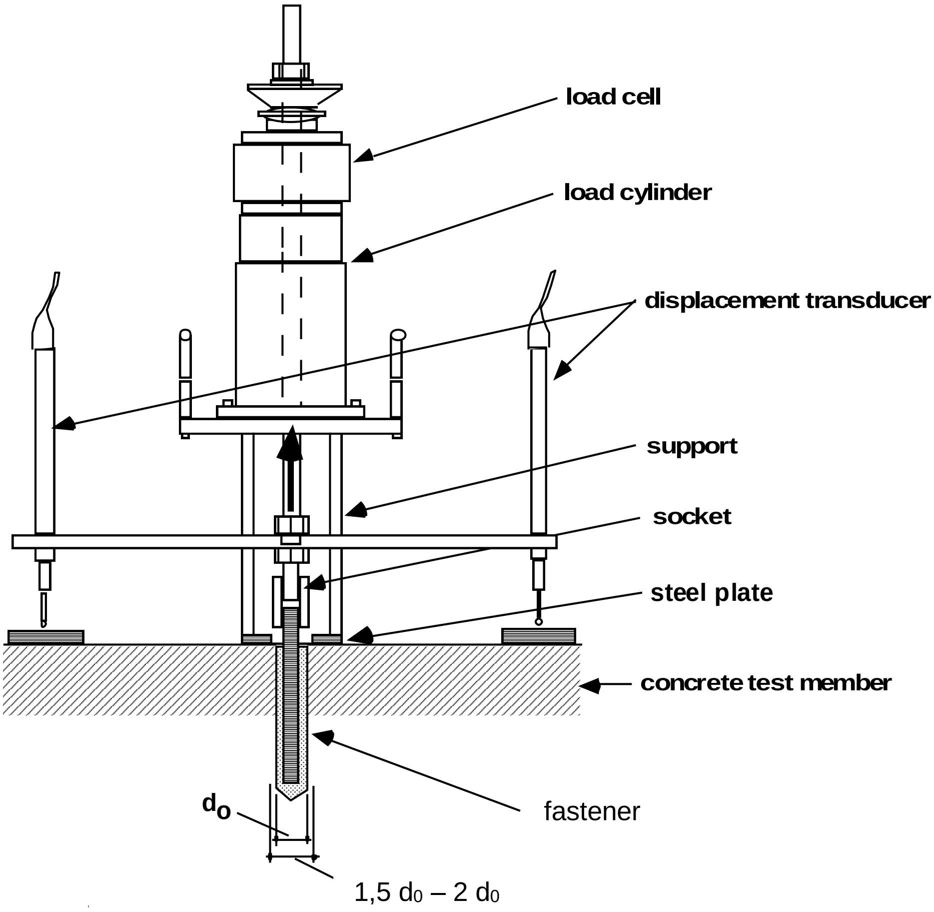


Figure D.4 Example of a tension test rig for confined tests

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, where required, shall be applied to the fastener by a torque wrench that has a documented calibration. The measuring error shall not exceed 5 % of the applied torque throughout the whole measurement range.

For torque controlled bonded expansion fasteners, about 10 minutes after torqueing 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.8).

For the tests for "robustness to installation" only the required special conditions for the fastener types concerned are specified in 2.2.5 or section of this Annex.

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).

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, 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.

The diameter of the cutting edges as a function of the nominal drill bit diameter is given in Figure D.5.

The diameter of the drill bit shall be checked every 10 drilling operations to ensure continued compliance.

If special drilling bits like stop-drills or diamond core drill bits are required no standards on the specification of these products are available. In this case the manufacturer of the fastener has to specify the dimensions and tolerances of the bits and tests shall be performed with bits within the specifications. The definition of a required or corresponding diameter shall be laid down by the responsible TAB.

Note D.2 *The tolerances need also be defined and specified for alternate drilling method for which no standards exist. These tolerances need to be specified in the ETA (so that it is known for which tolerances the performance has been evaluated) as well as in the MPII (in order to be able to stay within these tolerances on the job site).*

Note D.3 *Furthermore, the diamond drilling tool may have an influence on the performance of mechanical fasteners (e.g. expansion fasteners) and bonded fasteners as it affects the geometry of the hole. One may need to specify the diamond drilling tool for which the fastener has been assessed in the ETA.*

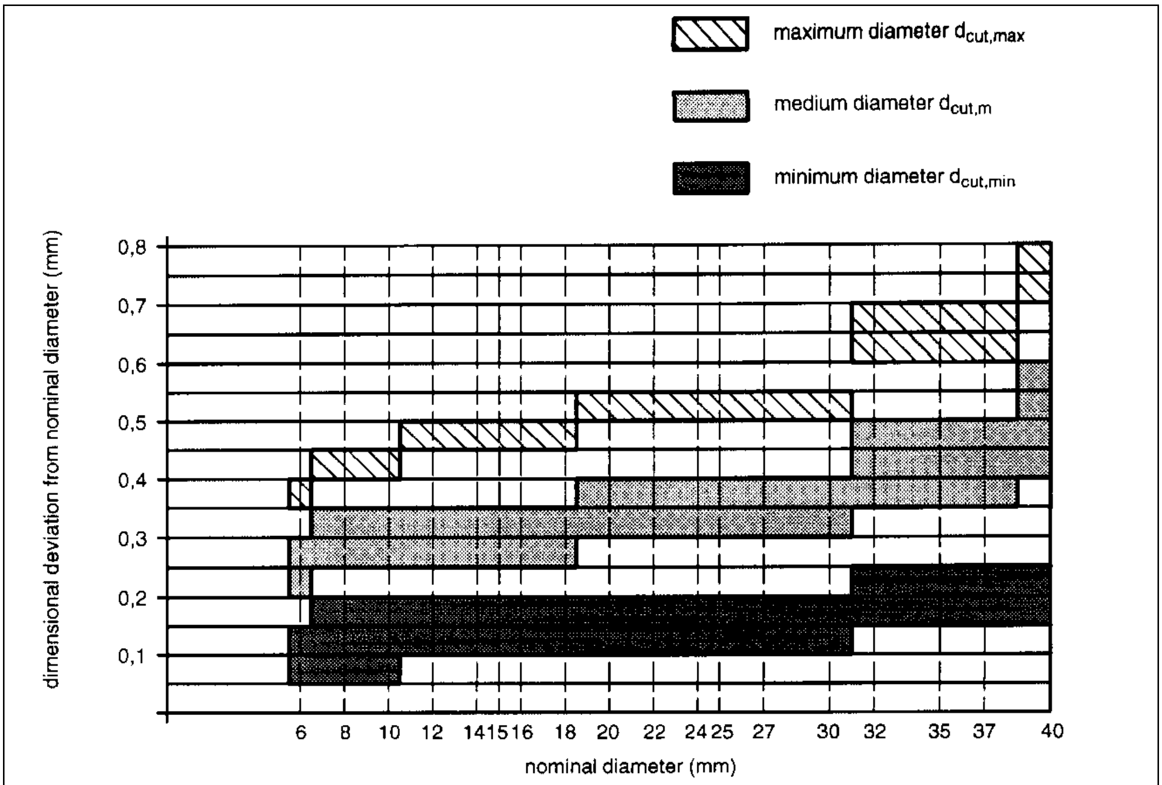


Figure D.5 Cutting diameter of hard metal hammer-drill bits

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 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.7. Only in shear tests without edge influence where steel failure is expected this distance may be less than 2 c_1.

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

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

During tension tests the load shall be applied concentrically to the fastener. To achieve this, hinges shall be incorporated between the loading device and the fastener. 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.

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.6). 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.7. 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.

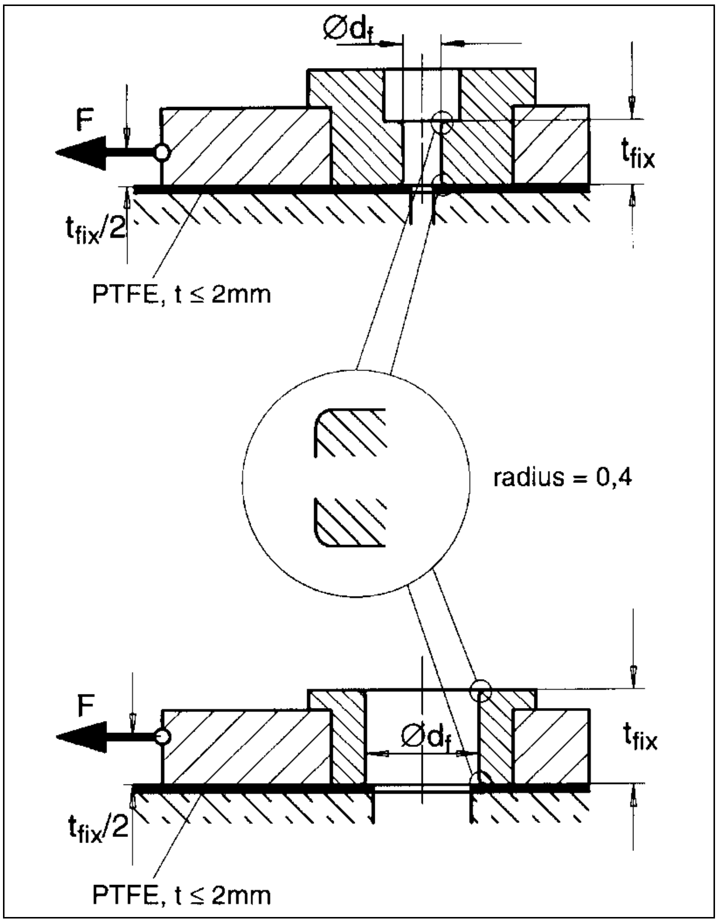


Figure D.6 Examples of shear test sleeves

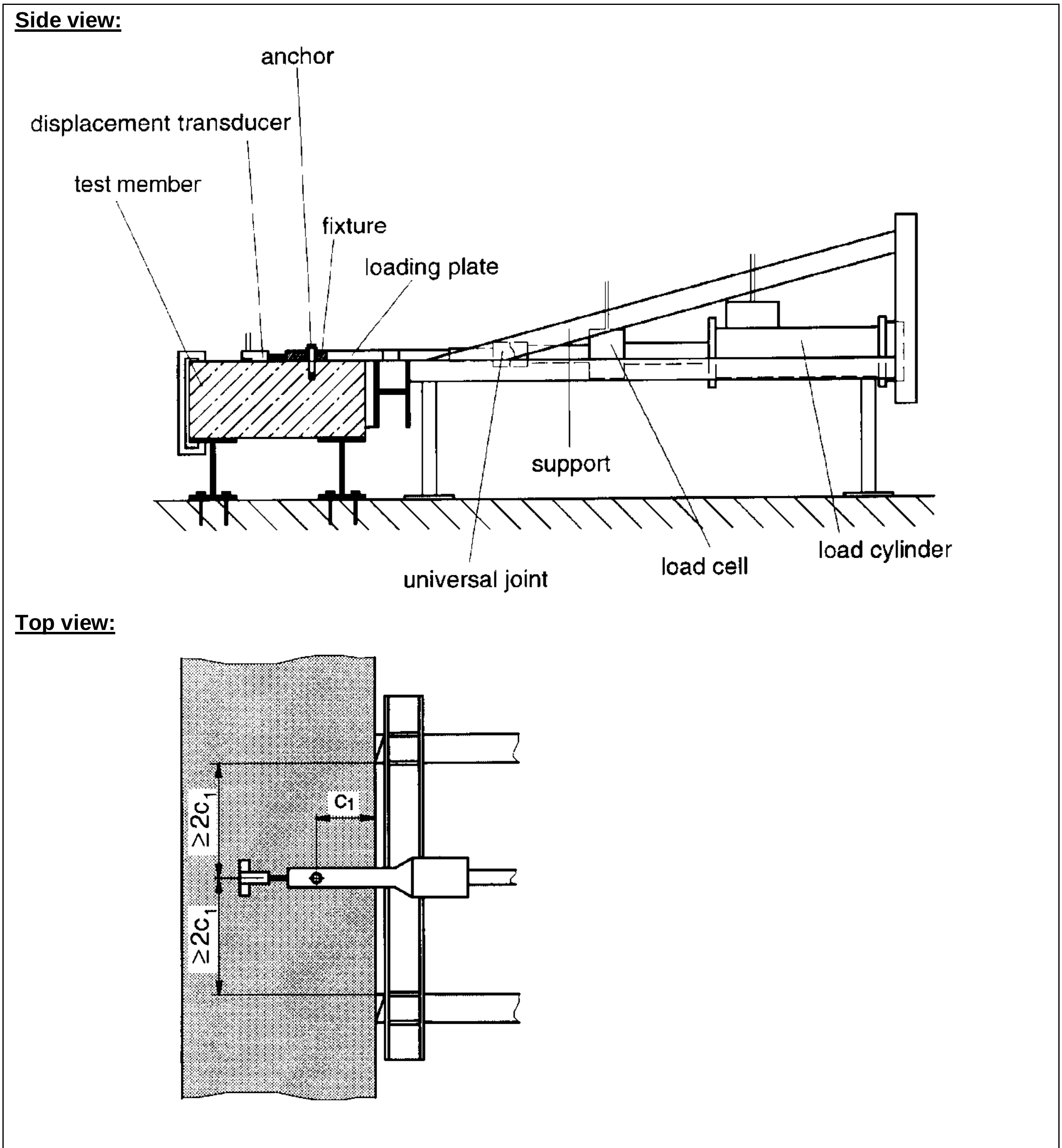


Figure D.7 Example of a shear test rig

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.8).

