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EAD 330232-02-0601

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European Assessment Document for

Mechanical fasteners for use in concrete

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

Contents

1 SCOPE OF THE EAD

1.1 Description of the construction product

This EAD covers post-installed mechanical metal fasteners placed into pre-drilled holes perpendicular to the surface (maximum deviation 5°) in concrete and anchored therein by mechanical means such as friction or mechanical interlock. Mechanical fasteners are often used to connect structural elements and non-structural elements to structural components.

The metal parts of the fastener are made of carbon steel, stainless steel or malleable cast iron. The fasteners can include non-load bearing material, e.g., plastic parts, for rotation prevention. The fasteners are directly anchored in the concrete and transmit the applied loads.

The product is not fully covered by EAD 330232-01-0601 [1]. Compared to the previous version of the EAD, the following changes are introduced:

- Reduced test programme for additional drilling methods
- Revision of crack cycling tests
- Revision of assessment of fastener displacements
- Implementation of EAD 330232-01-0601-v01 (Durability of zinc-based coated fasteners)
- Implementation of EAD 330232-01-0601-v02 (Improved resistance to concrete cone failure)
- Implementation of EAD 330232-01-0601-v03 (Variable embedment depth)
- Implementation of EAD 330232-01-0601-v04 (Stiffness characteristics)
- Implementation of EAD 330232-01-0601-v05 (Mechanical fasteners for use in concrete C12/15 to C90/105 and in steel fibre reinforced concrete)
- Implementation of EAD 330232-01-0601-v06 (100 years working life)

The following operating principles of mechanical fasteners are covered by this EAD:

- Torque-controlled expansion fastener (TC)
- Deformation-controlled expansion fastener (DC)
- Undercut fastener (UC)
- Concrete screw (CS)

This EAD applies to fasteners with the following minimum dimensions:

Table 1.1.1 Minimum fastener dimensions

Conditions	Dry internal exposure only and	All other applications
	Statically indeterminate structural components, when in case of failure the load can be distributed to other fasteners	
Nominal diameter	d_{nom} = M5 (5 mm)	d_{nom} = M6 (6 mm)
Embedment depth	h_{ef} = 30 mm (TC; DC; UC)	h_{ef} = 40 mm (TC; DC; UC)
	$h_{nom} - h_s$ = 30 mm (CS)	$h_{nom} - h_s$ = 40 mm (CS)

This EAD covers only fasteners with an embedment depth given in Table 1.1.1 under the conditions given in Table 1.1.1 which are anchored in an area where spalling will not occur.

Fasteners with internal thread are covered only if they have a thread length of at least d + 5 mm after taking account of possible tolerances.

This EAD covers screw fasteners which are not sensitive to hydrogen embrittlement due to moisture present in the concrete, see Clause 2.2.1.3.

This EAD covers fasteners which are not sensitive to foreseeable and unavoidable variations in the use conditions, see Clause 2.2.4.

Note: Deformation-controlled expansion fasteners (DC) typically require a controlled installation depth (see Figure 1.1.2 to Figure 1.1.5). This limits the feasibility for variable embedment for this type of fasteners.

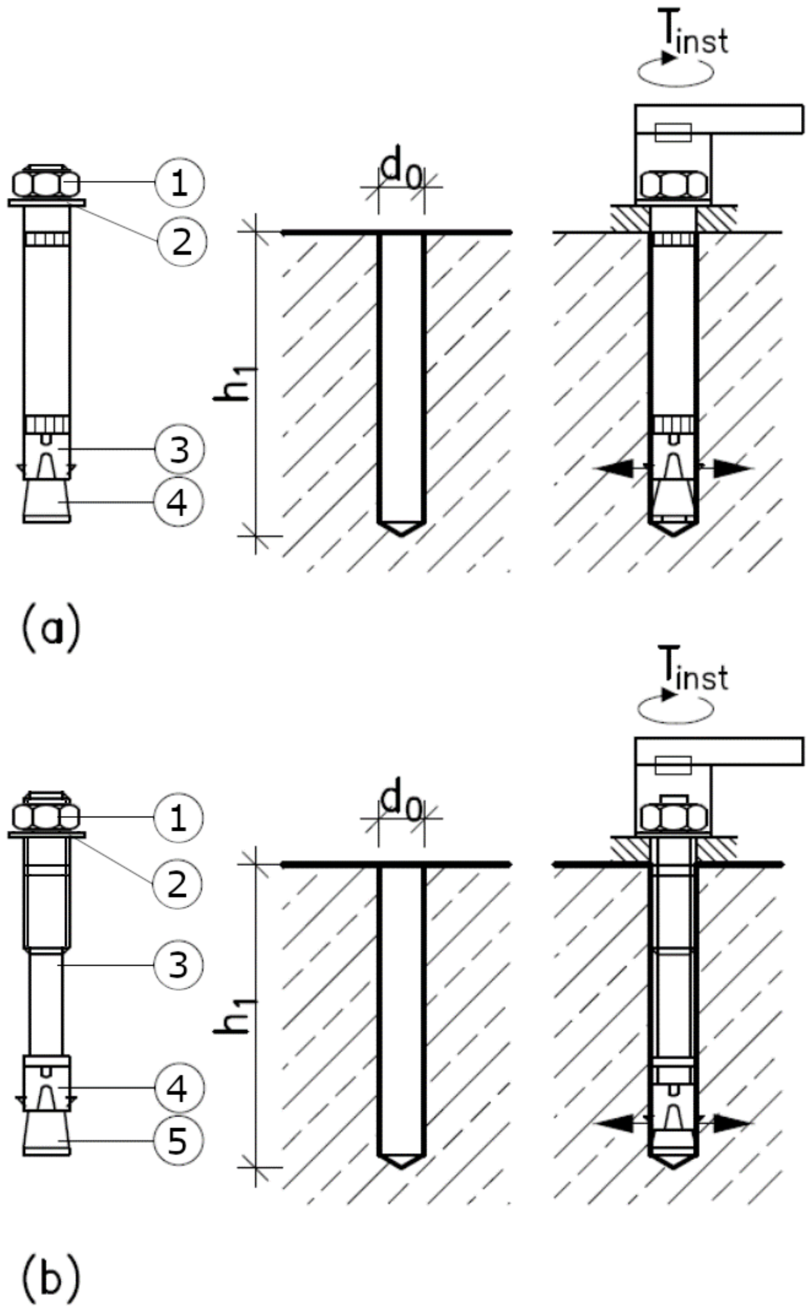
Note: The benefit of variable embedment depth versus multiple fixed embedment depths may only be established in the characteristic resistance $N_{Rk,p}$ for concrete screws (CS) with a thread along the entire length of the embedment depth.

The assessment of essential characteristics of mechanical fasteners for a continuous range of embedment depths (variable embedment depth) considers improved product performance within the range of embedment depths beyond the minimum embedment.

Torque-controlled expansion fasteners (TC)

The operating principle is shown in Figure 1.1.1.The expansion is achieved by a torque acting on the screw or bolt. The tension force applied to the fastener is transferred into the concrete via friction and, to a limited extent, via keying (mechanical interlock) between the expansion sleeve and the deformed concrete. The following types of torque-controlled fasteners are distinguished:

- Sleeve type (Figure 1.1.1 a)
- Bolt type (Figure 1.1.1 b)



1 Hexagon nut
2 Washer
3 Expansion sleeve
4 Cone bolt

(a) Sleeve type

1 Hexagon nut
2 Washer
3 Cone bolt
4 Expansion sleeve
5 Cone

(b) Bolt type

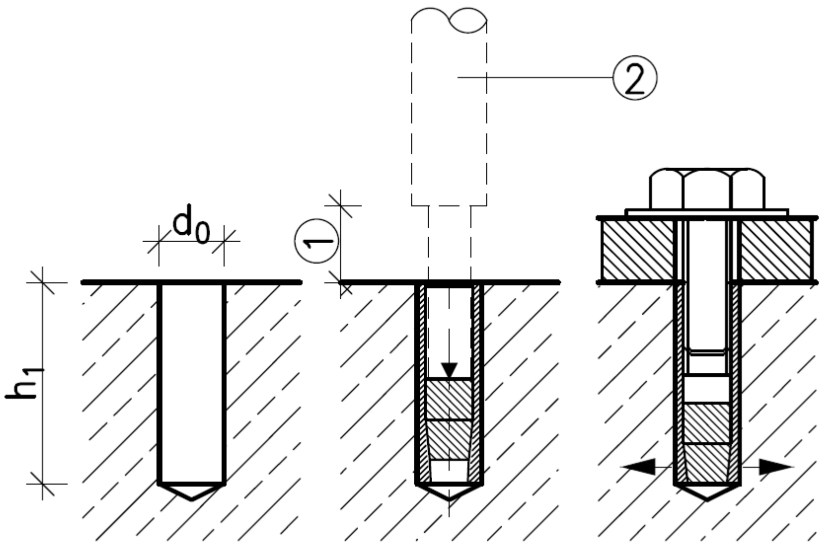
Figure 1.1.1 Example of torque-controlled expansion fasteners

Deformation-controlled expansion fasteners (DC)

Deformation-controlled expansion fasteners are installed by hammer blows or by percussion of a machine. The expansion of deformation-controlled expansion fasteners is generally achieved by impacts acting on a sleeve or cone. Expansion forces are created during fastener installation and tension forces are transferred into the concrete mainly by friction. The degree of expansion is not intended to be changed by loading the fastener. The following types of deformation-controlled fasteners are covered in this EAD:

- cone-down type fastener (drop-in fastener, Figure 1.1.2)
- shank-down type fastener (stud fastener, Figure 1.1.3)
- sleeve-down type fastener (Figure 1.1.4)
- sleeve-down type fastener (stud version, Figure 1.1.5)

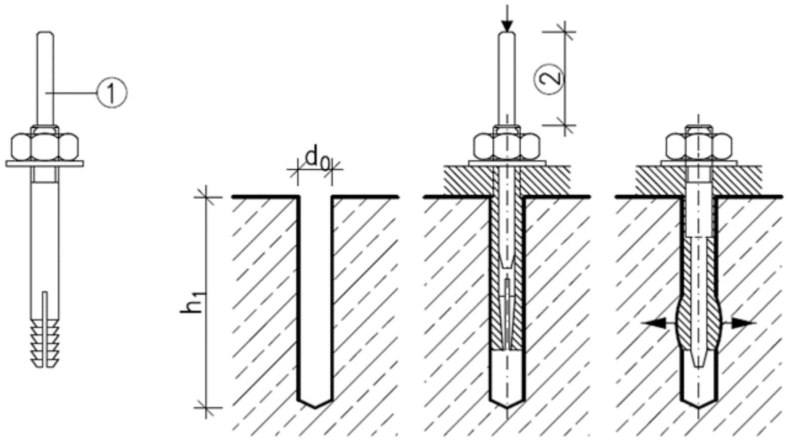
For the cone-down type the sleeve is expanded by driving in a cone. The fastening is controlled by the length of travel of the cone. A sleeve is driven over an expansion element in the case of sleeve-down type fasteners. The fastening is controlled by the travel of the sleeve over the expansion element.



1 Controlled installation depth

2 Setting tool

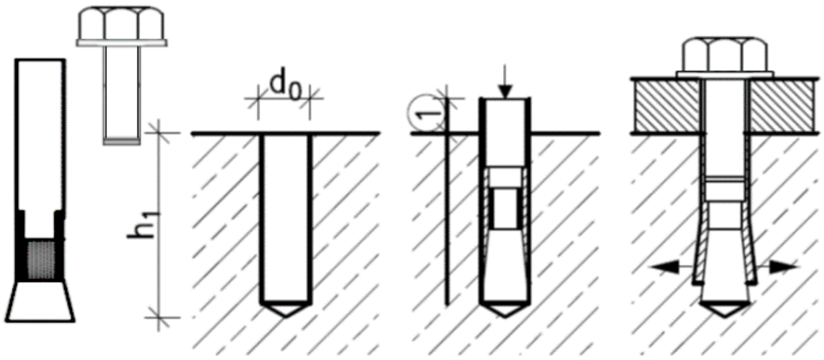
Figure 1.1.2 Cone-down type fastener (drop-in fastener)



1 Expansion nail

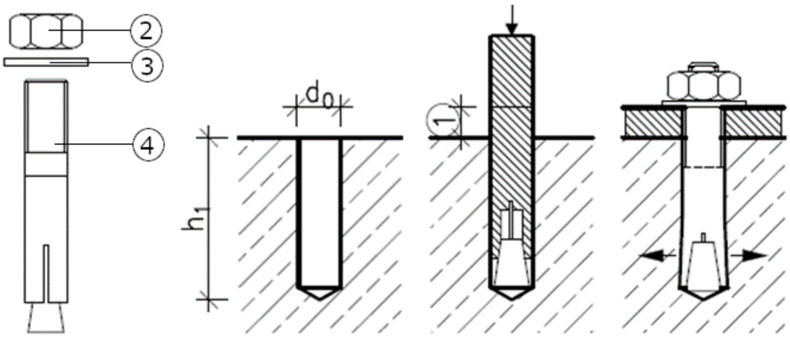
2 Controlled installation depth

Figure 1.1.3 Shank-down type fastener (stud fastener)



1 Controlled installation depth

Figure 1.1.4 Sleeve-down type fastener; drilling with stop drill



1 controlled installation depth
2 Hexagon nut
3 Washer
4 Bolt with internal cone

Figure 1.1.5 Sleeve-down type fastener (stud version), controlled e.g., by stop-drill

Undercut fasteners (UC)

Undercut fasteners are anchored by mechanical interlock provided by an undercut in the concrete. The undercutting can be achieved by hammering or rotating (or combination of both) the fastener sleeve into a drilled undercut hole (see e.g., Figure 1.1.6) or driving the fastener sleeve onto the tapered bolt in a cylindrical hole either by hammering or turning (or combination of both). In this case, the concrete is cut away rather than compressed (see e.g., Figure 1.1.9).

This EAD covers displacement-controlled and torque-controlled undercut fasteners. In case of displacement-controlled installation for fasteners in accordance with Figure 1.1.6, Figure 1.1.7, Figure 1.1.9 and Figure 1.1.10 the depth of the drill hole h1 needs to be ensured (e.g., by means of a stop-drill) The undercut shall be drilled before installation or the undercut is created by the fastener during installation. For torque-controlled installation the undercut is drilled before inserting the fastener in the drilled hole. Examples for the various types of installation are shown in the following.

a) Displacement-controlled installation - undercut drilled before installation

The different types of fastener installation are shown in
Figure 1.1.6 to Figure 1.1.8.

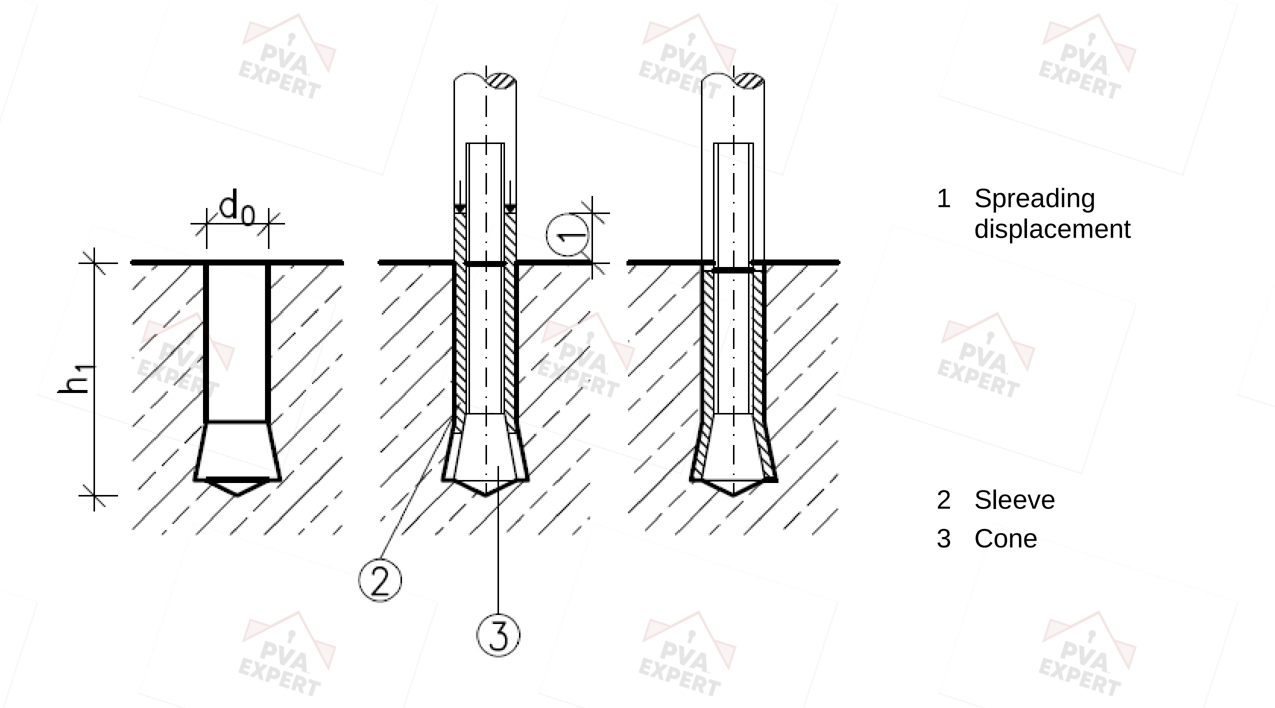
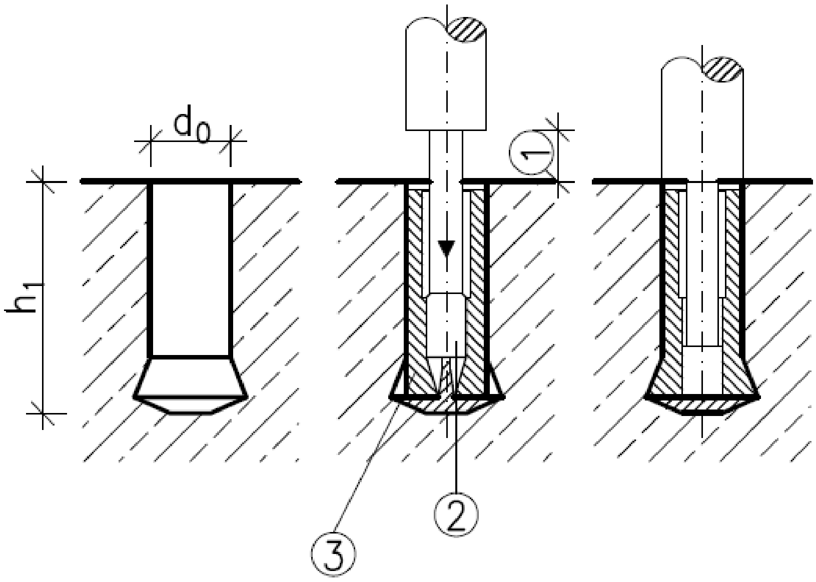
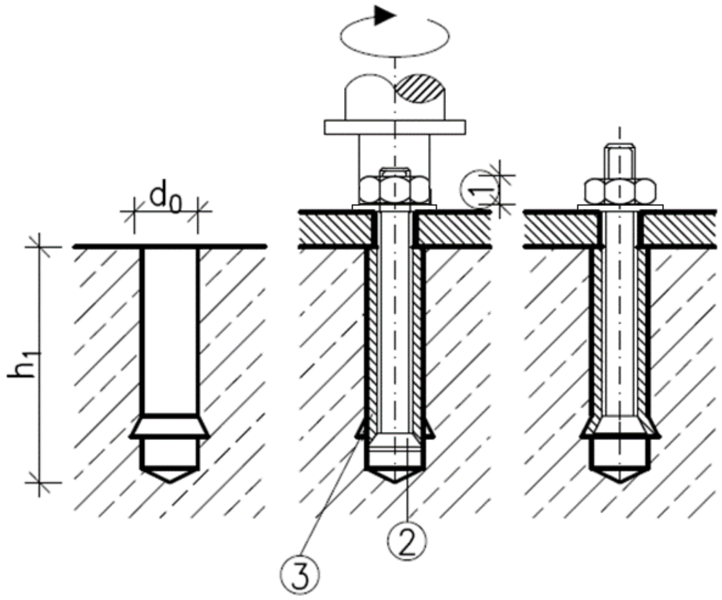


Figure 1.1.6 Fastener installation by hammering the fastener sleeve onto the cone



1 Spreading displacement
2 Expansion element
3 Sleeve

Figure 1.1.7 **Fastener installation by hammering the expansion element (cone) into the fastener sleeve**

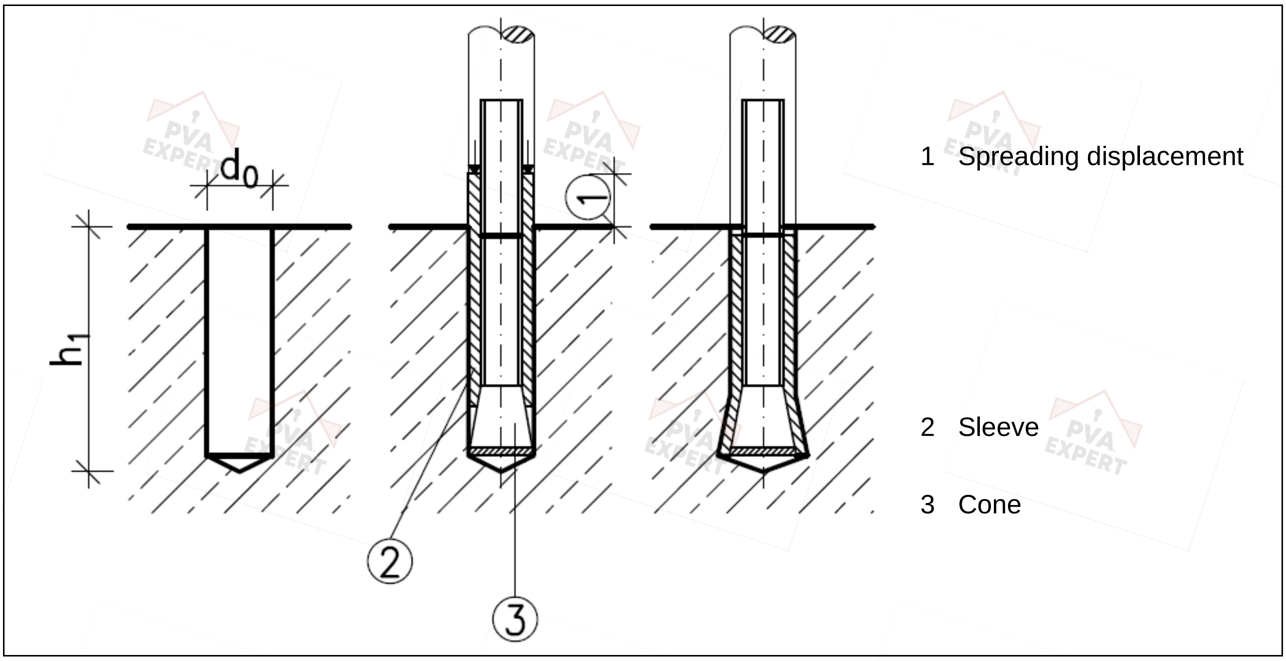


1 Spreading displacement
2 Sleeve
3 Cone

Figure 1.1.8 **Fastener installation by pulling the cone with a defined expansion displacement into the fastener sleeve by turning the nut (achieved by a special installation tool)**

b) Displacement-controlled installation - self-cutting undercut fasteners

The undercut is made during the setting process of the fastener. The different types of fastener installation are described in Figure 1.1.9 to Figure 1.1.12. A combination of Figure 1.1.9 and Figure 1.1.10 is also possible.

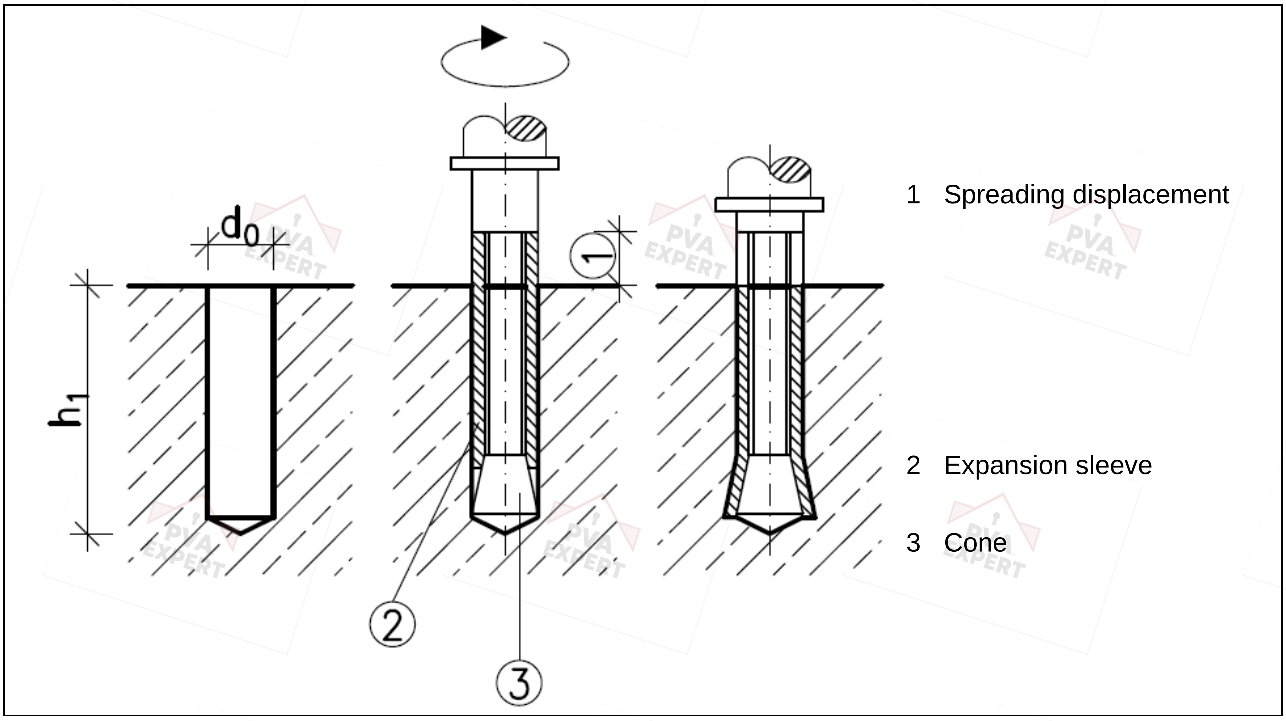


1 Spreading displacement

2 Sleeve

3 Cone

Figure 1.1.9 **Fastener installation by hammering the sleeve over the cone; e.g., by using a drilling machine**



1 Spreading displacement

2 Expansion sleeve

3 Cone

Figure 1.1.10 **Fastener installation by rotating the fastener sleeve, e.g., by means of the drilling machine; thereby undercutting the concrete and forcing the sleeve over the cone. To facilitate the undercutting, the end of the fastener sleeve can be specially designed (e.g., with cutting pins)**

c) Torque-controlled installations

The different types of fastener installation are shown in Figure 1.1.11 and Figure 1.1.12.

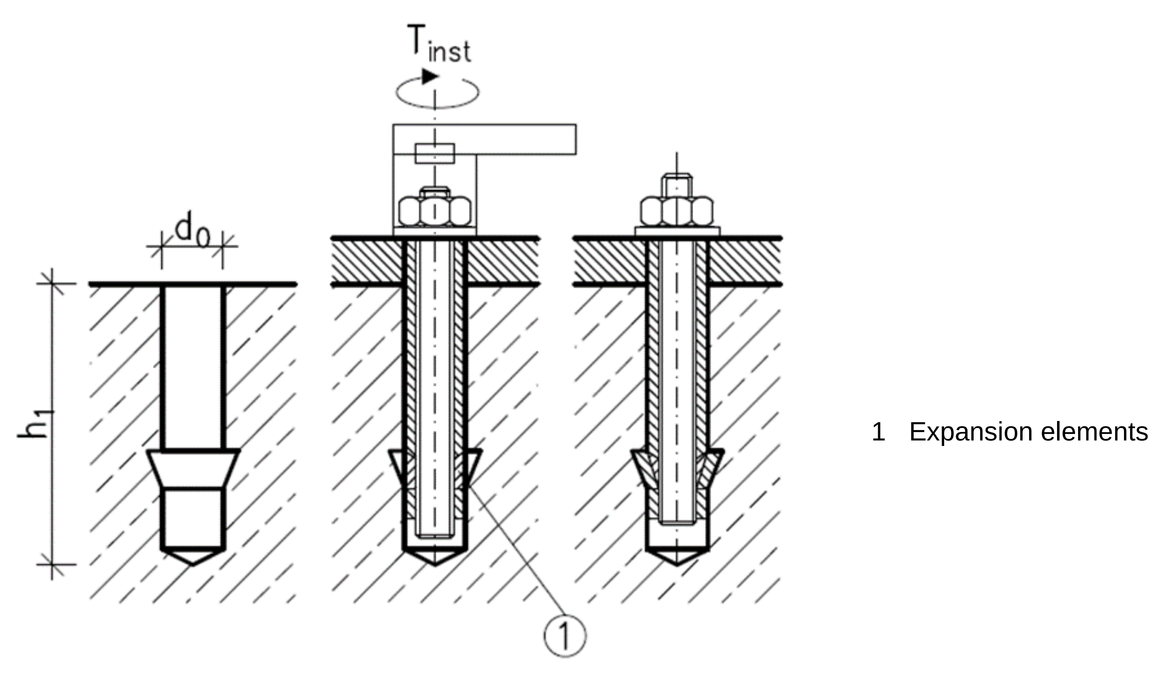


Figure 1.1.11 **Fastener installation by forcing the expansion elements against the undercut by applying a defined torque**

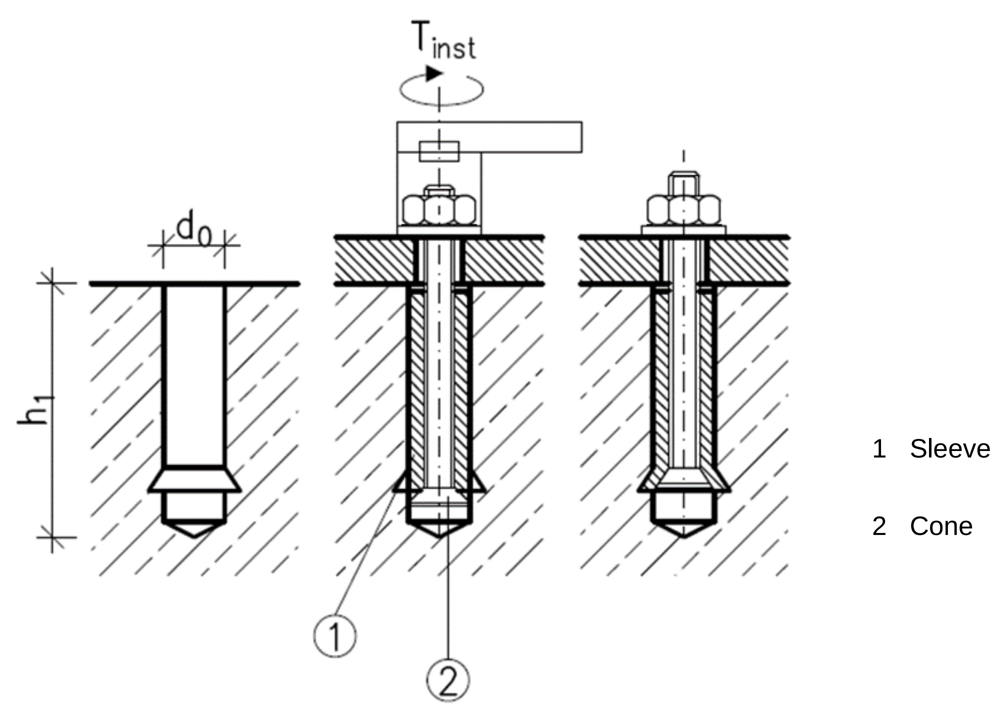
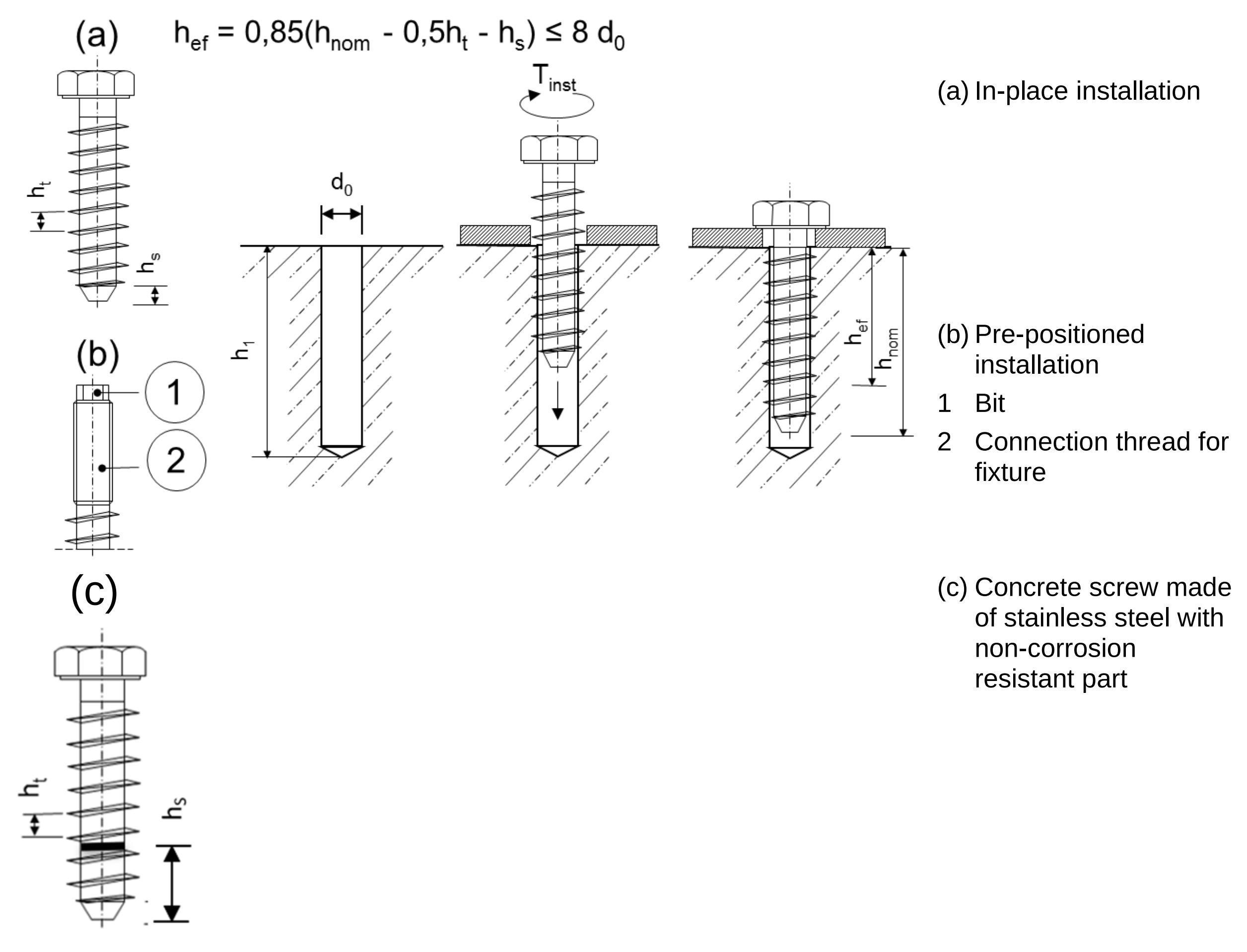


Figure 1.1.12 **Fastener installation by pulling the cone into the fastener sleeve by applying a defined torque**

Concrete screws (CS)

The effective fastening depth of concrete screws shall be determined in accordance with Figure 1.1.13.



$$h_{ef} = 0{,}85(h_{nom} - 0{,}5h_t - h_s) \le 8\ d_0$$

Figure 1.1.13 **Installation by driving the concrete screw with a self-cutting special thread with wrench or impact screw driver into a predrilled cylindrical hole.**

The fastener is screwed into a pre-drilled cylindrical hole. The special thread of the fastener cuts an internal thread into the test member while setting. The installation shall be done by a non-calibrated torque wrench, a calibrated torque spanner or an electrical or pneumatic torque impact screw driver. The fastening is characterised by mechanical interlock in the concrete thread.

Note: Concrete screws are sensitive to the applied torque or power while setting. Therefore, it is assumed that the manufacturer specifies a maximum installation torque or power limit for electric impact screw drivers. If this information is not provided in the MPII, the installation tools or equipment used in basic tension tests apply and are given in the ETA as the conditions for which the performance has been established.

De-installation and re-installation perhaps damage the concrete screw (e.g., wear of the threads) and therefore affect the performance characteristics of the fastener. This EAD assesses the performance for concrete screws that are only used once. ETAs issued based on this EAD shall indicate this scope.

Note: Concrete screws requiring loosening and retightening to facilitate attachment and realignment or allow levelling of the attached component are assessed according to EAD 330011 00 0601 [28].

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 in accordance with the manufacturer's instructions or (in absence of such instructions) according to the usual practice of the building professionals.

Relevant manufacturer's stipulations, e.g., with regard to the intended end use conditions, 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.

This EAD covers fasteners with a factor for robustness $\gamma_{inst} \leq 1{,}4$ in accordance with Clause 2.2.4.

1.2 Information on the intended use of the construction product

1.2.1 Intended use

In this EAD the assessment is made to determine characteristic values of the mechanical fastener for calculations in accordance with EN 1992-4 [10] [1].

> *Note: 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.).*

Mechanical fastener placed into pre-drilled holes for use in compacted reinforced or unreinforced normal weight concrete with strength classes in the range C12/15 to C90/105 all in accordance with EN 206 [12].

The fastener is intended to be used

- in uncracked concrete only (Table 1.2.1.1, option 7 – 12)
- in cracked and uncracked concrete (Table 1.2.1.1, option 1 – 6)
- under static or quasi-static actions
- under seismic actions (category C1, category C2)
- with requirements related to resistance to fire (only for fasteners which are assessed for cracked concrete, Table 1.2.1.1, option 1-6)

loaded in tension, shear or combined tension and shear.

> *Note: The loading on the fastener resulting from actions on the fixture (e.g. tension, shear, bending moment or torsion 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 hardened concrete is at least 21 days old.

The covered temperature range of the anchorage base concrete during the working life is within the range -40 °C to +80 °C.

This EAD covers mechanical fasteners intended to be used in concrete members with a thickness of:

1. $h \geq 80$ mm and $h \geq 1{,}5\ h_{ef}$ (fasteners intended for use in cracked or uncracked concrete)
2. $h \geq 80$ mm and $h \geq 2{,}0\ h_{ef}$ (fasteners intended for use in uncracked concrete only)

> *Note: If the thickness of the test member is smaller than required above, aspects such as e.g., bending of the test member under loading may affect the performance to an extent currently not accounted for in the assessment and corresponding design provisions. Hence, fastenings in such test members are not covered in this EAD.*

This EAD covers only fasteners with an embedment depth given in Table 1.1.1 under the conditions given in Table 1.1.1 which are intended to be used in an area where spalling will not occur.

Drilling methods

1 Rotary hammer: (electric drilling machine or driven by compressed air)

- *Hammer drilling with hard-metal drill bit and subsequent cleaning (cleaning procedure as defined by the manufacturer in the MPII)*
- *Hollow drilling (rotary hammer drilling using a hollow drill bit) with continuous vacuuming of the drilling dust with or without subsequent cleaning (cleaning procedure as defined by the manufacturer in the MPII)*

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

2 *Additional drilling methods:*

- *Diamond core drilling (with or without rig, with or without water cooling, with or without roughening procedures) and subsequent cleaning (as defined by the manufacturer in the MPII)*

Note: The surface roughness of the drill hole is regarded equivalent for hammer drilling and hollow drilling. Thus, hollow drilling is not defined as additional drilling method.

Note: The surface roughness of the drill hole is less rough with diamond core drilling than with hammer drilling. Depending on the type of diamond drill bit, the diameter of drilled holes may be specified by the manufacturer.

Any manufacturer's installation instructions (e.g., drilling technology, hole cleaning, installation tools, torque) shall be reported in the ETA.

Options for intended use

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

✓ Intended use covered by the assessment option

✗ Intended use not covered by the assessment option

Table 1.2.1.1 Options for intended use covered by this EAD

Option	Cracked concrete	Uncracked concrete	One value for all concrete strength classes	Different values for C12/15to C90/105	One value for load direction	Separate values for tension and shear capacity	c_{cr} / s_{cr}	c_{min} < c_{cr} / s_{min} < s_{cr}	Method in accordance with EN 1992-4 [10]
1	✓	✓	✗	✓	✗	✓	✓	✓	A
2			✓	✗					
3			✗	✓	✓	✗			B
4			✓	✗					
5			✗	✓			✓	✗	C
6			✓	✗					
7	✗	✓	✗	✓	✗	✓	✓	✓	A
8			✓	✗					
9			✗	✓	✓	✗			B
10			✓	✗					
11			✗	✓			✓	✗	C
12			✓	✗					

Use of fastener in fastener groups in accordance with EN 1992-4 [10]:

Mechanical fasteners are intended for use in fastener groups as defined in EN 1992-4 [10]. Fasteners covered by this EAD can be used in fastener groups, only when criteria for displacements at 50 % of the mean failure load cv_{δ} [%] specified in Clauses 2.2.2 and 2.2.5 are met.

Concrete screws

In accordance with this EAD concrete screws are intended to be used where the scatter of required torque for installation is lower than 30 % (see 2.2.2.7 and 2.2.2.8).

1.2.2 Working life/Durability

The assessment methods included or referred to in this EAD have been written based on the manufacturer's request to take into account a maximum working life of the fastener for the intended use of 50 and/or 100 years when installed in the works (provided that the fastener is subject to appropriate installation, see 1.1) These provisions are based upon the current state of the art and the available knowledge and experience.