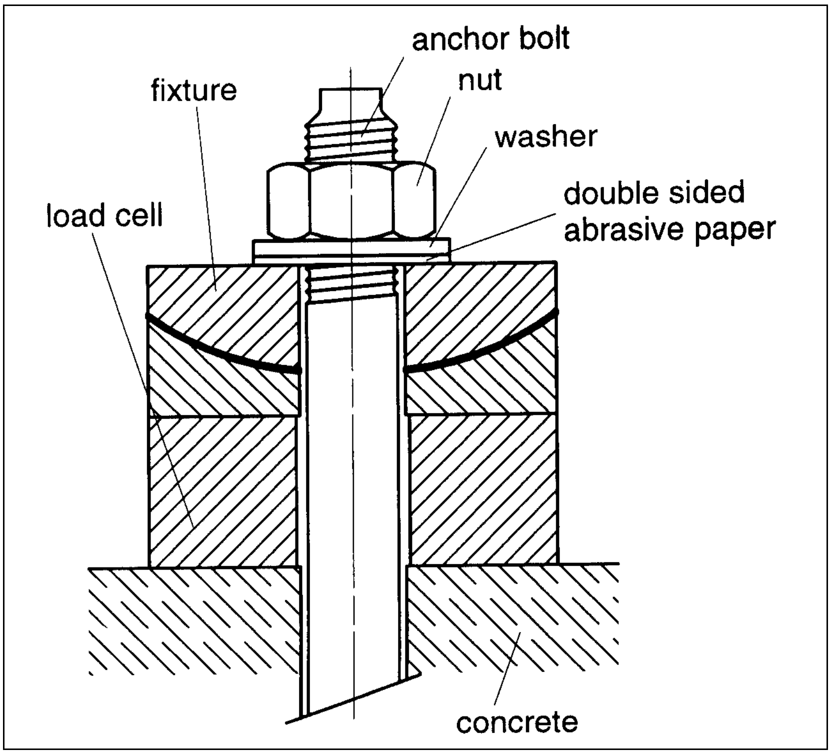


Figure D.8 Example for torque test (schematic)

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 section 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. However, the mean value of a series shall reflect the specified value.

Use one-sided tolerance for crack width.

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

- at a constant width, for example, by means of a servo system, or
- limited to a width close to the initial value by means of 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 non-cracked test member, the test rig shall be placed such that an unrestricted concrete failure towards the corner is possible (see Figure D.9). 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.

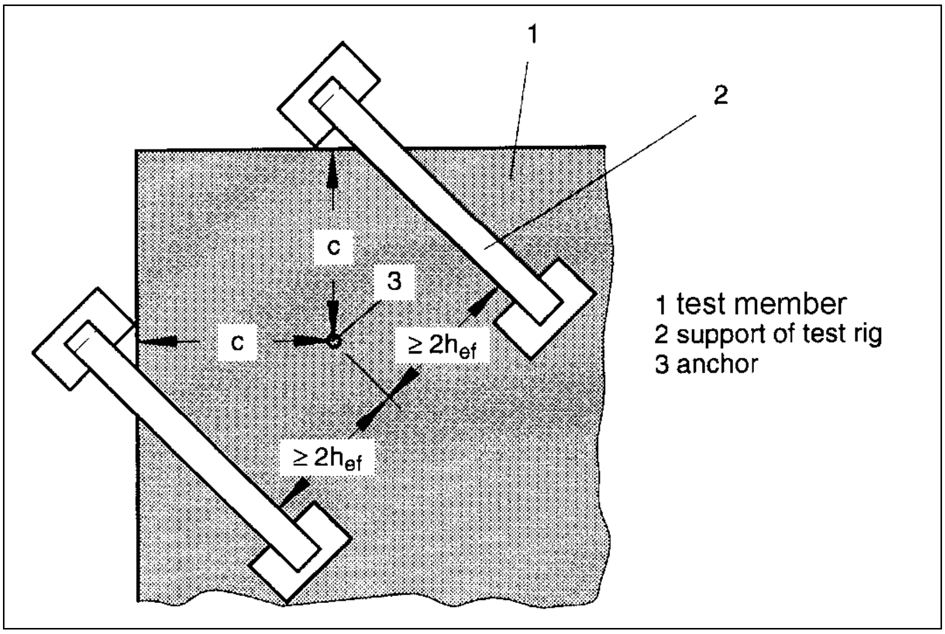


Figure D.9 Example of the test rig for tension tests on fasteners at a corner

D.3.3.2 Robustness to contact with reinforcement

Test for robustness to contact with reinforcement are not required for bonded fasteners.

(Figure D.10 removed from this Annex)

D.3.3.3 Crack cycling under load

After installation of the fastener the maximum (max N_s) and minimum (min N_s) loads applied to the test member shall be determined such that the crack width under max N_s is Δw_1 = 0,3 mm and under min N_s is Δw_2 = 0,1 mm. To stabilize crack formation, up to 10 load changes varying between max N_s and min N_s may be applied. Then a tensile load N_p as specified in the relevant EAD 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 crack width Δw_1 is kept approximately constant (see Figure D.11); for this purpose, the load max N_s applied to the test member may have to be reduced. The load min N_s is kept constant. Therefore, the crack width Δw_2 may increase during the test (see Figure D.11). The crack width difference Δw_1 - Δw_2, however, shall be ≥ 0,1 mm during the 1000 movements of the crack. If this condition cannot be fulfilled with Δw_1 = 0,3 mm, then either min N_s shall be reduced or Δw_1 shall be increased accordingly.

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 measured 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.

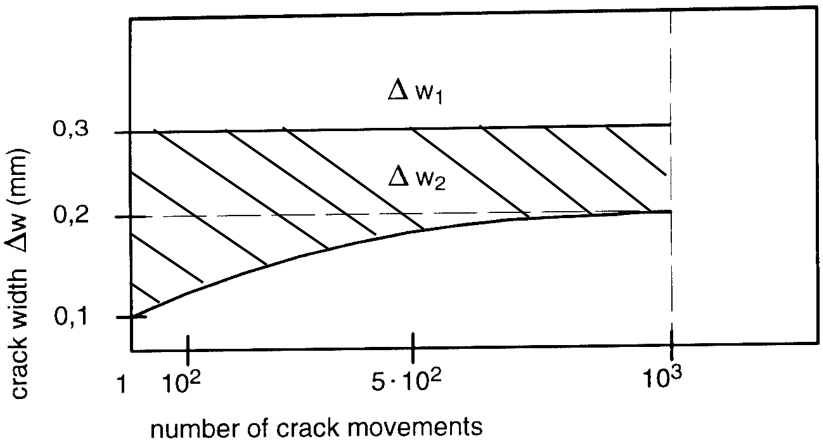


Figure D.11 Allowable crack opening variations during the crack movement test

D.3.3.4 Repeated loads

The test is performed in non-cracked 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. max N and min N, respectively, given in the relevant EAD. 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.

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).

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 $\cong d_f$ (d_f according to Figure 2.5).

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

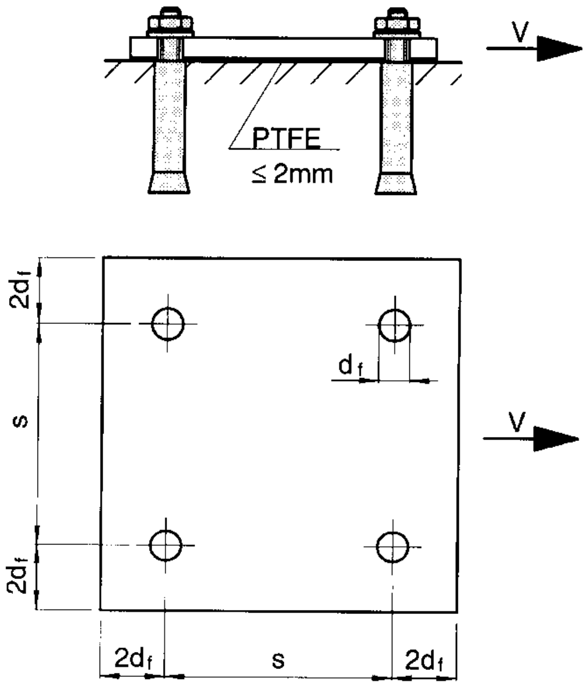
After installation, the fastener is connected to the test rig without gap between the fastener and the interchangeable sleeve in the loading plate and is then loaded to failure. The displacements of the fastener relative to the concrete shall be measured in the direction of the load application, e.g. by use of a displacement transducer fixed behind the fastener (seen from the direction of load application) on the concrete (see Figure D.7).

When testing in cracked concrete, D.3.2 applies. However, the crack widths shall be measured at a distance of approximately h_{ef} behind the fastener. The load shall be applied in the direction of the crack towards the edge.

If the fastener is requested to be assessed for different embedment depths for a specific diameter, the most unfavourable condition shall be tested. If the most unfavourable condition cannot be determined 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.13.



d_f diameter of clearance hole in the fixture

s spacing of fasteners

V shear load

Figure D.13 Dimensions of fixture

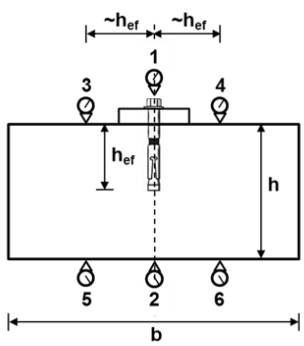
Below the fixture, a sheet of PTFE (sliding layer) with a maximum thickness of 2 mm shall be placed. The test arrangement shall simulate a hinged connection so that the 4 fasteners are loaded equally. The shear force may be applied to the front or back side of the fixture.

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 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_u = 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 acc. to "examples cross section" and "example for test member with bond breaking pipes"
dimensions		(l / w / h)
concrete mix		e.g. cement, aggregate type and content, w/c-ratio
curing conditions		
age of concrete member at time of testing		
type and grade of reinforcement		
longitudinal reinforcement quantity.		
longitudinal reinforcement size		
pre-debonding length		
type of bond breaker sheets		e.g. wood/ plastic/ metal/ none
reinforcement spacing		e.g. 254 mm horizontal, 50 mm from edges
distribution of reinforcement over depth of member		e.g. two rows, 100 mm from top and bottom
reinforcement is distributed double symmetrically		
3. Setting/ Installation information		
ratio member thickness / h_{nom}		e.g. 2,2
place of fastener installation		formwork side
type/ diameter of support		confined / unconfined d = 450 mm
spacing between rebar and fastener		200 mm
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)
Bonded fasteners only	
type and diameter of cleaning brush	
setting tool/ dispenser	e.g. torque wrench / impact screw driver xy / 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, a combination of failure modes may be reported.)	- (cc) concrete cone failure – give diameter and depth of concrete cone - (sp) splitting– test condition for tests in uncracked concrete in case when a first crack of the concrete is observed - (po) pull-out – pull-out failure may be combined with a shallow concrete breakout - (pt) pull-through– cone being pulled through the expansion sleeve - (s) steel failure– define position of the steel rupture over length of the fastener - (pr) pry-out – concrete breakout opposite to the load direction (may occur for shallow embedment) - (be) bond – element failure - (bbe) bond – borehole failure
Torque at failure (torque tests only)	
Diagram with displacement over time of testing (long term tests only)	

ANNEX E – BONDED FASTENERS IN CONCRETE UNDER SEISMIC ACTION

E.1 Scope

This Annex covers bonded fasteners and bonded expansion fasteners 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.

A precondition for seismic performance categories C1 and C2 is the complete assessment for use in cracked and non-cracked concrete (option 1 to 6).

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. If necessary the concrete compressive strength may be converted accordingly.

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 EN1992-4:2018.

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 (E.3.3.2) and tests under alternating shear load (E.3.3.3). The assessment of fasteners for category C2 includes reference tests up to failure (E.3.4.2), tests under pulsating tension load (C2.4.3), tests under alternating shear load (E.3.4.4) as well as tests under crack cycling (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 design information 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.

Detailed information regarding the various testing protocols and assessment criteria for both seismic performance categories is given in Chapters 2 and 3.

E.2 Abbreviation and Notation

The specific terms for assessment under seismic action are listed in section 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 are addressed in Section E.3 of this document, which overrule conflicting provisions in the Annex D.

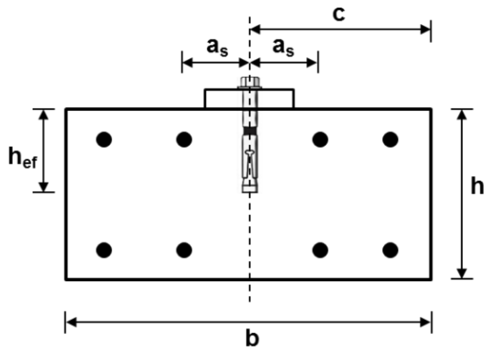
E.3.1.1 Test members

The thickness of the test member shall be at least the maximum of 1,5 h_{ef} and the minimum member thickness requested by the manufacturer which is given in the ETA. 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 (for crack widths ≥ 0,3 mm), 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 Δw_{hef} ≥ 0,3 mm.

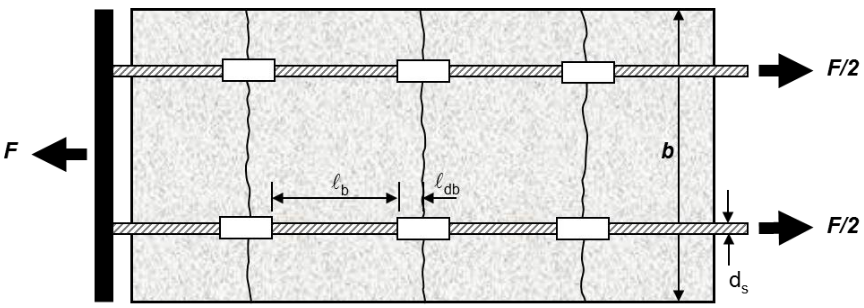
The reinforcement shall be of equal size and placed symmetrically (see Figure E.1). The spacing of the reinforcement in the test member shall be ≤ 400 mm. The capacity of the fastener shall not be affected by the reinforcement. The reinforcement shall remain well in the elastic range during each test. 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 E.2) 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 E.2). 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 E.1 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 E.2 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 $c \geq 2{,}0\ h_{ef}$.

The requirement that the capacity of the fastener is not affected by the reinforcement is considered to be fulfilled for unconfined tests if the distance a_s between the fastener and the nearest reinforcement bar (see Figure E.) is at least 75 mm and ≥ 0,60 h_{ef}. If for large embedment depths this distance requirement and the spacing requirement of the reinforcement ≤ 400 mm cannot be fulfilled at the same time an expertise is required showing that the nearest reinforcement bar does not affect the capacity of the fastener.

For confined tests the distance requirements between fastener and nearest reinforcement as stated in the previous paragraph do not apply.

Note E.1 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.1 and Table E.4) 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 E.3a) and Figure E.3b).

According to Figure E.3a) 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 E.3a) or at a distance of approximately h_{ef} on both sides of the fastener (locations 3 & 4 and 5 & 6 in Figure E.3a). 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 E.3b) 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}.

For test series C2.5 only one fastener shall be located in a crack at the time of testing.

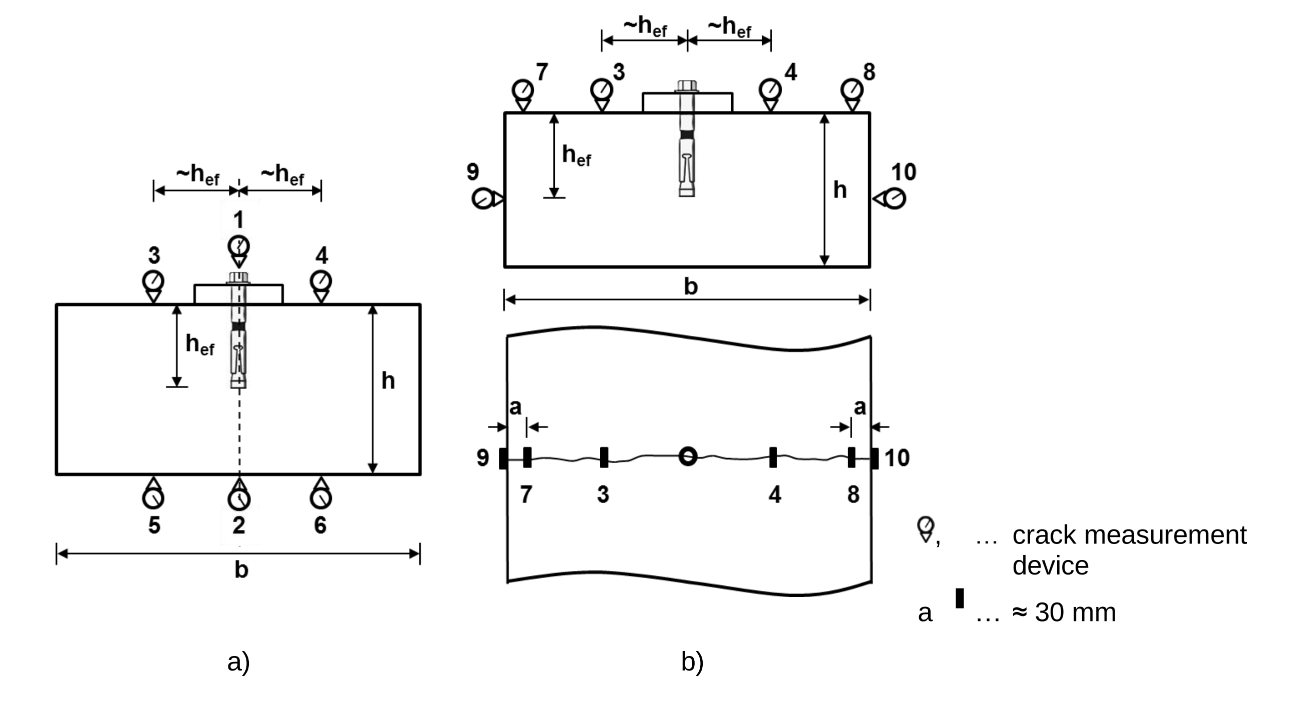


Figure E.3 Measurements to show fulfilment of the constant crack width requirement

E.3.1.2 Installation of fasteners

Install the fastener in a hairline crack according to Annex D, and the manufacturer's printed 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.

The installation torque T_{inst} required by the manufacturer shall be applied to the fastener by a torque wrench (which has a documented calibration) except in cases where the fastener is installed using a tool (such as e.g. an impact screw driver) specified in the MPII. The measuring error shall not exceed 5 % of the applied torque throughout the whole measurement range. After about 10 minutes of applying T_{inst} to the fastener, the installation torque shall be reduced to 0,5 T_{inst} to account for relaxation of the pre-stressing force with time.

If no torque is specified by the manufacturer's printed installation instructions, 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.

E.3.1.3 Crack measurement and tolerance on crack width

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 E.3a). 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 E.3a) or on both sides of the fastener (i.e. locations 3 & 4 (for Δw_{top}) and 5 & 6 (for Δw_{bot}) in Figure E.3a) 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 E.3b). 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 E.3. In confined tension tests the measuring devices 3, 4, 5 and 6 in Figure E.3a and 3 & 4 in Figure E.3b 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:

- for $\Delta w < 0,3$ mm: 20% of crack width specified for the test series
- for $\Delta w \geq 0,3$ mm: minimum of 10% of the crack width specified for the test series and 0,04 mm.

E.3.1.4 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 bonded fastener, over 1,5 times the length of the interaction zone h_{iz} of a torque-controlled expansion fastener or undercut fastener or bonded expansion fastener, see Figure E.4).

Note E.2 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 Annex D unless specified otherwise in the specific test section 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.5 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 Annex D) 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.

All tests with bonded fasteners shall be performed at normal ambient temperature (21°C ± 3°C).

Note E.3 The effect of high loading rates on the fastener behaviour is conservatively neglected.

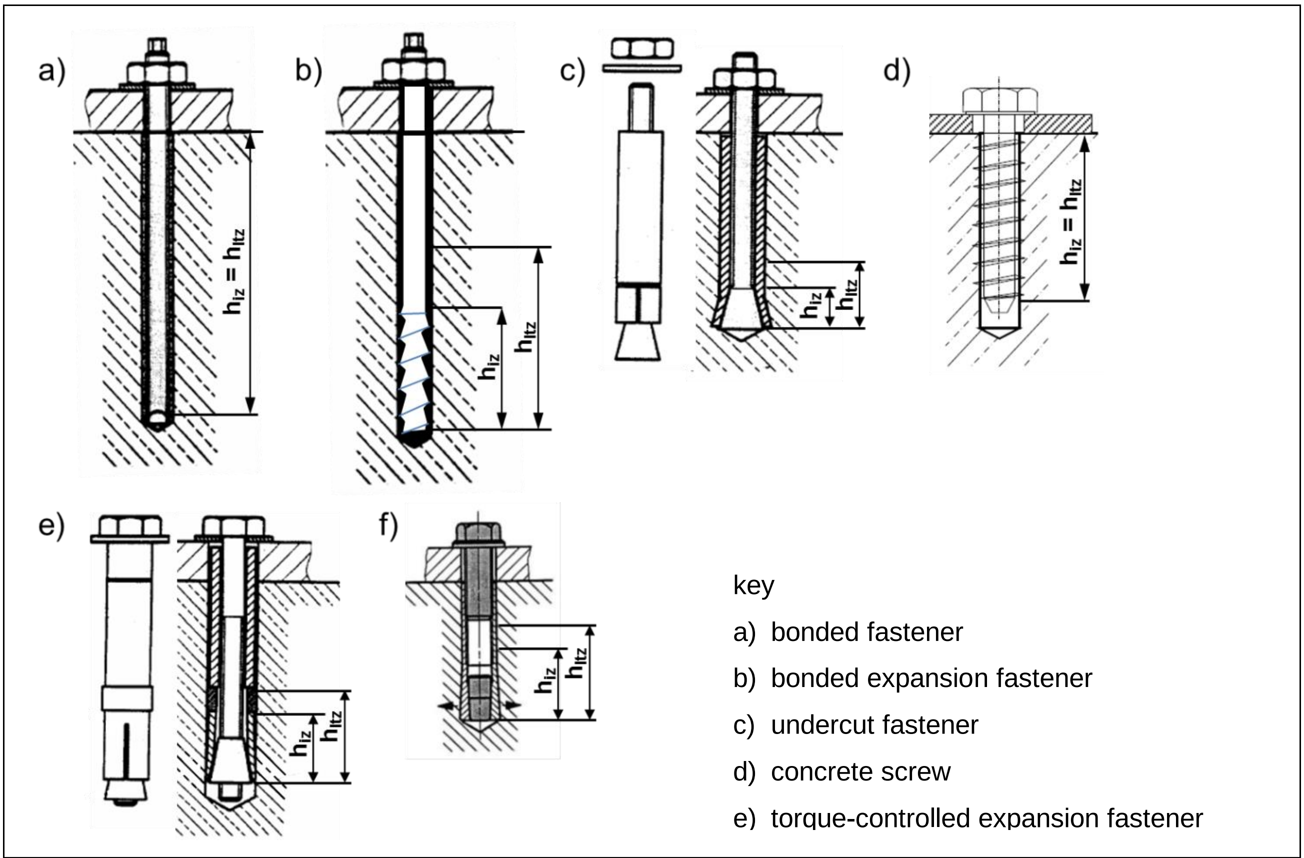


Figure E.4 Effective load transfer zone

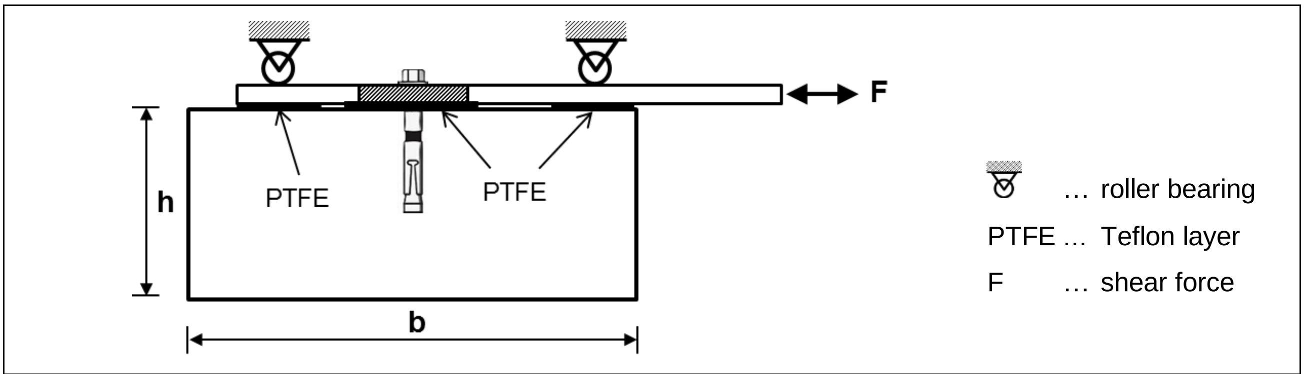


Figure E.5 Sketch of example for shear test setup with no significant friction forces

E.3.1.5 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 as defined in E.3.1.3 is controlled, either

a) at a constant width taking into account the requirements given in section E.3.1.1, 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 E.3.1.1).