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

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

1.3 Specific terms used in this EAD

1.3.1 Abbreviations

C1 = seismic performance category C1 (use in design in accordance with EN 1992-4 [10])

C2 = seismic performance category C2 (use in design in accordance with EN 1992-4 [10])

CS = concrete screw

DC = deformation-controlled expansion fastener

DM-A = design method A in accordance with EN 1992-4 [10]

DM-B = design method B in accordance with EN 1992-4 [10]

DM-C = design method C in accordance with EN 1992-4 [10]

MPII = manufacturer’s product installation instructions

TC = torque-controlled expansion fastener

UC = undercut fastener

1.3.2 Notation

a = length of square base plate in accordance with Table A.3.6.1.1

A = percentage elongation after fracture

a_1 = spacing between outer fasteners in adjoining fastening in direction 1

a_2 = spacing between outer fasteners in adjoining fastenings in direction 2

A_g = cross section rea of test member

A_s = stressed cross-section of the fastener used for determining the tensile capacity

A_5 = percentage rupture elongation for proportional samples with a length L_0 corresponding to five times the diameter see EN ISO 6892-1 [23]

b = width of test member

A_{sp} = splitting area determined for the assessment of test series F11 (minimum edge distance and spacing) and F12 (edge distance to prevent splitting under load)

$A_{sp,rqd}$ = required splitting area for $c_{cr,sp}$ for fasteners with variable embedment depth (2.2.6)

$A_{sp,t,F11}$ = splitting area calculated with tested parameters in test series F11 (minimum edge distance and spacing)

$A_{sp,t,F12}$ = splitting area calculated with tested parameters F12 (edge distance to prevent splitting under load)

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

C = edge distance in accordance with Figure A.3.3.2.1

c_1 = edge distance in direction 1

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

c_2 = edge distance in direction 2

c_{cr} = edge distance for ensuring the transmission of the characteristic resistance of a single fastener

$c_{cr,N}$ = edge distance for ensuring the transmission of the characteristic resistance in tension of a single fastener without edge and spacing effects in case of concrete cone failure

$c_{cr,sp}$ = edge distance for ensuring the transmission of the characteristic resistance in tension of a single fastener without edge and spacing effects in case of splitting failure

$c_{cr,V}$ = edge distance perpendicular to the direction of the shear load for ensuring the transmission of the characteristic resistance in shear of a single fastener without corner, spacing and member thickness effects in case of concrete failure

c_{min} = minimum allowable edge distance

c_t (s_t) = edge distance (spacing) as tested

cv_F = coefficient of variation [%] related to loads

cv_δ = coefficient of variation [%] related to displacements

d = fastener bolt / thread diameter

d_0 = drill hole diameter

d_{cut} = cutting diameter of drill bit

$d_{cut,m}$ = medium cutting diameter of drill bit (see Table A.3.1.4.1)

$d_{cut,max}$ = cutting diameter at the upper tolerance limit (see Table A.3.1.4.1) (maximum diameter bit)

$d_{cut,min}$ = cutting diameter at the lower tolerance limit (see Table A.3.1.4.1) (minimum diameter bit)

d_f = diameter of clearance hole in the fixture

d_{nom} = outside diameter of fastener including sleeve. For concrete screws (CS) the nominal core diameter of the main load bearing section

d_s = size of rebar diameter in test members (see Figure A.3.1.2.6.3)

d_1 = diameter of undercutting hole

d_2 = diameter of expanded undercut fastener

$d_{th,t}$ = external thread diameter of the main load bearing clause of the fastener (concrete screw) used in the test;

$d_{th,low}$ = lower limit of external thread diameter of the main load bearing clause of the fastener (concrete screw) according to the specification of the manufacturer.

$f_{c,i}$ = mean compressive strength of concrete in test series *i*

f_u = mean ultimate steel strength

f_{uk} = Characteristic ultimate steel strength

F = force in general (for the relevant test series N or V applies)

F_{Rk} (N_{Rk},V_{Rk}) = characteristic resistance stated in the ETA

$F_{Rk,0}$ = characteristic reference resistance (initial value)

$F_{u,m,n}$ = mean value of failure loads normalized to nominal concrete compressive strength C20/25 *(n=20)* or C50/60 *(n=50)*

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

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

$F_{u,m}$ = mean failure(ultimate) load of a test series

$F_{u,m,20}$ = mean failure (ultimate) load of a test series normalised to concrete strength C20/25

$F_{u,m,50}$ = mean failure (ultimate) load of a test series normalised to concrete strength C50/60

$F_{u,5\,\%,20}$ = 5 % fractile of failure (ultimate) loads of a test series normalised to concrete strength C20/25

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_{cm} = mean concrete compressive strength

f_{ck} = nominal characteristic concrete compressive strength (based on cylinder)

$f_{ck,cube}$ = nominal characteristic concrete compressive strength (based on cubes)

$f_{c,cube100}$ = concrete compressive strength measured on cubes with a side length of 100 mm

$f_{c,cube200}$ = concrete compressive strength measured on cubes with a side length of 200 mm

$f_{u,t}$ = mean ultimate tensile steel strength of the batch for the tested fastener

f_{uk} = nominal characteristic steel ultimate strength as specified in the technical specification of the manufacturer for the fastener

f_{yk} = nominal characteristic steel yield strength as specified in the technical specification of the manufacturer for the fastener.

h = thickness of the test member

h_{ef} = effective embedment depth (see EN 1992-4 [10], Figure. 3.3 a) to e) for TC, DC and UC and Figure 1.1.13 for CS). For expansion and undercut fasteners measured from the concrete surface to the deepest point at which the fastener tension load is transferred to the concrete

$h_{ef,min}$ = minimum effective embedment depth within the variable embedment depth range specified for each diameter

$h_{ef,max}$ = maximum effective embedment depth within the variable embedment depth range specified for each diameter

$h_{ef,max,t}$ = maximum effective embedment depth used in tests, which is less or equal to $h_{ef,max}$; this embedment depth may be selected for each diameter to be used in the test series as indicated in 2.2, and is relevant for the determination of the resistance to pull-out failure; $h_{ef,max,t} = h_{ef,max}$, if no other value is selected

h_{iz} = interaction zone between fastener and concrete

h_{ltz} = effective load transfer zone of fasteners

h_{min} = minimum thickness of test member

h_{nom} = overall fastener embedment depth in the concrete

h_o = depth of cylindrical drill hole at shoulder

h_s = non-load bearing tip of a concrete screw in accordance with Figure 1.1.13

h_t = pitch of the thread of a concrete screw in accordance with Figure 1.1.13

h_1 = depth of drilled hole to deepest point

k = stiffness of a loaded fastener in [N/m]

k_T = factor for required torque in Equation (2.2.5.3.3)

k_m = mean effectiveness factor

$k_{ucr,N}$ ($k_{cr,N}$) = effectiveness factor for uncracked (cracked) concrete

$k_{A\text{-}D,ucr}$ = stiffness characteristics in uncracked concrete in N/mm, see Figure 2.2.11.2.2

$k_{A\text{-}D,cr}$ = Stiffness characteristics in cracked concrete in N/mm, see Figure 2.2.11.2.2

L = largest size of the complete product range of each fastener type as supplied to the market

ℓ_b = bond length between possible crack planes (see Figure A.3.1.2.6.3)

ℓ_{db} = de-bonding length of rebar to create cracks in test members (see Figure A.3.1.2.6.3)

l_f = effective length of the fastener for transfer of shear load

$M^0_{Rk,s}$ = characteristic bending resistance of a single fastener

m = exponent for influence of concrete strength on resistance to pull-out failure as determined in A.2.1

n = number of tests of a test series

n_{cyc} = number of cycles

N = normal force (+N = tension force)

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_{max} = maximum tension load to be applied in the pulsating tension load test series C2.3

N_{min} = lower bound of tension load pulses in test series C2.3

N_p = tensile load applied during the test

$N^0_{Rk,c}$ = characteristic concrete cone resistance in cracked concrete in accordance with EN 1992-4 [10] Equation (7.2).

$N_{Rk,p}$ = characteristic tension pull-out 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

$N_{Rk,s}$ = characteristic steel tension resistance given in the ETA for static loading

$N_{Rk,s,fi}$ = characteristic resistance to steel failure under fire exposure

N_s = force applied to the test member to control the crack width in accordance with A.3.3.2

N_{sl} = load at which uncontrolled slip of the fastener occurs (see Figure A.2.5.1)

$N_{st,m}$ = mean ultimate steel capacity determined from tensile tests on fastener specimens (CS)

$N_{u,m}$ = mean ultimate tensile load of the tests in concrete

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 < $\Delta w \le 0{,}8$ mm) of the varying crack width test series C2.5

n_{min} = minimum number of tests for a test series

$p_1 – p_5$ = fitting parameter

R_{p02} = 0,2% yield limit in accordance with EN ISO 898-1 [24]

rqd. α = required value of α in accordance with Table A.1.1

s = smallest size of the complete product range of each fastener type as supplied to the market

s_{cr} = spacing for ensuring the transmission of the characteristic resistance of a single fastener

$s_{cr,N}$ = spacing for ensuring the transmission of the characteristic resistance in tension of a single fastener without edge and spacing effects in case of concrete cone failure

$s_{cr,sp}$ = spacing for ensuring the transmission of the characteristic resistance in tension of a single fastener without edge and spacing effects in case of splitting failure

$s_{cr,V}$ = spacing perpendicular to the direction of the shear load for ensuring the transmission of the characteristic resistance in shear of a single fastener without corner, spacing and member thickness effects in case of concrete failure

s_{min} = minimum allowable spacing

s_1 = spacing of fasteners in a fastener group in direction 1

s_2 = spacing of fasteners in a fastener group in direction 2

t = time

T = torque

T_{inst} = required setting torque specified by the manufacturer for expansion, installation or pre-stressing of fastener

T_{max} = torque at which the formation of the first hairline crack occurs in the test of test series F11 (minimum edge distance and spacing, Clause 2.2.5)

t_{fix} = thickness of the fixture

t = thickness of attachment in accordance with Figure A.3.6.1.1 and Table A.3.6.1.1

t_u = time to failure in tests under fire exposure

V = shear force

V_{C1} = maximum shear load to be applied in the seismic shear test series C1.2

V_i = intermediate shear load to be applied in the seismic shear test series C1.2

V_m = minimum shear load to be applied in the seismic shear test series C1.2

V_{max} = maximum shear load to be applied in the alternating shear load test series C2.4

$V_{Rk,s,Cx}$ = characteristic steel shear resistance under seismic action reported in the ETA for seismic performance category C1, C2

$V_{u,m}$ = mean shear capacity

$V^0_{Rk,s}$ = characteristic steel shear resistance given in the ETA for static loading

W_{el} = elastic section modulus calculated from the stressed cross section

w_{ini} = initial crack width after applying N_{w1} in test series C2.5

z = distance between flanges in accordance with Table A.3.6.1.1

α = reduction factor for load in accordance with A.2.4

$\alpha_{C2.x}$ = reduction factor resulting from assessment of test series C2.x

α_{ucr} = ratio load at point of change of stiffness to ultimate load, in uncracked concrete

α_{cr} = ratio load at point of change of stiffness to ultimate load, in uncracked and cracked concrete

$\alpha_{N,C1}$, $\alpha_{N,C2}$ = seismic reduction factor for tension resistance for seismic performance category C1, C2

$\alpha_{V,C1}$, $\alpha_{V,C2}$ = seismic reduction factor for shear resistance for seismic performance category C1, C2

α_1 = reduction factor for uncontrolled slip in accordance with A.2.5

α_{ag} = factor for accounting the group behaviour of concrete screws

α_v = factor for shear capacity of the single fastener

ß$_{cv}$ = reduction factor for large scatter in accordance with A.2.2

$\beta_{cv,C2.x}$ = 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

γ_M = recommended material partial factor in accordance with EN 1992-4 [10] of the corresponding failure mode

γ_{inst} = factor accounting for the sensitivity to installation of post-installed fasteners as determined in Clause 2.2.4

$\delta_{0,5Nu,m}$ = displacement of the fastener at 50 % of the mean failure load in a test series

$\delta_{0,1Nu,m}$ = displacement of the fastener at 10 % of the mean failure load in a test series

δ_{m1} = mean fastener displacement after 10^3 crack movements

δ_{m2} = mean displacement in the repeated load tests after 10^5 load cycles or the sustained load tests after terminating the tests (see 2.2.10); the larger value is decisive

$\delta_{N50years}$, $\delta_{N,100years}$ = long-term tension displacement

$\delta(\delta_N, \delta_V)$ = displacement (movement) of the fastener at the concrete surface relative to the concrete surface outside the failure area in direction of the load (tension, shear) the displacement includes the steel and concrete deformations and a possible fastener slip

$\delta_{N,lim}$ = 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

Δw = required crack width, in addition to the initial hairline crack width as measured after the installation of the fastener

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

Δw_1 = Upper limit of crack width in accordance with Figure A.3.3.3.1

Δw_2 = Lower limit of crack width in accordance with Figure A.3.3.3.1

$\Delta\sigma_s$ = working stroke of action in repeated load tests

ℓ_b = bond length (see Figure A.3.1.2.6.3)

ℓ_{db} = de-bonding length (see Figure A.3.1.2.6.3)

μ = ratio of reinforcement (see Clause A.3.1.2.6)

1.3.3 Indices

cal = calculated
cr = cracked concrete
fi = fire
i = individual test result for i = 1 to n
k = characteristic
r = reference tests
t = as tested
rqd = required
red = reduced
R = resistance
s = steel
sp = splitting
st = short-term loading
t = parameter value used in tests or obtained in tests
u = ultimate – situation when failure occurs
ucr = uncracked concrete
20 = related to concrete strength class C20/25
50 = related to concrete strength class C50/60
5 % = 5 % fractile

1.3.4 Definitions

fastener = a manufactured component for achieving fastening between the base material (concrete) and the fixture; it may consist of assembled components

fastener group = several fasteners (working together)

fastening = an assembly comprising base material (concrete), fastener or fastener group and component fixed to the concrete

fixture = component fixed to the concrete with the use of fasteners

full expansion = expansion achieved when setting the fastener according to the MPII; full expansion is used in the tests for determination of admissible service conditions functional coating = organic or inorganic lacquer or plastic hoses, which is applied on parts of the fastener in order to reduce friction between cone and sleeve or between nut and bolt.

installation expansion = expansion achieved by applying a specified expansion energy which is reduced in relation to reference expansion (see A.3.5); installation expansion is used in the tests for installation factor

reference expansion = expansion achieved by applying specified expansion energy (see A.3.5); reference expansion is used in any other tests

test member = test member in which the fastener is tested

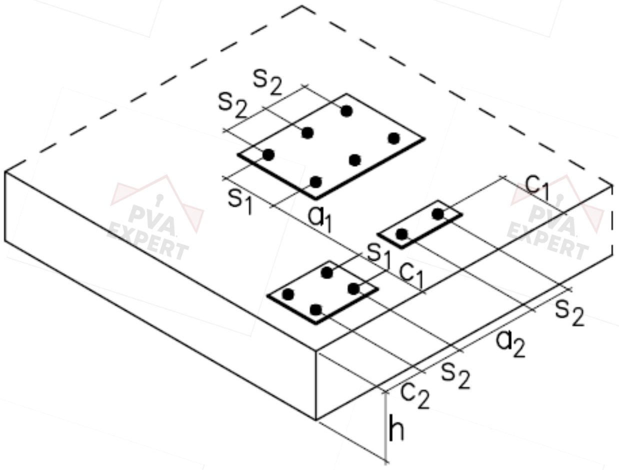
impact screw driver = electric tool with sudden rotational force for setting and loosening screws

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

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

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

Variable embedment depth = an effective embedment depth that may be selected to install the product within a given continuous range of effective embedment depths limited by a lower and upper bound, i.e., $h_{ef,min}$ and $h_{ef,max}$, respectively.



c_1 Edge distance to edge 1
c_2 Edge distance to edge 2
s_1 Axial spacing perpendicular to edge 1
s_2 Axial spacing perpendicular to edge 2
h thickness of the concrete member

Figure 1.3.4.1 **Definitions - concrete member, fastener spacing and edge distance**

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1.1 shows how the performance of mechanical fasteners for use in concrete is assessed in relation to the essential characteristics.

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

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability			
Characteristic resistance to tension load (static and quasi-static loading) Method A			
1	Resistance to steel failure under tension load	2.2.1	$N_{Rk,s}$ [N]
2	Resistance to pull-out failure	2.2.2	$N_{Rk,p,ucr}$, $N_{Rk,p,cr}$ [N], $\psi_{c,cr}$, $\psi_{c,ucr}$ [-]
3	Resistance to concrete cone failure	2.2.3	$k_{cr,N}$, $k_{ucr,N}$ [-], h_{ef}, $c_{cr,N}$ [mm]
4	Robustness	2.2.4	γ_{inst} [-]
5	Minimum edge distance and spacing	2.2.5	c_{min}, s_{min}, h_{min} [mm]
6	Edge distance to prevent splitting under load	2.2.6	$N^0_{Rk,sp}$ [N], $c_{cr,sp}$ [mm]
Characteristic resistance to shear load (static and quasi-static loading)			
7	Resistance to steel failure under shear load	2.2.7	$V^0_{Rk,s}$ [N], $M^0_{Rk,s}$ [Nm], k_7 [-]
8	Resistance to pry-out failure	2.2.8	k_8 [-]
Characteristic resistance for simplified methods			
9	Method B	2.2.9.1	F^0_{Rk} [N], $M^0_{Rk,s}$ [Nm], ψ_c [-], c_{cr}, s_{cr}, s_{min}, c_{min}, h_{min} [mm]
10	Method C	2.2.9.2	F_{Rk} [N], $M^0_{Rk,s}$, [Nm], c_{cr}, s_{cr}, h_{min} [mm]
Displacements			
11	Displacements under static and quasi-static loading	2.2.10	δ_{N0}, $\delta_{N50years}$, $\delta_{N,100years}$, δ_{V0}, $\delta_{V\infty}$ [mm]
Stiffness			
12	Stiffness in the elastic range under tension loading	2.2.11.1	$k_{A,ucr}$, $k_{A,cr}$ [N/mm]
13	Stiffness characteristics for tension loading for non-linear spring models	2.2.11.2	$k_{A,ucr}$, $k_{B,ucr}$, $k_{C,ucr}$, $k_{D,ucr}$, [N/mm] $k_{A,cr}$, $k_{B,cr}$, $k_{C,cr}$ and $k_{D,cr}$ [N/mm]
Characteristic resistance for seismic performance category C1			
14	Resistance to tension load	2.2.12	$N_{Rk,s,C1}$, $N_{Rk,p,C1}$ [N]
15	Resistance to shear load, factor for annular gap	2.2.13	$V_{Rk,s,C1}$ [N]

No	Essential characteristic	Assessment method	Type of expression of product performance
Characteristic resistance and displacements for seismic performance category C2			
16	Resistance to tension load and displacements	2.2.14	$N_{Rk,s,C2}$, $N_{Rk,p,C2}$ [N] $\delta_{N,C2(0,5)}$, $\delta_{N,C2(0,8)}$ [mm]
17	Resistance to shear load and displacements, factor for annular gap	2.2.15	$V_{Rk,s,C2}$ [N] $\delta_{V,C2(0,5)}$, $\delta_{V,C2(0,8)}$ [mm]
Basic Works Requirement 2: Safety in case of fire			
18	Reaction to fire	2.2.16	Class (A1)
Resistance to fire			
19	Fire resistance to steel failure under tension load	2.2.17	$N_{Rk,s,fi}$ [N]
20	Fire resistance to pull-out failure	2.2.18	$N_{Rk,p,fi}$ [N]
21	Fire resistance to steel failure under shear load	2.2.19	$V_{Rk,s,fi}$ [N], $M^0_{Rk,s,fi}$ [Nm]
Aspects of durability			
22	Durability	2.2.20	Description

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

This chapter is intended to provide instructions for TABs. Therefore, the use of wordings such as “shall be stated in the ETA” or “it shall 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.

An overview of the test programme 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.

2.2.1 Resistance to steel failure under tension load

2.2.1.1 Steel capacity (test series N1)

Purpose of the assessment

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

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

If the steel strength differs along the length of the element, calculate the steel capacity for the specified steel strengths and the corresponding nominal stressed cross sections $N_{Rk,s,i}$ [N] in accordance with following Equations

Steel capacity tension $N^0_S = \min (N_{Rk,s,i} / x_i)$ with $x_i = \max (1{,}4;1{,}2\ f_{uk}/f_{yk})$ (2.2.1.1.2)

$N_{Rk,s} = x \cdot N^0_S$ with x = the factor x_i which delivers the decisive failure load N^0_S (2.2.1.1.3)

Tests are needed only if 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.

Assessment method

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

Determine the 5 % fractile of the failure loads. This value shall be normalized to account for over-strength of tested specimen in accordance with Equation (A.2.1.6).

Expression of results

$N_{Rk,s}$ [N] and corresponding steel ultimate strength f_{uk} and steel yield strength f_{yk}

2.2.1.2 Maximum torque (test series N2)

Purpose of the assessment

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

Assessment method

The tests shall be 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 in accordance with Table A.3.1.4.1. The diameter of the clearance hole in the fixture shall correspond to the values given in Table 2.2.7.1.1.

Deformation-controlled expansion fasteners (DC) shall be set with reference expansion in accordance with A.3.5.

For undercut fastener (UC) the cylindrical hole and (if required) the undercut shall be drilled with a drill bit of medium cutting edge diameter ($d_{cut,m}$). The fastener shall be installed according to the MPII.

The torque shall be applied until 1,3 T_{inst}.

The schematic test set-up is shown in Figure A.3.1.5.3. The tension force in the bolt or screw shall be recorded as a function of the applied torque.

Determine the mean value of the tension force $N_{1,3Tinst,m}$ [N] and the 95 % fractile of the tension force $N_{1,3Tinst,95\,\%}$ [N] at 1,3 T_{inst}.

Criteria

All of following criteria shall be fulfilled.

1. The 95 % fractile of the tension force generated in the fastener at a torque T = 1,3 T_{inst} shall be smaller than the nominal yield force ($A_s \cdot f_{yk}$) of the bolt or screw.

   At 1,3 T_{inst}, the connection shall be capable of being unscrewed (no power actuated (electric or pneumatic) tools shall be used; during the unscrewing process, it is not allowed to block or clamp the bolt or the fastener's body to prevent rotation.)
2. For sleeve-down type deformation-controlled expansion fasteners (drop-in fasteners) in accordance with Figure 1.1.4 it shall be shown that the screw is not in contact with the cone by applying a torque of T = 1,3 T_{inst} when using the longest screw.

If the criteria are not fulfilled, T_{inst} shall be reduced until the criteria are met.

Expression of results

The load-bearing capacity of the fastener is not impaired by applying the installation torque. T_{inst} [Nm].

2.2.1.3 Hydrogen embrittlement (CS, test series N3)

Purpose of the assessment

The tests are only required for concrete screws (see Figure 1.1.13).

Screws of high strength may be sensitive to brittle fracture due to hydrogen embrittlement caused by the production process or by corrosion during (even short-time) exposure to moisture. The test is designed to detect fasteners with a high susceptibility to hydrogen induced brittle fracture and will be performed under conditions of constant mechanical load and hydrogen evolution on the surface of the screw. For this purpose, an electrolyte similar to concrete pore solution (saturated calcium hydroxide solution) will be applied while the specimen is kept under constant and defined electrochemical conditions (at constant potential of –955 mV versus normal hydrogen electrode (NHE)) by potentiostatic control. The potential is controlled by means of a reference electrode. The test setup is shown schematically in Figure 2.2.1.3.1.

This test for concrete screws shall be performed if

- concrete screws are not made of stainless steel, or
- it is not ensured by factory production control, that the strength of the steel in the area of load transfer is less than 1000 N/mm² and hardness is smaller than 350 HV referring to the total cross section for both surface and core hardness in accordance with EN ISO 6507 [21] below; < 36 HRC in accordance with EN ISO 6508 [22].

Preparation of specimen:

In case the screws are coated or galvanized, the coating shall be removed partially (in shape of a longitudinal strip) to allow hydrogen evolution on the steel surface. The coating shall be removed without damaging the surface of the screw; scratch and other induced irregularity of the surface shall be carefully avoided during removal of the coating. If a chemical process is used to remove the coating, it shall be demonstrated that such method does not add or remove diffused atoms of hydrogen in the steel subject to the process.

Test conditions:

The tests shall be performed with all diameter sizes of the fastener in uncracked high strength concrete with a strength class of C50/60. The tests shall be performed with the most adverse head form of the product. If the most adverse head form is not obvious, all head forms shall be tested.

For fasteners assessed for variable embedment depth, the tests shall be performed with the minimum embedment depth $h_{ef,min}$ and the maximum embedment depth $h_{ef,max,t}$.

In Equation (2.2.1.3.1) the value of $N_{u,m}$ shall be taken from the reference test in uncracked concrete with strength class C50/60 performed with the corresponding embedment depth, i.e., $h_{ef,min}$ and $h_{ef,max,t}$.

The temperature range shall be between 20°C and 25°C.

Test solution:

Saturated solution (in distilled or deionized water with a conductivity not greater than 20 µS/cm at 25°C±2°C) of calcium hydroxide with small excess of $Ca(OH)_2$ powder to obtain a milky appearance.

The pH value will then attain about 12,6 (± 0,1) at 25°C and shall remain almost constant during the test. Calcium hydroxide powder shall be kept in an air-tight containment and shall not be stored longer than one year.

The test solution shall be filled into a bottomless container covering an area of at least 96 cm^2 with a height of at least 25 mm, which shall be affixed to the concrete (see Figure 2.2.1.3.1). During the test the head of the concrete screw shall be submerged in the fluid.

Sustained load:

$$N_{HE} = \min \{0{,}5\ N_{st,m};\ 0{,}7\ N_{u,m}\} \qquad (2.2.1.3.1)$$

In Equation (2.2.1.3.1) the value for $N_{u,m}$ shall be taken from the reference tests in uncracked concrete with strength class C50/60.

The fastener shall be set on bevelled washers (inclination angle ≥ 4°) as shown in Figure 2.2.1.3.1.

Electrochemical conditions:

Potential: -955 mV versus NHE

Reference electrode: any kind of „second order"electrode (calomel, silver/silver chloride etc.) shall be used. The potential value shall be corrected according to the reference value given by the manufacturer of the electrode, e.g., for a saturated calomel electrode with E_{cal} = +245 mV versus N_{HE} the correct potential will be E = -955 - 245 = -1200 mV (±10 mV).

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

Duration of test:

100 hours

Following the test, after unloading the screw, an unconfined tension test to failure shall be performed.

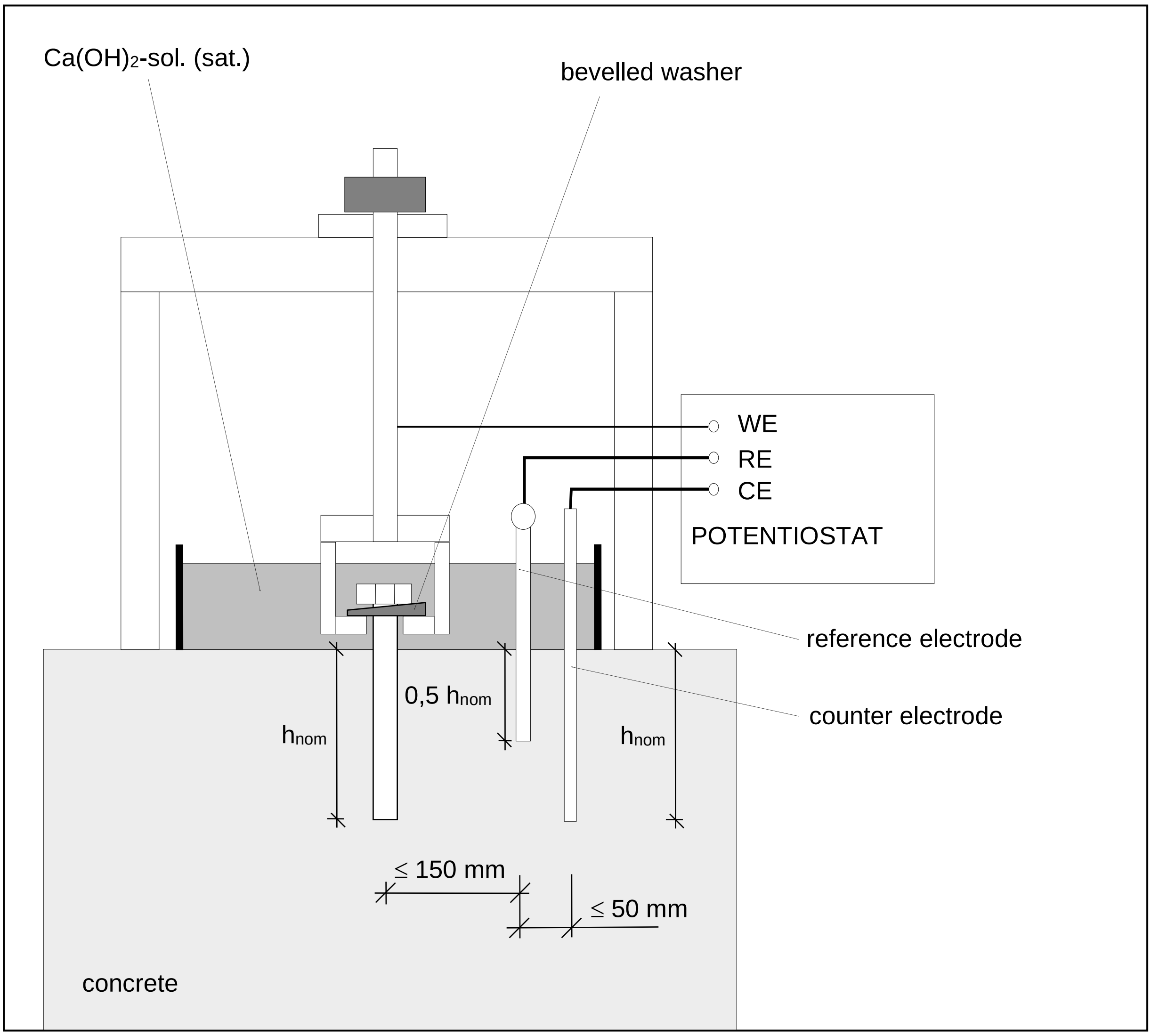


Figure 2.2.1.3.1 Test setup (schematic) for sensitivity to brittle fracture

Following the test, after unloading the screw, a tension test to failure shall be performed.

Assessment

During the constant load portion of the test (100 hours), no fastener shall fail. If concrete failure occurs the test shall be repeated.

The assessment of the residual capacity shall be performed as follows:

<u>Failure loads</u>

- Determine the mean value of failure loads $N_{u,m}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Determine the 5 % fractile of the failure loads $N_{u,5\,\%}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Determine the reduction factor α in accordance with Equation (A.2.4.1) comparing the test results with reference test series in accordance with Table A.1.1 line A2.

If steel failure during the constant load portion of the test occurs or the residual failure load does not fulfil the required $\alpha = 0{,}90$, the product does not meet the product description in accordance with 1.1.

For assessment of variable embedment depth, the results of the tests with $h_{ef,min}$ and $h_{ef,max,t}$ shall be assessed separately. In each assessment the factor α shall be determined. The smaller value is decisive for the assessment.

2.2.2 Resistance to pull-out failure

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

(1) The standard assessment shall be made for C20/25 to C50/60.

(2) Separate assessment for minimum concrete strength class in accordance with Clause A.2.7.

(3) For an assessment of concrete stronger than C50/60 in accordance with Table A.1.1 and Clause A.2.8, it shall be checked that the characteristic resistance $N_{Rk,p}$ for the maximum concrete class is not smaller than $N_{Rk,p}$ for concrete class C50/60. If this condition is not fulfilled the maximum concrete strength class is C50/60.

The factor ψ_c in accordance with Equation (A.2.1.5) shall be used as a factor to express the characteristic resistance $N_{Rk,p}$ for different concrete strength classes C20/25 to C50/60. For concrete stronger than C50/60 no further increase of the characteristic resistance $N_{Rk,p}$ shall be taken into account.

2.2.2.1 Basic tension tests

Purpose of the assessment

Test series A1 to A4) are performed to determine the tension capacity of a single fastener without edge influence and thereby establishing the baseline values for the assessment of the performance under tension load $N_{Rk,0}$. The results of the basic tension tests are used as reference in assessment of test series F1 to F12 of Table A.1.1. The tests are also used to determine the stiffness characteristics, which shall be assessed according to the Clause 2.2.11.

Assessment method

The tests shall be performed in accordance with A.3.3.2.

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

If the manufacturer applies for intended use in uncracked concrete only, only the test series in uncracked concrete in accordance with Table A.1.1, lines A1and A2, shall be performed.

If the manufacturer applies for one tension resistance for all concrete strength classes in uncracked concrete only, the tests in high strength concrete in accordance with Table A.1.1, line A1shall be performed.

For fasteners intended to be assessed for SFRC see Clause B.3.1.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit in accordance with Table A.3.1.4.1. Deformation-controlled expansion fasteners (DC) shall be set with full expansion in accordance with A.3.5 a).

For the determination of the stiffness characteristics, direct measurement of the displacements at the free end of the fastener is required.

For fasteners assessed for variable embedment depth, the assessment shall be made for each fastener size (diameter) with the minimum embedment depth $h_{ef,min}$ and the maximum embedment depth $h_{ef,max,t}$, such that steel failure is avoided (see Figure 2.2.2.1.1).

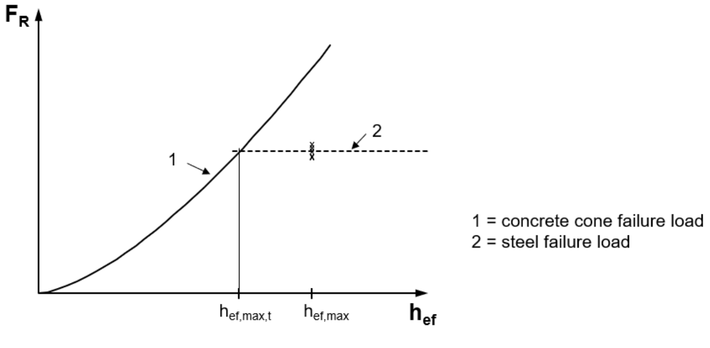


Figure 2.2.2.1.1 Determination of maximum effective embedment depth used in tests, $h_{ef,max,t}$, to avoid steel failure

For concrete screws with variable embedment depth an additional A3 test series at intermediate embedment depth $h_{ef,i}$ shall be performed for assessment in accordance with Clause 2.2.2.10 b)

In case of steel failure

- The failure load is allocated also to pull-out failure.
- If the MPII allow smaller embedment depth repeat the test with reduced embedment depth such that steel failure is avoided.

The following assessment shall be made for each fastener size and for each embedment depth:

Failure loads:

- Determine the mean value of failure loads $N_{u,m}$ [N], converted to the nominal strength in accordance with A.2.1, accounting for the relevant failure mode.
- Determine $N_{Rk,0,ucr}$ and $N_{Rk,0,cr}$ from the 5 % fractile of the failure loads $N_{u,5\%}$ [N], converted to the nominal strength in accordance with A.2.1, accounting for the relevant failure mode.
- Verify the coefficient of variation of failure loads. If the coefficient of variation cv_F > 15 %, determine the reduction factor for large scatter $ß_{cv}$ in accordance with A.2.2,
- Determine the increasing factor $\psi_{c,ucr}$ and $\psi_{c,cr}$ in accordance with Equation (A.2.1.5).

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [N] in accordance with A.2.5.
- Where the requirement given in Equations (A.2.5.1) and (A.2.5.2) is not met in a test, meaning $N_{sl,t} < 0,7\ N_{Ru,t}$ and $N_{sl,t} < 0,8\ N_{Ru,t}$, respectively, the reduction factor α_1 shall be determined according to Equation (A.2.5.3).
- Use the reduction factor α_1 together with rqd. $\alpha_1 = 0,7$ (in cracked concrete) in Equation (2.2.2.10.2) and rqd. $\alpha_1 = 0,8$ (in uncracked concrete) in Equation (2.2.2.10.1).
- Determine the mean value of the failure loads $N_{u,m}$ [N] 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 [%] in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm, cv_δ shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results:

$N_{Rk,0,ucr}$ and $N_{Rk,0,cr}$ [N] to be used in 2.2.2.10

Increasing factor for high strength concrete $\psi_{c,ucr}$ and $\psi_{c,cr}$ [-],

2.2.2.2 Maximum crack width and large hole diameter

Purpose of the assessment

Test series F1 shall be performed to evaluate the sensitivity to low strength concrete and large hole diameter drilled with $d_{cut,max}$.

Assessment method

The tests series F1 shall be performed in accordance with A.3.3.2.

For fasteners intended to be assessed for SFRC see Clause B.3.2.

If the fastener is intended to be used in cracked concrete (option 1 – 6), the influence of increased crack width $\Delta w = 0,50$ mm in combination with drill bits at the upper limit of tolerances (large hole diameter) shall be checked. If the fastener is intended to be used in uncracked concrete only, the tests shall be performed in uncracked concrete accordingly. The tests shall be performed in concrete C20/25.

The holes shall be drilled with a cutting diameter $d_{cut,max}$ of the drill bit in accordance with Table A.3.1.4.1. Deformation-controlled expansion fasteners (DC) shall be set with reference expansion in accordance with A.3.5 b).

For all fasteners, except CS: the test shall be performed with the maximum embedment depth $h_{ef,max,t}$. In this case, the obtained test results shall be applicable for the full embedment depth range.

For all fasteners: the tests shall be performed with the minimum embedment depth $h_{ef,min}$ and the maximum embedment depth $h_{ef,max,t}$. In this case, the test results obtained in the assessment shall be differentiated for $h_{ef,min}$ and $h_{ef,max,t}$.

If the resistance to tension for seismic performance category C2 is assessed for variable embedment depth and C2 tension tests are performed with $h_{ef,min}$ in addition (compare clause A.5.2 b), the F1tests at minimum embedment depth $h_{ef,min}$ shall be performed as well, as the characteristic value of these tests is used to establish the characteristic tension resistance for seismic actions.

If for fasteners assessed for variable embedment depths only tests with $h_{ef,max,t}$ are conducted, the reduction factors α, α_1 and β_{cv} together with the corresponding values for rqd. α and rqd. α_1 shall be used for the assessment of the performance for the full embedment depth range ($h_{ef,min}$ to $h_{ef.max}$).

If for fasteners assessed for variable embedment depths tests with $h_{ef,max,t}$ and $h_{ef,min}$ are conducted, the assessment of tests with $h_{ef,min}$ and $h_{ef,max,t}$ shall be performed separately and the resulting reduction factors shall be used for the assessment of the performance at the corresponding embedment depths.

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Determine the 5 % fractile of the failure loads $N_{u,5\,\%}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Verify the coefficient of variation of failure loads. If the coefficient of variation $cv_F > 20\,\%$, determine the reduction factor for large scatter $ß_{cv}$ in accordance with A.2.2.
- Determine the reduction factor α in accordance with Equation (A.2.4.1) comparing the test results with reference test series in accordance with Table A.1.1, line A3 (cracked concrete) or test series A1 (uncracked concrete only with a rqd. $\alpha = 0{,}8$.

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [N] in accordance with A.2.5.
- Where the requirement given in Equations (A.2.5.1) and (A.2.5.2) is not met in a test, meaning $N_{sl,t} < 0{,}7\ N_{Ru,t}$ and $N_{sl,t} < 0{,}8\ N_{Ru,t}$, respectively, the reduction factor α_1 shall be determined according to Equation (A.2.5.3).
- Use the reduction factor α_1 together with rqd. $\alpha_1 = 0{,}7$ (in cracked concrete) in Equation (2.2.2.10.2) and rqd. $\alpha_1 = 0{,}8$ (in uncracked concrete) in Equation (2.2.2.10.1).
- Determine the mean value of the failure loads $N_{u,m}$ [N] 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 [%] in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm, cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results

Reduction factors α, α_1, $ß_{cv}$ [-] to be used in 2.2.2.10.

2.2.2.3 Maximum crack width and small hole diameter

Purpose of the assessment

Test series F2 shall be performed to evaluate the sensitivity to high strength concrete and small hole diameter drilled with $d_{cut,min}$.

Assessment method

The tests shall be performed in accordance with A.3.3.2.

For fasteners intended to be assessed for SFRC see Clause B.3.2.

If the fastener is intended to be used in cracked concrete, the influence of increased crack width $\Delta w = 0{,}5$ mm in combination with drill bits at the lower limit of tolerances (small hole diameter) shall be checked. If the fastener is intended to be used in uncracked concrete only, the tests shall be performed in uncracked concrete accordingly. The tests shall be performed in concrete C50/60.

The holes shall be drilled with a cutting diameter $d_{cut,min}$ of the drill bit in accordance with Table A.3.1.4.1. Deformation-controlled expansion fasteners (DC) shall be set with reference expansion in accordance with A.3.5 b).

All fasteners shall be tested with the minimum embedment depth $h_{ef,min}$ and the maximum embedment depth $h_{ef,max,t}$. In this case, the test results obtained in the assessment shall be differentiated for $h_{ef,min}$ and $h_{ef,max,t}$.

For all fasteners, except CS: the test shall be performed with the maximum embedment depth $h_{ef,max,t}$. In this case, the obtained test results shall be applicable for the full embedment depth range.

If the resistance to tension for seismic performance category C2 is assessed for variable embedment depth and C2 tension tests are performed with $h_{ef,min}$ in addition (compare clause A.5.2 b), the F2tests at minimum embedment depth $h_{ef,min}$ shall be performed as well, as the characteristic value of these tests is used to establish the characteristic tension resistance for seismic actions.

If for fasteners assessed for variable embedment depths only tests with $h_{ef,max,t}$ are conducted, the reduction factors α, α_1 and β_{cv} together with the corresponding values for rqd. α and rqd. α_1 shall be used for the assessment of the performance for the full embedment depth range ($h_{ef,min}$ to $h_{ef,max}$).

If for fasteners assessed for variable embedment depths tests with $h_{ef,max,t}$ and $h_{ef,min}$ are conducted, the assessment of tests with $h_{ef,min}$ and $h_{ef,max,t}$ shall be performed separately and the resulting reduction factors shall be used for the assessment of the performance at the corresponding embedment depths.

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Determine the 5 % fractile of the failure loads $N_{u,5\,\%}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Verify the coefficient of variation of failure loads. If the coefficient of variation cv_F > 20 %, determine the reduction factor for large scatter $ß_{cv}$ in accordance with A.2.2.
- Determine the reduction factor α in accordance with Equation (A.2.4.1). The following test series are used as corresponding reference test series:
  - For fasteners with intended use in cracked concrete compare the test results with test series in accordance with Table A.1.1, line A4 (cracked concrete) with a rqd. $\alpha = 0{,}8$.
  - For fasteners with intended use in uncracked concrete only compare the test results with test series in accordance with Table A.1.1, line A2 (uncracked concrete) with rqd. $\alpha = 1{,}0$.

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [N] in accordance with A.2.5.
- Where the requirement given in Equations (A.2.5.1) and (A.2.5.2) is not met in a test, meaning $N_{sl,t} < 0{,}7\ N_{Ru,t}$ and $N_{sl,t} < 0{,}8\ N_{Ru,t}$, respectively, the reduction factor α_1 shall be determined according to Equation (A.2.5.3).Use the reduction factor α_1 together with rqd. $\alpha_1 = 0{,}7$ (in cracked concrete) in Equation (2.2.2.10.2) and rqd. $\alpha_1 = 0{,}8$ (in uncracked concrete) in Equation (2.2.2.10.1).
- Determine the mean value of the failure loads $N_{u,m}$ [N] 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 [%] in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm, cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results

Reduction factors α, α_1, $ß_{cv}$ [-] to be used in 2.2.2.10.

2.2.2.4 Crack cycling under load

Purpose of the assessment

In test series F3 it shall be shown that fasteners intended for use in cracked concrete, in the long-term, continue to function effectively when the width of the crack is subject to changes in the range covered by this EAD.

Assessment method

The tests shall be performed in accordance with Clauses A.3.1.2.6, A.3.3.2 and A.3.3.3.

For fasteners intended to be assessed for 100 years working life see Clause C.2. For deformation-controlled fasteners, set the fastener to full expansion according to MPII. After installation the concrete surface shall be inspected and free of cracks.

The holes shall be drilled with a cutting diameter $d_{cut,max}$ (for TC and DC type fasteners) and diameter $d_{cut,m}$ (for CS and UC type fasteners) of the drill bit in accordance with Table A.3.1.4.1.

The tensile load N_p applied to the fastener during the crack cycling test is defined in Equation (2.2.2.4.1).

$$N_p = 0{,}40 \cdot N_{Rk,0,cr} \cdot (f_{c,t} / f_{ck})^{m_{cr}} / \gamma_{inst} \qquad (2.2.2.4.1)$$

where

$N_{Rk,0,cr}$ = characteristic tensile resistance as evaluated in test series A3 and A4 converted to f_c = 20 N/mm² in accordance with Annex A.2.1 or to the lowest strength applied for lower than C20/25, e.g., f_c = 12 N/mm² for C12/15.

γ_{inst} = Factor assessed in Clause 2.2.4

Note The applied load for the test N_p represents approximately 90 % of the maximum applied load at service level.

This test series shall be performed only for fasteners which are intended to be used in cracked concrete only.

Deformation-controlled expansion fasteners (DC) shall be set with reference expansion in accordance with A.3.5 b).

For all fasteners, except CS: the test shall be performed with the maximum embedment depth $h_{ef,max,t}$. In this case, the obtained test results shall be applicable for the full embedment depth range.

For all fasteners: the tests shall be performed with the minimum embedment depth $h_{ef,min}$ and the maximum embedment depth $h_{ef,max,t}$. In this case, the test results obtained in the assessment shall be differentiated for $h_{ef,min}$ and $h_{ef,max,t}$.

For concrete screws with variable embedment depth an additional A3 test series at intermediate embedment depth $h_{ef,i}$ shall be performed for assessment in accordance with Clause 2.2.2.10 b) or 2.2.12 b).

In Equation (2.2.2.4.1) the parameter $N_{Rk,0,cr}$ represents the characteristic tensile resistance as evaluated in test series A3 (and converted to f_c = 20 N/mm^2 or to the lowest strength applied for lower than C20/25, e.g., f_c = 12 N/mm² for C12/15in accordance with Clause A.2.1) for the same embedment depth for which this test series is conducted.

If for fasteners assessed for variable embedment depths only tests with $h_{ef,max,t}$ are conducted, the reduction factor α_p as well as α, α_1 and β_{cv} together with the corresponding values for rqd. α and rqd. α_1 shall be used for the assessment of the performance for the full embedment depth range ($h_{ef,min}$ to $h_{ef,max(,t)}$).

If for fasteners assessed for variable embedment depths tests with $h_{ef,max,t}$ and $h_{ef,min}$ are conducted, the assessment of tests with $h_{ef,min}$ and $h_{ef,max,t}$ shall be performed separately and the resulting reduction factors shall be used for the assessment of the performance at the corresponding embedment depths.

Displacements during crack cycles

In each test the rate of variation of fastener displacements, plotted in a half-logarithmic scale (see Figure 2.2.2.4.1), shall either decrease or be almost constant: the criteria of the allowable displacement after 20 (δ_{20}) and 1000 (δ_{1000}) cycles of crack opening are graduated as a function of the number of tests as follows:

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

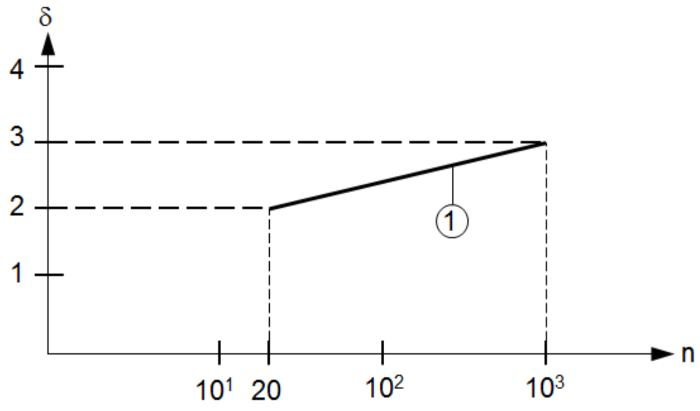
≥10 tests: $\delta_{20,mean} \leq 2$ mm and $\delta_{20,max} \leq 3$ mm

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

Where

$\delta_{20,mean}$	mean displacement of all tests after 20 cycles
$\delta_{20,max}$	maximum displacement of all tests after 20 cycles
$\delta_{1000,mean}$	mean displacement of all tests after 1000 cycles
$\delta_{1000,max}$	maximum displacement of all tests after 1000 cycles

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



1	maximum allowable displacement
n	number of crack cycles
δ	displacement of the fastener in [mm]

Figure 2.2.2.4.1 Criteria for results of tests with variable crack width

If in the tests the above given criteria 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 criteria are fulfilled. The characteristic resistance shall be reduced by applying the reduction factor $\alpha_{p,cr} = N_{p,red}/N_p$ in Equation (2.2.2.10.1).

Failure loads of tension tests after completion of crack cycles (residual load tests)

- Determine the mean value of failure loads $N_{u,m}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Determine the 5 % fractile of the failure loads $N_{u,5\,\%}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Verify the coefficient of variation of failure loads. If the coefficient of variation $cv_F > 20\,\%$, determine the reduction factor for large scatter $ß_{cv}$ in accordance with A.2.2.
- Determine the reduction factor α in accordance with Equation (A.2.4.1) comparing the test results with reference test series in accordance with Table A.1.1, line A3.
- Use the reduction factor α together with rqd. $\alpha = 0,9$ in Equation (2.2.2.10.2).

Load displacement behaviour in the residual load tests:

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [N] in accordance with A.2.5.
- Where the requirement given in Equations (A.2.5.1) and (A.2.5.2) is not met in a test, meaning $N_{sl,t} < 0,7\ N_{Ru,t}$ and $N_{sl,t} < 0,8\ N_{Ru,t}$, respectively, the reduction factor α_1 shall be determined according to Equation (A.2.5.3).Use the reduction factor α_1 together with rqd. $\alpha_1 = 0,7$ (cracked concrete) in Equation (2.2.2.10.2).
- Determine the mean value of the failure loads $N_{u,m}$ [N] 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 [%] in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm, cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results

Reduction factors α, $\alpha_{p,cr}$ and $ß_{cv}$, [-] to be used in 2.2.2.10.

Displacement $\delta_{1000,mean}$ to be used in 2.2.10

2.2.2.5 Repeated loads

Purpose of the assessment

Test series F4 are performed to determine the performance of the fastener under repeated loads simulating service loads that are subject to variation over time.

Assessment method

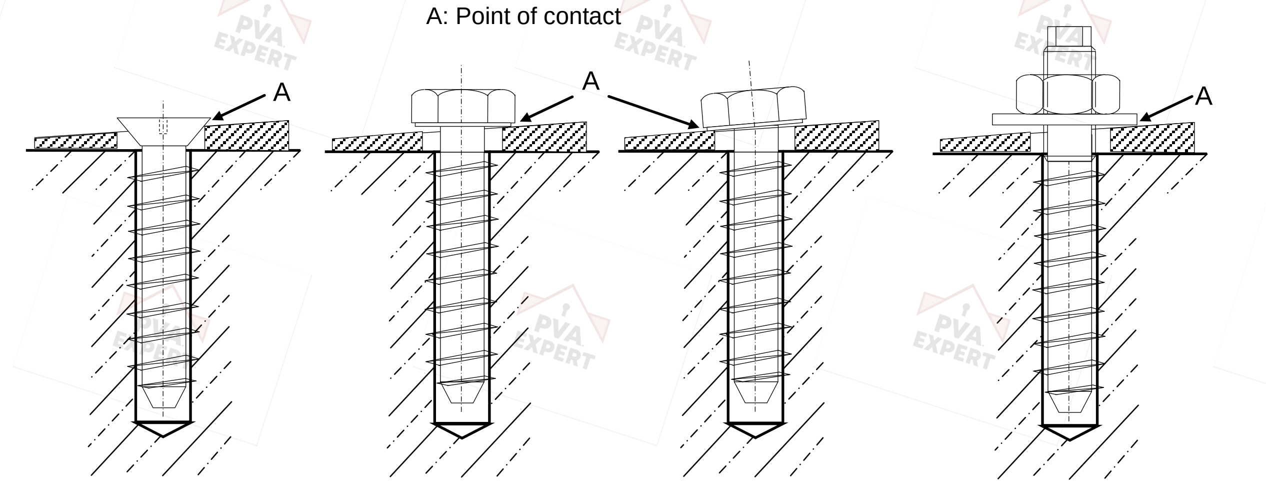
The test shall be performed in uncracked concrete. The test setup shall comply with Clause A.3.3.2. An example of load application via adapter is given in Figure A.3.3.2.2. The fastener is subjected to 10^5 load cycles with a maximum frequency of approximately 6 Hz. During each cycle the load shall change as a sine curve between maximum and minimum value, i.e., max N and min N, respectively. The displacements shall be recorded 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 recorded and a tension test to failure performed.

For concrete screws the tests under repeated loads shall be modified as follows:

The concrete screw shall be set on bevelled washers (inclination angle ≥ 4°) and shall be installed according to the MPII. The corner of the hexagon nut shall rest on the bevelled washer. The position is shown in Figure 2.2.2.5.1. When the installation torque $T = T_{inst}$ is applied, the fastener head might just reach the bevelled washer (see Figure 2.2.2.5.1 b) or might be fully pressed against the washer (see Figure 2.2.2.5.1 c). Any position of the fastener head between the extreme positions shown in Figure 2.2.2.5.1 is acceptable.

If the manufacturer applies for different head forms of concrete screws, the fastener with the most unfavourable head form shall be tested. The greatest torque in the shaft and the greatest notch effect shall be considered. If the most unfavourable head form is not obvious all head forms shall be tested.



a) countersunk head b) hex. head (stiff) c) hex. head (weak) d) External thread with washer and hex. nut

Figure 2.2.2.5.1 Position of the concrete screw head on bevelled washers in tests with repeated loads

For fasteners intended to be assessed for 100 years working life see Clause C.3.

The test series shall be performed with medium diameter of the fastener in uncracked concrete C20/25. The tests with concrete screws shall be performed with all sizes.

For concrete screws the bending effect of an inclination angle of the drilling hole (max 5° in accordance with 1.1) shall be reflected. Drill the hole perpendicular to the concrete surface and install the concrete screw on bevelled washers (inclined angle 4 to 5°, see Figure 2.2.2.5.1). An alternative test setup ensuring the inclination angle during testing is considered equivalent.

In addition, torque-controlled expansion fasteners (TC) and deformation-controlled expansion fasteners (DC), which are intended for use in uncracked concrete only, the tests shall also be performed in uncracked high strength concrete C50/60 with medium diameter of the fastener.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit in accordance with Table A.3.1.4.1. Deformation-controlled expansion fasteners (DC) shall be set with reference expansion in accordance with A.3.5 b).

The maximum and minimum load during the load cycles are given as:

$$\max N = \text{smaller value of } 0{,}6\ N_{Rk,0,ucr} \cdot (f_{c,t} / f_{ck})^{mucr} \text{ and } 0{,}8 \cdot A_s \cdot f_{yk}\ [N] \qquad (2.2.2.5.1)$$

$$\min N = \text{higher value of } 0{,}25\ N_{Rk,0,ucr} \cdot (f_{c,t} / f_{ck})^{mucr} \text{ and } \max N - A_s \cdot \Delta\sigma_s\ [N] \qquad (2.2.2.5.2)$$

where:

$N_{Rk,0,ucr}$ = characteristic value of the failure load in tension in uncracked concrete for the concrete strength of the test member. This value shall be by merging A1 and A2 test results (normalized to the same minimum concrete strength in accordance with A.2.1).

$\Delta\sigma_s$ = 120 N/mm^2

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 criteria are not met, repeat the test with load values max N and min N determined based on a reduced value max N_{red} until the criteria are met. The characteristic resistance shall be reduced by applying the reduction factor $\alpha_{p,ucr}$ = max N_{red} / 0,6 $N_{Rk,ucr}$ in Equation (2.2.2.10.1)).

The test shall be performed with the maximum embedment depth $h_{ef,max,t}$. In this case, the obtained test results shall be applicable for the full embedment depth range.

The tests shall be performed with the minimum embedment depth $h_{ef,min}$ and the maximum embedment depth $h_{ef,max,t}$. In this case, the test results obtained in the assessment shall be differentiated for $h_{ef,min}$ and $h_{ef,max,t}$.

If for fasteners assessed for variable embedment depths only tests with $h_{ef,max,t}$ are conducted, the reduction factor α_p as well as α, α_1 and β_{cv} together with the corresponding values for rqd. α and rqd. α_1 shall be used for the assessment of the performance for the full embedment depth range ($h_{ef,min}$ to $h_{ef,max(,t)}$).

If for fasteners assessed for variable embedment depths tests with $h_{ef,max,t}$ and $h_{ef,min}$ are conducted, the assessment of tests with $h_{ef,min}$ and $h_{ef,max,t}$ shall be performed separately and the resulting reduction factors shall be used for the assessment of the performance at the corresponding embedment depths.

The assessment of the residual capacity portion of the test shall be carried out in terms of failure loads and load displacement behaviour as follows:

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Determine the 5 % fractile of the failure loads $N_{u,5\,\%}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Verify the coefficient of variation of failure loads. If the coefficient of variation cv_F > 20 %, determine the reduction factor for large scatter $ß_{cv}$ in accordance with A.2.2.
- Determine the reduction factor α in accordance with Equation (A.2.4.1). The following test series shall be used as corresponding reference test series:
  - For tests performed in concrete C20/25 use the test results of test series in accordance with Table A.1.1, line A1
  - For tests performed in concrete C50/60 use the test results of the test series in accordance with Table A.1.1, line A2
- Use the reduction factor α together with rqd. α = 1,0 in Equation (2.2.2.10.1).

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [N] in accordance with A.2.5.
- Where the requirement given in Equations (A.2.5.1) and (A.2.5.2) is not met in a test, meaning $N_{sl,t} < 0{,}7\ N_{Ru,t}$ and $N_{sl,t} < 0{,}8\ N_{Ru,t}$, respectively, the reduction factor α_1 shall be determined according to Equation (A.2.5.3).Use the reduction factor α_1 together with rqd. α_1 = 0,8 (in uncracked concrete) in Equation (2.2.2.10.2).
- Determine the mean value of the failure loads $N_{u,m}$ [N] 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 [%]in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm, cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results

Reduction factors α, $\alpha_{p,ucr}$ and $ß_{cv}$, [-] to be used in 2.2.2.10,

Displacement after 10^5 load cycles to be used in 2.2.10

2.2.2.6 Robustness of sleeve-down type fasteners (DC)

Purpose of the assessment

For sleeve down type deformation-controlled fasteners the position of the sleeve in relation to the cone is not visible after installation. Test series F5 determine the robustness of sleeve-down type fasteners.

Assessment method

The tests shall be performed in low strength uncracked concrete C20/25 and cracked concrete C20/25 with a crack width $\Delta w = 0{,}5$ mm for sleeve-down type deformation-controlled fasteners (see Figure 1.1.4 and Figure 1.1.5).

After achieving full expansion of the fastener in accordance with A.3.5. a), two more blows shall be applied with the impact device in accordance with Figure A.3.5.1.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit in accordance with Table A.3.1.4.1.

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Determine the 5 % fractile of the failure loads $N_{u,5\,\%}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Verify the coefficient of variation of failure loads. If the coefficient of variation $cv_F > 20$ %, determine the reduction factor for large scatter $ß_{cv}$ in accordance with A.2.2.
- Determine the reduction factor α in accordance with Equation (A.2.4.1). The following test series shall be used as corresponding reference test series:
    - For fasteners for use in cracked and uncracked concrete use test series in accordance with Table A.1.1, line A3.
    - For fasteners for use in uncracked concrete only use test series in accordance with Table A.1.1, line A1.
- Use the reduction factor α together with rqd. $\alpha = 0{,}8$ in Equation (2.2.2.10.1) and Equation (2.2.2.10.2).

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [N] in accordance with A.2.5.
- Where the requirement given in Equations (A.2.5.1) and (A.2.5.2) is not met in a test, meaning $N_{sl,t} < 0{,}7\ N_{Ru,t}$ and $N_{sl,t} < 0{,}8\ N_{Ru,t}$, respectively, the reduction factor α_1 shall be determined according to Equation (A.2.5.3).Use the reduction factor α_1 together with rqd. $\alpha_1 = 0{,}7$ (in cracked concrete) in Equation (2.2.2.10.2) and rqd. $\alpha_1 = 0{,}8$ (in uncracked concrete) in Equation (2.2.2.10.1).
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%] in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm, cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results

Reduction factors α, α_1 and $ß_{cv}$ [-] to be used in 2.2.2.10.

2.2.2.7 Torquing in low strength concrete (CS)

Purpose of the assessment

Test series F6 are only required for concrete screws in accordance with Figure 1.1.13. The tests shall be performed to check if failure occurs during setting (turn-through of the concrete screw), which would then reduce the performance of the fastener.

The tests shall be performed if the MPII allow setting with a torque wrench.

Assessment method

Perform 10 tests with each size of the fastener in uncracked concrete C20/25. If the MPII allow different embedment depths, the tests shall be performed with minimum embedment depth. The holes shall be drilled with a cutting diameter $d_{cut,max}$ of the drill bit in accordance with Table A.3.1.4.1.

The fastener shall be set with a calibrated torque wrench up to the designated depth. In tests with the pre-positioned fastener version with connecting thread the fastener shall be supported on the bottom of the drill hole ($h_1 \approx h_{nom}$, see also Figure 1.1.13). Afterwards the torque shall be increased up to failure. The ultimate torque (T_u) and the 5 % fractile of the ultimate torque ($T_{u,5\,\%}$) of the test series shall be determined.

For fasteners assessed for variable embedment depth, the tests shall be performed with minimum embedment depth $h_{ef,min}$.

The following conditions shall be met:

(1) It shall be possible to properly set the fastener. The maximum torque to set the fastener with the designated setting depth and the torque to tighten the fixture shall be ≤ T_{inst}. T_{inst} is the installation torque recommended by the manufacturer. If no installation torque is specified by the manufacturer, T_{inst} shall be determined in high strength concrete, where T_{inst} is the maximum torque required to completely set the fastener in tests in accordance with 2.2.2.8. In case of scatter greater than cv = 15 % but not greater than 30 %, the factor β_{cv} shall be determined in accordance with Equation (A.2.2.1). For cv ≤ 15 % the factor β_{cv} = 1,0.

(2) Tests with steel failure:

$$T_{u,5\,\%} \geq 1{,}5 \cdot T_{inst}\,(f_{u,t} / f_{uk}) / ß_{cv} \qquad (2.2.2.7.1)$$

(3) Tests with concrete failure

$$T_{u,5\,\%} \geq 2{,}1 \cdot T_{inst}\,(f_{c,t} / f_{ck})^{0,5} / ß_{cv} \qquad (2.2.2.7.2)$$

where

f_{ck} = nominal concrete strength required for the test (e.g., 20 N/mm² measured on cylinders for concrete C20/25)

Note: The factor 1,5 in Equation (2.2.2.7.1) was established to take into account the scatter of steel failure due to torque. The factor 2,1 in Equation (2.2.2.7.2) was established to take into account the scatter of concrete failure due to torque.

Expression of results

The ETA shall specify the installation torque T_{inst} for which the criteria are fulfilled.

2.2.2.8 Torquing in high strength concrete (CS)

Purpose of the assessment

Test series F7 are only required for concrete screws in accordance with Figure 1.1.13. The tests shall be performed to check if steel failure occurs due to the torsion during setting.

The tests shall be performed if the MPII allow setting with a torque wrench.

Assessment method

Perform 10 tests with each size of the fastener in uncracked concrete C50/60. If the MPII allow different embedment depths, the tests shall be performed with maximum embedment depth. The holes shall be drilled with a cutting diameter $d_{cut,min}$ of the drill bit in accordance with Table A.3.1.4.1.

The fastener shall be set with a calibrated torque wrench up to the designated depth. In tests with the pre-positioned fastener version with connecting thread the fastener shall be supported on the bottom of the drill hole ($h_1 \approx h_{nom}$, see also Figure 1.1.13). The maximum value of the required torque shall be measured. Afterwards the torque shall be increased up to failure. The ultimate torque (T_u) and the 5 % fractile of the ultimate torque ($T_{u,5\,\%}$) of the test series shall be determined.

For fasteners assessed for variable embedment depth, the tests shall be performed with maximum embedment depth $h_{ef,max}$.

For fasteners intended to be assessed for SFRC see Clause B.3.3.

The following test criteria shall be met:

(1) It shall be possible to properly set the fastener. The maximum torque to set the fastener with the designated setting depth and the torque to tighten the fixture shall be ≤ T_{inst}. T_{inst} is the installation torque recommended by the manufacturer. If no installation torque is specified by the manufacturer, T_{inst} shall be taken as the maximum torque required to completely set the fastener. In case of scatter greater than cv = 15 % but not greater than 30 %, the factor β_{cv} shall be determined in accordance with Equation (A.2.2.1). For cv ≤ 15 % the factor β_{cv} = 1,0.

(2) Tests with steel failure: see Equation (2.2.2.7.1).

(3) Tests with concrete failure: see Equation (2.2.2.7.2).

Expression of results

The ETA shall specify the installation torque T_{inst} for which the criteria are fulfilled.

2.2.2.9 Impact screw driver (CS)

Purpose of the assessment

Test series F8 are only required for concrete screws in accordance with Figure 1.1.13. The tests shall be performed to check if steel failure of the concrete screw occurs while setting with impact screw drivers.

The tests shall be performed if the MPII do allow setting with an impact screw driver.

The test series in high strength concrete is required to check if the screw can be installed without steel failure also in high strength concrete with impact screw driver if test series F7 was omitted.

Assessment method

The tests shall be performed with the most adverse head form of the product. If the most adverse head form is not obvious all head forms shall be tested.

For fasteners assessed for variable embedment depth, the tests shall be performed in C20/25 with minimum embedment depth $h_{ef,min}$ and in C50/60 with maximum embedment depth $h_{ef,max}$.

For fasteners intended to be assessed for SFRC see Clause B.3.3.

The following test conditions shall be kept:

- Uncracked concrete C20/25 (in addition, also in C50/60, if test series F7 was omitted);
- Cutting diameter of drill bits C20/25: $d_{cut} = d_{cut,max}$; for C50/60: $d_{cut} = d_{cut,min}$;
- If the MPII allow different embedment depths, the tests shall be performed in C20/25 with minimum embedment depth and in C50/60 with maximum embedment depth.
- 15 tests with each fastener size;
- Impact screw driver with maximum power output as given by the manufacturer in MPII or, if not, as recommended by the TAB based on experiences and stated in the ETA.
- The fastener shall be screwed to touch gently its final position (in contact with substrate or with a fixture). Then the impact screw driver shall be set on the head of the fastener with maximum power output. The screw driver shall be switched off automatically after 5 seconds.

In all 15 tests no failure shall occur. If one failure occurs, the TAB shall increase the test number to n = 30 with one failure allowed. If more than 1 failure occurs, then the manufacturer cannot declare suitability of the product for the impact screw driver used in the test.

Expression of results

The ETA shall specify the type(s) of impact screw driver for which the criteria are fulfilled.

2.2.2.10 Characteristic resistance to pull-out failure

The initial value $N_{Rk,0}$ shall be taken as the 5 % fractile of failure loads in the reference tension test series for uncracked concrete in accordance with Table A.1.1, line A1 and A2 and for cracked concrete line A3 and A4 normalized to concrete strength C20/25 in accordance with clause A.2.1, if statistical equivalence is shown.

If statistical equivalence is not shown then the initial value $N_{Rk,0}$ shall be taken as the 5 % fractile of failure loads in the reference tension test series for uncracked concrete in accordance with Table A.1.1, line A1 and for cracked concrete line A3 normalized to concrete strength C20/25 in accordance with Clause A.2.1.

Statistical equivalence of test results in uncracked concrete is shown, if the results of series A2 lay in the same scatter band (5 % fractile as a lower boundary and 95 % fractile as a higher boundary with a confidence level of 90 %) of test series A1.

Statistical equivalence of test results in cracked concrete is shown if the results of series A4 lay in the same scatter band (5 % fractile as a lower boundary and 95 % fractile as a higher boundary with a confidence level of 90 %) of test series A3.

The characteristic tension resistance shall be reduced if certain criteria are not met as described in the following:

(1) Load/displacement behaviour, tension loading

If the criteria on uncontrolled slip in accordance with A.2.5 are not fulfilled by the tension tests (test series A1-A4 assessed in Clause 2.2.2.1, test series F1-F5 assessed in Clauses 2.2.2.2 to 2.2.2.6, test series F9-F12 assessed in Clauses 2.2.4 to 2.2.6), the characteristic resistance shall be reduced in accordance with Equation (2.2.2.10.1) and Equation (2.2.2.10.2). For the tension test series, the factor α_1 shall be determined. The smallest value for the ratio $\alpha_1/(rqd.\alpha_1)$ applies.

(2) Applied load in repeated load tests $\alpha_{p,ucr}$

For characteristic resistance in uncracked concrete $\alpha_{p,ucr}$ in accordance with Clause 2.2.2.5 (tests with repeated loads) is accounted for in Equation (2.2.2.10.1).

(3) Applied load in crack cycling tests $\alpha_{p,cr}$
For characteristic resistance in cracked concrete $\alpha_{p,cr}$ in accordance with Clause 2.2.2.4 (tests with crack cycling) is accounted for in Equation (2.2.2.10.2).

(4) Ultimate load in any other tests
If the criteria on the ultimate load in test series in accordance with Table A.1.1, lines N3, F1 to F5 are not fulfilled in one or more test series, the characteristic resistance shall be reduced in accordance with Equation (2.2.2.10.1) and Equation (2.2.2.10.2). The smallest value of the ratio α/(rqd. α) applies. If not all sizes of fasteners have been tested, for untested sizes the smallest reduction factor of the neighbouring fasteners(s) size(s).

Characteristic resistance in uncracked concrete

$$N_{Rk,p,ucr} = N_{Rk,0,ucr} \cdot min\, \beta_{cv} \cdot min\left\{\alpha_{p,ucr}; \min\left(\frac{\alpha_1}{rqd.\alpha_1}\right); min\left(\frac{\alpha}{rqd.\alpha}\right)\right\} \qquad (2.2.2.10.1)$$

Characteristic resistance in cracked concrete

$$N_{Rk,p,cr} = N_{Rk,0,cr} \cdot min\, \beta_{cv} \cdot min\left\{\alpha_{p,cr}; \min\left(\frac{\alpha_1}{rqd.\alpha_1}\right); min\left(\frac{\alpha}{rqd.\alpha}\right)\right\} \qquad (2.2.2.10.2)$$

If the criteria for the displacement behaviour and the ultimate load are not fulfilled, the case giving the lowest value of $N_{Rk,p}$ governs.

The characteristic resistances $N_{Rk,p,ucr}$ and $N_{Rk,p\ cr}$ shall be rounded down to one decimal place.

The characteristic resistance of a fastener in case of pull-out failure in concrete of strength > C20/25 shall be determined by multiplying the characteristic value for concrete C20/25 by a factor ψ_c in accordance with A.2.1.

The characteristic resistance of a fastener in case of pull-out failure in concrete of strength < C20/25 shall be determined by multiplying the characteristic value for concrete C12/15 by a factor ψ_c in accordance with A.2.1.

For fasteners assessed for variable embedment depth, the following provisions apply.

The initial value $N_{Rk,0}$ shall be determined for both the minimum embedment depth $h_{ef,min}$ and the maximum tested embedment depth $h_{ef,max,t}$.

If test series F1 to F4 are performed with one embedment depth only, i.e., either $h_{ef,min}$ or $h_{ef,max,t}$ (depending on the specific test series), the reduction factor α_p as well as the factors α, α_1 and β_{cv} together with the corresponding values for rqd. α and rqd. α_1 shall be used for the assessment of the performance for both embedment depths, i.e., $h_{ef,min}$ to $h_{ef,max,t}$.

If test series F1 to F4 are performed with two embedment depths, i.e., $h_{ef,min}$ and $h_{ef,max,t}$, the reduction factor α_p as well as the factors α, α_1 and β_{cv} together with the corresponding values for rqd. α and rqd. α_1 shall be used respectively for the assessment of the performance for each embedment depths, i.e., $h_{ef,min}$ and $h_{ef,max,t}$.

The characteristic resistances in uncracked concrete $N_{Rk,p,ucr}$ and in cracked concrete $N_{Rk,p,cr}$ shall be calculated for each embedment depth, i.e., $h_{ef,min}$ and $h_{ef,max,t}$, in accordance with Equations (2.2.2.10.1) and (2.2.2.10.2), respectively.

<u>Torque-controlled expansion fastener (TC) and undercut fastener (UC):</u>

For an embedment depth h_{ef} within the range [$h_{ef,min}$, $h_{ef,max,t}$], the characteristic resistance shall be obtained by linear interpolation.

The characteristic resistance $N_{Rk,p}$ obtained for $h_{ef,max,t}$ is valid for an embedment depth $h_{ef} \geq h_{ef,max,t}$.

<u>Concrete screw fastener (CS):</u>

For concrete screws (CS) with a thread along the entire length of the embedment depth, the characteristic resistance $N_{Rk,p}$ for an embedment depth h_{ef} within the range [$h_{ef,min}$, $h_{ef,max,t}$] shall be obtained by linear interpolation if

a) the characteristic resistance $N_{Rk,p}$ is greater than the corresponding concrete cone capacity for both embedment depths $h_{ef,min}$ and $h_{ef,max,t}$; or

b) the reduction factors obtained in test series A3 and in test series F3, which shall be additionally carried out for an intermediate embedment depth, shall be equal or greater than the minimum reduction factor obtained for $h_{ef,min}$ and $h_{ef,max,t}$ in the corresponding test series. The intermediate embedment depth shall be determined as $h_{ef,i} = [h_{ef,min} + h_{ef,max,t}]/2$ rounded to the next integer.

In all other cases the assessment of the pull-out resistance shall be performed for fixed embedment depth.

All types of fasteners covered in this EAD:

The factor ψ_c shall be determined for both embedment depths $h_{ef,min}$ and $h_{ef,max,t}$ and the smaller value shall be taken for the full embedment depth range $[h_{ef,min}, h_{ef,max}]$.

Expression of results

Characteristic resistance to pull-out failure in uncracked and cracked concrete $N_{Rk,p,ucr}$, $N_{Rk,p,cr}$ [N], $\psi_{c,cr}$ [-], $\psi_{c,ucr}$ [-].

2.2.3 Resistance to concrete cone failure

The determination of the characteristic resistance to concrete cone failure based on compressive cylinder strength of concrete in accordance with EN 1992-4 [10] requires the factors $k_{ucr,N}$ and $k_{cr,N}$. The following default factors and characteristic edge distance can be taken without further testing.

$k_{ucr,N}$ = 11,0
$k_{cr,N}$ = 7,7
$c_{cr,N}$ = 1,5 h_{ef}
h_{ef} = effective embedment depth in accordance with EN 1992-4 [10], 3.1.26; for concrete screws: h_{ef} shall be determined in accordance with Figure 1.1.13.

Purpose of test

For fasteners assessed for variable embedment, $h_{ef,max,t}$ shall be used as the maximum embedment depth.

If the factors $k_{ucr,N}$ and $k_{cr,N}$ are determined based on tests, the testing and assessment shall be performed as described in this Clause.

The stiffness characteristics for non-linear spring models $k_{A,ucr}$, $k_{B,ucr}$, $k_{C,ucr}$, $k_{D,ucr}$, $k_{A,cr}$, $k_{B,cr}$, $k_{C,cr}$ and $k_{D,cr}$ shall be determined with idealized load displacement curves to be assessed in 2.2.11.2.

Test conditions

Annex A applies with regards to provisions for all tests.

Perform tests in uncracked and cracked concrete with strength classes C20/25 and C50/60 as given in Table A.1.1, lines A1 to A4 and described in Clause 2.2.2.1.

If the manufacturer applies for an intended use in uncracked concrete only, only the test series in uncracked concrete in accordance with Table A.1.1, lines A1 and A2 shall be performed.

Perform tests for each diameter and embedment depth of the fastener for which the factor $k_{ucr,N}$ ($k_{cr,N}$) shall be determined.

In case of variable embedment depth, perform tests for each diameter of the fastener at minimum and maximum embedment depth, $h_{ef,min}$ and $h_{ef,max}$, for which the factor $k_{ucr,N}$ ($k_{cr,N}$) shall be determined. Tests at an additional intermediate embedment depth shall be performed, if the failure mode (concrete cone failure or pull-out failure) is not the same in tests at minimum and maximum embedment depth.

In each test series, a minimum of two different concrete batches shall be used. The minimum number of tests in each test series is n_{min}=10 with a minimum of 5 tests per batch. The number of tests in different batches shall be approximately the same with a maximum allowed deviation of ± 20 %: e.g., in case of tests conducted in 3 batches, one batch with 10 tests allows for a minimum of 8 tests and a maximum of 12 tests in the other two batches.

The definition of different batches shall consist of: different W/C ratio, and/or different compressive strength, and/or different cement type, and/or different types of aggregates, and/or different grading curves, and/or different suppliers (batches of concrete composed in compliance with Clause A.3.1.2).

If the coefficient of variation of failure loads c_{vF} obtained from a test series (combining all tested batches after normalisation) does not meet the criteria given in the assessment section below, the number of tests shall be increased.

If the criterion for the coefficient of variation of failure loads of $c_v \leq 15$ % cannot be fulfilled, the default effectiveness factors apply.

If steel failure occurs for the tested embedment depth of the fastener, tests shall be performed with a reduced embedment depth as defined in the assessment clause.

Assessment

In case of a reduced test programme for additional drilling methods in accordance with Clause A.4 and Table A.4.1 or Table A.4.2:

- determined effectiveness factor in uncracked and in cracked concrete shall be equal or
- minimum k-factor shall be considered for both drilling methods

Annex A applies with regards to general assessment methods.

Basic criteria

The load-displacement behaviour shall be assessed in accordance with Clause A.2.5.

Normalize the test results to the nominal concrete strength in accordance with A.2.1 and determine the coefficient of variation of failure loads cv_F in each test series. The coefficient of variation shall not exceed 15 % ($cv_F \leq 15$ %) in any test series. In the case that the coefficient of variation cv_F does not meet this criterion, the number of tests in the corresponding test series shall be increased.

The mean value and the coefficient of variation of the displacements cv_δ [%] at 50 % of the mean of the normalized failure load for each test series shall be determined. If the mean value of displacements at 50 % of the normalized failure load is greater than 0,4 mm, the coefficient of variation cv_δ shall equal or less than 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

When one of the basic requirements above is not met, the default value for factor $k_{ucr,N}$ ($k_{cr,N}$) applies.

Determination of effectiveness factors $k_{ucr,N}$ and $k_{cr,N}$:

The results of the tests performed in low- and high-strength concrete, i.e., in concrete with strength class C20/25 and C50/60, respectively, normalized to the nominal compressive strength of C20/25 in accordance with Clause A.2.1 shall be considered together for the determination of the effectiveness factor, if the coefficient of variation cv_F of the combined normalized test results does not exceed 15 %.

Determine the mean value of the failure loads $N_{u,m,20(A1/A2)}$ and $N_{u,m,20(A3/A4)}$ for combined test series and calculate the mean effectiveness factor $k_{m,cr}$ and $k_{m,ucr}$ using Equation (2.2.3.1)**Fehler! Verweisquelle konnte nicht gefunden werden.** and Equation (2.2.3.2).

$$k_{m,cr} = \frac{N_{u,m,20(A3,A4)}}{h_{ef}^{1,5}\sqrt{f_{c,20}}} \tag{2.2.3.1}$$

$$k_{m,ucr} = \frac{N_{u,m,20(A1,A2)}}{h_{ef}^{1,5}\sqrt{f_{c,20}}} \tag{2.2.3.2}$$

where $N_{u,m,20(A3,A4)}$ = mean value of the failure loads [N] of the combined test series A3 and A4, normalized to the nominal compressive strength of C20/25 in accordance with Clause A.2.1

$N_{u,m,20(A1,A2)}$ = mean value of the failure loads [N] of the combined test series A1 and A2, normalized to the nominal compressive strength of C20/25 in accordance with Clause A.2.1

$f_{c,20}$ = 20 N/mm^2 = nominal concrete compressive strength of C20/25, used for normalization of test series A1 to A4

If the criterion for the coefficient of variation cv_F is not met, the effectiveness factor shall be determined separately from the test results in low- and high-strength concrete and the smaller value of both shall be declared.

Determine the mean value of the failure loads $N_{u,m,\,,A1}$, $N_{u,m,\,A2}$, $N_{u,m,\,A3}$ and $N_{u,m,\,A4}$ [N] of the test series A1 to A4, and calculate the mean effectiveness factor $k_{m,cr}$ and $k_{m,ucr}$ using Equations (2.2.3.3) and (2.2.3.4).

$$k_{m,cr} = \min\left(\frac{N_{u,m,A3}}{h_{ef}^{1,5}\sqrt{f_{c,A3}}}\ ;\ \frac{N_{u,m,A4}}{h_{ef}^{1,5}\sqrt{f_{c,A4}}}\right) \tag{2.2.3.3}$$

$$k_{m,ucr} = \min\left(\frac{N_{u,m,A1}}{h_{ef}^{1,5}\sqrt{f_{c,A1}}}\ ;\ \frac{N_{u,m,A2}}{h_{ef}^{1,5}\sqrt{f_{c,A2}}}\right) \tag{2.2.3.4}$$

where $N_{u,m,A3}$ = mean value of the failure loads [N] of the test series A3 ,

$f_{c,A3}$ = concrete compressive strength measured on cylinders in the test series A3,

$N_{u,m,A4}$ = mean value of the failure loads [N] of the test series A4,

$f_{c,A4}$ = concrete compressive strength measured on cylinders in the test series A4,

$N_{u,m,A1}$ = mean value of the failure loads [N] of the test series A1,

$f_{c,A1}$ = concrete compressive strength measured on cylinders in the test series A1,

$N_{u,m,A2}$ = mean value of the failure loads [N] of the test series A2,

$f_{c,A2}$ = concrete compressive strength measured on cylinders in the test series A2.

The effectiveness factor $k_{ucr,N}$ ($k_{cr,N}$) shall be determined in accordance with Table 2.2.3.1.

Table 2.2.3.1 Values of effectiveness factors $k_{ucr,N}$ and $k_{cr,N}$

	Range of calculated value of k_m	Effectiveness factor
Cracked concrete	$10,2 \leq k_{m,cr} < 11,0$	$k_{cr,N} = 7,7$
	$11,0 \leq k_{m,cr} < 11,8$	$k_{cr,N} = 8,3$
	$k_{m,cr} \geq 11,8$	$k_{cr,N} = 8,9$
Uncracked concrete	$14,6 \leq k_{m,ucr} < 15,7$	$k_{ucr,N} = 11,0$
	$15,7 \leq k_{m,ucr} < 16,9$	$k_{ucr,N} = 11,8$
	$k_{m,ucr} \geq 16,9$	$k_{ucr,N} = 12,7$

Note: For cracked concrete and uncracked concrete, the smallest value for the effectiveness factor in Table 2.2.3.1 *corresponds to the default value given in Clause 2.2.3 and the largest value corresponds to the default value for cast-in headed fasteners (see EN 1992-4, Clause 7.2.1.4 (2), Note).*

If the calculated mean effectiveness factor k_m is less than the minimum value given in Table 2.2.3.1, the default value for factor $k_{ucr,N}$ ($k_{cr,N}$) applies.

Steel failure:

The types of failure and the level of failure loads in the tests depend on the embedment depth of the fasteners in the test, see Figure 2.2.3.1.