E.3.2 Fastener types to be tested

In general, the tests described in E.3.2.6 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, head configurations (mechanical fasteners), types of inserts (threaded rod, threaded sleeve or rebar for bonded fasteners), different mortar versions of bonded fasteners 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, 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 Torque controlled expansion fasteners

Torque controlled expansion fasteners are not covered by this EAD.

(Figure E.6 has been removed from this Annex)

E.3.2.2 Undercut fasteners (not including concrete screws)

Undercut fasteners are not covered by this EAD.

E.3.2.3 Concrete screws

Concrete screws are not covered by this EAD.

E.3.2.4 Bonded fasteners

E.3.2.4.1 Type of insert

E.3.2.4.1.1 Tension tests:

If the bond strength is equal for bonded fasteners with different types of inserts (threaded rod, rebar, internal threaded sleeve etc.) tests can be performed with the most adverse type of insert and the results shall be applied to all other types of inserts. If the bond strength is different, all types of inserts shall be tested.

E.3.2.4.1.2 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 $\alpha_{V,C1}$ of the neighbouring tested sizes shall be used.

E.3.2.4.2 Steel type, steel grade and production method

E.3.2.4.2.1 Tension tests

For bonded fasteners only one steel type needs to be tested. The steel type with the highest strength shall be selected. The measured displacements shall be applied to fasteners of all steel types and grades.

E.3.2.4.2.2 Shear tests

Only fasteners made of galvanized steel of the highest grade and lowest rupture elongation (percentage of elongation after fracture, A, see EN ISO 898-1:2013) need to be tested if the reduction of the characteristic steel shear resistance due to simulated seismic shear testing as compared to the characteristic steel shear resistance under static loading is accepted for all steel types and steel grades. Otherwise all steel types and steel grades shall be tested. The measured displacements shall be applied to the fasteners made from other steel types, steel grades or by other production methods.

E.3.2.4.3 Embedment depth

E.3.2.4.3.1 Tension tests:

a) Fasteners under category C1 (test series C1.1):
If multiple embedment depths are specified only the minimum and maximum embedment depths need to be tested.

b) Fasteners under category C2:
If multiple embedment depths are specified, test series C2.1, C2.3 and C2.5 may only be performed with an embedment depth of $h_{ef} = 7d$ 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.72) and Equation (E.73), 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 $h_{ef} = 7d$ steel failure occurs, 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 as confined or unconfined tests. Perform test series C2.3 in uncracked concrete (ie. Δw = 0,0mm) with the highest steel strength for use in seismic applications and an embedment depth ensuring steel failure. Determine the mean tension capacity of the steel element $N_{u,m,C2.1a}$ used for the definition of N_{max} and for the assessment of this C2.3 test series as given in Equation (E.1).

$$N_{u,m,C2.1a} = A_s \cdot f_{u,C2.3} \tag{E.1}$$

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.72) and Equation (E.73), 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 insert.

E.3.2.4.3.2 Shear tests:

a) Fasteners under category C1 (test series C1.2):
If there is more than one embedment depth specified for a fastener diameter, tests need to be performed for the minimum and maximum embedment depth only. If in the tests with minimum embedment depth steel failure occurs tests at the maximum embedment depth may be omitted if the reduction factor $\alpha_{V,C1}$ according to Equation (C26) is applied to all embedment depths.
b) 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 $\alpha_{V,C2}$ according to Equation (E.74) is accepted for all embedment depths. If at the minimum embedment depth pry-out failure is encountered, 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.3.2.4.4 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.3.2.5 Bonded expansion fasteners

E.3.2.5.1 Steel type, steel grade and production method

E.3.2.5.1.1 Tension tests

If all of the following conditions are fulfilled, and the eventual reduction factor is accepted for all fastener types, 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 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 statistically equivalent. 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 statistically equivalent.

The measured displacements shall be applied to the fasteners made from other steel types, steel grades or by other production methods.

E.3.2.5.1.2 Shear tests

See E.3.2.4.2.2.

E.3.2.5.2 Head configuration

The specific test series shall be performed with the most adverse head configuration of the product in respect to functioning and ultimate load. If the most adverse head configuration is not obvious all head configurations shall be tested.

E.3.2.5.3 Embedment depth

See E.3.2.4.3.

E.3.2.5.4 Drilling method

See E.3.2.4.4.

E.3.2.6 Deformation controlled expansion fasteners

No reduction of number of variants to be tested is allowed for this type of fasteners.

E.3.3 Tests for category C1

E.3.3.1 Tests program

The additional tests for category C1 are shown in Table E.1.

Table E.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 Section	**Assessment criteria** see Section
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 bonded fasteners: for each type of insert with the same mechanical properties the number of tested sizes can be reduced in accordance with Table 2.7.
4) For bonded fasteners: test smallest, medium and largest diameter

All tests shall be performed with fasteners with a steel strength not smaller than the nominal value f_{uk}.

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:

The test shall be performed with an unconfined test setup according to Annex D with the following modifications for bonded fasteners.

In general, bonded fasteners shall be tested with a confined test setup in accordance with Annex D. If multiple embedment depths are specified, an embedment depth of $h_{ef} = 7d$ is recommended for tests with the minimum embedment depth. Alternatively, tests with an unconfined test set-up may be performed. In this case the minimum embedment depth shall be selected such that pull-out failure is ensured.

Note E.6 In order to select the proper embedment depth for pull-out failure for bonded fasteners it shall be demonstrated that Equation (E.2) is fulfilled for the embedment depth h_{ef} *used. If Equation (E.2) is not fulfilled with the chosen embedment depth, the embedment depth shall be increased until Equation (E.2) is fulfilled, where steel failure is avoided. If Equation (E.2) cannot be fulfilled in unconfined tests, confined tests shall be conducted (see above).*

$$7 \cdot h_{ef,test}^{1,5} \cdot \sqrt{f_{c,C1.1}} \leq N_{u,m} \cdot \left(\frac{f_{c,C1.1}}{f_{c,3}} \right)^n \leq 10 \cdot h_{ef,test}^{1,5} \cdot \sqrt{f_{c,C1.1}} \qquad (E.2)$$

where

$N_{u,m}$ = [N] - *mean tension capacity from service condition tests "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 Table 2.5;*

$h_{ef,test}$ = *[mm] - effective embedment depth;*

$f_{c,C1.1}$ = *[N/mm²] - mean compressive strength of concrete measured with cubes used for the test series C1.1 at the time of testing;*

$f_{c,3}$ = *[N/mm²] - mean compressive strength of concrete measured with cubes used for the service condition test series "characteristic resistance for tension loading not influenced by edge and spacing effects" in concrete C20/25 according to Table 2.5 at the time of testing;*

n = *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.2 and Figure E.7, where N_{eq} is given in Equation (E.3) in case of concrete or bond failure and in Equation (E.4) in case of steel failure, N_i is given in Equation (E.5), and N_m is given in Equation (E.6). 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_{eq} and 200 N.

$$N_{eq} = 0,5 \cdot N_{u,m} \cdot \left(\frac{f_{c,C1.1}}{f_{c,3}} \right)^n \quad \text{[N]} \quad \text{(concrete, pull-out or bond failure)} \qquad (E.3)$$

where

$N_{u,m}$ = [N] - all fasteners except bonded fasteners:
mean tension capacity from "reference tension tests" in cracked concrete C20/25 for the considered embedment depth;

[N] - bonded fasteners with unconfined test setup in test series C1.1:
mean tension capacity from service condition tests "characteristic resistance for tension loading not influenced by edge and spacing effects" according to Table 2.5 for the considered embedment depth

bonded fasteners with confined test setup in test series C1.1:
mean tension capacity from service condition tests "characteristic resistance for tension loading not influenced by edge and spacing effects" for the considered embedment depth [N];

$f_{c,C1.1}$ = [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 Table 2.5 or (as applicable) at the time of testing;

n = normalization exponent.

$$N_{eq} = 0{,}5 \cdot N_{u,m} \cdot \left(\frac{f_{u,C1.1}}{f_{u,3}} \right) \quad \text{[N]} \quad \text{(steel failure)} \tag{E.4}$$

where

$N_{u,m}$ = [N] - mean tension steel capacity 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.4) 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 are taken from the same production lot.

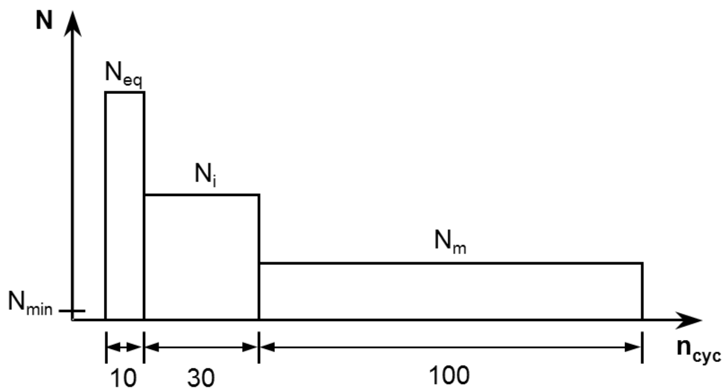
If mixed failure modes occur in the tests for "characteristic resistance for tension loading not influenced by edge and spacing effects" according to Table A.1, the load N_{eq} shall be determined assuming that the failure mode, which was observed in the majority of tests in the test series, occurred in all tests.

$$N_i = 0{,}75 \cdot N_{eq} \quad \text{[N]} \tag{E.5}$$

$$N_m = 0{,}5 \cdot N_{eq} \quad \text{[N]} \tag{E.6}$$

Table E.2 Required loading history for test series C1.1

Load level	N_{eq}	N_i	N_m
Number of cycles (n_{cyc})	10	30	100



N … load

n_{cyc} … number of cycles

Figure E.7 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.

If the fastener fails to fulfil the requirements given in the corresponding assessment (see E.4.1.1) it shall be permitted to conduct the tests with a reduced load level.

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 and Figure E.8, where V_{eq} is given in Equation (E.7), Equation (E.8), or Equation (E.9) as applicable, V_i is given in Equation (E.10) and V_m is given in Equation (E.11). The cycling frequency shall be between 0,1 and 2 Hz.

$$V_{eq} = 0{,}5 \cdot V_{u,m} \cdot \left(\frac{f_{u,C1.2}}{f_{u,5}} \right) \quad \text{[N]} \quad \text{(fasteners without sleeve in shear plane)} \tag{E.7}$$

where

$V_{u,m}$ = [N] - mean shear capacity from tests for “characteristic resistance to steel failure under shear load" in non-cracked concrete C20/25.

$f_{u,C1.2}$ = [N/mm²] - mean ultimate tensile strength of steel fastener elements used in test series C1.2;

$f_{u,5}$ = [N/mm²] - mean ultimate tensile strength of steel fastener elements used in tests for “characteristic resistance to steel failure under shear load” in non-cracked concrete C20/25

For fasteners with a sleeve in the shear plane V_{eq} shall be calculated according to Equation (E.8).

$$V_{eq} = 0{,}5 \cdot V_{u,m} \cdot \left(\frac{f_{u,bol,C1.2}}{f_{u,bol,5}} \cdot \frac{A_{s,bol}}{A_{s,fas}} + \frac{f_{u,sle,C1.2}}{f_{u,sle,5}} \cdot \frac{A_{s,sle}}{A_{s,fas}} \right) \text{[N]} \tag{E.8}$$

where

$V_{u,m}$ = [N] - as defined in Equation(E.7);

$f_{u,bol,C1.2}$ = [N/mm²] - mean ultimate tensile strength of bolt used in test series C1.2;

$f_{u,sle,C1.2}$ = [N/mm²] - mean ultimate tensile strength of sleeve used in test series C1.2;

$f_{u,bol,5}$ = [N/mm²] - mean ultimate tensile strength of bolt used in in tests for “characteristic resistance to steel failure under shear load” in non-cracked concrete C20/25.

$f_{u,sle,5}$ = [N/mm²] - mean ultimate tensile strength of sleeve used in in tests for “characteristic resistance to steel failure under shear load” in non-cracked concrete C20/25.