If steel failure occurs in the tests with the anchorage depth h_{ef}, the tests shall be repeated with a reduced embedment depth $h_{ef,red}$. The reduced embedment depth $h_{ef,red}$ is the maximum anchorage depth at which steel failure is avoided and concrete failure is expected (see Figure 2.2.3.1).

In lieu of repeating the tests, the failure loads $N_{u,m}$, normalized to the nominal concrete strength in accordance with A.2.1, in Equation **Fehler! Verweisquelle konnte nicht gefunden werden.** can be used conservatively or the default values for $k_{cr,N}$ and $k_{ucr,N}$ shall be retained.

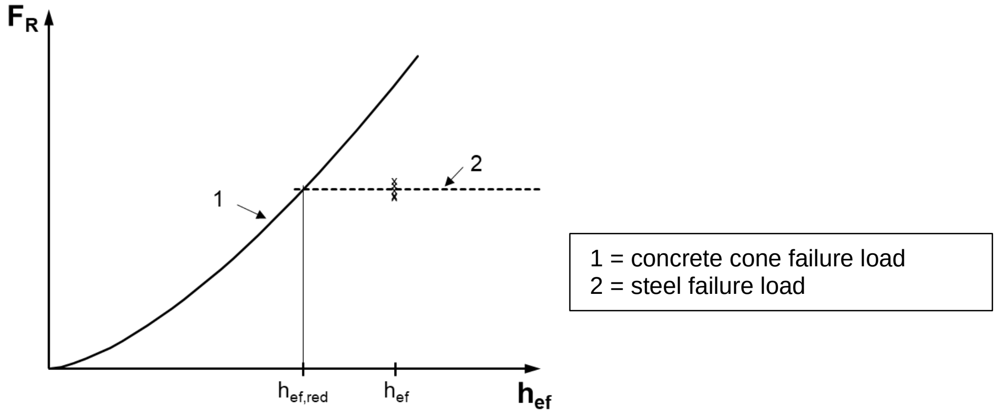


Figure 2.2.3.1 **Determination of effectiveness factor in case of steel failure**

The reduced embedment depth $h_{ef,red}$ and subsequently the effectiveness factor shall be determined separately from the test results in low- and high-strength concrete.

$$h_{ef,red} = \left(\frac{N_{Rk,s}}{k_m \cdot \sqrt{f_{c,t}}} \right)^{2/3} \tag{2.2.3.5}$$

where $N_{Rk,s}$ = characteristic steel tension resistance [N],

k_m = mean effectiveness factor for which the largest k-factor is assigned, i.e., k_m = 16,9 for uncracked concrete and k_m = 11,8 for cracked concrete,

= mean effectiveness factor determined from tests with $h_{ef,min}$ for the assessment of fasteners with variable embedment depth range and steel failure for $h_{ef} = h_{ef,max}$,

$f_{c,t}$ = concrete strength of the test member in which the tests with the reduced embedment depth are performed (upper limit of compressive cylinder strength f_c for the concrete strength class of the test member in accordance with A.3.1.2.5).

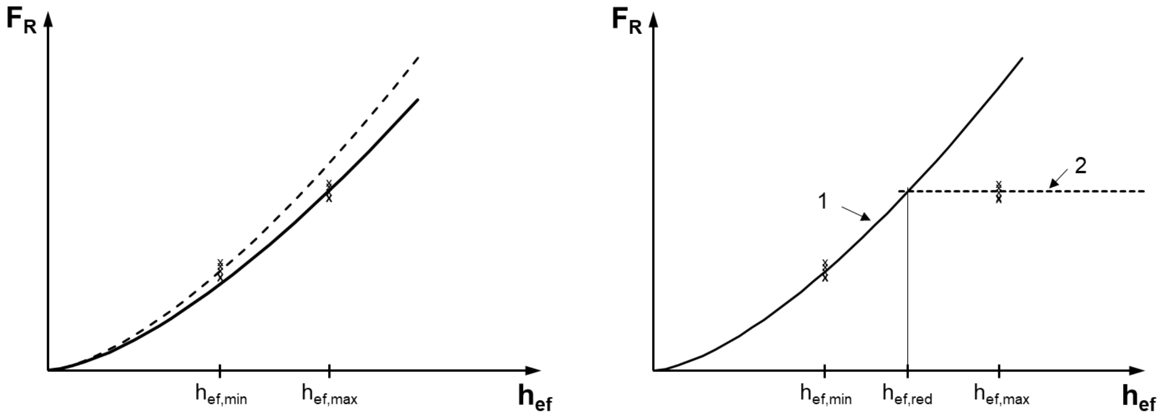
The value of the embedment depth determined from Equation (2.2.3.5) shall be rounded down to a multiple of 5 mm to obtain the value of $h_{ef,red}$ for the tests with reduced embedment depth.

Determine the effectiveness factor from the test results with $h_{ef,red}$ in accordance with Equation **Fehler! Verweisquelle konnte nicht gefunden werden.** and Table 2.2.3.1. The smaller effectiveness factor $k_{ucr,N}$ ($k_{cr,N}$) from tests in low- and high-strength concrete is decisive for the embedment depth h_{ef}.

Variable embedment depth:

For the assessment of a fastener with a variable embedment depth range, the test series with $h_{ef,min}$ and $h_{ef,max}$ shall be assessed separately and the corresponding effectiveness factors shall be determined.

If concrete cone failure is observed for tests with $h_{ef,min}$ and $h_{ef,max}$ (see Figure 2.2.3.2 (a)), the smallest effectiveness factor $k_{ucr,N}$ ($k_{cr,N}$) is decisive for the variable embedment depth range.



(a) concrete cone (cc) (b) mixed failure modes (1: cc; 2: pull-out or steel failure)

Figure 2.2.3.2 Determination of effectiveness factor for variable embedment depth

If concrete cone failure is observed for the tests with $h_{ef,min}$ and steel failure or pull-out failure (as characterised by a mean effectiveness factor k_m less than the minimum value given in Table 2.2.3.1) occurs for the tests with $h_{ef,max}$ (see Figure 2.2.3.2 (b)), additional tests with an intermediate embedment depth $h_{ef,red}$ (i.e., the largest embedment depth anticipating concrete cone failure and avoid steel or pull-out failure) are necessary for the determination of the effectiveness factor for the variable embedment depth range.

Using an intermediate embedment depth $h_{ef,red}$, the assessment of the effectiveness factor shall be performed separately from the test results in low- and high-strength concrete. Therefore, the following determination of $h_{ef,red}$ shall be performed for tests results in low-strength concrete as well as high-strength concrete resulting in possibly two different values. Calculate the embedment depth for which the pull-out capacity or steel failure load (i.e., the characteristic value of the failure loads $N_{u,k,t}$ [N] for $h_{ef,max}$) intersects the concrete cone capacity (calculated with k_m determined for $h_{ef,min}$) as shown in Figure 2.2.3.2 (b) and given in Equation (2.2.3.6).

$$h_{ef,red} = \left(\frac{N_{u,k,t}}{k_m \cdot \sqrt{f_{c,t}}} \right)^{2/3} \qquad (2.2.3.6)$$

where $N_{u,k,t}$ = characteristic value of the failure loads [N] from test series A1, A2, A3 or A4 (both batches) for tests with $h_{ef,max}$,

k_m = mean effectiveness factor determined from tests with $h_{ef,min}$,

$f_{c,t}$ = upper limit of compressive cylinder strength f_c for the concrete strength class of the test member (in accordance with Clause A.3.1.2.5) in which the additional tests shall be performed.

The value of the embedment depth determined from Equation (2.2.3.6) shall be rounded down to a multiple of 5 [mm] to obtain the value of $h_{ef,red}$ for the additional tests in the corresponding concrete strength class.

Determine the effectiveness factors from the test results with $h_{ef,red}$ in accordance with Equation **Fehler! Verweisquelle konnte nicht gefunden werden.** and Table 2.2.3.1 for the tests in low-strength and high-strength concrete. Compare these two values for $k_{ucr,N}$ ($k_{cr,N}$) with the one for the embedment depth $h_{ef,min}$. The smallest effectiveness factor $k_{ucr,N}$ ($k_{cr,N}$) is decisive for the variable embedment depth range.

Expression of results

Effectiveness factors $k_{ucr,N}$, $k_{cr,N}$ [-], embedment depth h_{ef}, edge distance $c_{cr,N}$ [mm].

2.2.4 Robustness

2.2.4.1 Robustness to variation in use conditions)

Purpose of the assessment

Test series F9 are performed to determine the sensitivity of the performance to foreseeable and unavoidable variations in the use conditions and to determine the factor γ_{inst} for the sensitivity to installation.

For fasteners with several embedment depths of one fastener size, the tests shall be performed at minimum embedment depth and at the maximum embedment which does not create steel failure.

Tests at maximum embedment depth shall be performed, if in tests with minimum embedment depth pull-out or concrete failure occurs.

Assessment method

The assessment of the factor γ_{inst} shall be performed for the following range of concrete strength classes:

(1) The standard assessment shall be made for C20/25 to C50/60.

(2) Separate assessment for minimum concrete strength class in accordance with Clause A.2.7.

(3) For an assessment of concrete stronger than C50/60 in accordance with Table A.1.1 and Clause A.2.8, it shall be checked that the factor γ_{inst} for the maximum concrete class is smaller than or equal to γ_{inst} for concrete class C50/60. If this condition is not fulfilled the maximum concrete strength class is C50/60.

The tension tests shall be performed in accordance with A.3.3.2.

For fasteners intended to be assessed for SFRC see Clause B.3.2.

For fasteners assessed for variable or multiple embedment depth, the tests shall be performed:

- with minimum embedment depth $h_{ef,min}$ and with maximum embedment depth $h_{ef,max,t}$,
- with maximum embedment depth $h_{ef,max,t}$, if concrete cone capacity is achieved with $h_{ef,min}$ for the reference tests. In this case the reduction factors obtained in the assessment shall be accepted for the full embedment depth range. (TC)

Different test conditions for torque-controlled expansion fasteners (TC), deformation-controlled fasteners (DC), undercut fasteners (UC) and concrete screws (CS) are given in the following.

Torque-controlled expansion fasteners (TC)

The tests shall be performed in high strength concrete C50/60 for use in cracked and uncracked concrete and in low strength concrete C20/25 for use in uncracked concrete only.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit in accordance with Table A.3.1.4.1. The fastener shall be installed with an applied torque T = 0,5 T_{inst}.

Deformation-controlled expansion fasteners (DC)

The tests shall be performed in low strength concrete C20/25. The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit in accordance with Table A.3.1.4.1. The fastener shall be set with installation expansion in accordance with A.3.5 c).

Undercut fasteners (UC)

The test conditions shall be based on the type of fastener and type of installation (Displacement-controlled installation or Torque-controlled installation). In these tests the fastener shall be installed such that a minimum bearing area is achieved. This condition is fulfilled if the following provisions are met:

(a) Displacement-controlled installation

The tests shall be carried out in low strength concrete only, because in case of concrete cone failure for a constant bearing area the ratio concrete pressure in the bearing area to concrete compressive strength decreases with increasing concrete strength.

Fastener installation in accordance with:

- Diameter of drill bit for cylindrical hole d_0: $d_{cut,max}$
- Length of drill bit for cylindrical hole: maximum length according to specified tolerances
- Diameter of drill bit for undercutting d_1: $d_{cut,max}$
- Installation of the fastener, flush with the concrete surface or the fixture

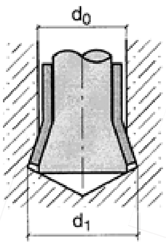


Figure 2.2.4.1.1 Diameter of drill bits d_0 and d_1

Fastener installation in accordance with Figure 1.1.7

- Diameter of drill bit for cylindrical hole d_0: $d_{cut,max}$
- Diameter of drill bit for undercutting d_1: $d_{cut,max}$

Displacement of expansion element shall be defined depending on the fastener design either as a function of the required displacement, if the full fastener displacement can easily be recognized (e.g., by indentation of the fastener sleeve by the setting tool) or as a function of the required input energy for full expansion of the fastener in accordance with A.3.5 a) or as a combination of both.

Fastener installation in accordance with Figure 1.1.8:

- Diameter of drill bit for cylindrical hole d_0: $d_{cut,max}$
- Diameter of drill bit for undercutting d_1: $d_{cut,max}$

Fastener installation in accordance with Figure 1.1.9 and Figure 1.1.10:

- Diameter of drill bit for cylindrical hole d_0: $d_{cut,max}$
- Length of drill bit for cylindrical hole: maximum length according to specified tolerances
- Installation of the fastener, flush with the concrete surface or the fixture.
- If it is required by the manufacturer to apply a defined torque, then the fastener shall be torqued with $T = 1{,}0\ T_{inst}$, after about 10 minutes the torque shall be reduced to $T = 0{,}5\ T_{inst}$. If no defined torque shall be applied, then the fastener shall not be torqued before testing ($T = 0$).

(b) *Torque-controlled installation*

For undercut fasteners which are installed by torque control in accordance with Figure 1.1.11 and Figure 1.1.12 the test conditions in the robustness tests are defined as follows:

- Diameter of drill bit for cylindrical hole d_0: $d_{cut,max}$
- Diameter of drill bit for undercutting d_1: $d_{cut,max}$ and $d_{cut,min}$ (fastener in accordance with Figure 1.1.11 only)
- Torque $T = 0{,}5\ T_{inst}$
- Concrete strength C20/25 and C50/60

Concrete screws (CS)

The tests shall be performed in low strength concrete C20/25.

The test shall be performed with the minimum mechanical interlock. The minimum mechanical interlock is obtained by determining the diameter of the drill bit for the cylindrical hole d_0 as follows:

- The cutting diameter of the drill bit to be used in the test shall be $d_{cut,max}$ in accordance with Table A.3.1.4.1 increased by the difference in the main load bearing clause of the fastener as of Figure 2.2.4.1.2 between the thread diameter in the test and the lower limit of the thread diameter according to the specification of the manufacturer, i.e.,
    - $d_0 \geq d_{cut,max} + (d_{t,t} - d_{t,low})$
    - $d_{t,t}$ outer diameter of thread in accordance with Figure 2.2.7.2.3 of the concrete screw in the main load bearing clause measured on the concrete screw used in the test
    - $d_{t,low}$ lower limit outer diameter of thread in accordance with Figure 2.2.7.2.3 of the concrete screw in the main load bearing clause according to the specification of the manufacturer

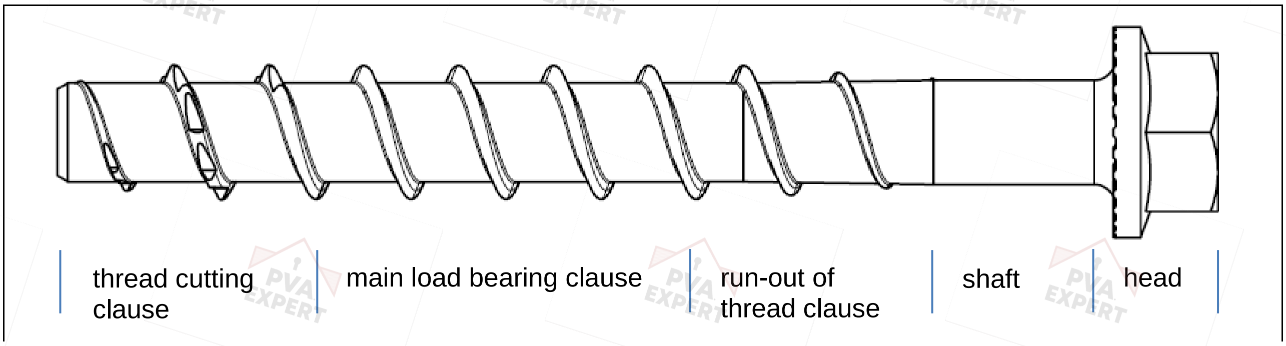


Figure 2.2.4.1.2 Possible clause s of a concrete screw

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Determine the 5 % fractile of the failure loads $N_{u,5\,\%}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Verify the coefficient of variation of failure loads. If the coefficient of variation cv_F > 20 %, determine the reduction factor for large scatter $ß_{cv}$ in accordance with A.2.2.
- Determine the reduction factor α in accordance with Equation (A.2.4.1). The following test series are used as corresponding reference test series:
    - TC for use in cracked and uncracked concrete: test series A4
    - TC for use in uncracked concrete only: test series A1
    - DC, UC and CS for use in cracked and uncracked concrete: test series A3
    - DC, UC and CS for use in uncracked concrete only: test series A1
- Determine the factor to account for the sensitivity to installation γ_{inst} in accordance with Table 2.2.4.1.1.
- For UC and CS compare the factor γ_{inst} with the result of test series "robustness to contact with reinforcement". The larger value governs.

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [N] in accordance with A.2.5.
- Where the requirement given in Equations (A.2.5.1) and (A.2.5.2) is not met in a test, meaning $N_{sl,t} < 0{,}7\ N_{Ru,t}$ and $N_{sl,t} < 0{,}8\ N_{Ru,t}$, respectively, the reduction factor α_1 shall be determined according to Equation (A.2.5.3).Use the reduction factor α_1 together with rqd. $\alpha_1 = 0{,}7$ (in cracked concrete) in Equation (2.2.2.10.2) and rqd. $\alpha_1 = 0{,}8$ (in uncracked concrete) in Equation (2.2.2.10.1).
- Determine the mean value of the failure loads $N_{u,m}$ [N] 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 [%] in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm, cv_δ shall be equal to or less than 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

The largest factor γ_{inst} of a fastener diameter shall be applied for all other embedment depths for this fastener diameter.

Table 2.2.4.1.1 Values of γ_{inst} for robustness to variation in use conditions

Factor γ_{inst}		rqd. α
$\gamma_{inst} = 1{,}0$	when	$\alpha \geq 0{,}95$
$\gamma_{inst} = 1{,}2$	when	$0{,}95 > \alpha \geq 0{,}80$
$\gamma_{inst} = 1{,}4$	when	$0{,}80 > \alpha \geq 0{,}70$

If $\alpha < 0{,}70$ the fastener is not covered by this EAD.

2.2.4.2 Robustness to contact with reinforcement (UC, CS)

Purpose of the assessment

Test series F10 shall be performed to evaluate proper installation and performance of undercut fasteners and concrete screws placed close to reinforcement and to determine the factor γ_{inst} for the sensitivity to installation.

Assessment method

The tests shall be performed in accordance with A.3.3.1.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit in accordance with Table A.3.1.4.1.

These tests shall be performed for fasteners with h_{ef} < 80 mm to be used in concrete members with a reinforcement of spacing < 150 mm. Perform tests in cracked concrete C20/25 with a crack width of Δw = 0,30 mm and a position of the reinforcement relative to the fastener as given in A.3.3.1.

For fasteners assessed for variable or multiple embedment depth, the tests shall be performed at least:

- with minimum embedment depth $h_{ef,min}$, (CS)
- with the largest embedment depth which is smaller than 80 mm, rounded down to the next multiple of 5 mm (UC and CS).

Undercut fasteners: The cutting diameter of drill bits shall be $d_0 = d_{cut,m}$ and $d_1 = d_{cut,m}$

Concrete screws: Use drill bits with a diameter $d_0 = d_{cut,max}$. The dimensions of fasteners in the given tolerance range shall be about the minimum external diameter of the thread and minimum core diameter. If the dimensions of the fastener do not comply with these limits, drill bits with larger cutting diameter shall be used to provide minimum mechanical interlock.

Perform tests in accordance with A.3.3.1.

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Determine the 5 % fractile of the failure loads $N_{u,5\,\%}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Verify the coefficient of variation of failure loads. If the coefficient of variation cv_F > 20 %, determine the reduction factor for large scatter $ß_{cv}$ in accordance with A.2.2.
- Determine the reduction factor α in accordance with Equation (A.2.4.1). Test series A3 is used as the corresponding reference test series.
- Determine the factor to account for the sensitivity to installation γ_{inst} in accordance with Table 2.2.4.2.1.
- Compare the factor γ_{inst} with the result of test series "robustness to variation in the use conditions". The larger value governs.

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [N] in accordance with A.2.5.
- Determine the mean value of the failure loads $N_{u,m}$ [N] 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 [%] in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm, cv_δ shall not exceed 40 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

The largest factor γ_{inst} of a fastener size shall be applied for all other embedment depths.

Table 2.2.4.2.1 Values of γ_{inst} for contact with reinforcement

Factor γ_{inst}		rqd. α
γ_{inst} = 1,0	when	$\alpha \geq 0{,}85$
γ_{inst} = 1,2	when	$0{,}85 > \alpha \geq 0{,}70$
γ_{inst} = 1,4	when	$0{,}70 > \alpha \geq 0{,}60$

If α < 0,60 the fastener is not covered by this EAD.

Expression of results

Factor γ_{inst} [-].

2.2.5 Minimum edge distance and spacing

Purpose of the assessment

Test series F11 shall be performed to check that splitting of the concrete does not occur during the installation of the fastener.

2.2.5.1 Test conditions for fixed and variable embedment depth

The minimum edge distance c_{min} and minimum spacing s_{min} of the fasteners shall be taken from the MPII. If c_{min} and s_{min} are not specified in the MPII, then c_{min} = 1,5 h_{ef} and s_{min} = 3 h_{ef} apply.

Edge distance c_{min} and axial spacing s_{min} shall be rounded to at least 5 mm. They shall not be smaller than 4 d_0 and 35 mm.

The assessment of the minimum edge distance c_{min} and minimum spacing s_{min} shall be performed for the following range of concrete strength classes:

(1) The tests shall be performed in uncracked concrete C20/25 for the standard assessment valid for concrete strength classes ≥ C20/25.

(2) If the manufacturer applies for minimum concrete strength class < C20/25, additional tests shall be performed in the minimum concrete strength class as applied for. The minimum edge distance c_{min} and minimum spacing s_{min} are also valid for higher concrete strength classes but lower than C20/25.

A drill bit of diameter $d_{cut,m}$ in accordance with Table A.3.1.4.1 shall be used for drilling the holes in which the fasteners are installed.

The tests shall be carried out in a slab with minimum thickness of member ($s = s_{min}$, $c = c_{min}$, $h = h_{min}$) with double fasteners with a spacing $s = s_{min}$ and an edge distance $c = c_{min}$. The double fasteners shall be placed with a distance $a > 3\ h_{ef}$ between neighbouring groups. The dimensions of the fixture shall be width = 3 d_f, length = s_{min} + 3 d_f and thickness $\cong d_f$. If the MPII do not specify otherwise, c_{min} = 1,5 cm, rounded up to half centimetres and s_{min} = 2 c_{min}. h_{min} shall comply with clause 1.2.1.

For deformation-control fasteners and displacement-controlled fasteners

Set the fastener to full expansion according to MPII. After installation the concrete surface shall be inspected and free of cracks. If cracks occur, repeat the test with increased c_{min}, s_{min} or h_{min} in steps of at least 0,5 cm.

For fasteners with absence of a specified installation torque T_{inst} or T_{max}

If no installation torque is applied according to the MPII, e.g., for undercut fasteners, concrete screws or other setting tools than torque wrenches, set the fastener with s_{min} and c_{min} and h_{min}. If cracks occur, repeat the test with increased c_{min}, s_{min} or h_{min} in steps of at least 0,5 cm.

For all other types of fasteners

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 torque cannot be increased further or if cracking of the concrete occurs. If cracks occur, repeat the test with increased c_{min}, s_{min} or h_{min} in steps of at least 0,5 cm.

The number of revolutions per load step shall be recorded for both fasteners. Furthermore, the torque at the formation of the first hairline crack at one or both fasteners and the maximum torque that can be applied to the two fasteners shall be recorded.

Specific provisions for concrete screws

Install the two concrete screws (CS1 and CS2) in accordance with the following sequence:

- Drill the holes using a drill bit diameter $d_{cut,m}$.
- Set the concrete screws CS1 and CS2 until reaching a distance of 2-3 mm from the fixture.
- Continue to set CS1 until the fixture is reached. For concrete screws allowed to be installed with an impact screwdriver, continue setting for 3 seconds using the screwdriver with the maximum power specified in the MPII. For installation with a torque wrench only, continue setting until reaching $1{,}3 \cdot T_{inst}$, with the maximum torque T_{inst} recommended by the manufacturer. Apply same procedure to CS2.

For concrete screw which shall be set with electric torque impact screw drivers according to the MPII only, set the first screw to contact on the fixture, then set the second screw to full contact and apply the maximum power output of the tool for 5 seconds. After that, apply the maximum power output of the tool for 5 seconds on the first screw without unscrewing the second screw.

2.2.5.2 Specific provisions in case of variable embedment depth

For fasteners assessed for variable embedment depth, the tests and assessment shall be performed for each diameter of the fastener separately.

For fasteners assessed for variable embedment depth, the tests to determine minimum edge distance and spacing distances shall be performed either following Method A, that is conservative, or Method B. The selection of the method shall be done based on the following criteria:

- Method A is based on a minimum of two configurations to be tested and represents a conservative approach allowing for a selection of edge and spacing values;
- Method B is based on a minimum of three configurations to be tested with fixed definitions of geometrical conditions.

These both methods apply for torque-controlled expansion fasteners (TC), undercut fasteners (UC) and concrete screws (CS) only.

Testing Method A:

For each diameter perform at least two test series (n_{min} = 5) with groups of two fasteners (double fasteners) installed with the minimum embedment depth $h_{ef,min}$

A-1) at minimum edge distance $c_t = c_{min}$ and corresponding spacing $s_t \leq 2{,}5 \cdot c_{min}$ (as specified by the manufacturer) in a test member with the minimum thickness h_{min} as applied for the fastener for $h_{ef,min}$; and

A-2) at minimum spacing $s_t = s_{min}$ and corresponding edge distance $c_t \leq 1{,}5 \cdot h_{ef}$ (as specified by the manufacturer) in a test member with the minimum thickness h_{min} as applied for the fastener for $h_{ef,min}$.

The spacing s_t in A-1) and the edge distance c_t in A-2) shall be selected such that the torque moment at the formation of the first hairline crack can be determined.

When the assessment is based on two test series only, the trendline shall fulfil the criterion of passing through the origin. This procedure is considered conservative.

If in the assessment the resulting required splitting area $A_{sp,rqd}$ is less than the smallest tested $A_{sp,t,F11}$, an additional test series shall be performed with fasteners installed with minimum embedment depth $h_{ef,min}$ at minimum edge distance $c_t = c_{min}$ and a corresponding spacing s_t such that $A_{sp,t,F11} \leq A_{sp,rqd}$ in a test member with the minimum thickness h_{min} as applied for the fastener.

With this additional test series, a joint assessment of all test series shall be performed without the criterion of the trendline passing through the origin (see Figure 2.2.5.4.1).

Note *This testing procedure described in Method A considers the aspect that some experience with this type of fastener exists, allowing for a reasonable selection of edge and spacing values. On the other hand, this procedure leads to adding additional test series based on the assessment of the test results (see above).*

Testing Method B:

Method B is a testing procedure with fixed definitions of geometrical conditions (test series B-1) to B-3)). For each diameter perform at least three test series (n_{min} = 5) with groups of two fasteners. The following values for edge distance c_t, spacing s_t, embedment depth h_{ef} and member thickness h shall be applied:

B-1) $c_t = c_{min}$, $s_t = s_{min}$, $h_{ef} = h_{ef,min}$, $h = h_{min}$; (these geometrical conditions result in $A_{sp,1}$ as determined in accordance with the assessment clause below).

B-2) $c_t = c_{min}$, $s_t = 2{,}5 \cdot c_{min}$, $h_{ef} = h_{ef,min}$, $h = h_{min}$; (resulting in $A_{sp,2}$)

B-3) $c_t = c_{min}$, $h_{ef} = h_{ef,min}$, $h = h_{min}$, s_t shall be determined such that $A_{sp,3} = 0{,}5 \cdot [A_{sp,1} + A_{sp,2}]$, where $A_{sp,1}$ and $A_{sp,2}$ are the splitting areas calculated for the test conditions given in B-1) and B-2), respectively; s_t shall be rounded up to a multiple of 5mm; $A_{sp,3}$ shall be determined based on this rounded value for s_t; for determination of A_{sp} see the assessment clause below;

In test conditions B-1) to B-3) h_{min} represents the minimum member thickness associated with the embedment depth $h_{ef,min}$.

The tests shall result in the formation of a hairline crack. If testing with the given spacing s_t in B-2) does not results in the formation of a hairline crack, a smaller value for s_t shall be selected.

The trendline (see Figure 2.2.5.4.1), used in the assessment, shall be determined based on the results of all of the three test series.

2.2.5.3 Assessment method for fixed embedment depth

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 leads to different values of (s_{min}, c_{min}) for applications in cracked or uncracked concrete.

If cracks occur while setting the fasteners (either in between the fasteners or in the direction towards the edge), repeat the test with enlarged edge distance or spacing until no cracks occur during the setting.

Provisions for all fasteners with specified installation torque T_{inst} or T_{max}, method a)

After the successful test setting enlarge the projected splitting area $A_{sp,t,F11}$ in accordance with Equation (2.2.5.3.1) or (2.2.5.3.2) with a factor of 1,3 (cracked) and 1,7 (uncracked concrete) to obtain rqd. A_{sp}:

$$A_{sp,t,F11} = (3\ c_{min,t} + s_{min,t})(1{,}5\ c_{min,t} + h_{ef}) \quad \text{when } h > (1{,}5\ c_t + h_{ef}) \qquad (2.2.5.3.1)$$

$$A_{sp,t,F11} = (3\ c_{min,t} + s_{min,t})\ h \quad \text{when } h \le (1{,}5\ c_t + h_{ef}) \qquad (2.2.5.3.2)$$

For use in cracked concrete: rqd. $A_{sp} = 1{,}3 \cdot A_{sp,t}$

For use in uncracked concrete only: rqd. $A_{sp} = 1{,}7 \cdot A_{sp,t,F11}$

Use Equations (2.2.5.3.1) and (2.2.5.3.2) to determine $c_{min} \ge c_{min,t}$ and $s_{min} \ge s_{min,t}$ such that the criteria for rqd A_{sp} are fulfilled (projected splitting area see Figure 2.2.5.3.1.

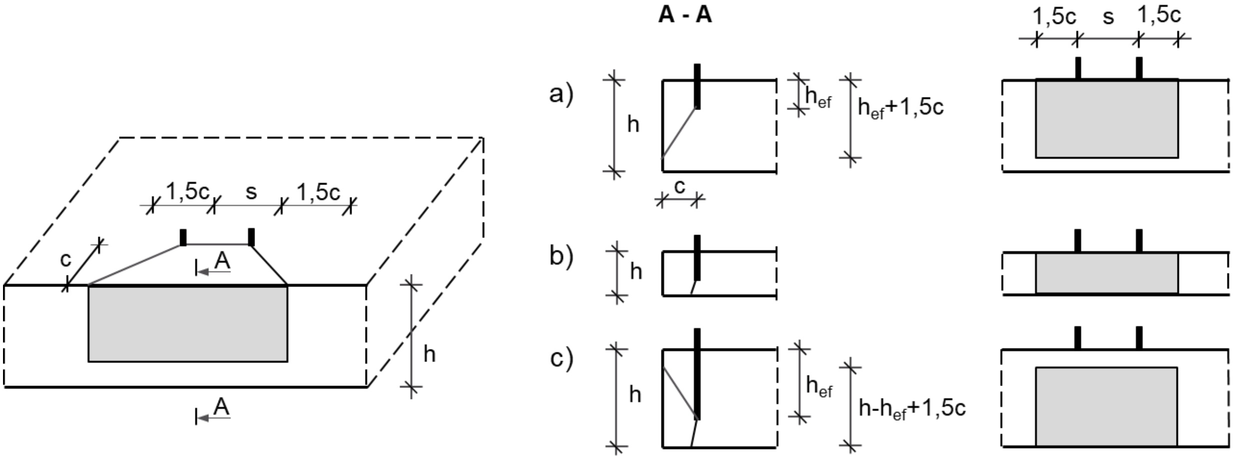


Figure 2.2.5.3.1 Projecting splitting area A_{sp}

Provisions for all fasteners with specified installation torque T_{inst} or T_{max}, method b)

The minimum spacing s_{min} and minimum edge distance c_{min} shall be evaluated from the results of installation tests with double fastener groups ($c = c_{min,t}$, $s = s_{min,t}$). The 5 % fractile of the torque, $T_{5\,\%}$, calculated in accordance with Equation (2.2.5.3.3) at which a hairline crack has been observed at one fastener of the double fastener group, shall fulfil Equation (2.2.5.3.3).

$$T_{5\,\%} \ge k_T \cdot \text{rqd. } T_{inst}\ (f_{c,t} / f_{ck})^{0,5} \quad \text{(for concrete failure)} \qquad (2.2.5.3.3)$$

The following values for k_T shall be taken:

(a) Scatter of the friction coefficients which determine the magnitude of the splitting forces at the required or recommended torque respectively is controlled during production to the values present with the fasteners used in the tests
  - k_T = 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 torque respectively is not controlled during production to the values present with the fasteners used in the tests
  - k_T = 1,5 fastenings in cracked concrete
    = 2,1 fastenings in uncracked concrete.

The choice of (a) or (b) in the assessment shall be reflected in the factory production control (FPC).
The splitting forces at the required or recommended torque respectively depend on the pre-stressing force generated during torquing and the ratio splitting force to pre-stressing force.

Note: 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.

Provisions for all fasteners with absence of specified installation torque T_{inst} or T_{max}

After installation of the fasteners, if cracking of concrete didn't occur, $c_{min,t} = c_{min}$, $s_{min,t} = s_{min}$, $h_{min,t} = h_{min}$.

2.2.5.4 Assessment method for variable embedment depth

Depending on where the hairline crack occurs, use Equations (2.2.5.4.1) to (2.2.5.4.3) to determine for each test the projected splitting area $A_{sp,t}$ (see Figure 2.2.5.3.1).

$A_{sp,t,F11} = (3 \cdot c_t + s_t)\ (1{,}5 \cdot c_t + h_{ef})$ when $h > (1{,}5 \cdot c_t + h_{ef})$ (Figure 2.2.5.3.1 a) (2.2.5.4.1)

$A_{sp,t,F11} = (3 \cdot c_t + s_t)\ h$ when $h \leq (1{,}5 \cdot c_t + h_{ef})$ (Figure 2.2.5.3.1 b) (2.2.5.4.2)

$A_{sp,t,F11} = (3 \cdot c_t + s_t)\ (h - h_{ef} + 1{,}5 \cdot c_t)$ when $h \leq (1{,}5 \cdot c_t + h_{ef})$; $h_{ef} > 1{,}5 \cdot c_t$ (Figure 2.2.5.3.1 c) (2.2.5.4.3)

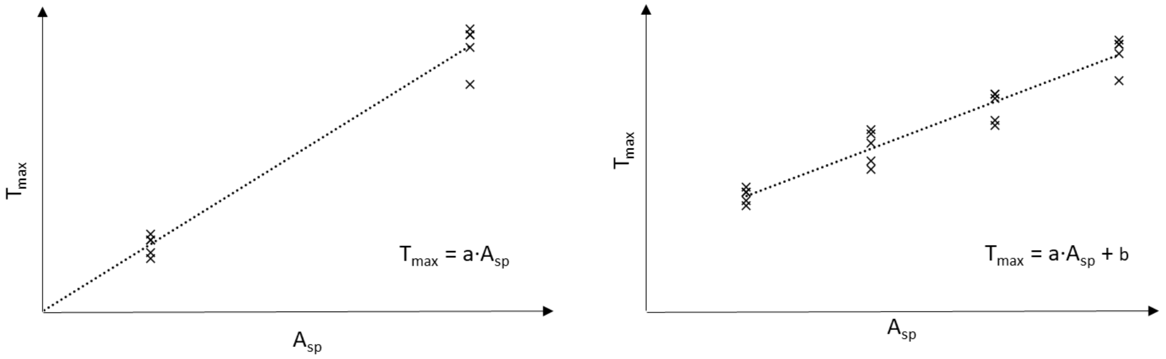
Plot the normalized torque, i.e., $T_{max} = T_{max,t} \cdot (f_{ck}/f_{c,t})^{0,5}$ as a function of A_{sp}, where $T_{max,t}$ is the torque at which the formation of the first hairline crack has occurred in the test.

If Method A with test series A-1) and A-2) has been used, determine a linear trendline that passes through the origin (see Figure 2.2.5.4.1 a)) by using the method of the least square fit in accordance with the following equation:

$$T_{max} = a \cdot A_{sp} \qquad (2.2.5.4.4)$$

If Method A with all test series (i.e., A-1), A-2) and additional test series) or alternative Method B has been used, determine a and b by a linear regression approach (see Figure 2.2.5.4.1 b)) using the method of the least square fit in accordance with the following Equation:

$$T_{max} = a \cdot A_{sp} + b \qquad (2.2.5.4.5)$$



a) linear trendline passing through the origin (Method A with two test series A-1) and A-2))

b) linear trendline based on at least three test series (Method A, Method B)

Figure 2.2.5.4.1 Normalized torque plotted as a function of $A_{sp,t,F11}$ (A_{sp})

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 leads to different values of (s_{min}, c_{min}) for applications in cracked or uncracked concrete.

Determine the 5 % fractile $T_{max,5\,\%} = a_{5\,\%} \cdot A_{sp} + b_{5\,\%}$, which shall be calculated according to statistical procedures for a confidence level of 90 %. A normal distribution and an unknown standard deviation of the population shall be assumed. For Method A with test series A-1) and A-2) the value of $b_{5\,\%} = 0$.

The following equation shall be fulfilled:

$$T_{max,5\,\%} \geq k \cdot T_{inst} \qquad (2.2.5.4.6)$$

Based on this criterion the corresponding required splitting area $A_{sp,rqd}$ shall be determined for applications in cracked concrete as well as uncracked concrete as follows:

$$A_{sp,rqd,cr(ucr)} \geq (k \cdot T_{inst} - b_{5\,\%}) / a_{5\,\%} \qquad (2.2.5.4.7)$$

where:

k = 1,3 for applications in cracked concrete if clause 2.2.5.3 a) applies
= 1,5 for applications in cracked concrete if clause 2.2.5.3 b) applies
= 1,7 for applications in uncracked concrete if, clause 2.2.5.3 a) applies
= 2,1 for applications in uncracked concrete if clause 2.2.5.3 b) applies

The resulting required splitting areas $A_{sp,rqd,cr}$ and $A_{sp,rqd,ucr}$ are valid for the tested diameter, with $c \geq c_{min,t}$ and $s \geq s_{min,t}$ and $h \geq h_{min,t}$

Other c_{min}, s_{min} and h_{min} can be determined, but the resulting splitting area shall be at minimum $A_{sp,rqd}$. Equations for these determinations are given in Equations (2.2.5.4.8) to (2.2.5.4.13) depending on the relevant conditions according to Figure 2.2.5.4.2. Use the Equations (2.2.5.4.8) to (2.2.5.4.13) to determine c_{min}, s_{min} and h_{min} such, that these equations are fulfilled.

For fasteners assessed for variable embedment depth, use Equations (2.2.5.4.8) to (2.2.5.4.10) to determine c and s (i.e., actual projected area $A_{sp,a}$) such that

$$A_{sp,rqd,cr(ucr)} \leq A_{sp,a} = (3 \cdot c + s)(1{,}5 \cdot c + h_{ef}) \quad \text{when:} \quad h > (1{,}5 \cdot c + h_{ef}) \tag{2.2.5.4.8}$$

$$A_{sp,rqd,cr(ucr)} \leq A_{sp,a} = (3 \cdot c + s)\, h \quad \text{when:} \quad h \leq (1{,}5 \cdot c + h_{ef}) \tag{2.2.5.4.9}$$

$$A_{sp,rqd,cr(ucr)} \leq A_{sp,a} = (3 \cdot c + s)(h - h_{ef} + 1{,}5 \cdot c) \quad \text{when:} \quad h \leq (1{,}5 \cdot c + h_{ef});\ h_{ef} > 1{,}5 \cdot c \tag{2.2.5.4.10}$$

distinguishing between applications where fasteners are installed in cracked concrete and applications where fasteners are installed in uncracked concrete.

If a second edge is closer than $1{,}5 \cdot c$ to a fastener ($c_2 < 1{,}5 \cdot c$), such as in a corner situation (Figure 2.2.5.4.2), the actual projected area $A_{sp,a}$ shall be calculated as given in Equations (2.2.5.4.11) to (2.2.5.4.13).

$$A_{sp,rqd,cr(ucr)} \leq A_{sp,a} = (1{,}5 \cdot c + s + c_2)\,(1{,}5 \cdot c + h_{ef}) \quad \text{when:}\ h > (1{,}5 \cdot c + h_{ef}) \tag{2.2.5.4.11}$$

$$A_{sp,rqd,cr(ucr)} \leq A_{sp,a} = (1{,}5 \cdot c + s + c_2)\, h \quad \text{when:}\ h \leq (1{,}5 \cdot c + h_{ef}) \tag{2.2.5.4.12}$$

$$A_{sp,rqd,cr(ucr)} \leq A_{sp,a} = (1{,}5 \cdot c + s + c_2)\,(h - h_{ef} + 1{,}5 \cdot c) \quad \text{when:}\ h \leq (1{,}5 \cdot c + h_{ef});\ h_{ef} > 1{,}5 \cdot c \tag{2.2.5.4.13}$$

Information regarding the determination of the actual projected area $A_{sp,a}$ for the various cases shall be provided in the European Technical Assessment (actual projected splitting area see Figure 2.2.5.4.2).

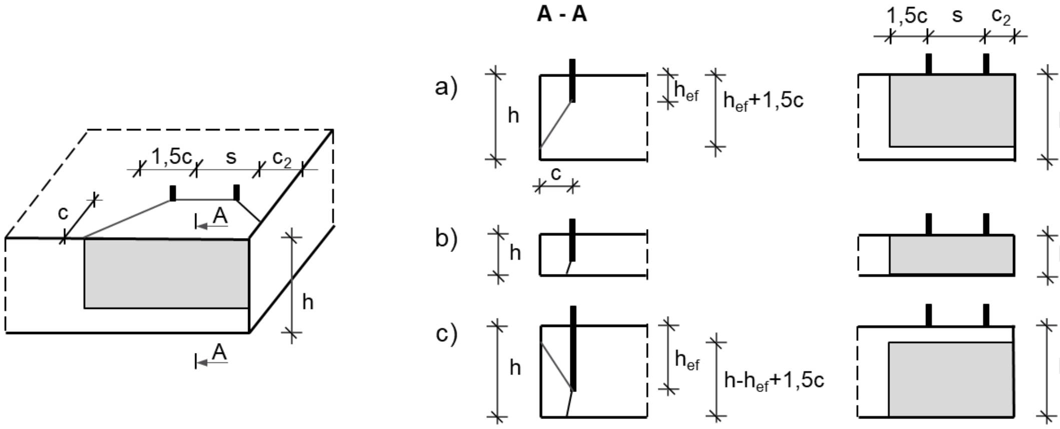


Figure 2.2.5.4.2 Actual projected splitting area $A_{sp,a}$ for corner condition ($c_2 < 1{,}5 \cdot c$)

Expression of results

c_{min}, s_{min}, h_{min} [mm].

2.2.6 Edge distance to prevent splitting under load

Purpose of the assessment

Concrete splitting failure due to loading of the fastener shall be avoided. For calculations of concrete splitting failure in accordance with EN 1992-4 [10], 7.2.1.7 the characteristic edge distance in the case of splitting under load is needed as an input. Test series F12 shall be performed to determine the characteristic edge distance in the case of splitting under load is not decisive.

Test conditions

The characteristic edge distance $c_{cr,sp}$ shall be evaluated from the results of tension tests on single fasteners at the corner ($c_1 = c_2 = c_{cr,sp}$).

The assessment of the characteristic edge distance $c_{cr,sp}$ shall be performed for the following range of concrete strength classes:

(1) The standard assessment shall be made for C20/25 to C50/60. The characteristic edge distance $c_{cr,sp}$ is also valid for concrete stronger than C50/60.

(2) Separate assessment for minimum concrete strength class in accordance with Clause A.2.7.

The characteristic edge distances for concrete strength class C20/25 shall be increased by the factor of 1,75 for concrete strength classes lower than C20/25, unless the manufacturer applies for testing a smaller edge distance. Test fasteners in uncracked concrete C20/25. Install the fastener 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 $c_{cr,sp}$ and minimum thickness of the concrete h_{min} shall be taken from the MPII. If the MPII do not specify $c_{cr,sp}$ and h_{min}, then the edge distance in the test shall be taken as $c_1 = c_2 = 1{,}5\ h_{ef}$ and h_{min} shall be taken in accordance with 1.2.1. Perform a tension test in accordance with A.3.3.2.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit in accordance with Table A.3.1.4.1. Deformation-controlled expansion fasteners (DC) shall be set with full expansion in accordance with A.3.5 a).

Assessment method for fixed embedment depth

The failure loads in the tests with fasteners at the corner shall be statistically equivalent to the results of the test series with a fastener without edge and spacing effects (Table A.1.1, line A1) and the mean value of failure loads in the tests with fasteners at the corner shall be equal or greater than $N^0_{Rk,c}$ / 0,75 for the same concrete strength ($N^0_{Rk,c}$ calculated in accordance with EN 1992-4 [10] Equation (7.2)). If these conditions are not fulfilled, the edge distance shall be increased accordingly.

Failure loads:

- Determine the mean value of failure loads $N_{u,m}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Determine $N_{Rk,sp}$ from the 5 % fractile of the failure loads $N_{u,5\,\%}$ [N], converted to the nominal strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Verify the coefficient of variation of failure loads. If the coefficient of variation $cv_F > 15$ %, determine the reduction factor for large scatter $ß_{cv}$ in accordance with Clause A.2.2.

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [N] as well as the factor α_1 in accordance with A.2.5.
- Where the requirement given in Equations (A.2.5.1) and (A.2.5.2) is not met in a test, meaning $N_{sl,t} < 0{,}7\ N_{Ru,t}$ and $N_{sl,t} < 0{,}8\ N_{Ru,t}$, respectively, the reduction factor α_1 shall be determined according to Equation (A.2.5.3).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 [%] in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm, cv_δ shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

The characteristic resistance to splitting $N^0_{Rk,sp}$ shall be determined by Equation (2.2.6.1). It is the lower result of either characteristic resistance to pull-out failure $N_{Rk,p}$ in accordance with Equation (2.2.2.10.1) or to concrete failure $N^0_{Rk,c}$ in accordance with EN 1992-4 [10], Equation (7.2).

$$N^0_{Rk,sp} = \min \{N^0_{Rk,c};\ N_{Rk,p}\} \tag{2.2.6.1}$$

Assessment method for variable embedment depth

For fasteners assessed for variable embedment depth, perform the following test series (each with $n_{min} = 4$) for each diameter with minimum and maximum embedment depth h_{ef} in members of minimum thickness h_{min} and edge distances as given in 1) to 4). The values for embedment depth h_{ef}, edge distance c_t and member thickness h_{min} in accordance with 1.2.1 are given as follows:

1) $h_{ef} = h_{ef,min}$, $c_{t,1} = k_{F12} \cdot h_{ef}$, $h = h_{min}(h_{ef,min})$;
2) $h_{ef} = h_{ef,min}$, $c_{t,2} = c_{t,1} + 0{,}5 \cdot h_{ef}$, $h = h_{min}(h_{ef,min})$;
3) $h_{ef} = h_{ef,max}$, $c_{t,3} = k_{F12} \cdot h_{ef}$, $h = h_{min}(h_{ef,max})$;
4) $h_{ef} = h_{ef,max}$, $c_{t,4} = c_{t,3} + 0{,}5 \cdot h_{ef}$, $h = h_{min}(h_{ef,max})$.

with:

k_{F12} = 1,5 for concrete cone failure (capacity) being decisive in test series A1

= 1,0 for pull-out or steel failure (capacity) being decisive in test series A1

If h_{min} is greater than $4 \cdot h_{ef}$ or no value is given for h_{min}, perform the tests with $h_{min} = 4 \cdot h_{ef}$.

If in the test series with testing conditions 1) splitting occurs during installation, increase $c_1 = c_2$ until splitting during installation is avoided.

Note *Splitting during installation may occur for testing conditions 1) for small values of* $h_{ef,min}$.

Note *Guidance for selecting the proper increase of* c_t *may be obtained from the test results of test series F11.*

If in the test series with testing conditions 1) splitting does not occur and the mean failure load meets the criterion given in Equation (2.2.6.2) in the corresponding paragraph in the assessment, tests with testing conditions 2) shall be omitted.

If for testing conditions 3) the mean failure load in the tests meets the criterion given in Equation (2.2.6.2) in the corresponding paragraph in the assessment, tests with test conditions 4) shall be omitted.

If in a test series splitting does not occur and in the assessment the test results are at a level of full capacity (basic tension test series A1), i.e., the mean failure load meets the criterion given in Equation (2.2.6.2), it is acceptable to repeat the test series with a reduced edge distance.

The mean value $N_{u,m}$ shall be compared to the result of the basic tension test series (test series A1), i.e., $N_{u,m,A1}$, taking into account possible reductions due to α_1 in both test series, and meet Formula (2.2.6.2). If the criterion is not fulfilled, the tests shall be repeated with increased edge distance.

$$N_{u,m} \cdot \min [1; \alpha_1/0,8] \geq 0,95 \cdot N_{u,m,A1} \cdot \min [1; \alpha_{1,A1}/0,8] \quad (2.2.6.2)$$

All test series shall be assessed with respect to failure loads and load displacement behaviour as given in assessment method for fixed embedment depth (see above).

Determination of required splitting area $A_{sp,rqd}$ and characteristic edge distance $c_{cr,sp}$:

Tests performed at minimum and maximum embedment depths shall be evaluated together for each diameter.

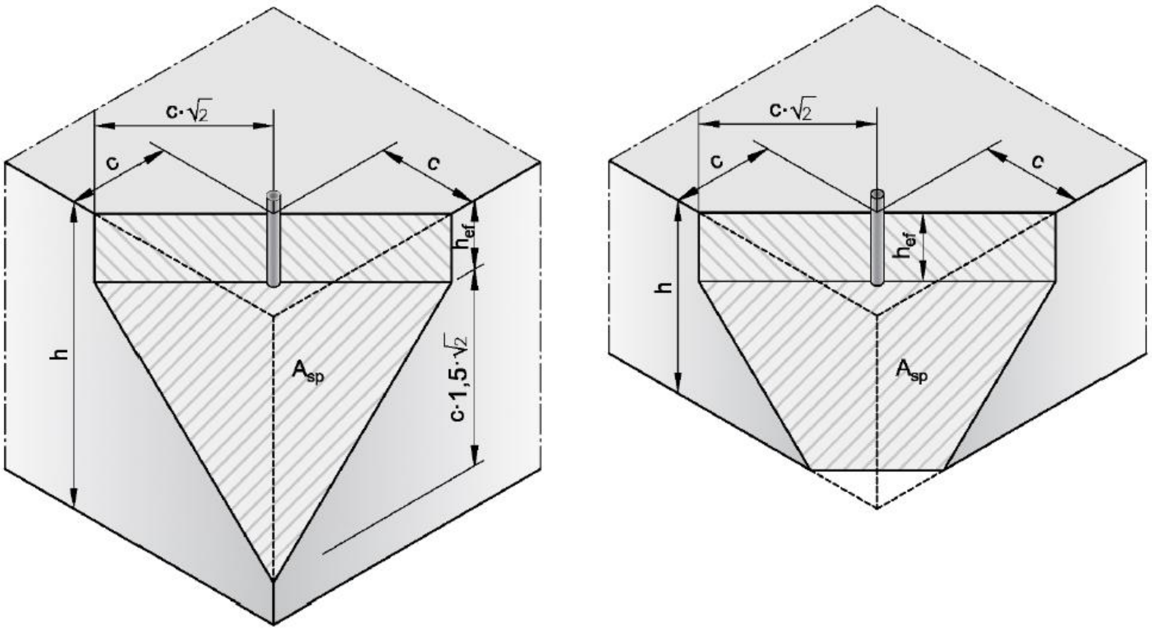
Determine for each test the minimum splitting area $A_{sp,t,F12}$ (i.e., area A_{sp} shown in Figure 2.2.6.1) in accordance with Equation (2.2.6.3).

$$A_{sp,t,F12} = \min [\, 3,41 \cdot c \cdot h_{min,cal} - 0,59 \cdot c \cdot h_{ef} - 0,8 \cdot (h_{min,cal} - h_{ef})^2 \,;\, c \cdot h_{min,cal} \cdot \sqrt{8}] \quad (2.2.6.3)$$

with:

$$h_{min,cal} = \min [\, h_{min} \,;\, h_{ef} + 1,5 \cdot c \cdot \sqrt{2}\,] \quad (2.2.6.4)$$

Note *Equation (2.2.6.3) is only valid for a member thickness of* $h \leq h_{ef} + 1,5 \cdot c \cdot \sqrt{2}$ *(see Figure 2.2.6.1 b) as the theoretical splitting area remains constant for values of h greater than that. Figure 2.2.6.1 a) shows all the geometrical conditions relevant for the calculation of the splitting area.*



a) for member thickness $h > h_{ef} + 1{,}5 \cdot c \cdot \sqrt{2}$ b) for member thickness $h \leq h_{ef} + 1{,}5 \cdot c \cdot \sqrt{2}$

Figure 2.2.6.1 Splitting area A_{sp} [mm²].

Plot the failure load N_u normalized to C20/25 concrete as a function of $A_{sp,t}$ calculated for each test configuration. Determine the parameters a and b of a linear trendline by the method of the least square fit according to the following equation:

$$N_{u,20/25} = a \cdot A_{sp,t,F12} + b \qquad (2.2.6.5)$$

Calculate the coefficient of variation c_v of $N_{u,20/25} / (a \cdot A_{sp,t,F12} + b)$.

$N_{u,5\,\%}$ of the normalized failure loads shall be calculated according to statistical procedures for a confidence level of 90 %. A normal distribution and an unknown standard deviation of the population shall be assumed.

$$N_{u,5\,\%} = a_{5\,\%} \cdot A_{sp,t,F12} + b_{5\,\%} \text{ [kN]} \qquad (2.2.6.6)$$

with:

$$a_{5\,\%} = a \cdot (1 - k_s \cdot c_v)$$

$$b_{5\,\%} = b \cdot (1 - k_s \cdot c_v)$$

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

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

Determine the required splitting area $A_{sp,rqd}$ that corresponds to the geometrical condition where the resistance of the fastener without edge and spacing effects is reached. $A_{sp,rqd}$ shall be calculated as follows:

$$A_{sp,rqd} = (N^0_{Rk,sp} - b_{5\,\%}) / a_{5\,\%} \text{ [mm}^2\text{]}. \qquad (2.2.6.7)$$

where:

$$N^0_{Rk,sp} = \min \{N^0_{Rk,c} \,;\, N_{Rk,p}\} \qquad (2.2.6.8)$$

with $N^0_{Rk,c}$ representing the characteristic resistance to cone failure for a single fastener.

The characteristic edge distance $c_{cr,sp}$ can then be calculated in accordance with the following formula:

$$\begin{aligned} c_{cr,sp} &= \min \left[(A_{sp,rqd} + 0{,}8 \cdot (h_{min} - h_{ef})^2) / (3{,}41 \cdot h_{min} - 0{,}59 \cdot h_{ef}) \,;\, A_{sp,rqd} / (h_{min} \cdot \sqrt{8}) \right] \\ &\geq 1{,}5 \cdot h_{ef} \text{, if concrete cone failure is decisive } (N^0_{Rk,sp}) \end{aligned} \qquad (2.2.6.9)$$

where:

h_{min} = minimum member thickness associated with the embedment depth h_{ef} under consideration $\leq 4 \cdot h_{ef}$

Expression of results

$c_{cr,sp}$ [mm], $N^0_{Rk,sp}$ [kN].

2.2.7 Resistance to steel failure under shear load

2.2.7.1 Single fastener (test series V1)

Purpose of the assessment

These tests are performed to determine the shear capacity of a single fastener without edge influence and thereby establishing the performance characteristics $V^0_{Rk,s}$ and $M^0_{Rk,s}$ as well as for the determination of the displacement under shear load.

Assessment method

The characteristic bending resistance of a single fastener shall be calculated in accordance with Equation (2.2.7.1.1).

$$M^0_{Rk,s} = 1{,}2 \cdot W_{el} \cdot f_{uk} \quad [\text{Nm}] \qquad (2.2.7.1.1)$$

The following default resistance can be taken without further testing for concrete strength classes C20/25 and above for steel elements with constant strength over the length of the fastener as given below. The smallest cross section of the fastener in the area of load transfer applies.

$$V^0_{Rk,s} = 0{,}5 \cdot A_s \cdot f_{uk} \quad [\text{N}] \qquad (2.2.7.1.2)$$

For concrete strength classes smaller than C20/25 and if a constant strength over the length is not given, the characteristic resistance to steel failure $V^0_{Rk,s}$ shall be determined by tests.

- The characteristic resistance to steel failure $V^0_{Rk,s}$ shall be determined by tests, if the fastener has not a constant strength over the length of the load transfer, or
- the manufacturer applies for an intended use in concrete strength classes smaller than C20/25, or
- for assessment of the displacements under shear load.

Steel failure under shear load occurs as a result of displacement of the fastener under shear. Local break-out of concrete near to the surface and pull-out of the fastener caused by the bended fastener depend on the concrete strength. Therefore, steel failure under shear shall be tested in the lowest concrete strength applied for.

The assessment of the characteristic resistance $V^0_{Rk,s}$ shall be performed for the following range of concrete strength classes:

(1) The standard assessment shall be made for C20/25 to C50/60. The characteristic resistance $V^0_{Rk,s}$ is also valid for concrete stronger than C50/60.

(2) Separate assessment for minimum concrete strength class in accordance with Clause A.2.7.

The tests shall be performed in accordance with A.3.4.1.

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 (e.g., sockets of sleeve type fasteners or screwed in elements). For all other fasteners the shear capacity shall be determined in accordance with Equations (2.2.7.1.1) and (2.2.7.1.2).

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit in accordance with Table A.3.1.4.1.

For recording of displacements, the gap of the clearance hole shall not be considered.

Table 2.2.7.1.1 Diameter of clearance hole in the fixture

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

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

Deformation-controlled expansion fasteners (DC)

Deformation-controlled expansion fasteners (DC) shall be set with full expansion in accordance with A.3.5 a).

Concrete screws (CS):

The clearance hole for through-setting of concrete screws shall be chosen such that installation is possible.

All fasteners

For fasteners assessed for variable embedment depth, the tests shall be performed at least with minimum embedment depth $h_{ef,min}$.

The thickness of the test member shall be $h \geq h_{min}$, with h_{min} as applied for the fastener for $h_{ef,min}$.

The results of the tests are valid for the tested embedment depth and deeper embedment depth. If more than one embedment depth has been tested, the characteristic resistance for an intermediated embedment depth shall be determined by linear interpolation.

The following assessment shall be made for each fastener size and for each embedment depth:

Failure loads

- Determine the mean value of failure loads $V_{u,m}$.
- Determine $V^0_{Rk,s} = V_{u,5\,\%}$ as the 5 % fractile of the failure loads $V_{u,5\,\%}$ [N], converted to the nominal steel strength, in accordance with Clause A.2.1.

Load displacement behaviour:

- Determine the mean value of the failure loads $V_{u,m}$ [N] of the test series.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Vu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_δ [%] in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm, cv_δ shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results

Characteristic resistance to steel failure under shear load $V^0_{Rk,s}$ [N], $M^0_{Rk,s}$ [Nm],

2.2.7.2 Group of fasteners

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 [10].

The following default factors k_7 can be taken without further testing:

k_7 = 1,0 for ductile steel characterized by a rupture elongation $A_5 > 8$ % or if the MPII prescribe to fill the annular gap with an effective material (e.g., with a minimum compressive strength of 30 MPa)

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

If the MPII prescribe to fill the annular gap with an effective material (e.g., with a minimum compressive strength of 30 MPa). The TAB shall check if for a group of fasteners, the annular gap can be filled with the respective filling material according to the MPII.

For fasteners assessed for variable embedment depth, the tests shall be performed with maximum embedment depth $h_{ef,max,t}$.

The thickness of the test member shall be $h \geq h_{min}$, with h_{min} as applied for the fastener for $h_{ef,max,t}$.

Concrete screws (CS, Test series V3)

Concrete screws with hexagon heads shall be set through the fixture (push-through installation), but their thread is often greater than the clearance holes given in Table 6.1 of EN 1992-4 [10]. The steel strength and elongation are not constant over length and cross section of concrete screws due to the production process. In these cases, the factor k_7 shall be determined by tests.

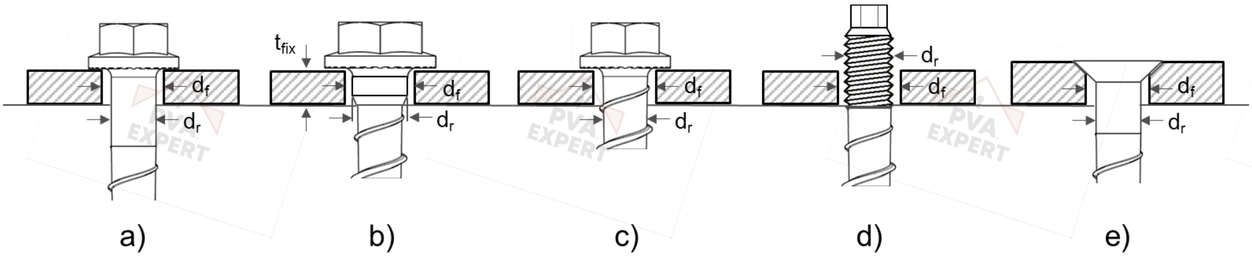
Purpose of the assessment

With regards to shear loading EN 1992-4 [10] covers fastenings with hole clearances in the direction of the shear load complying with Table 6.1 of EN 1992-4 [10]. Complying with these standard hole clearances the characteristic resistance of a group of fasteners is still influenced by the ductility of the fastener, which is accounted for by the factor k_7 as given above.

In case of hole clearances larger than the standard values, the resistance of the group in addition is affected by the resulting larger annular gap.

The test shall be performed to determine the shear resistance of a group of concrete screws, which do not comply with the standard hole clearance given in Table 6.1 of EN 1992-4 [10] and/or for which the rupture elongation A_5 cannot be determined in accordance with EN ISO 6892-1 [23]. The test accounts for the larger hole clearance as well as the ductility of the fastener.

The hole clearance is defined as the difference between the diameter of the clearance hole in the fixture d_f and the relevant diameter of the fastener d_r. For concrete screws the relevant diameter d_r is shown in Figure 2.2.7.2.1.

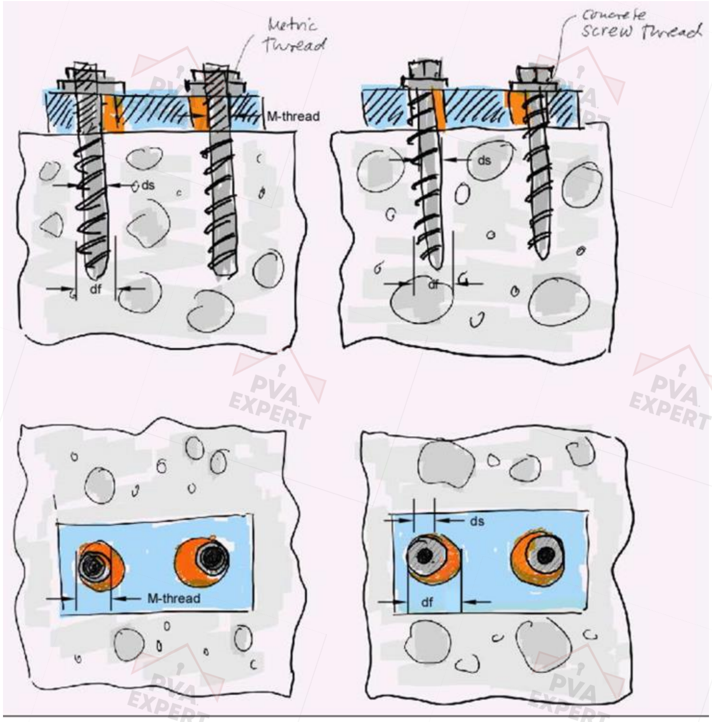


Key: d_r diameter of the relevant diameter of the fastener,
d_f diameter of the clearance hole in the fixture
t_{fix} thickness of fixture

Figure 2.2.7.2.1 Clearance hole for concrete screws

Description of the test

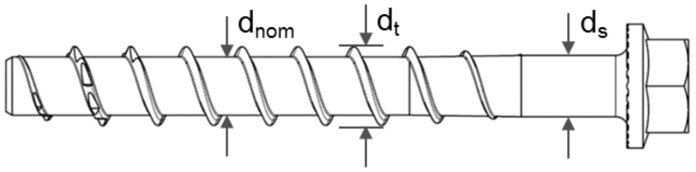
The test shall be performed for the most unfavourable condition, i.e., resulting in the largest annular gap, with a group of 2 fasteners (concrete screws) in uncracked concrete C20/25 (see Figure 2.2.7.2.2).



Key
d_s diameter of the shaft
d_f diameter of the clearance hole in the fixture
M-thread: outer diameter of the thread of a metric screw

Figure 2.2.7.2.2 Most unfavourable condition - largest annular gap for direction of loading force as given in Figure 2.2.7.2.4

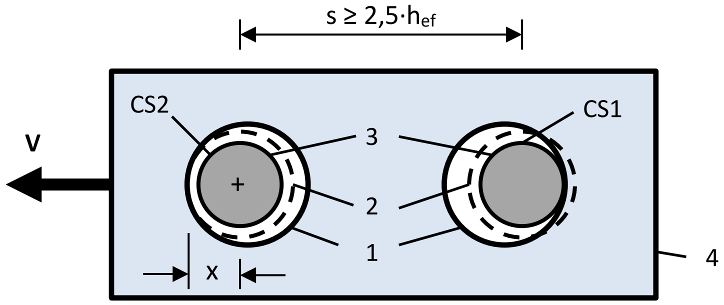
For concrete screws with a smooth shaft (see Figure 2.2.7.2.3) a test setup to determine the shear capacity of groups of concrete screws is shown in Figure 2.2.7.2.4 and the installation steps are given below. For concrete screws with other shaft/head configuration (see Figure 2.2.7.2.1 b) to e)) the installation needs to be adapted ensuring a resulting largest annular gap.



Key

d_s	diameter of shaft
d_t	outer diameter of thread

Figure 2.2.7.2.3 Concrete screw with a smooth shaft



Key

CS1	concrete screw 1
CS2	concrete screw 2
V	shear load
1	clearance hole
2	thread of concrete screw
3	shaft of concrete screw
4	fixture

Figure 2.2.7.2.4 Test condition for group of concrete screws

To get the most unfavourable test condition shown above the installation of the concrete screw shall be carried out as follows:

- drill the hole for the concrete screw CS1;
- position the fixture (which has pre-drilled clearance holes of maximum diameter d_f according to the manufacturer specifications at a spacing of s ≥ 2,5·h_{ef} to avoid pry-out during the test); if a manufacturer does not specify that diameter, the standard diameter in accordance with EN 1992-4 [10] is decisive.
- install the concrete screw CS1; before the head of the concrete screw touches the fixture, move the fixture such that the clearance hole touches the shaft of the concrete screw (see position of CS1 in Figure 2.2.7.2.4); finish installation of the concrete screw;
- drill the hole and install the second concrete screw CS2 such that, once CS2 is installed, the maximum clearance between the fixture and the shaft of the concrete screw is not greater than half of the difference between the maximum outer diameter of the thread d_t and the diameter of the shaft d_s (see Figure 2.2.7.2.3), taking into account possible tolerances; hence, the distance x given in Figure 2.2.7.2.4 shall fulfil Equation (2.2.7.2.1).

$$x \leq \frac{d_t}{2} + \frac{d_t - d_s}{2} \tag{2.2.7.2.1}$$

An alternative test setup using a fixture consisting of split plates or eccentric inserts in a single fixture is considered as equivalent to the setup described above if the criterion regarding the most unfavourable condition is fulfilled.

The concrete screws shall be installed such that the annular gap is maximized. Meaning, for concrete screws with a smooth shaft below the head, the threaded part shall be completely embedded in the concrete.

Perform a shear test in accordance with A.3.4.1 with the loading direction as shown in Figure 2.2.7.2.4. Where feasible, uplifting of the fixture is avoided during the test, which, if executed, applies for both the group test and the test with a single fastener.

The hardness of the fixture shall be greater than that of the concrete screw to avoid damage of the fixture.

Concrete screws from the same batch and concrete members from the same batch shall be used for the test series.

The group of two concrete screws is loaded to failure. The load on the group of fasteners shall be measured and the failure load V_u shall be determined.

Determine the mean value of the failure loads $V_{u,m}$ [N] and the corresponding coefficient of variation cv [%]. If the concrete screws used for the test series according Table A.1.1, line V1 and this test series are not taken from the same batch, normalization of the failure loads in accordance with A.2.1, Equation (A.2.1.7) shall be applied. The performance of a group of concrete screws shall be determined accounting for the ductility of the fastener.

Note: For fasteners complying with the criteria for hole clearance in Table 6.1 of EN 1992-4 [10] the characteristic resistance in case of steel failure of a group of fasteners loaded in shear shall be determined based on two values of k_7 as given above. For reasons of consistency the same distinction is made for the assessment of the test results.

Compare the mean value of the failure loads $V_{u,m}$ (group resistance) to twice the mean failure load of a single concrete screw and determine the corresponding reduction factor.

$$\alpha_{ag} = \frac{V_{u,m}}{2 \cdot V_{u,m,single}} \qquad (2.2.7.2.2)$$

Where

$V_{u,m}$ = mean failure load of the current test series with a group of two fasteners

$V_{u,m,single}$ = mean failure load of the test series in accordance with Table A.1.1, line V1 with a single fastener

If the concrete screws in the single fastener test and the group test are not from the same batch and the strength of concrete screws used in the group test is greater than that of the single fastener test, normalize failure loads down to the strength of the single fastener in accordance with A.2.1, Equation (A.2.1.7).

The coefficient of variation of the failure load $cv(V_u)$ shall not be greater than 20 % for the current test series as well as for the test series in accordance with Table A.1.1, line V1. If the coefficient of variation is in the range 10 % < $cv(V_u) \leq 20$ %, the factor β_{df} shall be determined in accordance with Equation (2.2.7.2.3).

$$\beta_{df} = \frac{1}{1+(cv(V_u)-10)\cdot 0{,}03} \leq 1{,}0 \qquad (2.2.7.2.3)$$

The factor k_7 accounting for the group behaviour of concrete screws is calculated as follows:

$k_7 = 1{,}0 \cdot \beta_{df}$ for $\alpha_{ag} \geq 0{,}95$ (2.2.7.2.4)

$k_7 = 0{,}8 \cdot \beta_{df}$ for $0{,}8 \leq \alpha_{ag} < 0{,}95$ (2.2.7.2.5)

$k_7 = \alpha_{ag} \cdot \beta_{df}$ for $0{,}7 \leq \alpha_{ag} < 0{,}8$ (2.2.7.2.6)

The factor k_7 determined based on this test series accounts for clearance holes greater than the values given in the design provisions such as EN 1992-4 [10], Table 6.1, that is associated with concrete screws. The design of a group of fasteners under shear loading shall therefore be carried out in the same way as given in EN 1992-4 [10]. This shall be indicated in the corresponding ETA.

Expression of results

Factor k_7 [-].

"The maximum diameter of the clearance hole d_f does not meet the values given in EN 1992-4 [10], Table 6.1. However, the group resistance under shear loading has been verified in the assessment through testing and accounted for in the factor k_7."

2.2.8 Resistance to pry-out failure

The default factors k_8 shall be applied in accordance with Table 2.2.8.1 unless the manufacturer requests for determination of more efficient factors k_8 by tests.

Purpose of the assessment

The test series shall be performed to determine the k_8 factor for design in accordance with EN 1992-4 [10] for pry-out failure.

Table 2.2.8.1 Default values for k_8

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

Other factors k_8 shall be determined by tests.

The tests shall be performed in accordance with A.3.4.2.

The test series shall be performed with a group of 4 fasteners in uncracked concrete C20/25 in accordance with A.3.4.2. The spacing is selected as $s = s_{cr,N}$ and the edge distance $c \geq c_{cr,N}$. If steel failure occurs, the spacing shall be reduced.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit in accordance with Table A.3.1.4.1. Deformation-controlled expansion fasteners (DC) shall be set with full expansion in accordance with A.3.5 a). All other fasteners shall be set according to the MPII.

The pry-out performance shall be derived by tests in accordance with Table A.1.1 line V2. The 5 % fractile of failure loads in the test series $V_{u,5\,\%,t}$ are compared to the characteristic resistance of the fastener group to tension load in uncracked concrete $N_{Rk,ucr}$ in accordance with Equations (2.2.8.1) and (2.2.8.2).

$$k_8 = \frac{V_{u,5\%,t}}{N_{Rk,ucr}} \tag{2.2.8.1}$$

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

where:

$V_{u,5\%,t}$ = 5 % fractile of failure loads in test series V2 according to clause A.2.3
k_{ucr} = factor $k_{ucr,N}$ according to clause 2.2.3
h_{ef} = effective embedment depth according to clause 2.2.3
s = spacing of fasteners in the tests, see Figure A.3.4.2
$f_{c,t}$ = mean compressive strength of concrete in test series

Note: Exponent 1,5 results from equation (7.2) in EN 1992-4 [10]

For fasteners assessed for variable embedment depth, the tests shall be performed at least with minimum embedment depth $h_{ef,min}$.

Load displacement behaviour:

- Determine the mean value of the failure loads $V_{u,m}$ [N] of the test series.
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Vu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv_{δ} [%] in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm, cv_{δ} shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results

Factor k_8 [-].

2.2.9 Characteristic resistance for simplified methods

Purpose of the assessment

The assessment shall be done to determine input values for simplified design methods in accordance with EN 1992-4 [10], Annex G.

Assessment method

The assessment shall be performed for the following range of concrete strength classes:

(1) The standard assessment shall be made for C20/25 to C50/60. The performance is also valid for concrete stronger than C50/60.

(2) Separate assessment for minimum concrete strength class in accordance with Table A.1.1 and Clause A.2.7.

2.2.9.1 Method B

The decisive failure load F^0_{Rk} [N] shall be determined for all load directions and all failure modes:

Pull-out capacity $N^0_p = N_{Rk,p} / x$ with $x = (1{,}5\ \gamma_{inst})$ (2.2.9.1.1)

Concrete cone capacity $N^0_c = N^0_{Rk,c} / x$ with $x = (1{,}5\ \gamma_{inst})$ (2.2.9.1.2)

Steel capacity tension $N^0_S = N_{Rk,s} / x$ with $x = \max(1{,}4;\ 1{,}2\ f_{uk}/f_{yk})$ (2.2.9.1.3)

Steel capacity shear

For $f_{uk} \le 800$ N/mm² and $f_{yk}/f_{uk} < 0{,}8$

$V^0_S = V^0_{Rk,s} / x$ with $x = \max(1{,}25;\ f_{uk}/f_{yk})$ (2.2.9.1.4)

For $f_{uk} > 800$ N/mm² or $f_{yk}/f_{uk} > 0{,}8$

$V^0_S = V^0_{Rk,s} / x$ With $x = V^0_{Rk,s} / 1{,}50$ (2.2.9.1.5)

$F^0 = \min(N^0_p, N^0_c, N^0_S, V^0_S)$ (2.2.9.1.6)

$F^0_{Rk} = x \cdot F^0$ with x= the factor x which delivers the minimum failure load F^0 (2.2.9.1.7)

$c_{cr} = c_{cr,N}$ (2.2.9.1.8)

$s_{cr} = s_{cr,N}$ (2.2.9.1.9)

where:

$N_{Rk,p}$ = according to clause 2.2.2
$N^0_{Rk,c}$ = according to EN 1992-4 [10], equation (7.2) with $k_{cr,N}$ [-] and h_{ef} according to clause 2.2.3
$N_{Rk,s}$ = according to clause 2.2.1.1
$V^0_{Rk,s}$ = according to clause 2.2.7
γ_{inst} = according to clause 2.2.4
$c_{cr,N}$ = according to clause 2.2.3
$s_{cr,N}$ = $2\ c_{cr,N}$

For fasteners assessed for variable embedment depth, the parameter F^0_{Rk} is determined for the minimum embedment depth $h_{ef,min}$ and conservatively applied to the full range of variable embedment depths.

Expression of results

F^0_{Rk} [N], $M^0_{Rk,s}$ [Nm], ψ_c [-], c_{cr}, s_{cr}, decisive failure mode
s_{min}, c_{min}, h_{min} [mm] as determined in 2.2.5

2.2.9.2 Method C

The decisive load bearing capacity F_{Rk} [N] shall be determined for all load directions and all failure modes:

Pull-out capacity $N^0_p = N_{Rk,p} / x$ with $x = (1{,}5\ \gamma_{inst})$ (2.2.9.2.1)

Concrete cone capacity $N^0_c = N^0_{Rk,c} / x$ with $x = (1{,}5\ \gamma_{inst})$ (2.2.9.2.2)

Steel capacity tension $N^0_S = N_{Rk,s} / x$ with $x = \max(1{,}4;1{,}2\ f_{uk}/f_{yk})$ (2.2.9.2.3)

Steel capacity shear

For $f_{uk} \le 800$ N/mm² and $f_{yk}/f_{uk} < 0{,}8$

$V^0_S = V^0_{Rk,s} / x$ with $x = \max(1{,}25;f_{uk}/f_{yk})$ (2.2.9.2.4)

For $f_{uk} > 800$ N/mm² or $f_{yk}/f_{uk} > 0{,}8$

$V^0_S = V^0_{Rk,s} / x$ With $x = V^0_{Rk,s} / 1{,}50$ (2.2.9.2.5)

$F^0 = \min(N^0_p, N^0_c, N^0_S, V^0_S)$ (2.2.9.2.6)

$F_{Rk} = x \cdot F^0$ with x = the factor x which delivers the decisive failure load F^0 (2.2.9.2.7)

$c_{cr} = c_{cr,N}$ (2.2.9.2.8)

$s_{cr} = s_{cr,N}$ (2.2.9.2.9)

where:

$N_{Rk,p}$ = according to clause 2.2.2
$N^0_{Rk,c}$ = according to EN 1992-4 [10], equation (7.2) with $k_{cr,N}$ [-] and h_{ef} according to clause 2.2.3
$N_{Rk,s}$ = according to clause 2.2.1.1
$V^0_{Rk,s}$ = according to clause 2.2.7
γ_{inst} = according to clause 2.2.4
$c_{cr,N}$ = according to clause 2.2.3
$s_{cr,N}$ = $2\ c_{cr,N}$

For fasteners assessed for variable embedment depth, the parameter F_{Rk} is determined for the minimum embedment depth $h_{ef,min}$ and conservatively applied to the full range of variable embedment depths.

Expression of results

F_{Rk} [N], $M^0_{Rk,s}$, [Nm], c_{cr}, s_{cr}, decisive failure mode

h_{min} [mm] as determined in 2.2.5

2.2.10 Displacements

The displacements under short-term and long-term tension and for shear loading shall be given in the ETA for a load F which corresponds approximately to the value in accordance with Equation (2.2.10.1)

$$F=\frac{F_{Rk}}{2{,}1\cdot\gamma_{inst}} \tag{2.2.10.1}$$

The displacements under short-term tension $\delta_{N0,A1}$ shall be evaluated from the tests on single fasteners without edge or spacing effects in accordance with Table A.1.1 line A1 for the minimum concrete strength class and uncracked concrete..

The displacements under short-term tension $\delta_{N0,A2}$ shall be evaluated from the tests on single fasteners without edge or spacing effects in accordance with Table A.1.1 line A2for the maximum concrete strength class and uncracked concrete.

The displacements under short-term tension $\delta_{N0,A3}$ shall be evaluated from the tests on single fasteners without edge or spacing effects in accordance with Table A.1.1 line A3 for the minimum concrete strength class and cracked concrete.

The displacements under short-term tension $\delta_{N0,A4}$ shall be evaluated from the tests on single fasteners without edge or spacing effects in accordance with Table A.1.1 line A4 for the maximum concrete strength class and cracked concrete.

The displacements under shear loading δ_{VO} shall be evaluated from the tests on single fasteners without edge or spacing effects in accordance with Table A.1.1 line V1.

The value derived shall correspond to the maximum value obtained in the test series for the given load level.

The displacements under short-term tension δ_{NO} and under short-term shear δ_{VO} depend on the concrete strength class and state of the concrete (uncracked, cracked). However, in general 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.

For fasteners assessed for use in uncracked and cracked concrete the long-term displacements under tension loading, $\delta_{N,50yeas}$ or $\delta_{N,100yeas}$, shall be calculated from the results of crack movement tests (see Table A.1.1 line F3) in accordance with Equation (2.2.10.2)

$$\delta_{N,50years\infty}=\frac{\delta_{m1,50years}}{1{,}5}$$
$$(\delta_{N,100years\infty}=\frac{\delta_{m1,100years}}{1{,}5}) \tag{2.2.10.2}$$

where:

$\delta_{m1,50years}$ = $\delta_{1000,mean}$ according to clause 2.2.2.4

= mean displacement of all tests after 1000 crack cycles

$\delta_{m1,100years}$ = $\delta_{2000,mean}$ according to clause C.2

= mean displacement of all tests after 2000 crack cycles

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 repeated load (see Table A.1.1 line F4) in accordance with Equation (2.2.10.3)

$$\delta_{N,50years}=\frac{\delta_{m2,50years}}{2{,}0}$$
$$(\delta_{N,100years}=\frac{\delta_{m2,100years}}{2{,}0}) \tag{2.2.10.3}$$

where:

$\delta_{m2,50years}$ = mean displacement of all tests after 100.000 load cycles according to clause 2.2.2.4
$\delta_{m2,100years}$ = mean displacement of all tests after 200.000 load cycles according to clause C.3

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

The load at which first slip occurs cannot, except in special cases, be ensured in the long-term because of the influence of shrinkage and creep of the concrete, crack formation, etc.

Expression of results

δ_{N0}, $\delta_{N,50\ years}$, $\delta_{N,100\ years}$, δ_{V0}, $\delta_{V\infty}$ [mm]

Under shear loading, the displacements might increase due to a gap between fixture and fastener. It shall be stated clearly in the ETA if this gap is taken into account in the assessment.

2.2.11 Stiffness

Purpose of the assessment

Stiffness characteristics are needed for design of a fixing point, consisting of a fixture with a base plate and a group of fasteners. The assessment of stiffnesses in the elastic range under tension loading is given in clause 2.2.11.1 and the assessment of stiffness characteristics for tension loading for non-linear spring models are given in clause 2.2.11.2.

Short-term assessment includes use of the fastening for temporary structures where the intended use of the fasteners covers their service conditions for a relatively short period of time, or permanent structures where the fasteners are not subjected to temperature fluctuations, shocks, load variations of the attached structure, changes in the state of stress of the structure.

Long-term assessment includes use of the fastening in places where the intended use of the fasteners covers permanent structures where the fasteners are subjected to temperature fluctuations, shocks, load variations of the of the attached structure changes in the state of stress of the structure.

2.2.11.1 Stiffness in the elastic range under tension loading

Purpose of assessment

Determination of the stiffness in the elastic range under tension loading for uncracked and cracked concrete $k_{Nm,ucr}$, $k_{Nm,cr}$ in [N/mm].