$A_{s,bol}$ = [mm²] - effective cross section of bolt

$A_{s,sle}$ = [mm²] - effective cross section of sleeve;

$A_{s,fas}$ = [mm²] - $A_{s,bol} + A_{s,sle}$;

Adjustment for different steel strengths in Equations (E.7) and (E.8) is not required if the fasteners tested in C1.2 and in in tests for “characteristic resistance to steel failure under shear load” in non-cracked 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, V_{eq} shall be permitted to be calculated in accordance with Equation (E.9).

$$V_{eq} = 0{,}35 \cdot A_s \cdot f_{uk} \text{ [N]} \tag{E.9}$$

where

A_s = [mm²] - effective stressed cross section area of steel element in the shear plane;

f_{uk} = [N/mm²] - characteristic steel ultimate tensile strength (nominal value) of the finished product;

$$V_i = 0{,}75 \cdot V_{eq} \quad \text{[N]} \tag{E.10}$$

$$V_m = 0{,}5 \cdot V_{eq} \quad \text{[N]} \tag{E.11}$$

Table E.3 Required loading history for test series C1.2

Load level	$\pm V_{eq}$	$\pm V_i$	$\pm V_m$
Number of cycles (n_{cyc})	10	30	100

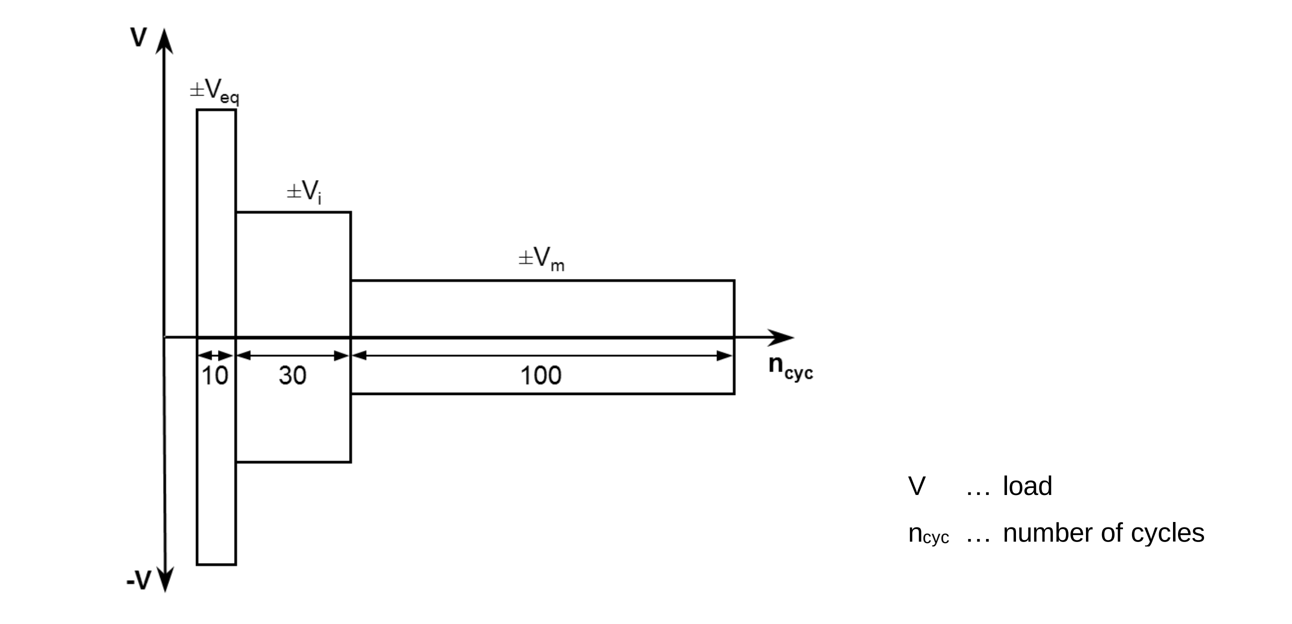


Figure E.8 Required load history for test series C1.2

To reduce the potential for uncontrolled slip during load reversal, the alternating shear loading (Figure E.9a) 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.9b, or by simply triangular loading cycles as shown in Figure E.9E.

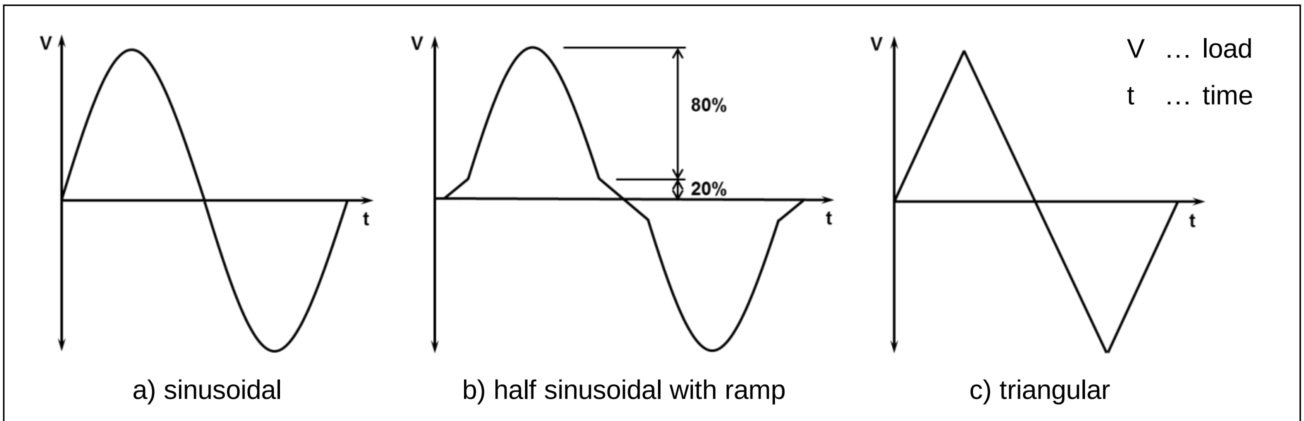


Figure E.9 Permitted seismic shear cycle C1.2

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.

If the fastener fails to fulfil the requirements given in the corresponding assessment (see E.4.1.2) it shall be permitted to conduct the tests with a reduced load level.

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.4.

Table E.4 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 Section	**Assessment criteria** see Section
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	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	0,5 ($\leq 0{,}5 \cdot N/N_{max}$) [4] 0,8 ($> 0{,}5 \cdot N/N_{max}$)	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	Δw_1 = 0,0 [5] Δw_2 = 0,8	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, head configurations (mechanical fasteners), types of inserts (bonded fasteners), 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:

Bonded fasteners shall be tested with a confined test setup in accordance with Annex D with an embedment depth and steel strength as defined in E.3.2.4.3. All other fasteners shall be tested with an unconfined test setup.

All tests shall be performed with fasteners with a steel strength not smaller than the nominal value 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 performed in accordance with Annex D, with a crack width as specified in Table E.4.

The test series C2.2 may be omitted if the results of the service condition 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 non-cracked 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 or pull-through of the fastener 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 Annex D and E.3.1.1 with the following modifications:

Open the crack by Δw = 0,5 mm (see exception in Footnote 4 of Table E.4). Subject the fastener to the sinusoidal tension loads specified in Table E.5 and Figure E.10 with a cycling frequency no greater than 0,5 Hz, where N_{max} is given by Equation (E.12) to Equation (C14). 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.

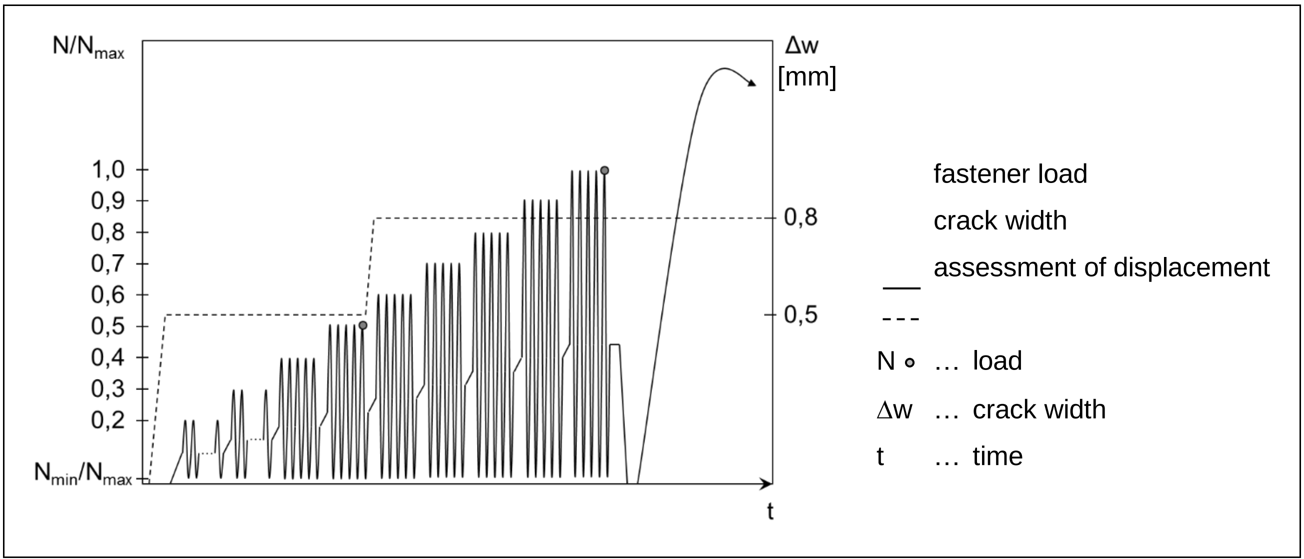


Figure E.10 Schematic test procedure C2.3

Table E.5 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

$$N_{\max} = 0{,}75 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{u,C2.3}}{f_{u,C2.1a}}\right) \text{ [N]} \quad \text{(E.12)}$$

Bond failure of bonded fasteners

$$N_{\max} = 0{,}75 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{c,C2.3}}{f_{c,C2.1a}}\right)^{n} \text{ [N]} \quad \text{(E.13)}$$

All other failure modes

$$N_{\max} = 0{,}75 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{c,C2.3}}{f_{c,C2.1a}}\right)^{0{,}5} \text{ [N]} \quad \text{(E.14)}$$

where

$N_{u,m,C2.1a}$ = [N] - mean tension capacity from the reference test series C2.1a [N];

$f_{u,C2.3}$ = [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;

n = normalization factor to account for concrete strength.

If mixed failure modes occur in test series C2.1a, the largest value of Equations (E.12) and (E.14) shall be applied.

Adjustment for different steel strengths in Equation (E.12) 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, 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.

If the fastener fails to fulfil the requirements given in the corresponding assessment (see E.4.2.4) it shall be permitted to conduct the tests with a reduced load level.

If the fastener meets the requirements given in the corresponding assessment but a smaller displacement at the first assessment point (i.e. at the end of load cycling at level $0{,}5 \cdot N/N_{max}$; see E.4.2.4 and Figure E.10 is intended it shall be permitted to conduct the test with a reduced load level.

E.3.4.4 Tests under alternating shear load (test series C2.4)

The tests shall be performed according to Annex D and E.3.1.1 with the following modifications:

Open the crack by Δw = 0,8 mm. Subject the fastener to the sinusoidal shear loads specified in Table E.6 and Figure E.11 with a cycling frequency no greater than 0,5 Hz, where V_{max} is given by Equation (E.15) or Equation (E.16) as applicable.

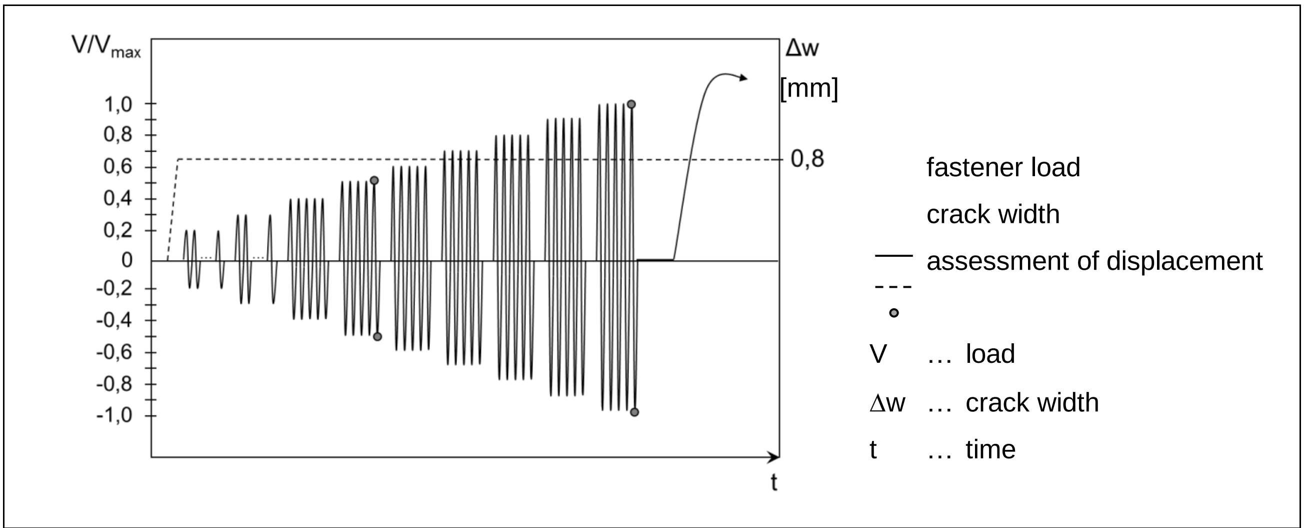


Figure E.11 Schematic test procedure C2.4

Table E.6 Required load amplitudes for test series C2.4

±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	

$$V_{\max} = 0{,}85 \cdot V_{u,m,C2.2}\left(\frac{f_{u,C2.4}}{f_{u,C2.2}}\right) \text{ [N]}$$ (fasteners without sleeve in shear plane) (E.15)

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.