Assessment method

Determine the mean value of stiffness $k_{A,test}$ using the results of displacements at 10 % and 50 % of the mean failure load for each test in uncracked concrete for series A1 and A2 in accordance with Equation (2.2.11.1.1) and Figure 2.2.11.1.1. Then, determine the stiffness in the elastic range under tension loading for uncracked concrete $k_{A,ucr}$ in accordance with Equation (2.2.11.1.2).

$$k_{A,test} = \frac{0{,}4N_{u,test}}{\delta(0{,}5N_{u,test}) - \delta(0{,}1N_{u,test})}\ [\text{N/mm}] \qquad (2.2.11.1.1)$$

$$k_{A,ucr} = \left[\left(\sum_{i=1}^{n(A1)} k^{i}_{A,test}\right) + \left(\sum_{i=1}^{n(A2)} k^{i}_{A,test}\right)\right] / n(A1+A2) \qquad (2.2.11.1.2)$$

Determine the mean value of stiffness $k_{N,test}$ using the results of displacements at 10 % and 50 % of the mean failure load for each test in uncracked concrete for series A3 and A4 in accordance with Equation (2.2.11.1.3). Then, determine the stiffness in the elastic range under tension loading for uncracked concrete $k_{A,ucr}$ in accordance with Equation (2.2.11.1.4).

$$k_{N,test} = \frac{0{,}4N_{u,test}}{\delta(0{,}5N_{u,test}) - \delta(0{,}1N_{u,test})}\ [\text{N/mm}] \qquad (2.2.11.1.3)$$

$$k_{A,cr} = \left[\left(\sum_{i=1}^{n(A3)} k^{i}_{A,test}\right) + \left(\sum_{i=1}^{n(A4)} k^{i}_{A,test}\right)\right] / n(A3+A4) \qquad (2.2.11.1.4)$$

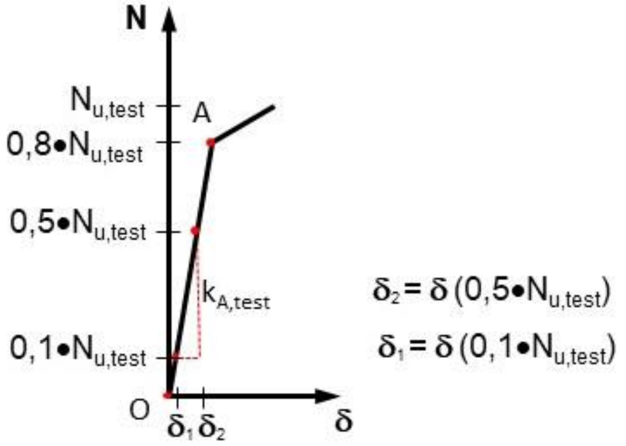


Figure 2.2.11.1.1 Determination of $k_{A,test}$

Expression of results:

Stiffness under short-term loading and long-term loading in uncracked and cracked concrete $k_{A,ucr}$, $k_{A,cr}$ in [N/mm] separately for the assessed minimum and maximum concrete strength classes.

2.2.11.2 Stiffness characteristics for tension loading for non-linear spring models

Purpose of assessment

Determination of the stiffness for uncracked and cracked concrete $k_{A,ucr}$, $k_{B,ucr}$, $k_{C,ucr}$, $k_{D,ucr}$, $k_{A,cr}$, $k_{B,cr}$, $k_{C,cr}$ and $k_{D,cr}$ in [N/mm].

Assessment method

The load-displacement curves obtained from tension tests on single fasteners shall be idealized to describe the load-displacement behaviour of a single fastener with a limited number of parameters. The aim of the idealization is to obtain the secant stiffness values $k_{A,ucr}$ – $k_{D,ucr}$ or $k_{A,cr}$ – $k_{D,cr}$ and the values α_{ucr} and α_{cr} to characterize the salient points A - D in uncracked and cracked concrete, respectively. The idea of the idealization is shown in Figure 2.2.11.2.1, whereas the method to derive the essential characteristics are described in Figure 2.2.11.2.2 and Table 2.2.11.2.1.

The stiffness characteristics shall be derived from unconfined reference tests in uncracked and cracked concrete in accordance with Table A.1.1, lines A1 to A4.

Reference tests shall be performed at an embedment depth for which clear concrete cone breakout occurs. If clear concrete cone failure does not occur at the tested embedment depth, the reference tests shall be repeated with reduced embedment depth.

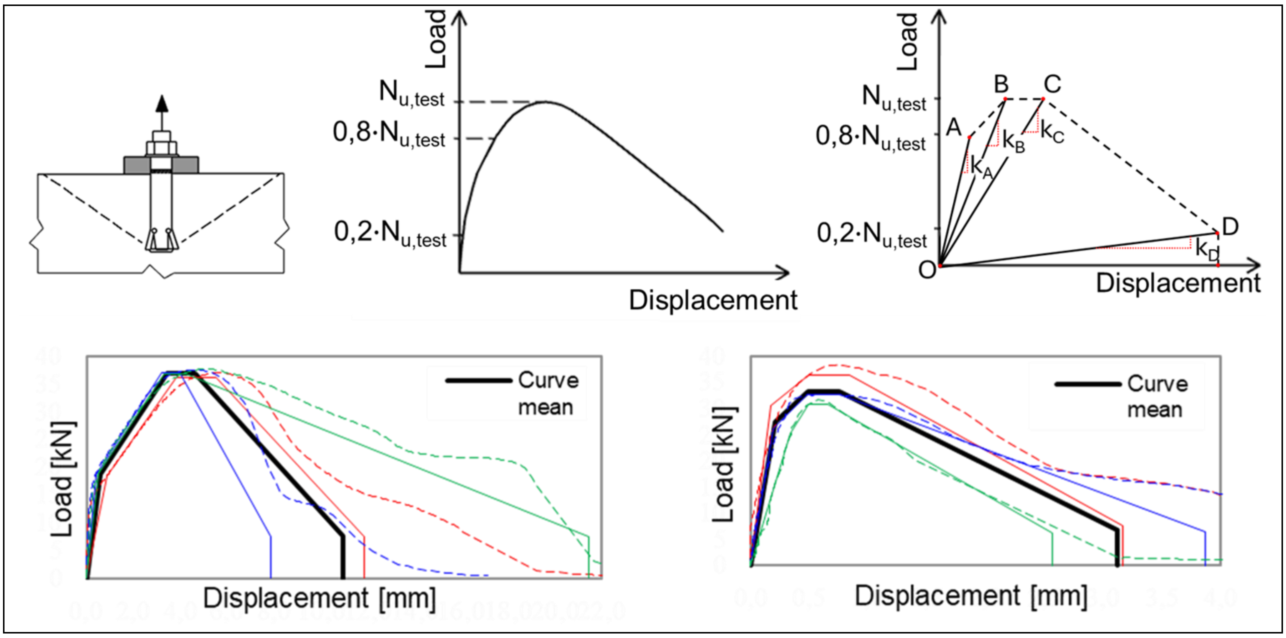


Figure 2.2.11.2.1 Representative load-displacement behaviour in case of concrete cone failure and recommended idealized load-displacement relationship to be used as non-linear spring properties

Typical idealization of experimentally obtained load-displacement curves in case of concrete cone failure are shown in Figure 2.2.11.2.2. The points 0 - E in the penta-linear format are defined by data pairs of load and displacement in accordance with Table 2.2.11.2.1.

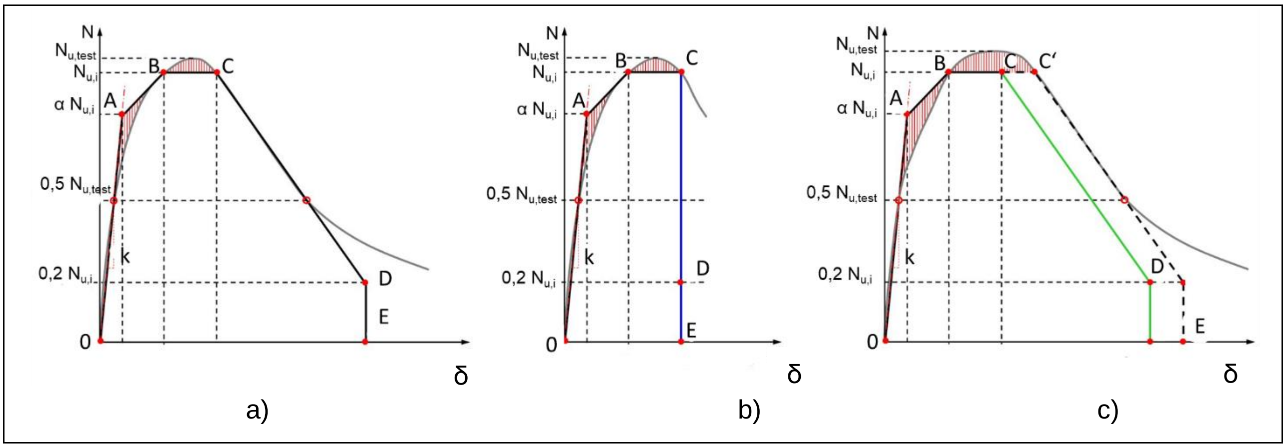


Figure 2.2.11.2.2 Principle of idealization of load-displacement curves depending on load displacement behaviour

Table 2.2.11.2.1 Salient points of the idealized spring characteristics in uncracked and cracked concrete

Point	Load	Displacement
0	0 0	$\delta_{0,ucr} = 0$ $\delta_{0,cr} = 0$
A	$\alpha_{ucr} \cdot N_{u,i,ucr}$ $\alpha_{cr} \cdot N_{u,i,cr}$	$\delta_{A,ucr} = \alpha_{ucr} \cdot N_{u,i,ucr} / k_{A,ucr}$ $\delta_{A,cr} = \alpha_{cr} \cdot N_{u,i,cr} / k_{A,cr}$
B	$N_{u,i,ucr}$ $N_{u,i,cr}$	$\delta_{B,ucr} = N_{u,i,ucr} / k_{B,ucr}$ $\delta_{B,cr} = N_{u,i,cr} / k_{B,cr}$
C	$N_{u,i,ucr}$ $N_{u,i,cr}$	$\delta_{C,ucr} = N_{u,i,ucr} / k_{C,ucr}$ $\delta_{C,cr} = N_{u,i,cr} / k_{C,cr}$
D	$0{,}2 \cdot N_{u,i,ucr}$ $0{,}2 \cdot N_{u,i,ucr}$	$\delta_{D,ucr} = 0{,}2 \cdot N_{u,i,ucr} / k_{D,ucr}$ $\delta_{D,cr} = 0{,}2 \cdot N_{u,i,cr} / k_{D,cr}$
E	0 0	$\delta_{E,ucr} = \delta_{E,ucr}$ $\delta_{E,cr} = \delta_{E,cr}$

First, an initial stiffness line shall be ascertained by joining the point corresponding to 10 % and 50 % of peak load on the ascending branch of the curve with the origin. This stiffness is applicable until point A (Figure 2.2.11.2.2). The segment AB and BC shall be adjusted such that algebraically the areas enclosed by the real curve and its idealization are equal. This means that the area gained due to the idealization (hatched area in Figure 2.2.11.2.2) is equal to the area lost due to idealization (vertically hatched area in Figure 2.2.11.2.2).

The following procedure shall be used for the idealization of each load-displacement curve:

1. The initial stiffness line shall be ascertained by joining the point corresponding to 10 % and 50 % of peak load ($N_{u,test}$) on the ascending branch of the curve. $k_{A,test}$ is the secant stiffness (see Figure 2.2.11.1.1).

$$k_{A,test} = \frac{0{,}4 N_{u,test}}{\delta(0{,}5 N_{u,test}) - \delta(0{,}1 N_{u,test})} \qquad (2.2.11.2.1)$$

   (i) The initial stiffness, k_A, is valid until point A for penta-linear format (Figure 2.2.11.2.2).

   The location of point B depends on fastener type and test result, and can be expressed by the values α_{ucr} and α_{cr}. The values α_{ucr} and α_{cr} shall be kept constant within one test series. If the following evaluation results in different α values for the single tests within one test series, the mean value of them shall be rounded up to one decimal place and taken as α for the test series.

$$\alpha = 0{,}8 \text{ if } \frac{\delta(0{,}8Nu,test)}{\delta(0{,}5Nu,test)} \leq 2{,}2$$

$$\alpha = 0{,}7 \text{ if } \frac{\delta(0{,}8Nu,test)}{\delta(0{,}5Nu,test)} > 2{,}2 \text{ and } \frac{\delta(0{,}7Nu,test)}{\delta(0{,}5Nu,test)} \leq 1{,}8$$

$$\alpha = 0{,}6 \text{ if } \frac{\delta(0{,}8Nu,test)}{\delta(0{,}5Nu,test)} > 2{,}2 \text{ and } \frac{\delta(0{,}7Nu,test)}{\delta(0{,}5Nu,test)} > 1{,}8 \text{ and } \frac{\delta(0{,}6Nu,test)}{\delta(0{,}5Nu,test)} \leq 1{,}4$$

$$\alpha = 0{,}5 \text{ if } \frac{\delta(0{,}6Nu,test)}{\delta(0{,}5Nu,test)} > 1{,}4 \text{ and } \frac{\delta(0{,}7Nu,test)}{\delta(0{,}5Nu,test)} > 1{,}8 \text{ and } \frac{\delta(0{,}8Nu,test)}{\delta(0{,}5Nu,test)} > 2{,}2$$

2. The horizontal segment BC shall be ascertained by making the areas enclosed by the real curve and its idealization equal algebraically. The line segments on the idealized load-displacement curve shall be located using an iterative graphical procedure that approximately balances the area above and below the curve.

   (i) Point B and point C in Figure 2.2.11.2.2 a) and b) point B and point C' in Figure 2.2.11.2.2 c) shall be situated on the load displacement curve. The load value of point-B and point C in Figure 2.2.11.2.2 a) and b) and point B and point C’ in Figure 2.2.11.2.2 c) (equal load, horizontal line) shall be used to achieve equal areas.

3. Point C governs the length of the plateau generated by the idealization. To avoid having extremely large plateaus, the distance between points B and C is restricted, see Figure 2.2.11.2.2 c). Therefore, the following restrictions apply to δ_C:

   (i) $\delta_C = \min \{(2\ \delta_A + \delta_B); (2{,}5\ \delta_B); (\delta_{C'})\}$

4. The descending branch of the idealized curve defined by the line segment CD shall simulate the descending branch of the actual curve.

5. The following restrictions apply to δ_D:

   (i) If sufficient number of points are measured for the descending branch (minimum 10 measured points between $N_{u,test}$ and $0{,}5N_{u,test}$), then $\delta_D \leq 2{,}5\delta_C$.

   (ii) Otherwise, or in absence of more detailed evaluation, conservatively, δ_D shall be taken equal to δ_C. $\delta_D = \delta_C$ (see Figure 2.2.11.2.2 b), blue line).

The final spring characteristics (stiffness values $k_{A,ucr} – k_{D,ucr}$, $k_{A,cr} – k_{D,cr}$ and the ratio α) given in the ETA shall be derived as average values of the single stiffness values derived from each test in low and high strength uncracked concrete (test series A1 and A2) and in low and high strength cracked concrete (test series A3 and A4).

$$k_{A,ucr} = \left[\left(\sum_{i=1}^{n(A1)} k^i_{A,test}\right) + \left(\sum_{i=1}^{n(A2)} k^i_{A,test}\right)\right] / n(A1+A2) \tag{2.2.11.2.2}$$

$$k_{B,ucr} = \left[\left(\sum_{i=1}^{n(A1)} k^i_{B,test}\right) + \left(\sum_{i=1}^{n(A2)} k^i_{B,test}\right)\right] / n(A1+A2) \tag{2.2.11.2.3}$$

$$k_{C,ucr} = \left[\left(\sum_{i=1}^{n(A1)} k^i_{C,test}\right) + \left(\sum_{i=1}^{n(A2)} k^i_{C,test}\right)\right] / n(A1+A2) \tag{2.2.11.2.4}$$

$$k_{D,ucr} = \left[\left(\sum_{i=1}^{n(A1)} k^i_{D,test}\right) + \left(\sum_{i=1}^{n(A2)} k^i_{D,test}\right)\right] / n(A1+A2) \tag{2.2.11.2.5}$$

$$\alpha_{ucr} = \left[\left(\sum_{i=1}^{n(A1)} \alpha^i\right) + \left(\sum_{i=1}^{n(A2)} \alpha^i\right)\right] / n(A1+A2) \tag{2.2.11.2.6}$$

$$k_{A,cr} = \left[\left(\sum_{i=1}^{n(A3)} k^i_{A,test}\right) + \left(\sum_{i=1}^{n(A4)} k^i_{A,test}\right)\right] / n(A3+A4) \tag{2.2.11.2.7}$$

$$k_{B,cr} = \left[\left(\sum_{i=1}^{n(A3)} k^i_{B,test}\right) + \left(\sum_{i=1}^{n(A4)} k^i_{B,test}\right)\right] / n(A3+A4) \tag{2.2.11.2.8}$$

$$k_{C,cr} = \left[\left(\sum_{i=1}^{n(A3)} k^i_{C,test}\right) + \left(\sum_{i=1}^{n(A4)} k^i_{C,test}\right)\right] / n(A3+A4) \tag{2.2.11.2.9}$$

$$k_{D,cr} = \left[\left(\sum_{i=1}^{n(A3)} k^i_{D,test}\right) + \left(\sum_{i=1}^{n(A4)} k^i_{D,test}\right)\right] / n(A3+A4) \tag{2.2.11.2.10}$$

$$\alpha_{cr} = \left[\left(\sum_{i=1}^{n(A3)} \alpha^i\right) + \left(\sum_{i=1}^{n(A4)} \alpha^i\right)\right] / n(A3+A4) \tag{2.2.11.2.11}$$

Where:

n = number of tests in series A1, A2 and in A3, A4, respectively

Expression of results:

The stiffness characteristics for uncracked and cracked concrete shall be stated in the ETA: $k_{A,ucr}$, $k_{B,ucr}$, $k_{C,ucr}$, $k_{D,ucr}$, $k_{A,cr}$, $k_{B,cr}$, $k_{C,cr}$ and $k_{D,cr}$ in [N/mm] and Figure 2.2.11.2.3.

- The stiffness characteristics k_A-k_D are intended to be used in finite element calculations, such as linear- and non-linear spring models (k_A for linear spring model and k_A-k_D for non-linear spring model), for the design of the fastener group as a function of fastener displacements and the anchor plate stiffness.
- For linear spring model: mean displacement for any load N: $\delta_{mean} = N / k_A$

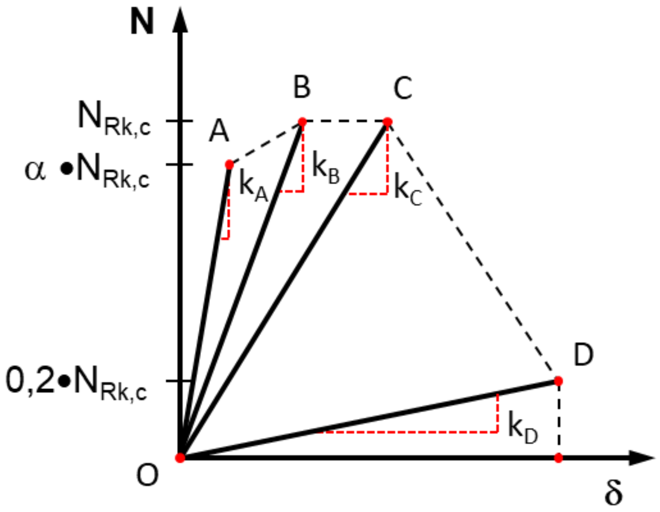


Figure 2.2.11.2.3 Figure to be stated in the ETA

2.2.12 Resistance to tension load for seismic performance category C1

Purpose of the assessment

Test series C.1.1 are intended to evaluate the performance of fasteners under simulated seismic pulsating tension loading, including the effects of cracks, and without edge effects for seismic performance category C1.

Test procedure

Provisions given in Clause A.5 shall be observed.

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 2.2.12.1 and Figure 2.2.12.1, where N_{C1} is given in Equation (2.2.12.1) in case of concrete or bond failure and in Equation (2.2.12.2) in case of steel failure, N_i is given in Equation (2.2.12.3), and N_m is given in Equation (2.2.12.4). The cycling frequency shall be between 0,1 and 2 Hz. The bottom of the tension load pulses shall be taken to be slightly greater than zero to avoid servo control problems but shall not exceed N_{min}, with N_{min} being the maximum of 3% of N_{C1} and 200 N.

$$N_{C1} = 0{,}5 \cdot N_{u,m} \cdot \left(\frac{f_{c,C1.1}}{f_{c,3}}\right)^m \qquad \text{[N]} \qquad \text{(concrete or pull-out failure)} \qquad (2.2.12.1)$$

where

$N_{u,m}$ = [N] - all fasteners:
mean tension capacity from “basic tension tests” in cracked concrete C20/25 in accordance with Table A.1.1, for the considered embedment depth;

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

$f_{c,3}$ = [N/mm²] - mean compressive strength of concrete used for the "Basic tension tests" in accordance with Table A.1.1 at the time of testing;

m = m_{cr} = normalization exponent in accordance with Clause A.2.1.

$$N_{C1} = 0{,}5 \cdot N_{u,m} \cdot \left(\frac{f_{u,C1.1}}{f_{u,3}} \right) \qquad [N] \qquad \text{(steel failure)} \qquad (2.2.12.2)$$

where

$N_{u,m}$ = [N] - mean tension steel capacity from "Basic tension tests" in cracked concrete C20/25 in accordance with Table A.1.1;

$f_{u,C1.1}$ = [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 "Basic tension tests" in accordance with Table A.1.1;

Adjustment for different steel strengths in Equation (2.2.12.2) is not required if the fasteners used in test series C1.1 and "Basic tension tests" in accordance with Table A.1.1 are taken from the same production lot.

If mixed failure modes occur in the "Basic tension tests" in accordance with Table A.1.1, the load N_{C1} shall be determined assuming that the failure mode, which was observed in the majority of tests in the test series, occurred in all tests.

$$N_i = 0{,}75 \cdot N_{C1} \quad [N] \qquad (2.2.12.3)$$

$$N_m = 0{,}5 \cdot N_{C1} \quad [N] \qquad (2.2.12.4)$$

Table 2.2.12.1 Required loading history for test series C1.1

Load level	N_{C1}	N_i	N_m
Number of cycles (n_{cyc})	10	30	100

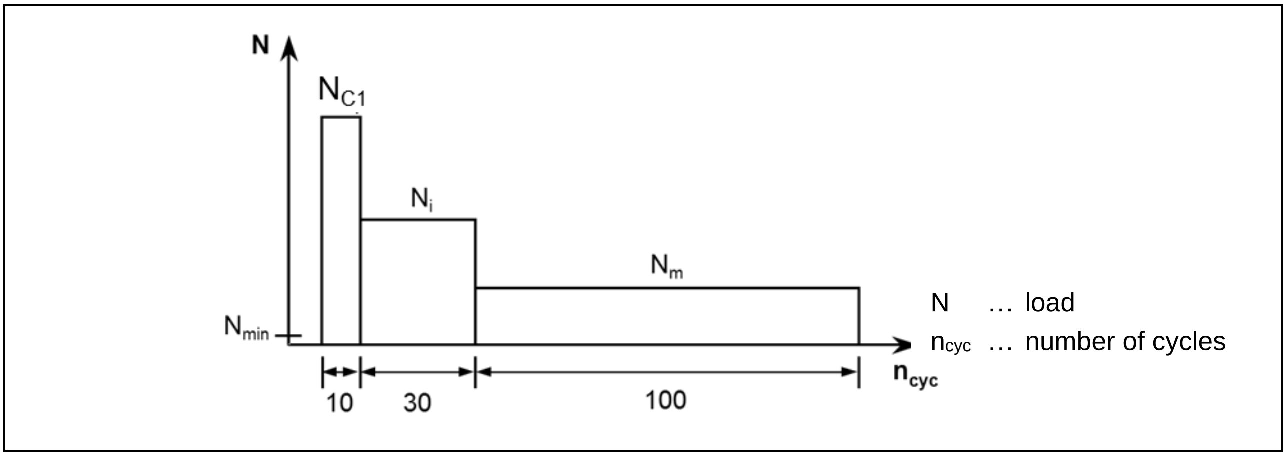


Figure 2.2.12.1 Required loading history for test series C1.1

Record the crack width, fastener displacement and applied tension load. Following completion of the simulated seismic tension cycles, open the crack by Δw = 0,5 mm, but not less than the crack opening width as measured at the end of the cyclic test and load the fastener in tension to failure. Record the maximum tension load (residual tension capacity), the corresponding displacement, the crack width, and plot the load-displacement response.

If the fastener fails to fulfil the criteria the tests shall be conducted with a reduced load level.

Assessment method

All fasteners in a test series shall complete the simulated seismic tension load history specified in Table 2.2.12.1 and Figure 2.2.12.1. Failure of a fastener to develop the required resistance in any cycle prior to completing the load history specified in Table 2.2.12.1 and Figure 2.2.12.1 shall be recorded as an unsuccessful test. The mean-residual capacity of the fasteners in the test series shall be equal to or greater than 160 % of N_{C1} as given by Equation (2.2.12.1) or (2.2.12.2), as applicable.

Successful completion of the cyclic loading history and fulfilment of the residual tension capacity criteria of this Clause shall be stated in the test report. In this case the seismic reduction factor for tension loading in accordance with Equation (2.2.12.5) is $\alpha_{N,C1} = 1{,}0$.

If the fastener fails to fulfil one of the above criteria at N_{C1}, this test series shall be conducted with reduced cyclic loads $N_{C1,red}$ until the criteria are met. The loading history specified in Table 2.2.12.1 and Figure 2.2.12.1 shall be applied, where $N_{C1,red}$, $N_{i,red}$ and $N_{m,red}$ are substituted for N_{C1}, N_i and N_m, respectively. All fasteners in a test series shall complete the simulated seismic tension load history. Failure of a fastener to develop the required tension resistance in any cycle prior to completing the loading history given in Table 2.2.12.1 and Figure 2.2.12.1 shall be recorded as an unsuccessful test. The mean residual capacity of the fasteners in the test series shall be at least 160 % of the reduced load $N_{C1,red}$. Successful completion of the cyclic loading history with reduced load values and fulfilment of the residual tension capacity criterion of this clause 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 (2.2.12.5).

$$\alpha_{N,C1} = \frac{N_{C1,red}}{N_{C1}} \qquad (2.2.12.5)$$

If the fastener successfully completes the cyclic loading history but does not fulfil the residual capacity criterion, a linear reduction (in the extent of actual residual capacity divided by required residual capacity) shall 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 shall be obtained.

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:

$$N_{Rk,s,C1} = \alpha_{N,C1} \cdot N_{Rk,s} \quad [N] \qquad (2.2.12.6)$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,p} \quad [N] \qquad (2.2.12.7)$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,c} \quad [N] \quad \text{(if no pull-out failure occurs for static loading)} \qquad (2.2.12.8)$$

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 in accordance with Equation (2.2.12.5).

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:

$$N_{Rk,s,C1} = N_{Rk,s} \quad [N] \qquad (2.2.12.9)$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,p} \quad [N] \qquad (2.2.12.10)$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,c} \quad [N] \quad \text{(if no pull-out failure occurs for static loading)} \qquad (2.2.12.11)$$

For $N_{Rk,s}$, $N_{Rk,p}$, $N_{Rk,c}$, and $\alpha_{N,C1}$ see a.

Torque-controlled fastener (TC) and undercut fastener (UC) with variable embedment depth:

The test shall be performed with the maximum embedment depth $h_{ef,max,t}$. In this case, the obtained test results shall be applicable for the full embedment depth range.

The tests shall be performed with the minimum embedment depth $h_{ef,min}$ and the maximum embedment depth $h_{ef,max,t}$. In this case, the test results obtained in the assessment shall be differentiated for $h_{ef,min}$ and $h_{ef,max,t}$.

If for fasteners assessed for variable embedment depths only tests with $h_{ef,max,t}$ are conducted, the reduction factor $\alpha_{N,C1}$ is also used for the assessment of the performance at minimum embedment depth $h_{ef,min}$.

If for fasteners assessed for variable embedment depth, the tests are conducted with $h_{ef,min}$ and $h_{ef,max,t}$, the assessment of tests with $h_{ef,min}$ and $h_{ef,max,t}$ are performed separately and the resulting reduction factors $\alpha_{N,C1}$ are used for the assessment of the performance at the corresponding embedment depths.

The characteristic resistances for seismic design are determined for $h_{ef,min}$ and $h_{ef,max,t}$.

For an embedment depth h_{ef} within the range [$h_{ef,min}$, $h_{ef,max,t}$], the characteristic resistances $N_{Rk,p,C1}$ and $N_{Rk,s,C1}$ are determined as follows:

- The characteristic resistance for pull-out $N_{Rk,p,C1}$ shall be obtained by linear interpolation between the values obtained for $h_{ef,min}$ and $h_{ef,max,t}$.
- The characteristic resistance for steel tension $N_{Rk,s,C1}$ shall be determined as the smaller of the two values obtained for $h_{ef,min}$ and $h_{ef,max,t}$.

The characteristic resistance $N_{Rk,p,C1}$ obtained for $h_{ef,max,t}$ is also valid for an embedment depth $h_{ef} > h_{ef,max,t}$.

Concrete screw fastener (CS) with variable embedment depth:

For fasteners assessed for variable embedment depth, tests shall be performed with the minimum embedment depth $h_{ef,min}$ and the maximum embedment depth $h_{ef,max,t}$.

For concrete screws (CS) with a thread along the entire length of the embedment depth, the characteristic resistance $N_{Rk,p,C1}$ for an embedment depth h_{ef} within the range [$h_{ef,min}$, $h_{ef,max,t}$] shall be obtained by linear interpolation if

a) the characteristic resistance $N_{Rk,p,C1}$ is greater than the corresponding concrete cone capacity for both embedment depths $h_{ef,min}$ and $h_{ef,max,t}$; or
b) the reduction factors obtained in test series A3, F3 and C1.1, which are additionally carried out for an intermediate embedment depth, are equal or greater than the minimum reduction factor obtained for $h_{ef,min}$ and $h_{ef,max,t}$ in the corresponding test series. The intermediate embedment depth shall be determined as $h_{ef,i} = [h_{ef,min} + h_{ef,max,t}]/2$ rounded to the next integer.

In all other cases the assessment of the pull-out resistance shall be performed for fixed embedment.

The characteristic resistance for steel tension $N_{Rk,s,C1}$ for an embedment depth h_{ef} within the range [$h_{ef,min}$, $h_{ef,max,t}$] shall be determined as the smaller of the two values obtained for $h_{ef,min}$ and $h_{ef,max,t}$.

Expression of results

Characteristic resistance to tension load for seismic performance category C1 $N_{Rk,s,C1}$ $N_{Rk,p,C1}$ [N].

2.2.13 Resistance to shear load for seismic performance categories C1, factor for annular gap

Purpose of the assessment

Test series C1.2 are intended to evaluate the performance of fasteners under simulated seismic alternating shear loading, including the effects of cracks, and without edge effects for seismic performance category C1.

Test procedure

Provisions given in A.5 shall be observed.

The test shall be performed in accordance with A.3.4.1 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 2.2.13.1 and Figure 2.2.13.1, where V_{C1} is given in Equation (2.2.13.1), Equation (2.2.13.2), or Equation (2.2.13.3) as applicable, V_i is given in Equation (2.2.13.4) and V_m is given in Equation (2.2.13.5). The cycling frequency shall be between 0,1 and 2 Hz.

$$V_{C1} = 0{,}5 \cdot V_{u,m} \cdot \left(\frac{f_{u,C1.2}}{f_{u,5}} \right) \quad [N] \quad \text{(fasteners without sleeve in shear plane)} \quad (2.2.13.1)$$

where

$V_{u,m}$ = [N] - mean shear capacity from tests for “characteristic resistance to steel failure under shear load" in uncracked concrete C20/25 in accordance with clause 2.2.7.1;

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

$f_{u,5}$ = [N/mm^2] - mean ultimate tensile strength of steel fastener elements used in tests for “characteristic resistance to steel failure under shear load” in uncracked concrete C20/25.

For fasteners with a sleeve in the shear plane V_{C1} shall be calculated in accordance with Equation (2.2.13.2).

$$V_{C1} = 0{,}5 \cdot V_{u,m} \cdot \left(\frac{f_{u,bol,C1.2}}{f_{u,bol,5}} \cdot \frac{A_{s,bol}}{A_{s,fas}} + \frac{f_{u,sle,C1.2}}{f_{u,sle,5}} \cdot \frac{A_{s,sle}}{A_{s,fas}} \right) [\mathrm{N}] \qquad (2.2.13.2)$$

where

$V_{u,m}$ = [N] - as defined in Equation (2.2.13.1);

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

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

$f_{u,bol,5}$ = [N/mm^2] - mean ultimate tensile strength of bolt used in in tests for “characteristic resistance to steel failure under shear load” in uncracked concrete C20/25;

$f_{u,sle,5}$ = [N/mm^2] - mean ultimate tensile strength of sleeve used in in tests for “characteristic resistance to steel failure under shear load” in uncracked concrete C20/25;

$A_{s,bol}$ = [mm^2] - effective cross section of bolt;

$A_{s,sle}$ = [mm^2] - effective cross section of sleeve;

$A_{s,fas}$ = [mm^2] - $A_{s,bol} + A_{s,sle}$;

Adjustment for different steel strengths in Equations (2.2.13.1) and (2.2.13.2) is not required if the fasteners tested in C1.2 and in in tests for “characteristic resistance to steel failure under shear load” in uncracked concrete C20/25 in accordance with Table A.1.1 series V1, are taken from the same production lot.

If tests for “characteristic resistance to steel failure under shear load” have not been performed in accordance with Table A.1.1 series V1, (which is allowed only for fasteners with no significantly reduced clause along the length of the bolt and no sleeve in the shear plane, that is taken into account in the shear resistance), V_{C1}, shall be calculated in accordance with Equation (2.2.13.3).

$$V_{C1} = 0{,}35 \cdot A_s \cdot f_{uk} \; [\mathrm{N}] \qquad (2.2.13.3)$$

where

A_s = [mm^2] - effective stressed cross section area of steel element in the shear plane;

f_{uk} = [N/mm^2] - characteristic steel ultimate tensile strength (nominal value) of the finished product;

$$V_i = 0{,}75 \bullet V_{C1} \quad [\mathrm{N}] \qquad (2.2.13.4)$$

$$V_m = 0{,}5 \bullet V_{C1} \quad [\mathrm{N}] \qquad (2.2.13.5)$$

Table 2.2.13.1 Required loading history for test series C1.2

Load level	$\pm V_{C1}$	$\pm V_i$	$\pm V_m$
Number of cycles (n_{cyc})	10	30	100

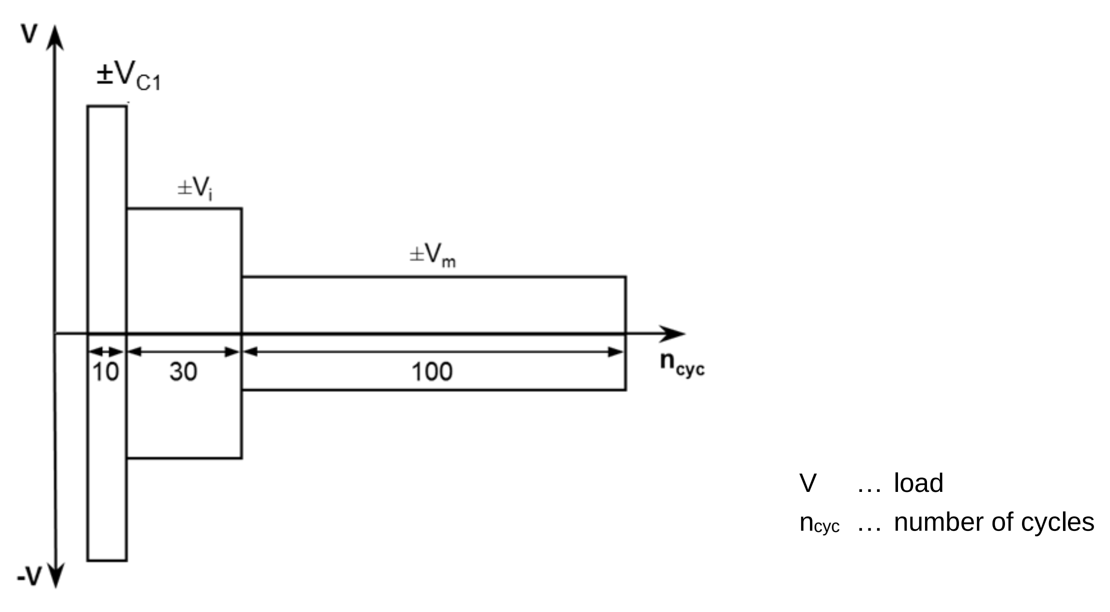
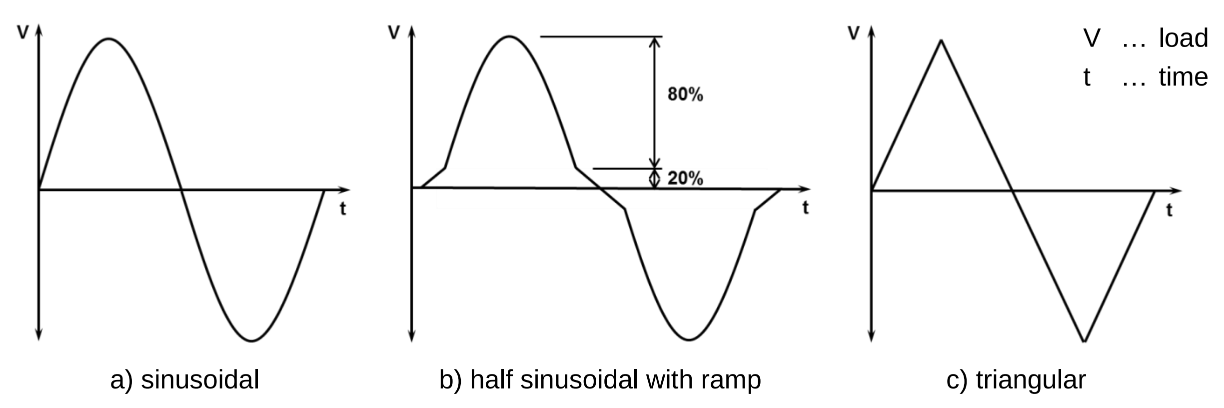


Figure 2.2.13.1 Required load history for test series C1.2

To reduce the potential for uncontrolled slip during load reversal, the alternating shear loading (see Figure 2.2.13.2 b) is approximated by two half-sinusoidal load cycles at the required frequency connected by a reduced speed, ramped load as shown in Figure 2.2.13.2 b, or by simply triangular loading cycles as shown in Figure 2.2.13.2 c.



a) sinusoidal b) half sinusoidal with ramp c) triangular

Figure 2.2.13.2 Permitted seismic shear cycle C1.2

Record the crack width, fastener displacement and applied shear load. Plot the load-displacement history in the form of hysteresis loops.

Following completion of the simulated seismic shear cycles, open the crack by Δw = 0,5 mm, but not less than the crack opening width as measured at the end of the cyclic shear test and load the fastener in shear to failure. Record the maximum shear load (residual shear capacity), the corresponding displacement, the crack width, and plot the load-displacement response.

If the fastener fails to fulfil the criteria given in the assessment the tests shall be conducted with a reduced load level.

For fasteners assessed for variable embedment depth, tests shall be performed with the minimum embedment depth $h_{ef,min}$ and with the maximum embedment depth $h_{ef,max,t}$. Tests with the maximum embedment depth $h_{ef,max,t}$ shall be performed, if in the tests with minimum embedment depth $h_{ef,min}$ pull-out or concrete failure occurs and the associated reduction factor $\alpha_{V,C1}$ is applied to the full embedment depth range.

The characteristic resistance $V_{Rk,s,C1}$ is valid for all embedment depths greater than the tested embedment depth. If tests have been performed for $h_{ef,min}$ and $h_{ef,max,t}$, $\alpha_{V,C1}$ shall be determined by linear interpolation for an embedment depth h_{ef} within the range [$h_{ef,min}$, $h_{ef,max,t}$].

The displacement obtained is valid for all embedment depths greater than the tested embedment depth.

Assessment method

All fasteners in a test series shall complete the simulated seismic shear load history specified in Table 2.2.13.1, Figure 2.2.1.3.1and Figure 2.2.13.2. Failure of a fastener to develop the required resistance in any cycle prior to completing the loading history specified in Table 2.2.13.1, Figure 2.2.1.3.1and Figure 2.2.13.2 shall be recorded as an unsuccessful test. The mean residual capacity of the fasteners in the test series shall be at least 160 % of V_{C1} given by Equation (2.2.13.1), Equation (2.2.13.2) or Equation (2.2.13.3), as applicable.

Successful completion of the cyclic loading history and fulfilment of the residual shear capacity criterion of this clause shall be stated in the test report. In this case the seismic reduction factor for shear loading in accordance with Equation (2.2.13.6) is $\alpha_{V,C1}$ = 1,0.

If the fastener fails to fulfil one of the above criteria at V_{C1}, the test shall be conducted with reduced cyclic loads $V_{C1,red}$ until the criteria are met. The loading history specified in Table 2.2.13.1, Figure 2.2.1.3.1and Figure 2.2.13.2 shall be applied, where $V_{C1,red}$, $V_{i,red}$ and $V_{m,red}$ are substituted for V_{C1}, V_i and V_m, respectively. All fasteners in a test series shall complete the simulated seismic shear load history. Failure of a fastener to develop the required shear resistance in any cycle prior to completing the loading history given in Table 2.2.13.1, Figure 2.2.1.3.1and Figure 2.2.13.2 shall be recorded as an unsuccessful test. The mean residual capacity of the fasteners in the test series shall be at least 160 % of the reduced load $V_{C1,red}$. Successful completion of the cyclic history with reduced load values and fulfilment of the residual capacity criterion of this clause shall be recorded together with a corresponding reduction factor $\alpha_{V,C1}$, which is calculated as given in Equation (2.2.13.6).

$$\alpha_{V,C1} = \frac{V_{C1,red}}{V_{C1}} \qquad \textbf{(2.2.13.6)}$$

If the fastener successfully completes the cyclic loading history but does not fulfil the residual capacity criterion, a linear reduction (in the extent of actual residual capacity divided by required residual capacity) shall be applied in terms of $\alpha_{V,C1}$ without repeating the test series.

The reduction factor $\alpha_{V,C1}$ shall be used to determine the characteristic resistance for seismic loading in accordance with Equation (2.2.13.7).