For fasteners with a sleeve in the shear plane V_{eq} shall be calculated according to Equation (E.16).

$$V_{max} = 0{,}85 \cdot V_{u,m,C2.2} \cdot \left(\frac{f_{u,bol,C2.4}}{f_{u,bol,C2.2}} \cdot \frac{A_{s,bol}}{A_{s,fas}} + \frac{f_{u,sle,C2.4}}{f_{u,sle,C2.2}} \cdot \frac{A_{s,sle}}{A_{s,fas}}\right) \text{[N]} \quad \text{(E.16)}$$

where

$V_{u,m,C2.2}$ = [N] - as defined in Equation (E.15);

$f_{u,bol,C2.4}$ = [N/mm²] - mean ultimate tensile strength of bolt used in test series C2.4;

$f_{u,sle,C2.4}$ = [N/mm²] - mean ultimate tensile strength of sleeve used in test series C2.4;

$f_{u,bol,C2.2}$ = [N/mm²] - mean ultimate tensile strength of bolt used in test series C2.2;

$f_{u,sle,C2.2}$ = [N/mm²] - mean ultimate tensile strength of sleeve used in test series C2.2;

$A_{s,bol}$ = [mm²] - effective cross section of bolt;

$A_{s,sle}$ = [mm²] - effective cross section of sleeve;

$A_{s,fas}$ = [mm²] - $A_{s,bol} + A_{s,sle}$.

Adjustment for different steel strengths in Equations (E.15) and (E.16) 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.12b) or simply triangular loading cycles (see Figure E.12c) may be used in place of sinusoidal cycles (see Figure E.12a). The crack width shall be controlled during load cycling.

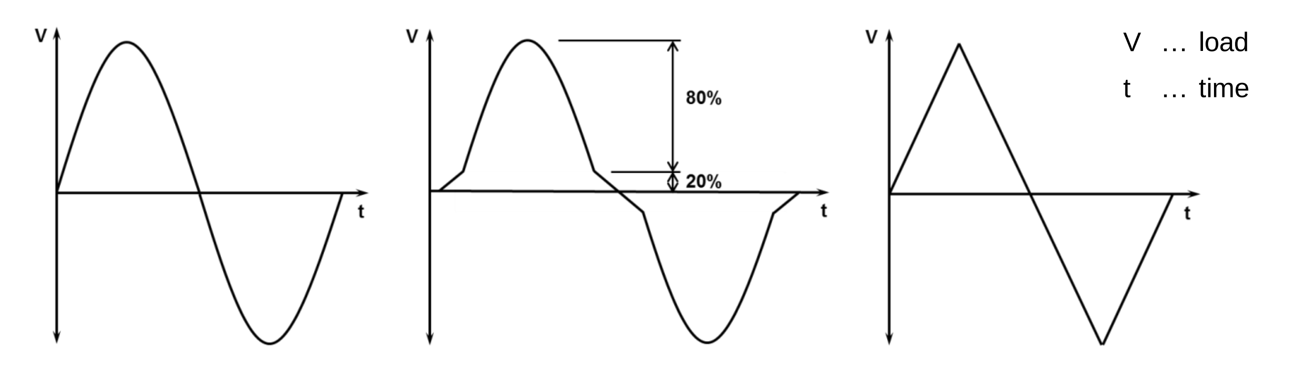


Figure E.12 Permitted seismic shear cycle C2.4

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.

If the fastener fails to fulfil the requirements given in the corresponding assessment (see E.4.2.5) it shall be permitted to conduct the tests with a reduced load level.

If the fastener meets the requirements given in the corresponding assessment but a smaller displacement at the first assessment point (i.e. at the end of load cycling at level $0{,}5 \cdot V/V_{max}$; see E.4.2.5 and Figure E.11) is intended it shall be permitted to conduct the test with a reduced load level.

If in the test series C2.4 failure is caused by pull-out or pull-through the test may be repeated with a larger embedment depth avoiding these failure modes (compare E.4.2.5).

Note E.7 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 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 Annex D and E.3.1.1 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.17).

$$C_{ini} = 0{,}01 \cdot f_{c,C2.5} \cdot A_g \quad \text{[N]} \tag{E.17}$$

where

A_g = [mm^2] - 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/mm^2] - 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 E.3.1.2. When C_{ini} is applied for testing bonded fasteners and bonded expansion fasteners the following procedure may be applied: remove the compression force C_{ini}, install the fastener according to E.3.1.2 and after curing again apply C_{ini} on the concrete test member.

Place crack measurement displacement transducers according to E.3.1.3 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.19) to Equation (E.21). With the fastener load N_{w1} held constant, begin the crack cycling program specified in Table E.7 and Figure E.13 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 C.1: 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.13).

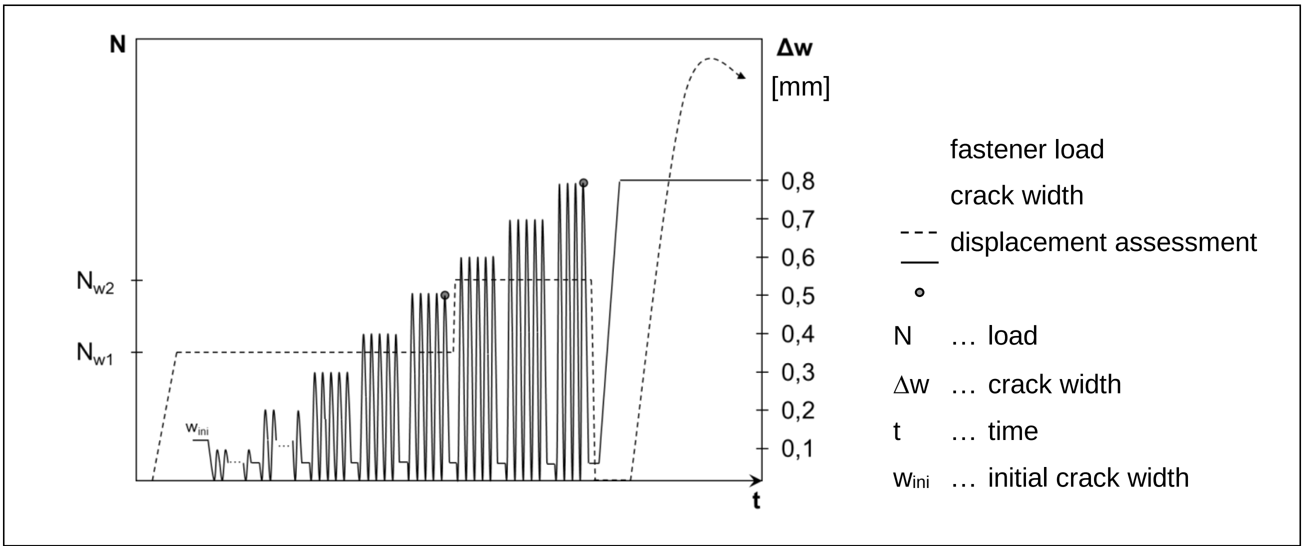


Figure E.13 Schematic test procedure C2.5

Table E.7 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.18).

$$C_{test} = 0{,}1 \cdot f_{c,C2.5} \cdot A_g \quad \text{[N]} \tag{E.18}$$

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.18), 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.4)

Depending on the failure mode observed in the test series C2.1a, N_{w1} is determined as follows:

Steel Failure

$$N_{w1} = 0{,}4 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{u,C2.5}}{f_{u,C2.1a}}\right) \text{ [N]} \tag{E.19}$$

Bond Failure of bonded fasteners

$$N_{w1} = 0{,}4 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{c,C2.5}}{f_{c,C2.1a}}\right)^{n} \text{ [N]} \tag{E.20}$$

All other failure modes

$$N_{w1} = 0{,}4 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{c,C2.5}}{f_{c,C2.1a}}\right)^{0{,}5} \text{ [N]} \tag{E.21}$$

where

$N_{u,m,C2.1a}$ = [N] - mean tension capacity from the test series C2.1a [N];

$f_{u,C2.5}$ = [N/mm^2] - ultimate mean steel strength of fasteners used in the test series C2.5;

$f_{u,C2.1a}$ = [N/mm^2] - ultimate mean steel strength of fasteners used in the test series C2.1a;

$f_{c,C2.5}$ = [N/mm^2] - mean compressive strength of concrete used at the time of testing in the test series C2.5;

$f_{c,C2.1a}$ = [N/mm^2] - mean compressive strength of concrete used at the time of testing in the test series C2.1a;

n = normalization factor to account for concrete strength.

If mixed failure modes occur in the test series C2.1a, the largest value of Equations (E.19) and (E.21) shall be applied.

After completion of the crack cycles at crack width $\Delta w = 0{,}5$ mm, increase the tension load on the fastener to N_{w2} as given by Equation (E.22) to Equation (E.24) 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

$$N_{w2} = 0{,}5 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{u,C2.5}}{f_{u,C2.1a}}\right) \text{ [N]} \tag{E.22}$$

Bond Failure of bonded fasteners

$$N_{w2} = 0{,}5 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{c,C2.5}}{f_{c,C2.1a}}\right)^{n} \text{ [N]} \tag{E.23}$$

All other failure modes

$$N_{w2} = 0{,}5 \cdot N_{u,m,C2.1a} \cdot \left(\frac{f_{c,C2.5}}{f_{c,C2.1a}}\right)^{0{,}5} \text{ [N]} \tag{E.24}$$

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.19) to Equation(E.21).

If mixed failure modes occur in the test series C2.1a, the largest value of Equations (E.22) and (E.24) shall be applied.

Adjustment for different steel strengths in Equation (E.19) and Equation (E.22) 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.

If the fastener fails to fulfil the requirements given in the corresponding assessment (see E.4.2.6) it shall be permitted to conduct the tests with a reduced load level.

If the fastener meets the requirements given in the corresponding assessment but a smaller displacement at the first assessment point (i.e. at the end of crack width cycling at level Δw = 0,5 mm; see E.4.2.6 and Figure E.13) is intended it shall be permitted to conduct the test with a reduced load level.

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.2 and Figure E.7. Failure of a fastener to develop the required resistance in any cycle prior to completing the load history specified in Table E.2 and Figure E.7 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_{eq} as given by Equation (E.3) or Equation (E.4), as applicable.

Successful completion of the cyclic loading history and fulfilment of the residual tension capacity requirement of this section shall be reported. In this case the seismic reduction factor for tension loading according to Equation (E.25) is $\alpha_{N,C1}$ = 1,0.

If the fastener fails to fulfil one of the above requirements at N_{eq}, it shall be permitted to conduct the test with reduced cyclic loads $N_{eq,red}$ until the requirements are met. The loading history specified in Table E.2 and Figure E.7 shall be applied, where $N_{eq,red}$, $N_{i,red}$ and $N_{m,red}$ are substituted for N_{eq}, 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.2 and Figure E.7 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 $N_{eq,reE.}$ Successful completion of the cyclic loading history with reduced load values and fulfilment of the residual tension capacity requirement of this section shall be recorded together with the type of failure mode causing the reduced load values and the reduction factor $\alpha_{N,C1}$, which is calculated as given in Equation (E.25).

$$\alpha_{N,C1} = \frac{N_{eq,red}}{N_{eq}} \qquad \text{(E.25)}$$

If the fastener successfully completes the cyclic loading history but does not fulfil the residual capacity requirement, 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, 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 and Figure E.8. Failure of a fastener to develop the required resistance in any cycle prior to completing the loading history specified in Table E.3 and Figure E.8 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_{eq} given by Equation (E.7), Equation (E.8) or Equation (E.9), as applicable.

Successful completion of the cyclic loading history and fulfilment of the residual shear capacity requirement of this section shall be reported. In this case the seismic reduction factor for shear loading according to Equation (E.26) is $\alpha_{V,C1}$ = 1,0.