The reduction factor $\alpha_{V,C1}$ in accordance with Equation (2.2.13.6) 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 shall be determined by linear interpolation.

The characteristic shear resistance for steel under seismic loading, $V_{Rk,s,C1}$, to be reported in the ETA shall be determined as follows:

$$V_{Rk,s,C1} = \alpha_{V,C1} \cdot V^0_{Rk,s} \qquad \text{[N]} \qquad (2.2.13.7)$$

where

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

$\alpha_{V,C1}$ = reduction factor α in accordance with Equation (2.2.13.6).

The value $V_{Rk,s,C1}$ in accordance with Equation (2.2.13.7) 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 shall be determined by linear interpolation.

Expression of results

Characteristic resistance to shear load for seismic performance category C1 $V_{Rk,s,C1}$ [N].

2.2.14 Resistance to tension load for seismic performance categories C2 and displacements

Purpose of the assessment

Test series C2.1, C2.3, C2.5 are intended to evaluate the performance of fasteners under simulated seismic pulsating tension loading, including the effects of cracks, and simulated seismic tension loading with varying crack width and without edge effects for seismic performance category C2.

2.2.14.1 Reference tests

Test conditions

Provisions given in A.5 shall be observed.

The tension test series C2.1 shall be performed in accordance with A.3.1.2.6, with a crack width as specified in Table A.1.1.

For fasteners intended to be assessed for SFRC see Clause B.3.6.

Assessment method

The following conditions apply:

1. Scatter of displacements:

$$cv(\delta(0{,}5 \cdot N_{u,m,C2.1})) \leq 40\% \qquad (2.2.14.1.1)$$

with

cv = [%] - coefficient of variation;

$\delta(0{,}5 \cdot N_{u,m,C2.1})$ = [mm] - displacement of the fastener at 50 % of mean ultimate load of test series C2.1a and b, i.e., $N_{u,m,C2.1a}$ and $N_{u,m,C2.1b}$, respectively.

If this condition is not fulfilled for one of the test series, the ETA shall include a sentence: "The displacements of the fasteners in seismic performance category C2 are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

It is allowed to increase the number of tests to fulfil this criterion. 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:

$$N_{u,m,C2.1a} \geq 0{,}8 \cdot N_{u,m,F1} \qquad (2.2.14.1.2)$$

with

$N_{u,m,C2.1a}$ = [N] - mean tension capacity from the tests for “seismic reference test series” in cracked concrete C20/25 in accordance with Table A.1.1 series C2.1a, normalized to concrete strength C20/25;

$N_{u,m,F1}$ = [N] - mean tension capacity from the tests for “maximum crack width and large hole diameter” in cracked concrete C20/25 in accordance with Table A.1.1 series F1;

If this condition is fulfilled, $\alpha_{C2.1a}$ = 1,0. If the condition is not fulfilled, the reduction factor $\alpha_{C2.1a}$ shall be determined for the test series C2.1a in accordance with Equation (2.2.14.1.3).

$$\alpha_{C2.1a} = \frac{N_{u,m,C2.1a}}{0{,}8 \cdot N_{u,m,F1}} \qquad (2.2.14.1.3)$$

In Equations (2.2.14.1.2) and (2.2.14.1.3) the resistances from the tests for “maximum crack width and large hole diameter” in cracked concrete C20/25 according Table A.1.1 series F1, shall be normalized in accordance with A.2.1, as applicable, to the strength in test series C2.1a (depending on the relevant failure mode).

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

$$N_{u,m,C2.1b} \geq 0{,}8 \cdot N_{u,m,F2} \qquad (2.2.14.1.4)$$

with

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

$N_{u,m,F2}$ = [N] - mean tension capacity from the tests for “maximum crack width and small hole diameter” in cracked concrete C50/60 in accordance with Table A.1.1 series F2.

If this condition is fulfilled, $\alpha_{C2.1b}$ = 1,0. If the condition is not fulfilled, the reduction factor $\alpha_{C2.1b}$ shall be determined for the test series C2.1b in accordance with Equation (2.2.14.1.5).

$$\alpha_{C2.1b} = \frac{N_{u,m,C2.1b}}{0{,}8 \cdot N_{u,m,F2}} \qquad (2.2.14.1.5)$$

In Equations (2.2.14.1.4) and (2.2.14.1.5) the resistances from the tests for “maximum crack width and small hole diameter” in cracked concrete C50/60 in accordance with Table A.1.1 series F2 shall be normalized in accordance with A.2.1, as applicable, to the strength in test series C2.1b.

The reduction factor $\alpha_{C2.1}$ shall be determined in accordance with Equation (2.2.14.1.6).

$$\alpha_{C2.1} = \min\left(\alpha_{C2.1a};\alpha_{C2.1b}\right) \qquad (2.2.14.1.6)$$

c) Scatter of ultimate loads:

$$cv(N_u) \le 20\% \qquad (2.2.14.1.7)$$

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 in accordance with Equation (2.2.14.1.8) and Equation (2.2.14.1.9), respectively.

$$\beta_{cv,C2.1a} = \frac{1}{1+\left(cv\left(N_{u,C2.1a}\right)-20\right)\cdot 0{,}03} \qquad (2.2.14.1.8)$$

$$\beta_{cv,C2.1b} = \frac{1}{1+\left(cv\left(N_{u,C2.1b}\right)-20\right)\cdot 0{,}03} \qquad (2.2.14.1.9)$$

where $cv(N_{u,C2.1a})$ and $cv(N_{u,C2.1b})$ are the coefficients of variation of the ultimate loads in test series C2.1a and C2.1b, respectively.

The factor $\beta_{cv,C2.1}$ shall be determined as given in Equation (2.2.14.1.10):

$$\beta_{cv,C2.1} = \min\left(\beta_{cv,C2.1a};\beta_{cv,C2.1b}\right) \qquad (2.2.14.1.10)$$

If $cv(N_u)$ is greater than 30 % in at least one test series, the ETA shall include a sentence: " Significant decrease of resistance to tension load of fasteners may occur.”. It shall be allowed to increase the number of tests in a test series to possibly fulfil this criterion.

Torque-controlled fastener (TC) and undercut fastener (UC) with variable embedment depth:

The test shall be performed with the maximum embedment depth $h_{ef,max,t}$. In this case, the obtained test results shall be applicable for the full embedment depth range.

The tests shall be performed with the minimum embedment depth $h_{ef,min}$ and the maximum embedment depth $h_{ef,max,t}$. In this case, the test results obtained in the assessment shall be differentiated for $h_{ef,min}$ and $h_{ef,max,t}$.

If for fasteners assessed for variable embedment depths only tests with $h_{ef,max,t}$ are conducted, the reduction factors $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ as well as the displacements are also used for the assessment of the performance at minimum embedment depth $h_{ef,min}$.

If for fasteners assessed for variable embedment depths tests with $h_{ef,max,t}$ and $h_{ef,min}$ are conducted, the assessment of tests with $h_{ef,min}$ and $h_{ef,max,t}$ are performed separately and the resulting reduction factors are used for the assessment of the performance at the corresponding embedment depths.

The characteristic resistances for seismic design are determined for $h_{ef,min}$ and $h_{ef,max,t}$.

For an embedment depth h_{ef} within the range [$h_{ef,min}$, $h_{ef,max,t}$]:

- the characteristic resistance for pull-out $N_{Rk,p,C2}$ shall be obtained by linear interpolation of the characteristic resistances determined for $h_{ef,min}$ and $h_{ef,max,t}$;
- the characteristic resistance for steel failure $N_{Rk,s,C2}$ shall be obtained by linear interpolation of the characteristic resistances determined for $h_{ef,min}$ and $h_{ef,max,t}$.

The characteristic resistance $N_{Rk,p,C2}$ obtained for $h_{ef,max,t}$ is also valid for an embedment depth $h_{ef} > h_{ef,max,t}$.

The displacements shall be obtained by linear interpolation of the displacements measured at minimum embedment depth $h_{ef,min}$ and maximum tested embedment depth $h_{ef,max,t}$.

Concrete screw fastener (CS) with variable embedment depth:

For fasteners assessed for variable embedment depth, the provisions given for multiple fixed embedment depths apply. Hence, the assessed performance is valid for the tested embedment depth only.

2.2.14.2 Tests under pulsating tension load

Test conditions

Test series C2.3 shall be performed in accordance with A.3.1.2.6 with the following modifications:

Open the crack by Δw = 0,5 mm. Subject the fastener to the sinusoidal tension loads specified in Table 2.2.14.2.1 and Figure 2.2.14.2.1 with a cycling frequency no greater than 0,5 Hz, where N_{max} is given by Equation (2.2.14.2.1) and Equation (2.2.14.2.2). Triangular loading cycles shall be used in place of sinusoidal cycles. The bottom of the tension load pulses shall 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.

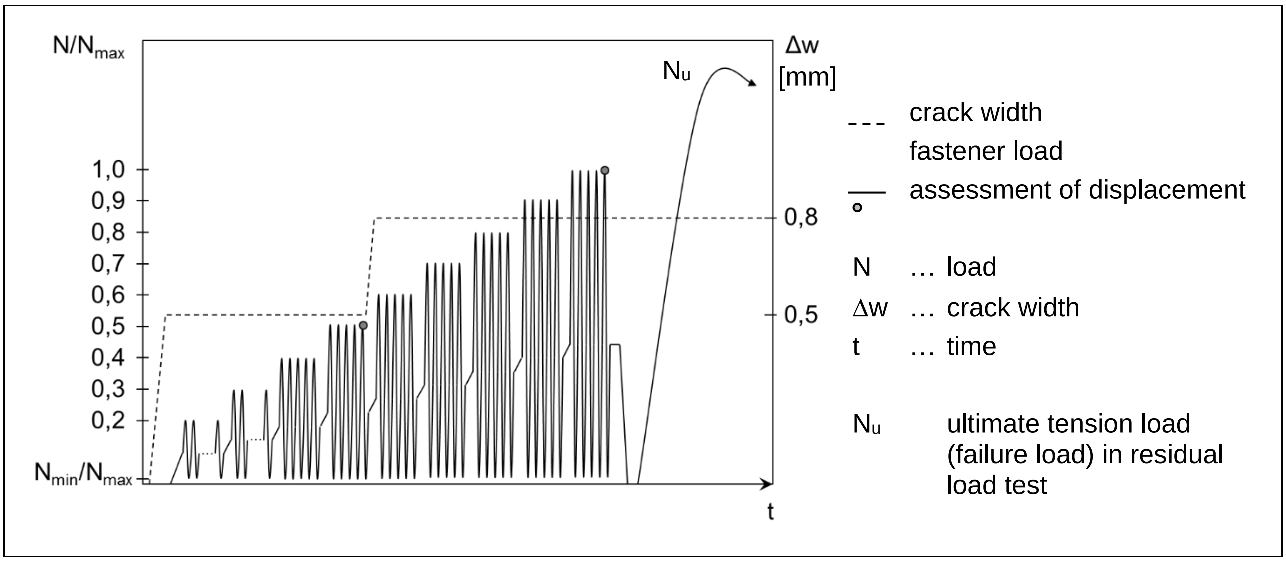


Figure 2.2.14.2.1 Schematic test procedure C2.3

Table 2.2.14.2.1 Required load amplitudes for test series C2.3

N/N_{max}	Number of cycles	Crack width Δw [mm]
0,2	25	0,5
0,3	15	0,5
0,4	5	0,5
0,5	5	0,5
0,6	5	0,8
0,7	5	0,8
0,8	5	0,8
0,9	5	0,8
1	5	0,8
SUM	75	

Depending on the failure mode observed in test C2.1a, N_{max} shall be determined as follows:

Steel failure

$$N_{max} = 0,75 \cdot N_{base} \left(\frac{f_{u,C2.3}}{f_{u,base}}\right) [N] \qquad (2.2.14.2.1)$$

All other failure modes

$$N_{max}=0{,}75\cdot N_{base}\left(\frac{f_{c,C2.3}}{f_{C20/25}}\right)^{0{,}5}[\mathrm{N}] \qquad (2.2.14.2.2)$$

where

N_{base} = min ($N_{u,m,C2.1a}$; 0,8 $N_{u,m,F1}$) [N];

$N_{u,m,F1}$ = [N] - mean tension capacity from the tests for “maximum crack width and large hole diameter” in cracked concrete C20/25 in accordance with Table A.1.1 series F1, normalized to concrete strength C20/25;

$N_{u,m,C2.1a}$ = [N] - mean tension capacity from the tests for “seismic reference test series” in cracked concrete C20/25 in accordance with Table A.1.1 series C2.1a, normalized to concrete strength C20/25;

$f_{u,C2.3}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.3;

$f_{u,base}$ = [N/mm²] ultimate mean steel strength of fasteners used in the test series C2.1a or F1 which is decisive for determination of N_{base};

$f_{c,C2.3}$ = [N/mm²] - mean compressive strength of concrete at the time of testing of the test series C2.3;

If mixed failure modes occur in test series C2.1a, the calculation for respective failure shall be performed according to Equations (2.2.14.2.1) and (2.2.14.2.2) and the largest value of N_{max}shall be applied.

Adjustment for different steel strengths in Equation (2.2.14.2.1) is not required if the fasteners tested in F1, 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 (for crack measurement, tolerances and determination of crack width see clause A.3.1.2.6, for control of crack width see clause A.3.1.2.6, first paragraph and Figure A.3.1.2.5, test procedure see clauses A.3.2 and A.3.3.3).

Following completion of the simulated seismic tension cycles unload the fastener. During the unloading of the fastener the crack width gets 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 criteria given in the corresponding assessment the tests shall be conducted with a reduced load level.

If the fastener meets the criteria 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 Figure 2.2.14.2.1) is intended the test shall be conducted with a reduced load level.

Assessment method

The following conditions apply:

1. All fasteners in a test series shall complete the pulsating tension load history specified in Figure 2.2.14.2.1 and Table 2.2.14.2.1. Failure of a fastener to develop the required resistance in any cycle prior to completing the loading history specified in Table 2.2.14.2.1 shall be recorded as an unsuccessful test. In case of an unsuccessful test, the test series shall be repeated with a reduced value $N_{max,red,1}$ until the criterion is fulfilled. In this case the reduction factor $\alpha_{C2.3a}$ shall be calculated in accordance with Equation (2.2.14.2.3).

$$\alpha_{C2.3a}=\frac{N_{max,red,1}}{N_{max}} \qquad (2.2.14.2.3)$$

with

N_{max} = [N] - maximum tension load in accordance with Equations (2.2.14.2.1) and (2.2.14.2.2).

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

2. Displacements shall be assessed during the last cycle at $0{,}5 \cdot N/N_{max}$ and at $1{,}0 \cdot N/N_{max}$ or at $0{,}5 \cdot N/N_{max,red,1}$ and at $1{,}0 \cdot N/N_{max,red,1}$, respectively, (refer to Figure 2.2.14.2.1). Displacements shall be reported in terms of the mean value.

   To avoid excessive displacement of the fastener a displacement limit at the end of load cycling at $0{,}5 \cdot N/N_{max}$ or $0{,}5 \cdot N/N_{max,red,1}$ (i.e., after 50 load cycles (see Figure 2.2.14.2.1 and Table 2.2.14.2.1) is introduced for the assessment of fasteners. The following condition shall be fulfilled:

   $$\delta_m(0{,}5 \cdot N/N_{\max}) \leq \delta_{N,\lim} \quad (2.2.14.2.4)$$

   with

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

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

   If this condition is not fulfilled repeat the tests with a reduced value $N_{max,red,2}$ until the criterion is fulfilled and calculate the reduction factor $\alpha_{C2.3b}$ in accordance with Equation (2.2.14.2.5).

   $$\alpha_{C2.3b} = \frac{N_{max,red,2}}{N_{max}} \quad (2.2.14.2.5)$$

   with

   N_{max} = [N] - maximum tension load in accordance with Equations (2.2.14.3.1) and (2.2.14.3.2);

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

   If the condition in accordance with Equation (2.2.14.2.6) is fulfilled but a smaller displacement is intended the tests shall be conducted with a reduced value $N_{max,red}$.

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

   a. Scatter of displacement:

   $$cv\left(\delta\left(0{,}5 \cdot N_{u,m,C2.3}\right)\right) \leq 40\% \quad (2.2.14.2.6)$$

   with

   $\delta\ (0{,}5 \cdot N_{u,m,C2.3})$ = [mm] - displacement of the fastener at 50 % of the mean ultimate tension load from the residual capacity tests of test series C2.3. Only the displacement in the residual capacity test is taken, i.e., the displacement that occurred during the cyclic loading is neglected.

   $N_{u,m,C2.3}$ = [N] - mean ultimate tension load from pulsating tension tests of test series C2.3 (ultimate tension load see Figure 2.2.14.2.1).

   If this condition is not fulfilled, the ETA shall include a sentence: "The displacements of the fasteners under seismic performance category C2 are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

   b. Ultimate load:

   $$N_{u,m,C2.3} \geq 0{,}9 \cdot N_{u,m,C2.1a} \quad (2.2.14.2.7)$$

   with

   $N_{u,m,C2.1a}$ = [N] - mean tension capacity from the tests for "seismic reference test series" in cracked concrete C20/25 in accordance with Table A.1.1 series C2.1a, normalized to concrete strength C20/25;;

   $N_{u,m,C2.3}$ = [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 in accordance with Equation (2.2.14.2.8).

   $$\alpha_{C2.3c} = \frac{N_{u,m,C2.3}}{0{,}9 \cdot N_{base}} \leq 1{,}0 \quad (2.2.14.2.8)$$

   with

   N_{base} = min ($N_{u,m,C2.1a}$; 0,8 $N_{u,m,F1}$) [N];

$N_{u,m,F1}$ = [N] - mean tension capacity from the tests for “maximum crack width and large hole diameter” in cracked concrete C20/25 in accordance with Table A.1.1 series F1, normalized to concrete strength in test series C2.3;

$N_{u,m,C2.1a}$ = [N] - mean tension capacity from the tests for “seismic reference test series” in cracked concrete C20/25 in accordance with Table A.1.1 series C2.1a, normalized to concrete strength in test series C2.3;

In Equations (2.2.14.2.7) and (2.2.14.2.8) the resistances from test series C2.1a shall be normalized in accordance with A.2.1, as applicable, to the strength in test series C2.3.

Equally, the test series C2.3 shall be repeated with a reduced value of N_{max} until the criterion given in Equation (2.2.14.2.7) is fulfilled.

c. Scatter of ultimate loads:

$$cv(N_u) \leq 20\% \qquad (2.2.14.2.9)$$

If this condition is fulfilled, $\beta_{cv,C2.3}$ = 1,0. If this condition is not fulfilled, $\beta_{cv,C2.3}$ shall be determined in accordance with Equation (2.2.14.2.10).

$$\beta_{cv,C2.3} = \frac{1}{1+(cv(N_u)-20)\cdot 0{,}03} \qquad (2.2.14.2.10)$$

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 greater than 30 % in at least one test series, the ETA shall include a sentence: "Significant decrease of resistance to tension load fasteners may occur.”. It shall be allowed to increase the number of tests in a test series to possibly fulfil this criterion.

The reduction factor $\alpha_{C2.3}$ resulting from the pulsating tension test series C2.3 shall be determined in accordance with Equation (2.2.14.2.11).

$$\alpha_{C2.3} = \min(\alpha_{C2.3a};\alpha_{C2.3b})\cdot \alpha_{C2.3c} \qquad (2.2.14.2.11)$$

Report the displacements after successful completion at 0,5·N/N_{max} and 1,0·N/N_{max} or at 0,5·$N/N_{max,red}$ and 1,0·$N/N_{max,red}$ in case the tests are repeated with a reduced load value, as applicable.

2.2.14.3 Tests with tension load and varying crack width

Test conditions

Test series C2.5 shall be performed in accordance with A.3.1.2.6 with the following modifications:

Tests shall be carried out on one fastener at a time with no other fasteners installed in the same crack.

Cracking of the concrete member shall be initiated before installation of the fastener in order to stabilize the relationship between crack width and tension load in the concrete 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 shall be closed by applying a centric compression force. Before installation of the fastener, it shall be ensured that the compression force is not greater than C_{ini} in accordance with Equation (2.2.14.3.1).

$$C_{ini} = 0{,}01\cdot f_{c,C2.5}\cdot A_g \quad [N] \qquad (2.2.14.3.1)$$

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.

Place crack measurement displacement transducers in accordance with Figure A.3.1.2.6.4 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 (2.2.14.3.3) to Equation (2.2.14.3.4). With the fastener load N_{w1} held constant, begin the crack cycling programme specified in Table 2.2.14.3.1 and Figure 2.2.14.3.1 with a cycling frequency no greater than 0,5 Hz. The first crack movement is in the direction of crack closure by applying a compression load on the test member.

Note: The initial crack width w_{ini} after applying N_{w1} shall 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 programme shall be performed starting with Δw = 0,1 mm (see Figure 2.2.14.3.1).

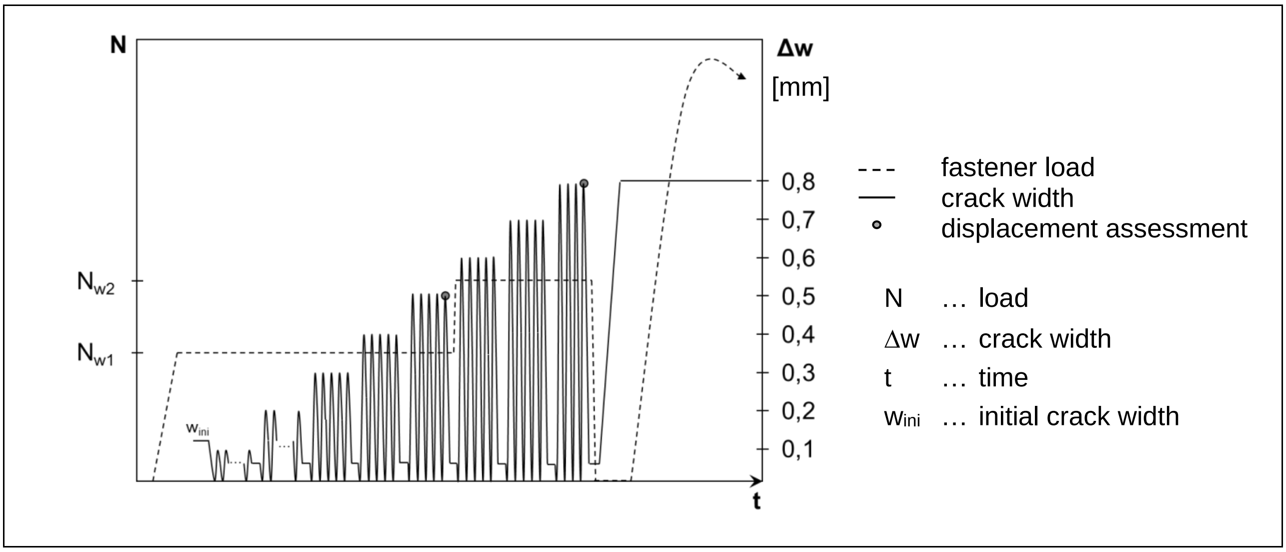


Figure 2.2.14.3.1 Schematic test procedure C2.5

Table 2.2.14.3.1 Required crack widths for test series C2.5

Fastener load	**Number of cycles**	**Crack width Δw [mm]**
N_{w1}	20	0,1
N_{w1}	10	0,2
N_{w1}	5	0,3
N_{w1}	5	0,4
N_{w1}	5	0,5
N_{w2}	5	0,6
N_{w2}	5	0,7
N_{w2}	4	0,8
	59	SUM

In each cycle the crack shall be closed by applying a centric compression force C_{test} in accordance with Equation (2.2.14.3.2).

$$C_{test} = 0{,}1 \cdot f_{c,C2.5} \cdot A_g \quad [\mathrm{N}] \tag{2.2.14.3.2}$$

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

If the crack is not closed to $\Delta w \leq 0{,}1$ mm when applying C_{test} in accordance with Equation (2.2.14.3.2), 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 criterion of $\Delta w_1 = 0$ mm (see Table A.1.1).

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

Steel Failure

$$N_{w1}= 0{,}4 \cdot N_{base} \left(\frac{f_{u,C2.5}}{f_{u,base}}\right) \text{ [N]} \qquad (2.2.14.3.3)$$

All other failure modes

$$N_{w1}=0{,}4 \cdot N_{base} \left(\frac{f_{c,C2.5}}{f_{C20/25}}\right)^{0,5} \text{ [N]} \qquad (2.2.14.3.4)$$

where

N_{base} = min ($N_{u,m,C2.1a}$; 0,8 $N_{u,m,F1}$) [N];

$N_{u,m,F1}$ = [N] - mean tension capacity from the tests for “maximum crack width and large hole diameter” in cracked concrete C20/25 in accordance with Table A.1.1 series F1, normalized to concrete strength C20/25;

$N_{u,m,C2.1a}$ = [N] - mean tension capacity from the tests for “seismic reference test series” in cracked concrete C20/25 in accordance with Table A.1.1 series C2.1a, normalized to concrete strength C20/25;

$f_{u,C2.5}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.5;

$f_{u,base}$ = [N/mm²] ultimate mean steel strength of fasteners used in the test series C2.1a or F1 which is decisive for determination of N_{base};

$f_{c,C2.5}$ = [N/mm²] - mean compressive strength of concrete used at the time of testing in the test series C2.5;

If mixed failure modes occur in the test series C2.1a, calculation for respective failure shall be performed according to Equations (2.2.14.3.3) and (2.2.14.3.4) and the largest value of N_{w1}shall be applied.

After completion of the crack cycles at crack width Δw = 0,5 mm, increase the tension load on the fastener to N_{w2} as given by Equation (2.2.14.3.5) to Equation (2.2.14.3.6) and then continue the crack cycling sequence to completion.

Depending on the failure mode observed in the test series C2.1a, N_{w2} shall be determined as follows:

Steel Failure

$$N_{w2}= 0{,}5 \cdot N_{base} \left(\frac{f_{u,C2.5}}{f_{u,base}}\right) \text{ [N]} \qquad (2.2.14.3.5)$$

All other failure modes

$$N_{w2}=0{,}5 \cdot N_{base} \left(\frac{f_{c,C2.5}}{f_{C20/25}}\right)^{0,5} \text{ [N]} \qquad (2.2.14.3.6)$$

with $N_{u,base}$, $f_{u,C2.5}$, $f_{u,base}$, $f_{c,C2.5}$, as defined in Equations (2.2.14.3.3) and (2.2.14.3.4).

If mixed failure modes occur in the test series C2.1a, the largest value of Equations (2.2.14.3.5) and (2.2.14.3.6) shall be applied.

Adjustment for different steel strengths in Equation (2.2.14.3.3) and Equation (2.2.14.3.5) is not required if the fasteners tested in F1, 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 a smaller crack width is acceptable. 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 criteria given in the corresponding assessment the tests shall be conducted with a reduced load level.

If the fastener meets the criteria 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 Figure 2.2.14.3.1) is intended the test shall be conducted with a reduced load level.

Assessment method

The following conditions apply:

1. All fasteners in the test series shall complete the varying crack width history under tension load specified in Table 2.2.14.3.1 and Figure 2.2.14.3.1. Failure of a fastener to develop the required resistance in any cycle prior to completing the crack cycling history specified in Table 2.2.14.3.1 shall be recorded as an unsuccessful test. In case of an unsuccessful test, the test series shall be repeated with proportionally reduced values of N_{w1} and N_{w2}, i.e., $N_{w1,red,1}$ and $N_{w2,red,1}$, respectively, until the criterion is fulfilled. The corresponding reduction factor $\alpha_{C2.5a}$ shall be calculated in accordance with Equation (2.2.14.3.7).

   $$\alpha_{C2.5a} = \frac{N_{w2,red,1}}{N_{w2}} \qquad (2.2.14.3.7)$$

   with

   N_{w2} = [N] - tension load in accordance with Equations (2.2.14.3.5) and (2.2.14.3.6) as applicable;

   $N_{w2,red,1}$ = [N] - reduced tension load to fulfil the criterion.

2. Displacements shall be assessed during the last cycle at Δw = 0,5 mm and Δw = 0,8 mm (see Figure 2.2.14.3.1). Displacements shall be reported in terms of the mean value.

   To avoid excessive displacement of the fastener a displacement limit at the end of cycling at Δw = 0,5 mm (i.e., at the end of cycle 45, see Figure 2.2.14.3.1 and Table 2.2.14.3.1) is introduced for the assessment of fasteners. Due to lack of sufficient test data this limit is assumed as $\delta_{N,lim}$ = 7 mm. The following condition shall be fulfilled:

   $$\delta_m(\Delta w = 0{,}5) \le \delta_{N,\mathrm{lim}} \qquad (2.2.14.3.8)$$

   with

   δ_m (Δw = 0,5) = [mm] - mean value of displacements of the fastener at the end of cycling at Δw = 0,5 mm of test series C2.5;

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

   If this condition is not fulfilled 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 criterion is fulfilled and calculate the reduction factor $\alpha_{C2.5b}$ in accordance with Equation (2.2.14.3.9).

   $$\alpha_{C2.5b} = \frac{N_{w2,red,2}}{N_{w2}} \qquad (2.2.14.3.9)$$

   with

   N_{w2} = [N] - tension load in accordance with Equation (2.2.14.3.5) and Equation (2.2.14.3.6);

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

   If the condition in accordance with Equation (2.2.14.3.8) is fulfilled but a smaller displacement is intended the tests shall be conduected 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:

   $$cv\left(\delta\left(0{,}5 \cdot N_{u,m,C2.5}\right)\right) \le 40\% \qquad (2.2.14.3.10)$$

   with

   δ (0,5 · $N_{u,m,C2.5}$) = [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 ETA shall include a sentence: " Significant decrease of resistance to tension load of fasteners may occur.”.

b. Ultimate load:

$$N_{u,m,C2.5} \geq 0{,}9 \cdot N_{u,m,C2.1a} \qquad (2.2.14.3.11)$$

with

$N_{u,m,C2.1a}$ = [N] - mean tension capacity from the tests for “seismic reference test series” in cracked concrete C20/25 in accordance with Table A.1.1 series C2.1a, normalized to concrete strength C20/25;

$N_{u,m,C2.5}$ = [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 in accordance with Equation (2.2.14.3.12).

$$\alpha_{C2.5c} = \frac{N_{u,m,C2.5}}{0{,}9 \cdot N_{base}} \leq 1{,}0 \qquad (2.2.14.3.12)$$

with

N_{base} = min ($N_{u,m,C2.1a}$; 0,8 $N_{u,m,F1}$) [N];

$N_{u,m,F1}$ = [N] - mean tension capacity from the tests for “maximum crack width and large hole diameter” in cracked concrete C20/25 in accordance with Table A.1.1 series F1, normalized to concrete strength in test series C2.5;

$N_{u,m,C2.1a}$ = [N] - mean tension capacity from the tests for “seismic reference test series” in cracked concrete C20/25 in accordance with Table A.1.1 series C2.1a, normalized to concrete strength in test series C2.5;

In Equations (2.2.14.3.11) and (2.2.14.3.12) the resistances from test series C2.1a shall be normalized in accordance with A.2.1, as applicable, to the strength in test series C2.5.

Equally, the test series C2.5 shall be repeated with a reduced value of N_{max} until the criterion given in Equation (2.2.14.3.13) is fulfilled.

c. Scatter of ultimate loads:

$$cv(N_u) \leq 20\% \qquad (2.2.14.3.13)$$

If this condition is fulfilled, $\beta_{cv,C2.5}$ = 1,0. If this condition is not fulfilled, $\beta_{cv,C2.5}$ shall be determined in accordance with Equation (2.2.14.3.14).

$$\beta_{cv,C2.5} = \frac{1}{1 + (cv(N_u) - 20) \cdot 0{,}03} \qquad (2.2.14.3.14)$$

If $cv(N_u)$ is greater than 30 %, the ETA shall include a sentence: " Significant decrease of resistance to tension load of fasteners may occur.” It shall be allowed to increase the number of tests in a test series to possibly fulfil this criterion.

The reduction factor $\alpha_{C2.5}$ resulting from the varying crack width test series C2.3 shall be determined in accordance with Equation (2.2.14.3.15).

$$\alpha_{C2.5} = \min(\alpha_{C2.5a}; \alpha_{C2.5b}) \cdot \alpha_{C2.5c} \qquad (2.2.14.3.15)$$

he displacements after successful completion at the end of crack cycling at Δw = 0,5 mm and Δw = 0,8 mm shall be given in the test report.

2.2.14.4 Characteristic resistance to tension for seismic performance category C2

Assessment method

The reduction factors $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ are determined in accordance with Equations (2.2.14.4.1) and (2.2.14.4.2), respectively.

$$\alpha_{N,C2} = \alpha_{C2.1} \cdot \min(\alpha_{C2.3}; \alpha_{C2.5}) \qquad (2.2.14.4.1)$$

where

$\alpha_{C2.1}$ = minimum reduction factor in accordance with Equations (2.2.14.1.3) and (2.2.14.1.5);

$\alpha_{C2.3}$ = reduction factor in accordance with Equation (2.2.14.2.3);

$\alpha_{C2.5}$ = minimum reduction factor in accordance with Equations (2.2.14.3.7) and (2.2.14.3.9).

$$\beta_{cv,N,C2} = \min(\beta_{cv,C2.1};\ \beta_{cv,C2.3};\ \beta_{cv,C2.5}) \qquad (2.2.14.4.2)$$

where

$\beta_{cv,C2.1}$ = minimum reduction factor accounting for large scatter in accordance with Equations (2.2.14.1.8) and (2.2.14.1.9);

$\beta_{cv,C2.3}$ = reduction factor accounting for large scatter in accordance with Equation (2.2.14.2.10);

$\beta_{cv,C2.5}$ = reduction factor accounting for large scatter in accordance with Equation (2.2.14.3.14).

The reduction factors in accordance with Equations (2.2.14.4.1) and (2.2.14.4.2) 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 are obtained.

The reduction factors $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ shall be used to determine the characteristic resistances under seismic loading in accordance with Equations (2.2.14.4.3) to (2.2.14.4.6)

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.

a) Steel failure caused reduction:
The characteristic resistances for steel tension and pull-out under seismic loading, i.e., $N_{Rk,s,C2}$ and $N_{Rk,p,C2}$, respectively, to be reported in the ETA are determined as follows:

$$N_{Rk,s,C2} = \alpha_{N,C2} \cdot \beta_{cv,N,C2} \cdot N_{Rk,s} \quad [N] \qquad (2.2.14.4.3)$$

$$N_{Rk,p,C2} = \alpha_{N,C2} \cdot \beta_{cv,N,C2} \cdot N_{Rk,p,0,5} \quad [N] \qquad (2.2.14.4.4)$$

where

$N_{Rk,p,0,5}$ = [N] – minimum 5 % fractile of the failure loads $N_{u,5\,\%}$ [N] as determined in 2.2.2.2 and 2.2.2.3 in tests with 0,5 mm crack width, normalized in accordance with A.2.1, accounting for the relevant failure mode.

Note: The characteristic value $N_{Rk,p,0,5}$ shall be determined as follows:

(1) determine the characteristic value of the test series F1 and F2 separately and take the minimum of the two;

(2) determine the characteristic value of the combined test data of the test series F1 and F2;

(3) take the maximum of (1) and (2).

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

$\alpha_{N,C2}$ = reduction factor as determined in Equation (2.2.14.4.1);

$\beta_{cv,N,C2}$ = reduction factor accounting for large scatter as determined in Equation (2.2.14.4.2).

b) Pull-out failure caused reduction:

The characteristic resistances for steel tension and pull-out under seismic loading, i.e., $N_{Rk,s,C2}$ and $N_{Rk,p,C2}$, respectively, to be reported in the ETA are determined as follows:

$$N_{Rk,s,C2} = N_{Rk,s} \quad [N] \qquad (2.2.14.4.5)$$

$$N_{Rk,p,C2} = \alpha_{N,C2} \cdot \beta_{cv,N,C2} \cdot N_{Rk,p,0,5} \le N_{Rk,p} \quad [N] \qquad (2.2.14.4.6)$$

with

$N_{Rk,p,0,5}$ *= as defined under Equation (2.2.14.4.4)*

$N_{Rk,s}$ *= in accordance with clause 2.2.1.1*

$N_{Rk,p}$ *= in accordance with clause 2.2.2.10*

$\alpha_{N,C2}$ *= in accordance with Equation (2.2.14.4.1)*

$\beta_{cv,N,C2}$ *= in accordance with Equation (2.2.14.4.2).*

Expression of results

Characteristic resistance to tension load for seismic performance category C2 $N_{Rk,s,C2}$, $N_{Rk,p,C2}$ [N].

2.2.14.5 Displacements

The displacements shall be determined as follows.

$\delta_{N,C2(0,5)}$	Maximum of the mean value of displacements reported at $0{,}5 \cdot N/N_{max}$ and $0{,}5 \cdot N/N_{max,red}$ (as applicable) of C2.3 tests and the mean value of displacements reported at Δw = 0,5 mm of C2.5 tests.
$\delta_{N,C2(0,8)}$	Maximum of the mean value of displacements reported at $1{,}0 \cdot N/N_{max}$ and $1{,}0 \cdot N/N_{max,red}$ (as applicable) of C2.3 tests and the mean value of displacements reported at Δw = 0,8 mm of C2.5 tests.

Expression of results

Displacements under tension load for seismic performance category C2 $\delta_{N,C2(0,5)}$, $\delta_{N,C2(0,8)}$ [mm].

2.2.15 Resistance to shear load for seismic performance categories C2 and displacements, factor for annular gap

Purpose of the assessment

Test series C2.2 and C2.4 are intended to evaluate the performance of fasteners under simulated seismic alternating shear loading, including the effects of cracks, and without edge effects for seismic performance category C2.

Fasteners with variable embedment depth:

For fasteners assessed for variable embedment depth, only tests with the minimum embedment depth $h_{ef,min}$ are required, if the associated reduction factors $\alpha_{V,C2}$ and $\beta_{cv,V,C2}$ and the measured displacements are accepted for all larger embedment depths. If at the minimum embedment depth $h_{ef,min}$ pry-out failure is encountered, select a larger embedment depth avoiding pry-out failure.

The characteristic resistance $V_{Rk,s,C2}$ is valid for the tested embedment depth and all larger embedment depths. If tests have also been performed with the maximum embedment depth $h_{ef,max,t}$, the reduction factors $\alpha_{V,C2}$ and $\beta_{cv,V,C2}$ for an embedment depth h_{ef} within the range [$h_{ef,min}$, $h_{ef,max,t}$] shall be determined by linear interpolation.

2.2.15.1 Reference tests

It is acceptable to use the results of test series V1 (characteristic resistance under shear load) in uncracked concrete C20/25 (Δw = 0,0 mm) as reference to reduce the test burden, unless the manufacturer requests otherwise.

Provisions given in A.5.2 shall be observed regarding fastener types to be tested. Provisions in A.5.2.3 shall be observed for the shear tests.

The steel properties of the specimen in the tests for “characteristic resistance to steel failure under shear load” in uncracked concrete C20/25, shall 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 can be repeated with a larger embedment depth avoiding these failure modes.

Assessment method

If calculated values or results of tests for “characteristic resistance to steel failure under shear load” in accordance with Table A.1.1 series V1, are taken as reference tests, this clause 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 ETA shall include a sentence: " Significant decrease of resistance to tension load of fasteners may occur.”. The test shall be repeated with a larger embedment depth avoiding these failure modes.

2. Ultimate load:

$$V_{u,m,C2.2} \geq 0{,}8 \cdot V_{u,m,5} \qquad (2.2.15.1.1)$$

with

$V_{u,m,C2.2}$ = [N] - mean ultimate shear load from test series C2.2;

$V_{u,m,5}$ = [N] - mean shear capacity from the tests for “characteristic resistance to steel failure under shear load" in accordance with Table A.1.1 series V1.

If this condition is fulfilled, $\alpha_{C2.2}$ = 1,0. If this condition is not fulfilled, the factor $\alpha_{C2.2}$ shall be determined in accordance with Equation (2.2.15.1.2).

$$\alpha_{C2.2} = \frac{V_{u,m,C2.2}}{0{,}8 \cdot V_{u,m,5}} \qquad (2.2.15.1.2)$$

In Equations (2.2.15.1.1) and (2.2.15.1.2) the resistances from the tests for “characteristic resistance to steel failure under shear load” in accordance with Table A.1.1 series V1, shall be normalized in accordance with Clause A.2.1, as applicable, to the strength in test series C2.2.

3. Scatter of ultimate loads:

$$cv(V_u) \leq 15\% \qquad (2.2.15.1.3)$$

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 in accordance with Equation (2.2.15.1.4).

$$\beta_{cv,C2.2} = \frac{1}{1 + (cv(V_u) - 15) \cdot 0{,}03} \qquad (2.2.15.1.4)$$

where $cv(V_u)$ is the coefficient of variation of the ultimate loads in test series C2.2.

If $cv(V_u)$ is greater than 30 %, then the ETA shall include a sentence: "Significant decrease of resistance to shear load of fasteners may occur.” It shall be allowed to increase the number of tests in a test series to possibly fulfil this criterion.

2.2.15.2 Tests under alternating shear load

Test conditions

Provisions given in A.5 shall be observed.

The test series C2.4shall be performed in accordance with A.3.1.2.6 with the following modifications:

Open the crack by Δw = 0,8 mm. Subject the fastener to the sinusoidal shear loads specified in Table 2.2.15.2.1 and Figure 2.2.15.2.1 with a cycling frequency no greater than 0,5 Hz, where V_{max} is given by Equations (2.2.15.2.1) or (2.2.15.2.2) as applicable.