If the fastener fails to fulfil one of the above requirements at V_{eq}, it shall be permitted to conduct the test with reduced cyclic loads $V_{eq,red}$ until the requirements are met. The loading history specified in Table E.3 and Figure E.8 shall be applied, where $V_{eq,red}$, $V_{i,red}$ and $V_{m,red}$ are substituted for V_{eq}, 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 and Figure E.8 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 $V_{eq,reE.}$ Successful completion of the cyclic history with reduced load values and fulfilment of the residual capacity requirement of this section shall be recorded together with a corresponding reduction factor $\alpha_{V,C1}$, which is calculated as given in Equation (E.26).

$$\alpha_{V,C1} = \frac{V_{eq,red}}{V_{eq}} \tag{E.26}$$

If the fastener successfully completes the cyclic loading history but does not fulfil the residual capacity requirement, 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 bonded fastener 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.26) is valid for all embedment depths greater than the tested embedment depth. If more than one embedment depth has been tested 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

$$N_{u,m}(f_u) = N_{u,m,test} \cdot \left(\frac{f_u}{f_{u,test}} \right) \quad [N] \tag{E.27}$$

$$V_{u,m}(f_u) = V_{u,m,test} \cdot \left(\frac{f_u}{f_{u,test}} \right) \quad [N] \tag{E.28}$$

For fasteners with a sleeve in the shear plane the normalization shall be calculated as follows:

$$V_{u,m}(f_u) = V_{u,m,test} \cdot \left(\frac{f_u}{f_{u,test}} \cdot \frac{A_{s,bol}}{A_{s,fas}} + \frac{f_{u,sle}}{f_{u,sle,test}} \cdot \frac{A_{s,sle}}{A_{s,fas}} \right) [N] \tag{E.29}$$

Bond Failure of bonded fasteners

$$N_{u,m}(f_c) = N_{u,m,test} \cdot \left(\frac{f_c}{f_{c,test}} \right)^n \quad [N] \tag{E.30}$$

All other failure modes

$$N_{u,m}(f_c) = N_{u,m,test} \cdot \left(\frac{f_c}{f_{c,test}}\right)^{0.5} \quad [N] \tag{E.31}$$

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 tension capacity;
$N_{u,m,test}$	=	[N] - mean tension capacity from the test series;
$V_{u,m}$	=	[N] - normalized mean shear capacity;
$V_{u,m,test}$	=	[N] - mean shear capacity 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 insert 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 insert of fasteners used in the tests;
n	=	normalization factor to account for concrete strength.

Adjustment for different steel strengths in Equation (E.27) to Equation (E.29) 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 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, and/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, 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:

$$cv(\delta(0{,}5 \cdot N_{u,m,C2.1})) \leq 40\% \tag{E.32}$$

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, 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:

$$N_{u,m,C2.1a} \geq 0{,}8 \cdot N_{u,m,3} \qquad \text{(E.33)}$$

with

$N_{u,m,C2.1a}$ = [N] - mean ultimate tension load from test series C2.1a;

$N_{u,m,3}$ = [N] - mean tension capacity from the tests for “sensitivity to increased crack width (F6)” in concrete C20/25 according to Table 2.5;

If this condition is fulfilled, $\alpha_{C2.1a}$ = 1,0. If the condition is not fulfilled, the reduction factor $\alpha_{C2.1a}$ is determined for the test series C2.1a according to Equation (E.34).

$$\alpha_{C2.1a} = \frac{N_{u,m,C2.1a}}{0{,}8 \cdot N_{u,m,3}} \qquad \text{(E.34)}$$

In Equations (E.33) and (E.34) the resistances from the tests for suitability tests “sensitivity to increased crack width (F6)” in concrete C20/25 according to Table 2.5 shall be normalized according to Equation (E.27), Equation (E.30) or Equation (E.31), as applicable, to the strength in test series C2.1a.

b. Test series C2.1b in high strength concrete C50/60:

$$N_{u,m,C2.1b} \geq 0{,}8 \cdot N_{u,m,4} \qquad \text{(E.35)}$$

with

$N_{u,m,C2.1b}$ = [N] - mean ultimate tension load from test series C2.1b;

$N_{u,m,4}$ = [N] - mean tension capacity from the tests for “maximum crack width and small hole diameter” in suitability tests “sensitivity to increased crack width (F7)” in concrete C50/60 according to Table 2.5.

If this condition is fulfilled, $\alpha_{C2.1b}$ = 1,0. If the condition is not fulfilled, the reduction factor $\alpha_{C2.1b}$ is determined for the test series C2.1b according to Equation (E.36).

$$\alpha_{C2.1b} = \frac{N_{u,m,C2.1b}}{0{,}8 \cdot N_{u,m,4}} \qquad \text{(E.36)}$$

In Equations (E.35) and (E.36) the resistances from the tests suitability tests “sensitivity to increased crack width (F7)” in concrete C50/60 according to Table 2.5 shall be normalized according to Equation (E.27), Equation (E.30) or Equation (E.31), as applicable, to the strength in test series C2.1b.

The reduction factor $\alpha_{C2.1}$ is determined according to Equation (E.37).

$$\alpha_{C2.1} = \min\left(\alpha_{C2.1a}; \alpha_{C2.1b}\right) \qquad \text{(E.37)}$$

3. Scatter of ultimate loads:

$$cv(N_u) \leq 20\% \qquad \text{(E.38)}$$

If this condition is fulfilled for both test series C2.1a and C2.1b, $\beta_{cv,C2.1a} = \beta_{cv,C2.1b}$ = 1,0. If this condition is not fulfilled in a test series, the factors $\beta_{cv,C2.1a}$ and/or $\beta_{cv,C2.1b}$ shall be calculated according to Equation (E.39) and Equation (E.40), respectively.

$$\beta_{cv,C2.1a} = \frac{1}{1 + \left(cv\left(N_{u,C2.1a}\right) - 20\right) \cdot 0{,}03} \qquad \text{(E.39)}$$

$$\beta_{cv,C2.1b} = \frac{1}{1 + \left(cv\left(N_{u,C2.1b}\right) - 20\right) \cdot 0{,}03} \qquad \text{(E.40)}$$

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.41):

$$\beta_{cv,C2.1} = \min\left(\beta_{cv,C2.1a}; \beta_{cv,C2.1b}\right) \quad \text{(E.41)}$$

If $cv(N_u)$ is larger than 30% in one test series, 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, this section does not apply. If test series C2.2 are performed for reference shear values the following conditions apply:

1. Failure mode:

   If failure is caused by pull-out or pull-through the fastener is not suitable for use in category C2. The test may be repeated with a larger embedment depth avoiding these failure modes.

2. Ultimate load:

$$V_{u,m,C2.2} \geq 0{,}8 \cdot V_{u,m,5} \quad \text{(E.42)}$$

   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, $\alpha_{C2.2}$ = 1,0. If this condition is not fulfilled, the factor $\alpha_{C2.2}$ shall be determined according to Equation (E.43).

$$\alpha_{C2.2} = \frac{V_{u,m,C2.2}}{0{,}8 \cdot V_{u,m,5}} \quad \text{(E.43)}$$

   In Equations (E.42) and (E.43) the resistances from the tests for "characteristic resistance to steel failure under shear load" shall be normalized according to Equation (E.28) or Equation (E.29), as applicable, to the strength in test series C2.2.

3. Scatter of ultimate loads:

$$cv(V_u) \leq 15\% \quad \text{(E.44)}$$

   If this condition is fulfilled, $\beta_{cv,C2.2}$ = 1,0. If this condition is not fulfilled, the factor $\beta_{cv,C2.2}$ shall be determined according to Equation (E.45).

$$\beta_{cv,C2.2} = \frac{1}{1 + \left(cv(V_u) - 15\right) \cdot 0{,}03} \quad \text{(E.45)}$$

   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%, 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.10 and Table E.5. Failure of a fastener to develop the required resistance in any cycle prior to completing the loading history specified in Table E.5 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.46).

$$\alpha_{C2.3a} = \frac{N_{max,red,1}}{N_{max}} \quad \text{(E.46)}$$

   with

   N_{max} = [N] - maximum tension load according to Equation (E.12) to Equation (E.14).

   $N_{max,red,1}$ = [N] - reduced tension load to fulfil the requirement.

2. Displacements are assessed during the last cycle at 0,5·N/N_{max} and at 1,0·N/N_{max} or at 0,5·$N/N_{max,red,1}$ and at 1,0·$N/N_{max,red,1}$, respectively, (refer to Figure E.10). 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·N/N_{max} or 0,5·$N/N_{max,red,1}$ (i.e. after 50 load cycles (see Figure E.10 and Table E.5) 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:

$$\delta_m(0{,}5 \cdot N/N_{\max}) \leq \delta_{N,\lim} \tag{E.47}$$

   with

   δ_m (0,5·N/N_{max}) = [mm] - mean value of displacements of the fastener after load cycling at 0,5·N/N_{max} or 0,5·$N/N_{max,red,1}$ of test series C2.3;

   $\delta_{N,lim}$ = 7 mm.

   If this condition is not fulfilled 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.48).

$$\alpha_{C2.3b} = \frac{N_{max,red,2}}{N_{max}} \tag{E.48}$$

   with

   N_{max} = [N] - maximum tension load according to Equation (E.12) to Equation (E.14);

   $N_{max,red,2}$ = [N] - reduced tension load to fulfil the requirement.

   If the condition according to Equation (E.47) is fulfilled but a smaller displacement is intended it shall be permitted to repeat the tests with a reduced value $N_{max,reE.}$

3. Residual capacity tests (all three conditions apply):

   a. Scatter of displacement:

$$cv\left(\delta\left(0{,}5 \cdot N_{u,m,C2.3}\right)\right) \leq 40\% \tag{E.49}$$

   with

   δ (0,5·$N_{u,m,C2.3}$) = [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, the fastener is not suitable for use in category C2.

   b. Ultimate load:

$$N_{u,m,C2.3} \geq 0{,}9 \cdot N_{u,m,C2.1a} \tag{E.50}$$

   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, $\alpha_{C2.3c}$ = 1,0. If this condition is not fulfilled, the factor $\alpha_{C2.3c}$ shall be determined according to Equation (E.51).

$$\alpha_{C2.3c} = \frac{N_{u,m,C2.3}}{0{,}9 \cdot N_{u,m,C2.1a}} \tag{E.51}$$

   In Equations (E.50) and (E.51) the resistances from test series C2.1a shall be normalized according to Equation (E.27), Equation (E.30) or Equation (E.31), as applicable, to the strength in test series C2.3.

   Alternatively, the test series C2.3 may be repeated with a reduced value of N_{max} until the requirement given in Equation (E.50) is fulfilled.

c. Scatter of ultimate loads:

$$cv(N_u) \leq 20\% \tag{E.52}$$

If this condition is fulfilled, $\beta_{cv,C2.3}$ = 1,0. If this condition is not fulfilled, $\beta_{cv,C2.3}$ shall be determined according to Equation (E.53).

$$\beta_{cv,C2.3} = \frac{1}{1+(cv(N_u)-20)\cdot 0{,}03} \tag{E.53}$$

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%, 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.54).

$$\alpha_{C2.3} = \min(\alpha_{C2.3a}; \alpha_{C2.3b}) \cdot \alpha_{C2.3c} \tag{E.54}$$

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.11 and Table E.6. Failure of a fastener to develop the required resistance in any cycle prior to completing the loading history specified in Table E.6 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.55).

$$\alpha_{C2.4a} = \frac{V_{max,red,1}}{V_{max}} \tag{E.55}$$

with

V_{max}	=	[N] - maximum shear load according to Equation (E.15) or Equation (E.16);
$V_{max,red,1}$	=	[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.11). 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.11 and Table E.6) 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:

$$\delta_m(0{,}5 \cdot V/V_{max}) \leq \delta_{V,lim} \tag{E.56}$$

with

δ_m $(0{,}5 \cdot V/V_{max})$	=	[mm] - max ($\lvert\delta_m(+0{,}5 \cdot V/V_{max})\rvert$; $\lvert\delta_m(-0{,}5 \cdot V/V_{max})\rvert$); 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 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.57).

$$\alpha_{C2.4b} = \frac{V_{max,red,2}}{V_{max}} \quad \text{(E.57)}$$

with

V_{max} = [N] - maximum shear load according to Equation (E.15) or Equation (E.16);

$V_{max,red,2}$ = [N] - reduced shear load to fulfil the requirement.

If the condition according to Equation (E.56) is fulfilled but a smaller displacement is intended 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 or pull-through 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:

$$V_{u,m,C2.4} \geq 0{,}95 \cdot V_{u,m,C2.2} \quad \text{(E.58)}$$

   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, $\alpha_{C2.4c} = 1{,}0$. If this condition is not fulfilled, the factor $\alpha_{C2.4c}$ shall be determined according to Equation (E.59).

$$\alpha_{C2.4c} = \frac{V_{u,m,C2.4}}{0{,}95 \cdot V_{u,m,C2.2}} \quad \text{(E.59)}$$

   In Equations (E.58) and (E.59) the resistances from test series C2.2 shall be normalized according to Equation (E.28) or Equation (E.29), as applicable, to the strength in test series C2.4.

   Alternatively, the test series C2.4 may be repeated with a reduced value of V_{max} until the requirement given in Equation (E.58) is fulfilled.

   c. Scatter of ultimate loads:

$$cv(V_u) \leq 15\% \quad \text{(E.60)}$$

   If this condition is fulfilled, $\beta_{cv,C2.4} = 1{,}0$. If this condition is not fulfilled, $\beta_{cv,C2.4}$ shall be determined according to Equation (E.61).

$$\beta_{cv,C2.4} = \frac{1}{1 + (cv(V_u) - 15) \cdot 0{,}03} \quad \text{(E.61)}$$

   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%, 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.62).

$$\alpha_{C2.4} = \min(\alpha_{C2.4a}; \alpha_{C2.4b}) \cdot \alpha_{C2.4c} \quad \text{(E.62)}$$

Report the displacements after successful completion at $\pm 0{,}5 \cdot V/V_{max}$ and $\pm 1{,}0 \cdot V/V_{max}$ or at $\pm 0{,}5 \cdot V/V_{max,red}$ and $\pm 1{,}0 \cdot V/V_{max,red}$ 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.13 and Table E.7. Failure of a fastener to develop the required resistance in any cycle prior to completing the crack cycling history specified in Table E.7 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.63).

$$\alpha_{C2.5a} = \frac{N_{w2,red,1}}{N_{w2}} \tag{E.63}$$

with

N_{w2} = [N] - tension load according to Equation (E.22) to Equation (E.24) 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.13). 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.13 and Table E.7) 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:

$$\delta_m(\Delta w = 0{,}5) \leq \delta_{N,\text{lim}} \tag{E.64}$$

with

$\delta_m\ (\Delta w = 0{,}5)$ = [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 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.65).

$$\alpha_{C2.5b} = \frac{N_{w2,red,2}}{N_{w2}} \tag{E.65}$$

with

N_{w2} = [N] - tension load according to Equation (E.22) to Equation (E.24);

$N_{w2,red,2}$ = [N] - reduced tension load to fulfil the requirement.

   If the condition according to Equation (E.64) is fulfilled but a smaller displacement is intended 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:

$$cv\left(\delta\left(0{,}5 \cdot N_{u,m,C2.5}\right)\right) \leq 40\% \tag{E.66}$$

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.

   If this condition is not fulfilled, the fastener is not suitable for use in category C2.

   b. Ultimate load:

$$N_{u,m,C2.5} \geq 0{,}9 \cdot N_{u,m,C2.1a} \tag{E.67}$$

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, $\alpha_{C2.5c}$ = 1,0. If this condition is not fulfilled, the factor $\alpha_{C2.5c}$ shall be determined according to Equation (E.68).

$$\alpha_{C2.5c} = \frac{N_{u,m,C2.5}}{0{,}9 \cdot N_{u,m,C2.1a}} \quad \text{(E.68)}$$

In Equations (E.67) and (E.6) the resistances from test series C2.1a shall be normalized according to Equation (E.27), Equation (E.30) or Equation (E.31), as applicable, to the strength in test series C2.5.

Alternatively, the test series C2.5 may be repeated with a reduced value of N_{max} until the requirement given in Equation (E.67) is fulfilled.

c. Scatter of ultimate loads:

$$cv(N_u) \leq 20\% \quad \text{(E.69)}$$

If this condition is fulfilled, $\beta_{cv,C2.5}$ = 1,0. If this condition is not fulfilled, $\beta_{cv,C2.5}$ shall be determined according to Equation (E.70).

$$\beta_{cv,C2.5} = \frac{1}{1 + (cv(N_u) - 20) \cdot 0{,}03} \quad \text{(E.70)}$$

If $cv(N_u)$ is larger than 30%, 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.71).

$$\alpha_{C2.5} = \min(\alpha_{C2.5a}; \alpha_{C2.5b}) \cdot \alpha_{C2.5c} \quad \text{(E.71)}$$

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.72) and(E.63), respectively.

$$\alpha_{N,C2} = \alpha_{C2.1} \cdot \min(\alpha_{C2.3};\ \alpha_{C2.5}) \quad \text{(E.72)}$$

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.

$$\beta_{cv,N,C2} = \min(\beta_{cv,C2.1};\ \beta_{cv,C2.3};\ \beta_{cv,C2.5}) \quad \text{(E.73)}$$

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.72) and Equation (E.73) are 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 failure modes are observed in these tests, 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.74) and (E.75), respectively.

$$\alpha_{V,C2} = \alpha_{C2.2} \cdot \alpha_{C2.4} \tag{E.74}$$

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.

$$\beta_{cv,V,C2} = \min(\beta_{cv,C2.2}; \beta_{cv,C2.4}) \tag{E.75}$$

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.74) and Equation (E.75) are valid for fasteners with the tested embedment depth and all larger embedment depths. If more than one embedment depth has been tested 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 All fasteners except bonded 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:

$$N_{Rk,s,C1} = \alpha_{N,C1} \cdot N_{Rk,s} \quad \text{[N]} \tag{E.76}$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,p} \quad \text{[N]} \tag{E.77}$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,c} \quad \text{[N]} \quad \text{(if no pull-out failure occurs for static loading)} \tag{E.78}$$

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:

$$N_{Rk,s,C1} = N_{Rk,s} \quad \text{[N]} \tag{E.79}$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,p} \quad \text{[N]} \tag{E.80}$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,c} \quad \text{[N]} \quad \text{(if no pull-out failure occurs for static loading)} \tag{E.81}$$

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:

$$N_{Rk,s,C1} = \alpha_{N,C1} \cdot N_{Rk,s} \quad [N] \tag{E.82}$$

$$\tau_{Rk,C1} = \alpha_{N,C1} \cdot \tau_{Rk,base} \quad [N] \tag{E.83}$$

where

$N_{Rk,s}$ = [N] - characteristic steel tension resistance as reported in the ETA for static loading;

$\tau_{Rk,base}$ = [N/mm²] - characteristic bond resistance for cracked concrete ($\tau_{Rk,cr}$) as reported in the ETA for static loading;

$\alpha_{N,C1}$ = reduction factor α according to E.4.1.1.

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:

$$N_{Rk,s,C1} = N_{Rk,s} \quad [N] \tag{E.84}$$

$$\tau_{Rk,C1} = \alpha_{N,C1} \cdot \tau_{Rk,base} \quad [N] \tag{E.85}$$

with $N_{Rk,s}$, $\tau_{Rk,base}$ and $\alpha_{N,C1}$ as defined in Equation (E.82) and Equation(E.83).

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:

$$V_{Rk,s,C1} = \alpha_{V,C1} \cdot V^0_{Rk,s} \cdot k_7 \quad [N] \tag{E.86}$$

where

$V^0_{Rk,s}$ = [N] - characteristic shear resistance as reported in the ETA for static loading;

k_7 = factor for ductility acc. 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.86) is valid for all embedment depths greater than the tested embedment depth. If more than one embedment depth has been tested 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

The characteristic values reported in the ETA are calculated as follows:

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 All fasteners except bonded fasteners

The clause does not apply to this EAD.

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:

$$N_{Rk,s,C2} = \alpha_{N,C2} \cdot \beta_{cv,N,C2} \cdot N_{Rk,s} \quad [N] \tag{E.91}$$

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.72) for tests in which steel failure occurred;

$\beta_{cv,N,C2}$ = reduction factor β_{cv} accounting for large scatter as determined in Equation (E.73) for tests in which steel failure occurred.

b) Pullout (bond) failure:

If pullout (bond) failure for bonded fasteners is given in terms of a characteristic bond resistance the corresponding resistance under seismic loading $\tau_{Rk,C2}$ is determined as follows:

$$\tau_{Rk,C2} = \alpha_{N,C2} \cdot \beta_{cv,N,C2} \cdot \tau_{Rk,base} \quad [N/mm^2] \tag{E.92}$$

with

$\tau_{Rk,base}$ = [N/mm²] - basic bond strength τ^0_{Rk} from tests “sensitivity to increased crack width (F6)” in concrete C20/25 according to Table 2.5 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 section 2.2.2 and the reduction resulting from tests “sensitivity to sustained loads” according to Table 2.5 (i.e. reduction resulting from sustained load); however, the reduction resulting from tests “sensitivity to crack movements (B13)” according to Table 2.5 (i.e. reduction resulting from functioning in crack movement) may not be applied.

$\alpha_{N,C2}$ = reduction factor α as determined in Equation (E.72) 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.73) 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, $V_{Rk,s,C2}$, to be reported in the ETA is determined as follows:

$$V_{Rk,s,C2} = \alpha_{V,C2} \cdot \beta_{cv,V,C2} \cdot V^0_{Rk,s} \cdot k_7 \quad [N] \tag{E.93}$$

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.74);

$\beta_{cv,V,C2}$ = reduction factor β_{cv} accounting for large scatter according to Equation (E.75);

k_7 = factor for ductility acc. to 2.2.7.2.

The characteristic resistance according to Equation (E.93) is valid for fasteners with the tested embedment depth and all larger embedment depths. If more than one embedment depth has been tested the characteristic resistance for an intermediate embedment depth may be determined by linear interpolation.

E.4.3.2.3 Displacements

The displacement values reported in the ETA are determined as given in Table E.8.

Table E.8 Displacement information

Displacement [1)]	**Obtained from**
$\delta_{N,C2(DLS)}$	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.
$\delta_{N,C2(ULS)}$	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.
$\delta_{V,C2(DLS)}$	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.
$\delta_{V,C2(ULS)}$	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.

[1)] DLS – Damage Limitation State (see EN 1998-1:2004, 2.2.1)
ULS – Ultimate Limit State (see EN 1998-1:2004, 2.2.1)

E.4.3.3 Reduction factor α_{gap}

When an annular gap is present between fastener and fixture, the forces on the fasteners are amplified under shear loading due to a hammer effect on the fastener.

In the design approach of EN 1992-4:2018 this effect is considered in the resistance of the fastening by introducing the reduction factor α_{gap}.

The factor α_{gap} is taken as equal to 0,5 for fasteners with hole clearance according to EN 1992-4:2018 Table 6.1 or equal to 1,0 if the product specifications and or the MPII require a proper filling of the annular gap and shear tests were carried out accordingly. The TAB shall check proper filling of the annular gap using the procedure given in the MPII for single fasteners as well as for groups of fasteners.

The value of α_{gap} is reported in the ETA as a product performance of the fastener as a function of the installation instructions.

When different performances are reported for installation with or without filling of the annular gap, consequently different values of α_{gap} have to be reported, respectively.

E.4.3.4 Content of the European Technical Assessment (ETA)

In the ETA the characteristic resistance for seismic performance category C1 or C2 for which the fastener has been assessed shall be reported. The design method for which the characteristic resistance applies shall be referred to.

An example of the information for characteristic values for design of fasteners under seismic action is shown in Table E.9 and Table E.10.

Table E.9 Sample ETA seismic design information for seismic performance category C1

Fastener type		**M…**	**…**	**M…**
(static design information)		xx		xx
Seismic design information				
$N_{Rk,s,C1}$	[kN]	xx		xx
$\gamma_{Ms,C1}$ [1)]	[-]	xx		xx
$\tau_{Rk,C1}$ ($N_{Rk,p,C1}$ for bonded expansion fasteners)	[N/mm²] [kN]	xx		xx
$\gamma_{Mp,C1}$ [1)]	[-]	xx		xx
$V_{Rk,s,C1}$	[kN]	xx		xx
$\gamma_{Ms,C1}$ [1)]	[-]	xx		xx

[1)] The recommended partial factors under seismic action ($\gamma_{M,C1}$) are the same as for static loading.

Table E.10 Sample ETA seismic design information for seismic performance category C2

Fastener type		**M…**	**…**	**M…**
(static design information)		xx		xx
Seismic design information				
$N_{Rk,s,C2}$ 2)	[kN]	xx		xx
$\gamma_{Ms,C2}$ 3)	[-]	xx		xx
$\tau_{Rk,eq}$ 2) ($N_{Rk,p,C2}$ for bonded expansion fasteners)	[N/mm²] [kN]	xx		xx
$\gamma_{Mp,C2}$ 3)	[-]	xx		xx
$\delta_{N,C2(DLS)}$ 1) 2)	[mm]	xx		xx
$\delta_{N,C2(ULS)}$ 1)	[mm]	xx		xx
$V_{Rk,s,C2}$ 2)	[kN]	xx		xx
$\gamma_{Ms,C2}$ 3)	[-]	xx		xx
$\delta_{V,C2(DLS)}$ 1) 2)	[mm]	xx		xx
$\delta_{V,C2(ULS)}$ 1)	[mm]	xx		xx
DLS – Damage Limitation State (see EN 1998-1:2004, 2.2.1) ULS – Ultimate Limit State (see EN 1998-1:2004, 2.2.1)				

1) The listed displacements represent mean values.

2) A smaller displacement may be required in the design provisions stated in section “Design of Anchorage”, e.g. in the case of displacement sensitive fastenings or “rigid” supports. The characteristic resistance associated with such smaller displacement may be determined by linear interpolation or proportional reduction.

3) The recommended partial factors under seismic action ($\gamma_{M,C2}$) are the same as for static loading.

E.5 Test Report

In addition to the minimum requirements listed in Annex D, the report shall include at least the following information regarding the optional 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_{eq}, N_i and N_m on fastener and method of applying the load in test series C1.1
    - Constant load levels V_{eq}, 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.