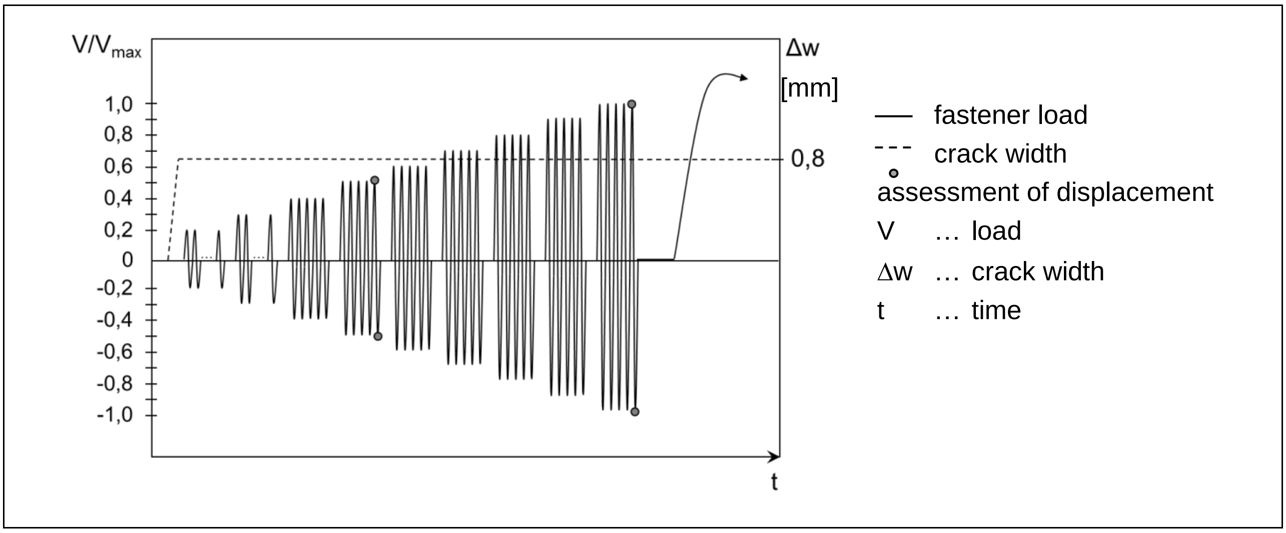


Figure 2.2.15.2.1 Schematic test procedure C2.4

Table 2.2.15.2.1 Required load amplitudes for test series C2.4

$\pm V/V_{max}$	Number of cycles	Crack width Δw [mm]
0,2	25	0,8
0,3	15	0,8
0,4	5	0,8
0,5	5	0,8
0,6	5	0,8
0,7	5	0,8
0,8	5	0,8
0,9	5	0,8
1	5	0,8
SUM	75	

$$V_{\max} = 0{,}85 \cdot V_{u,m,C2.2}\left(\frac{f_{u,C2.4}}{f_{u,C2.2}}\right) \text{ [N]} \qquad \text{(fasteners without sleeve in shear plane)} \qquad (2.2.15.2.1)$$

where

$V_{u,m,C2.2}$ = [N] - mean shear capacity from the reference test series C2.2;

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

$f_{u,C2.2}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.2.

For fasteners with a sleeve in the shear plane V_{max} shall be calculated in accordance with Equation (2.2.15.2.2).

$$V_{max} = 0{,}85 \cdot V_{u,m,C2.2} \cdot \left(\frac{f_{u,bol,C2.4}}{f_{u,bol,C2.2}} \cdot \frac{A_{s,bol}}{A_{s,fas}} + \frac{f_{u,sle,C2.4}}{f_{u,sle,C2.2}} \cdot \frac{A_{s,sle}}{A_{s,fas}}\right) \text{[N]} \qquad (2.2.15.2.2)$$

where

$V_{u,m,C2.2}$ = [N] - mean shear capacity from the reference test series C2.2;

$f_{u,bol,C2.4}$ = [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;

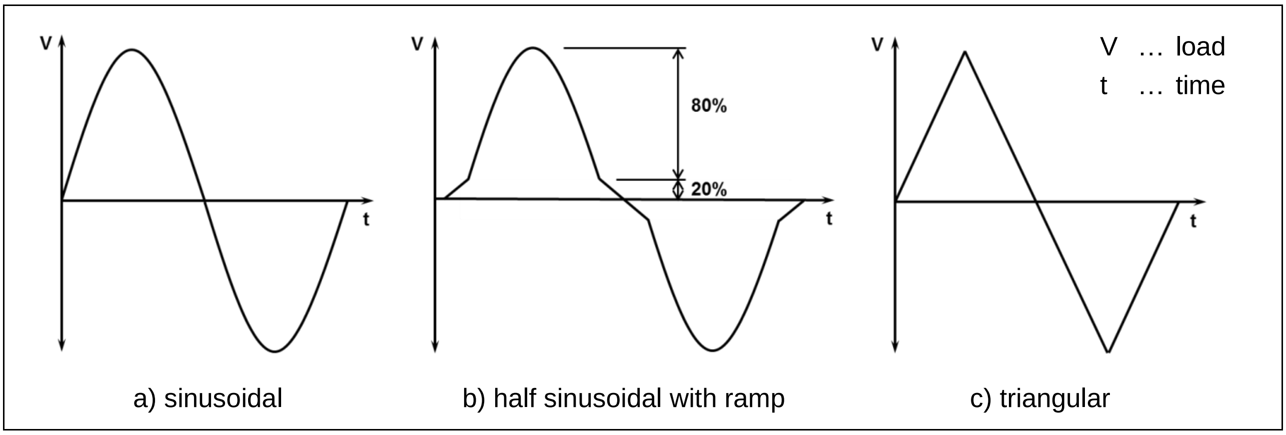
$A_{s,bol}$ = [mm²] - effective cross section of bolt;

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

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

Adjustment for different steel strengths in Equations (2.2.15.2.1) and (2.2.15.2.2) 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 2.2.15.2.2 b) or simply triangular loading cycles (see Figure 2.2.15.2.2 c) shall be used in place of sinusoidal cycles (see Figure 2.2.15.2.2 a). All loading modes are equivalent and lead to comparable results. The crack width shall be controlled during load cycling.



a) sinusoidal b) half sinusoidal with ramp c) triangular

Figure 2.2.15.2.2 Permitted seismic shear cycle C2.4

Record the crack width, fastener displacement and applied shear load continuously during the simulated seismic shear cycles. Report the displacements at minimum and maximum load and the crack width as a function of the number of load cycles.

Following completion of the simulated seismic shear cycles unload the fastener. 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 criteria the tests shall be conducted with a reduced load level.

If the fastener meets the criteria 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·V/V_{max}; see Figure 2.2.15.2.2) is intended the test shall be conducted with a reduced load level.

If in the test series C2.4 failure is caused by pull-out or pull-through the test shall be repeated with a larger embedment depth avoiding these failure modes.

Note: During the shear load cycling test, failure may occur in the embedded portion of the fastener. If such a failure occurs close to the embedded end of the fastener the residual capacity is not be significantly affected. Hence, in this case failure of the fastener during cycling is easily be overlooked. Attention shall be paid to this aspect.

<u>*Assessment method*</u>

The following conditions apply:

1. All fasteners in a test series shall complete the alternating shear load history specified in Table 2.2.15.2.1 and Figure 2.2.15.2.1. Failure of a fastener to develop the required resistance in any cycle prior to completing the loading history specified in Table 2.2.15.2.1 shall be recorded as an unsuccessful test. In case of an unsuccessful test, the test series shall be repeated with a reduced value $V_{max,red,1}$ until the criterion is fulfilled. In this case the reduction factor $\alpha_{C2.4a}$ shall be calculated in accordance with Equation (2.2.15.2.3).

$$\alpha_{C2.4a} = \frac{V_{max,red,1}}{V_{max}} \qquad (2.2.15.2.3)$$

with

V_{max} = [N] - maximum shear load in accordance with Equations (2.2.15.2.1) or (2.2.15.2.2);

$V_{max,red,1}$ = [N] - reduced shear load to fulfil the criterion.

2. Displacements shall be assessed during the last cycle at ±0,5·V/V_{max} and ±1,0·V/V_{max} or ±0,5·$V/V_{max,red,1}$ and ±1,0·$V/V_{max,red,1}$ (see Figure 2.2.15.2.1). Displacements shall be given in the test report 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 ±0,5·V/V_{max} (i.e., at load cycle 50 (see Table 2.2.15.2.1 and Figure 2.2.15.2.1) is introduced for the assessment of fasteners. Due to lack of sufficient test data this limit is assumed as $\delta_{V,lim}$ = 7 mm. The following condition shall be fulfilled:

$$\delta_m(0{,}5 \cdot V/V_{\max}) \leq \delta_{V,\text{lim}} \qquad (2.2.15.2.4)$$

with

δ_m $(0{,}5 \cdot V/V_{max})$ = [mm] - max ($|\delta_m$ $(+0{,}5 \cdot V/V_{max})|$; $|\delta_m$ $(-0{,}5 \cdot V/V_{max})|$); maximum of the mean value of displacements of the fastener after load cycling at $+0{,}5 \cdot V/V_{max}$ and the mean value of displacements of the fastener after load cycling at $-0{,}5 \cdot V/V_{max}$ of test series C2.4; if the tests have been performed with $V_{max,red,1}$ replace V_{max} by $V_{max,red,1}$;

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

If the condition is not fulfilled repeat the tests with a reduced value $V_{max,red,2}$ until the crierion is fulfilled. Determine the corresponding reduction factor $\alpha_{C2.4b}$ in accordance with Equation (2.2.15.2.5).

$$\alpha_{C2.4b} = \frac{V_{max,red,2}}{V_{max}} \qquad (2.2.15.2.5)$$

with

V_{max} = [N] - maximum shear load in accordance with Equations (2.2.15.2.1) or (2.2.15.2.2);

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

If the condition in accordance with Equation (2.2.15.2.6) is fulfilled but a smaller displacement is intended the tests shall be conducted with a reduced value $V_{max,red}$.

3. Residual capacity tests (both conditions apply):

   a. Failure mode:

      If failure is caused by pull-out or pull-through the ETA shall include a sentence: " Significant decrease of resistance to tension load of fasteners may occur.” The tests shall be repeated with a larger embedment depth avoiding these failure modes.

   b. Ultimate load:

$$V_{u,m,C2.4} \geq 0{,}95 \cdot V_{u,m,C2.2} \qquad (2.2.15.2.6)$$

      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 in accordance with Equation (2.2.15.2.7).

$$\alpha_{C2.4c} = \frac{V_{u,m,C2.4}}{0{,}95 \cdot V_{u,m,C2.2}} \qquad (2.2.15.2.7)$$

      In Equations (2.2.15.2.6) and (2.2.15.2.7) the resistances from test series C2.2 shall be normalized in accordance with 117, as applicable, to the strength in test series C2.4.

      Equally, the test series C2.4 shall be repeated with a reduced value of V_{max} until the criterion given in Equation (2.2.15.2.6) is fulfilled.

   c. Scatter of ultimate loads:

$$cv(V_u) \leq 15\% \qquad (2.2.15.2.8)$$

      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 (2.2.15.2.9).

$$\beta_{cv,C2.4} = \frac{1}{1 + (cv(V_u) - 15) \cdot 0{,}03} \qquad (2.2.15.2.9)$$

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 greater than 30 %, the ETA shall include a sentence: " Significant decrease of resistance to tension load of fasteners may occur.”. It shall be allowed to increase the number of tests in a test series to possibly fulfil this criterion.

The reduction factor $\alpha_{C2.4}$ resulting from the alternating shear load test series C2.4shall be determined according to Equation (2.2.15.2.10).

$$\alpha_{C2.4} = \min\left(\alpha_{C2.4a};\alpha_{C2.4b}\right)\cdot\alpha_{C2.4c} \qquad (2.2.15.2.10)$$

Report the displacements after successful completion at ±0,5·V/V_{max} and ±1,0·V/V_{max} or at ±0,5·$V/V_{max,red}$ and ±1,0·$V/V_{max,red}$ in case the tests are repeated with a reduced shear load, as applicable.

2.2.15.3 Characteristic resistance to shear for seismic performance category C2

Assessment method

The reduction factors $\alpha_{V,C2}$ and $\beta_{cv,V,C2}$ are determined according to Equations (2.2.15.3.1) and (2.2.15.3.2), respectively.

$$\alpha_{V,C2} = \alpha_{C2.2} \cdot \alpha_{C2.4} \qquad (2.2.15.3.1)$$

where

$\alpha_{C2.2}$ = reduction factor in accordance with Equation (2.2.15.1.2);

$\alpha_{C2.4}$ = reduction factor in accordance with Equation (2.2.15.2.10)

$$\beta_{cv,V,C2} = \min\left(\beta_{cv,C2.2};\ \beta_{cv,C2.4}\right) \qquad (2.2.15.3.2)$$

where

$\beta_{cv,C2.2}$ = reduction factor accounting for large scatter in accordance with Equation (2.2.15.1.4);

$\beta_{cv,C2.4}$ = reduction factor accounting for large scatter in accordance with Equation (2.2.15.2.9);

The reduction factors in accordance with Equation (2.2.15.3.1) and Equation (2.2.15.3.2) 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 shall 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.

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 shall be determined as follows:

$$V_{Rk,s,C2} = \alpha_{V,C2} \cdot \beta_{cv,V,C2} \cdot V^0_{Rk,s} \quad [\mathrm{N}] \qquad (2.2.15.3.3)$$

where

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

$\alpha_{V,C2}$ = reduction factor in accordance with Equation (2.2.15.3.1);

$\beta_{cv,V,C2}$ = reduction factor accounting for large scatter in accordance with Equation (2.2.15.3.2).

The characteristic resistance in accordance with Equation (2.2.15.3.3) 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 shall be determined by linear interpolation.

Expression of results

Characteristic resistance to shear load for seismic performance category C2 $V_{Rk,s,C2}$ [N].

2.2.15.4 Displacements

The displacements shall be determined as follows.

$\delta_{V,C2(0,5)}$	Mean value of displacements reported at 0,5·*V/V_{max}* and 0,5·*V/V_{max,red}* (as applicable) of C2.4 tests.
$\delta_{V,C2(0,8)}$	Mean value of displacements reported at 1,0·*V/V_{max}* and 1,0·*V/V_{max,red}* (as applicable) of C2.4 tests.

Expression of results

Displacements under shear load for seismic performance category C2 $\delta_{V,C2(0,5)}$, $\delta_{V,C2(0,8)}$ [mm].

2.2.16 Reaction to fire

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

Therefore, the performance of such fasteners is class A1.

2.2.17 Fire resistance to steel failure under tension load

Purpose of the assessment

Test series Fi1 are performed to determine the resistance to steel failure of the fasteners under tension load and fire exposure. The determination of the duration of the fire resistance is in accordance with the conditions given in EN 1363-1 [3] using the “Standard Temperature/Time Curve” (STC).

If no tests are performed default values for the resistance to steel failure shall be calculated in accordance with EN 1992-4 [10], Annex D.4.2.1.

Assessment method

For fasteners assessed for variable embedment depth, the tests shall at least be performed with minimum embedment depth $h_{ef,min}$.

The characteristic resistance to steel failure in tension $N_{Rk,s,fi}$ applies to the tested embedment depth as well as to deeper embedment depths.

The tests shall be carried out in accordance with A.3.6. The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit in accordance with Table A.3.1.4.1.

Step 1:

From the fire tests pair of variates [test load F / duration of failure t_u] shall be determined. The test loads F shall be converted into steel stresses σ_s and drawn for each fastener size in a diagram depending on the determined fire resistance duration t_u (see Figure 2.2.17.1). The tests shall be performed with different load levels such that the obtained results are reasonably distributed along the $t_u$axis within the interval [30 min and 120 min].

Step 2:

For the determination of the mean trend line, the data shall be displayed in terms of σ_s versus t_u (see Figure 2.2.17.1).

Step 3:

By linear regression of the pair of variates σ_s / (1/t_u) (see Figure 2.2.17.2) the formula (mean value curve) in accordance with Equation (2.2.17.1) shall be determined (for linear regression any commercial software can be used). The regression curve shall represent the test results as shown in Figure 2.2.17.1 (black line). If the fastener does not fail during the test, the result cannot be used for determination of the regression curve in accordance with Figure 2.2.17.1.

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

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

p_2 is the gradient of the regression line (Figure 2.2.17.2)

Step 4:

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

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

Step 5:

The characteristic steel stress for the duration of fire resistance of 60 min, 90 min and 120 min shall be calculated using Equation (2.2.17.2)) as follows (given as green circles in Figure 2.2.17.1):

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

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

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

Step 6:

Using the two pair of variates t_u = 60 min / $\sigma_{Rk,s,fi(60min)}$ and t_u = 90 min / $\sigma_{Rk,s,fi(90min)}$ the following linear Equation shall be derived (red line in Figure 2.2.17.1):

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

where p_4 is the value where the straight line (red line in Figure 2.2.17.1) cuts the y-axis
p_5 is the gradient of the straight line (red line in Figure 2.2.17.1)

Step 7:

The characteristic steel stress for duration of fire resistance of 30 min shall be calculated using Equation (2.2.17.3)) as follows:

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

Step 8:

The characteristic tension resistance to steel failure under fire exposure shall be calculated as follows:

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

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

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

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

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

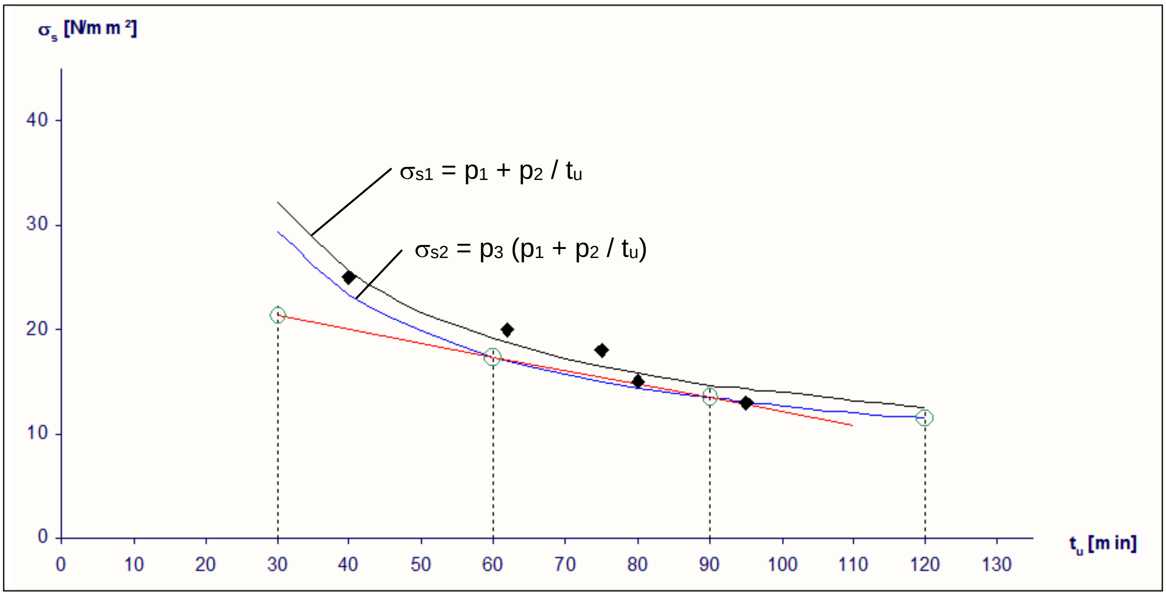


Figure 2.2.17.1 Determination of the characteristic steel stress

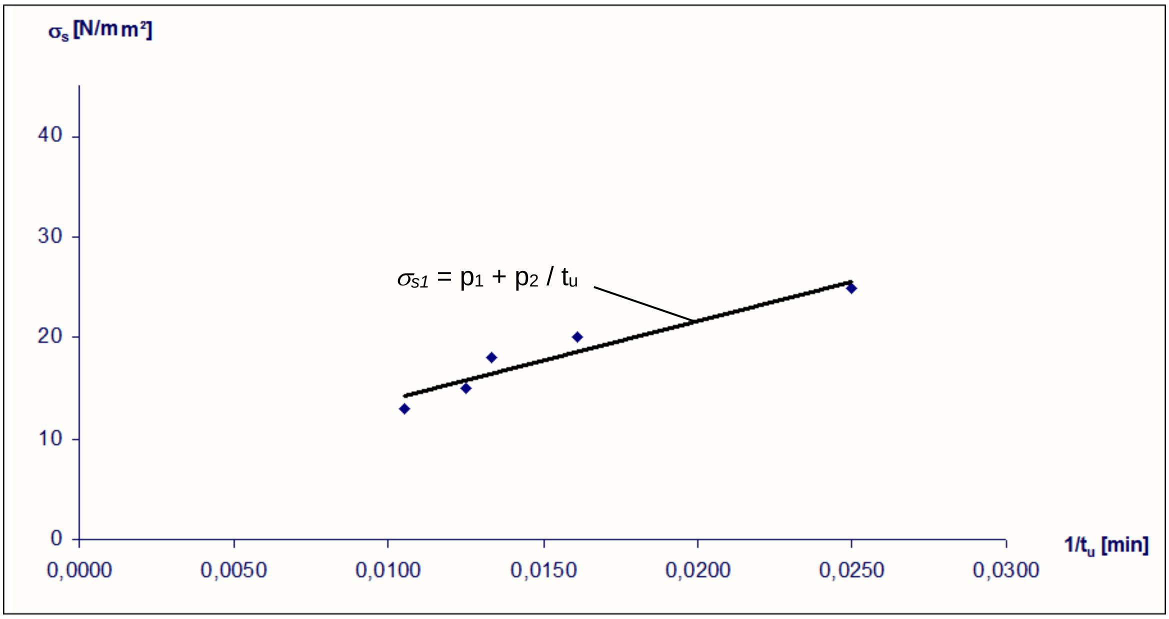


Figure 2.2.17.2 Determination of the regression Equation

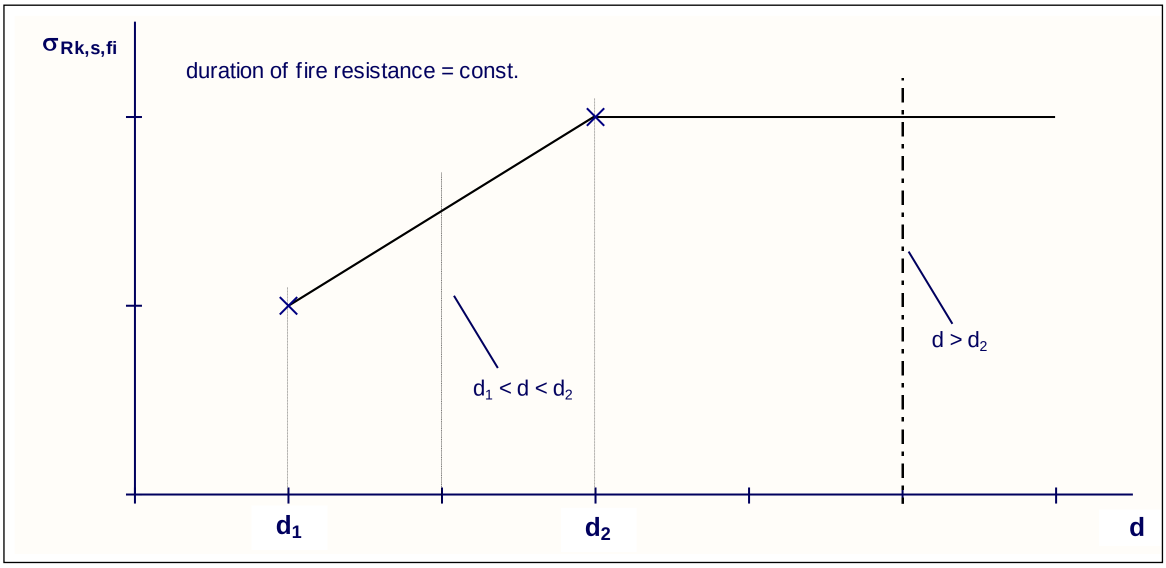


Figure 2.2.17.3 Interpolation of intermediate sizes for constant duration of fire resistance

Expression of results

$N_{Rk,s,fi}(30)$, $N_{Rk,s,fi}(60)$, $N_{Rk,s,fi}(90)$ and $N_{Rk,s,fi}(120)$ for 30, 60, 90 and 120 minutes fire exposure [N].

If default values are used, then in the ETA shall be given: "Calculated in accordance with EN 1992-4 [10], Annex D.4.2.1".

2.2.18 Fire resistance to pull-out failure

Purpose of the assessment

Test series Fi2 shall be performed to determine the resistance to pull-out failure of the fasteners under tension load and fire exposure. The determination of the duration of the fire resistance is in accordance with the conditions given in EN 1363-1 [3] using the “Standard Temperature/Time Curve” (STC).

It is acceptable to calculate the resistance to pull-out failure in accordance with EN 1992-4 [10], Annex D.4.2.3, unless the manufacturer requests to establish better characteristic resistance based on tests.

Test conditions

The assessment of reaction and resistance to fire shall be performed for the following range of concrete strength classes:

The standard assessment shall be made for C20/25 to C50/60. The performance is also valid for concrete stronger than C50/60.

The tests shall be performed in accordance with Clause A.3.6.2.The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit in accordance with Table A.3.1.4.1.

For fasteners assessed for variable embedment depth, the tests shall be performed with minimum embedment depth $h_{ef,min}$ and maximum embedment depth $h_{ef,max,t}$.

The characteristic pull-out resistance $N_{Rk,p,fi}$ for an embedment depth h_{ef} within the range [$h_{ef,min}$, $h_{ef,max,t}$] shall be obtain by linear interpolation.

Assessment

The assessment shall be carried out in the same way as for steel failure under tension load (see 2.2.17). The relation between the characteristic pull-out resistance $N_{Rk,p,fi}$ for the duration of fire resistance of 30 min, 60 min, 90 min, 120 min and the characteristic resistance for pull-out $N_{Rk,p}$ for cracked concrete C20/25 in accordance with 2.2.2 shall be used for all fastener sizes of the evaluated system.

Expression of results

Characteristic resistance to pull-out failure under fire exposure $N_{Rk,p,fi}(30)$, $N_{Rk,p,fi}(60)$, $N_{Rk,p,fi}(90)$ and $N_{Rk,p,fi}(120)$, for 30, 60, 90 and 120 min [N].

2.2.19 Fire resistance to steel failure under shear load

Purpose of the assessment

Test series Fi3 shall be performed to determine the resistance to steel failure of the fasteners under shear load and fire exposure. The determination of the duration of the fire resistance is in accordance with the conditions given in EN 1363-1 [3] using the “Standard Temperature/Time Curve” (STC). It is acceptable to omit tests for fire resistance under shear load and assign the steel stresses $\sigma_{Rk,s,fi}(30)$, $\sigma_{Rk,s,fi}(60)$, $\sigma_{Rk,s,fi}(90)$ and $\sigma_{Rk,s,fi}(120)$ under tension load to shear resistance for the corresponding fire resistance time 30, 60, 90 and 120 min. The test method shall be stated in the ETA along with the results.

Assessment method

For fasteners assessed for variable embedment depth, the tests shall at least be performed with minimum embedment depth $h_{ef,min}$.

The characteristic resistance to steel failure under shear loading $V_{Rk,s,fi}$ applies to the tested embedment depth as well as to deeper embedment depths.

The tests shall be performed in accordance with A.3.6.3. The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit in accordance with Table A.3.1.4.1.

The assessment shall be carried out in accordance with 2.2.17.

$$V_{Rk,s,fi} = \sigma_{Rk,s,fi} \cdot A_s \quad (2.2.19.1)$$

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

If testing and assessment given in Table A.1.1, series Fi3 was not conducted, then the results of tension fire test obtained from Table A.1.1, line Fi1 shall be transferred to shear if the steel element features a constant section throughout its length and that this section is the same subjected to tension and shear load, or the section is larger for shear load than for tension load. Transfer of results shall be conducted as follows for fire resistance classes R30, R60, R90 and R120:

$$V_{Rk,s,fi} = N_{Rk,s,fi} \quad (2.2.19.3)$$

$$M^0_{Rk,s,fi} = 1{,}2 \cdot \sigma_{Rk,s,fi} \cdot W_{el} \quad (2.2.19.4)$$

Where

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

> *Note: Some test results in the literature show that the fire resistance of steel to shear load obtained in* Table A.1.1*, line Fi3 may be greater than that of the fire resistance of steel to tension load obtained in* Table A.1.1*, line Fi1. This may be due to several factors such as: higher section subjected to shear load than that in tension, different test conditions leading to higher temperatures at the loaded part of the fastener in tension, different steel failure modes in tension (mix between rod and nut failure) and shear (pure shear failure of the rod), different displacement limits to reach failure. Equation* (2.2.19.3) *leads to slightly conservative* $V_{Rk,s,fi}$ *values than the results obtained from Table A.1, line F3.*

If testing and assessment given in Table A.1.1, lines Fi1 and Fi3 was not conducted, then the characteristic tension strength $\sigma_{Rk,s,fi}$ of a fastener in case of steel failure under fire conditions given in EN 1992-4 [10], Tables D.1 and D.2 for the covered steel materials are valid for the unprotected steel part of the fastener outside the concrete and shall be used in the design. These values are conservative against values assessed in accordance with Table A.1.1, lines Fi1 and Fi3.

Determine $V_{Rk,s,fi}$ where EN 1992-4 [10], Equation (D.6) applies.

Determine $M^0_{Rk,s,fi}$ where EN 1992-4 [10], Equation (D.7) applies.

Expression of results

Characteristic shear resistance to steel failure under fire exposure $V_{Rk,s,fi}(30)$, $V_{Rk,s,fi}(60)$, $V_{Rk,s,fi}(90)$ and $V_{Rk,s,fi}(120)$ for 30, 60, 90 and 120 min [N], $M^0_{Rk,s,fi}(30)$, $M^0_{Rk,s,fi}(60)$, $M^0_{Rk,s,fi}(90)$, $M^0_{Rk,s,fi}(120)$, for 30, 60, 90 and 120 min [Nm].

2.2.20 Durability

The fastener characteristics shall not change during the working life, therefore the mechanical properties on which the functioning and bearing behaviour of the fastener depends (e.g., material, coating) shall not be adversely affected by ambient physico-chemical effects such as corrosion and degradation caused by environmental conditions (e.g., alkalinity, moisture, pollution).

In the context of the assessment of durability of the construction product the following shall be considered regarding corrosion:

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 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 [11], Annex A:

Fasteners made of stainless steel according EN 1993-1-4 [11], Annex A, Tables A.3 and A.4 are considered to have sufficient durability for the corresponding Corrosion Resistance Class (CRC).

2.2.20.1 Durability of functional coating

Purpose of the assessment

Mechanical expansion fasteners with a friction-based expansion mechanism (TC) often need a special treatment of the steel surface to reduce the friction throughout the working life of the fastener. These coatings are types of organic or inorganic lacquer or plastic hoses. These coatings are applied on sleeves or cones to enable post-expansion of the fastener (e.g., to expand in crack openings) or to reduce the friction of the thread.

This clause addresses only fasteners with such a functional coating.

> *Note: Fasteners made of carbon steels are often zinc coated. Zinc coating is not considered as a functional coating in accordance with this clause. For durability of zinc coating see 2.2.20.*

The purpose of the assessment is to determine how environmental impacts affect the working life of the mechanical fastener. The assessment of durability for a working life of 50 years is given in this clause, specific provisions for working life of 100 years are given in Clause C.4.

Assessment methods

Test at least the medium fastener size (M12). In addition, tests of all fastener sizes with different type and thickness of coating or different cone angle shall be performed.

The concept is to simulate the environmental conditions by applying high concentrated alkaline and acid solutions on the fasteners. In 2.2.20.1.1 the fasteners shall be stored in the solutions and then installed, in 2.2.20.1.2 the solutions shall be applied after installation.

> *Note: The possible damage by the solutions prior to installation may have a negative effect on the installation of the fastener. So, applying the solution after the installation is closer to the field application, but needs more effort for testing.*

In addition, a more general assessment method in accordance with clause 2.2.20.1.3 is possible.

The assessment method in accordance with clause 2.2.20.1.1 is the reference method.

2.2.20.1.1 Assessment of fasteners directly exposed to alkaline and acid conditions (before installation)

This Clause addresses tests of fasteners, which are directly exposed to alkaline and acid conditions. The advantage of these tests is an easier test procedure (smaller dimensions) compared to Clause 2.2.20.1.2. However, testing fasteners directly exposed to alkaline and acid is more a tougher test. If any test criteria of Clause 2.2.20.1.1.1 to 2.2.20.1.1.3 are not fulfilled, it is acceptable to perform the relevant test (alkaline or acid or both) in accordance with Clause 2.2.20.1.2.

It is also acceptable to skip direct exposure of the fasteners and assess the durability in accordance with Clause 2.2.20.1.2.

2.2.20.1.1.1 Alkali storage conditions for fasteners directly exposed (before installation)

The expansion zone of the fasteners shall be stored in alkaline liquid: The alkaline solution shall be prepared by mixing water with KOH pellets until pH = 13,2 is achieved.

The alkalinity shall be pH = 13,2 with a tolerance of -0,20, +0,80 during the storage. The pH-value shall be checked and recorded periodically. 24 hours intervals are recommended. The storage time without any interrupt shall be at least 2000 h representing 50 years working life.

To ensure that only the expansion zone of the fasteners shall be exposed to alkalinity the threads shall be covered by a special rubber or plasticine. This shall ensure that no humidity can penetrate to the thread that results in a change of the friction or the coating properties. An example is given in the following Figure.

Figure 2.2.20.1.1.1.1 Storage in alkalinity environment of the fasteners with sealed threads

2.2.20.1.1.2 Acid storage conditions for fasteners directly exposed (before installation)

The expansion zone of the fasteners shall be exposed to a weathering cycle in accordance with EN ISO 22479 [18] Table 2, with a theoretical SO_2 concentration of 0,67%. This theoretical sulphur dioxide concentration corresponds to 2 litres of SO_2 for a test chamber volume of 300 litre. In a condense water climatic test facility with SO_2 introduction facility, the specimens shall be dewed with SO_2 at 40°C for 8 h. The expansion zone of the fasteners shall then be exposed to air for 16 h at room temperature.

These 24 h result in one cycle. At least 80 cycles for assumed working life of 50 years shall be carried out.

To ensure that only the expansion zone of the fasteners is exposed to acid the threads shall be covered by a special rubber or plasticine. This shall ensure that no humidity can penetrate to the thread that results in a change of the friction or the coating properties. An example is given in the following Figure.

Figure 2.2.20.1.1.2.1 Storage in sulphurous environment and fasteners with sealed threads stored

2.2.20.1.1.3 Functional tests after storage

Description of the tests

The fasteners shall be installed after exposure to alkaline and acid conditions in a concrete surface that has been cast against a form of the test member in accordance with Clause A.3.1.4. The fasteners shall be installed in accordance with the manufacturer's product installation instructions (MPII).

The installation torque, where required, shall be applied to the fastener by a torque wrench that has a documented calibration. About 10 minutes after torquing the fasteners with the installation torque T_{inst} according to the MPII, the installation torque shall be released and then torqued again to 0,5 T_{inst} to account for relaxation of the pre-stressing force with time.

All other conditions for test series A1 and A3 shall be fulfilled for the tests after exposure to alkaline and acid conditions.

Test at least the medium fastener size (M12). In addition, tests of all fastener sizes with different type and thickness of coating or different cone angle shall be performed.

The tests A1 and A3 shall be performed in accordance with Clause 2.2.2.1. The tests shall be performed at normal ambient temperature (+21 °C ± 3 K).

The tests in cracked concrete shall be performed for assessment of fasteners Option 1-6.

Table 2.2.20.1.1.3.1 Test programme

Test	d_{nom}	stainless	galvanized	Concrete	d_{cut}	Crack width	Reference	rqd α
Alkaline	m	5	5	C20/25	$d_{cut,m}$	0	A1	0,90
Alkaline	m	5	5	C20/25	$d_{cut,m}$	0,30 mm	A3	0,90
Acid	m	5	-	C20/25	$d_{cut,m}$	0	A1	0,90
Acid	m	5	-	C20/25	$d_{cut,m}$	0,30 mm	A3	0,90

Assessment of the tests

The following assessment shall be made for each tested fastener size. If several embedment depths are assessed, tests shall be performed with the maximum embedment depth, which does not cause steel failure. The aim is to compare the load displacement behaviour with and without exposure to alkaline and acid conditions of the fastener's expansion zone. The assessment shall show if the coating is essentially affected by exposure to alkalinity and acid that leads to a more unfavourable post-expansion behaviour after 2000 h of exposure for working life 50 years.

Failure loads (separately for cracked and uncracked concrete):

- Determine the mean value of failure loads $N_{u,m}$ [N], converted to the nominal concrete strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Determine $N_{Rk,0}= N_{u,5\ \%}$ [kN] (5 % fractile of the failure loads), converted to the nominal concrete strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- If the coefficient of variation cv > 15 %, determine the reduction factor for large scatter $ß_{cv}$ in accordance with Clause A.2.2.
- Determine the reduction factor α in accordance with Clause A.2.4. The following test series shall be used as corresponding reference test series:
  - For fasteners for use in cracked concrete use test series A3.
  - For fasteners for use in uncracked concrete use test series A1.
- Use the reduction factor α together with rqd. α = 0,90.

Load displacement behaviour (separately for cracked and uncracked concrete):

- Determine the load N_{Sl} [N] in accordance with Clause A.2.5.
- Where the requirement given in Equations (A.2.5.1) and (A.2.5.2) is not met in a test, meaning $N_{sl,t} < 0{,}7\ N_{Ru,t}$ and $N_{sl,t} < 0{,}8\ N_{Ru,t}$, respectively, the reduction factor α_1 shall be determined according to Equation (A.2.5.3).
- Use the reduction factor α_1 together with rqd. α_1 = 0,7 (in cracked concrete) and α_1 = 0,8 (in uncracked concrete) in Equation (A.2.5.3).
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Num}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv($\delta_{0,5Num}$) [%] in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm the cv($\delta_{0,5Num}$) shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results

For uncracked concrete:

$N_{Rk,0,ucr}$ [N], $ß_{cv}$, α_1 [-], α/rqd. α to be used in accordance with Clause 2.2.2.10.

For cracked concrete:

$N_{Rk,0,cr}$ [N], $ß_{cv}$, α_1 [-], α/rqd. α to be used in Clause 2.2.2.10.

2.2.20.1.2 Assessment of installed fasteners exposed to alkaline and acid conditions

These tests shall be performed if the criteria in accordance with Clause 2.2.20.1.1 with fasteners directly exposed to alkaline and acid conditions are not fulfilled.

2.2.20.1.2.1 Alkali storage conditions for installed fasteners

The fasteners shall be installed in a concrete surface that has been cast against a form of the test member in accordance with Clause A.3.1.4. The fasteners shall be installed according to the MPII of the manufacturer to be exposed to alkaline liquid as shown in Figure 2.2.20.1.2.1.1. For the tests in cracked concrete at storage the crack shall be closed (hairline crack). The torque T_{inst} shall be applied.

The alkaline solution shall be prepared by mixing water with KOH pellets until pH = 13,2 is achieved.

Above the fasteners a section of a plastic pipe shall be placed and sealed with, e.g., silicone to the concrete surface. The alkaline solution shall be filled into the pipe. The level of the alkaline solution above the concrete surface shall be at least 5 cm for the entire test duration.

Figure 2.2.20.1.2.1.1 Storage in alkalinity or acid environment of the fasteners installed fasteners in concrete

The alkalinity shall be pH = 13,2 with a tolerance of -0,20, +0,80 during the storage. Therefore, the pH-value shall be checked and recorded in 24 hours intervals.

The storage time without any interruption shall be at least 2000 h representing 50 years working life.

2.2.20.1.2.2 Acid storage conditions for installed fasteners

The fasteners shall be installed in a concrete surface that has been cast against a form of the test member in accordance with Clause A.3.1.4. The fasteners shall be installed according to the MPII of the manufacturer and stored in acid liquid. For the storage in cracked concrete at storage the crack shall be closed (hairline crack). The torque T_{inst} shall be applied.

The acid environment shall be mixed with sulphurous solution. By adding, e.g., sulfuric acid to water the pH value shall be decreased until it is approximately pH = 3,0.

Above the fasteners a section of a plastic pipe shall be placed and sealed with, e.g., silicone to the concrete surface. The acid solution shall be filled into the pipe. The level of the acid solution above the concrete surface shall be at least 5 cm for the entire test duration.

The acid shall be pH = 3,0 with a tolerance of ± 0,5 during the storage. Therefore, the pH-value and the level in the pipe shall be checked and recorded in 24 hours intervals.

The storage time without any interrupt shall be at least 2000 h representing 50 years working life.

2.2.20.1.2.3 Functional tests after storage of installed fasteners in concrete

Description of the tests

The fasteners place in uncracked concrete shall be loaded until failure of the fasteners and the load displacement behaviour shall be recorded. All other conditions for test series A1 and A3 shall be fulfilled for the tests with an exposure to alkaline and acid conditions including the detail of tests.

The tests A1 and A3 shall be performed in accordance with Clause 2.2.2.1.

Table 2.2.20.1.2.3.1 Summary of the tension tests

Test	d_{nom}	stainless	galvanized	Concrete	d_{cut}	Crack width	Reference	rqd α
Alkaline	m	5	5	C20/25	$d_{cut,m}$	0	A1	0,90
Alkaline	m	5	5	C20/25	$d_{cut,m}$	0,30 mm	A3	0,90
Acid	m	5	-	C20/25	$d_{cut,m}$	0	A1	0,90
Acid	m	5	-	C20/25	$d_{cut,m}$	0,30 mm	A3	0,90

The storage time without any interrupt shall be at least 2000 h representing 50 years working life.

Assessment of the tests

The following assessment shall be made for each tested fastener size. If several embedment depths are assessed, tests shall be performed with the maximum embedment depth, which does not cause steel failure. The aim is to compare the load displacement behaviour with and without storage of the fastener's expansion zone. The assessment shall indicate if the coating is essentially affected by exposure to alkalinity and acid that leads to a more unfavourable post-expansion behaviour 2000 h representing 50 years working life of exposure.

Failure loads:

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength in accordance with Clause A.2.1, accounting for the relevant failure mode.
- Determine $N_{Rk,0}$ from the 5 % fractile of the failure loads $N_{u,5\,\%}$ [kN], converted to the nominal concrete strength in accordance with, Clause A.2.1, accounting for the relevant failure mode.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 15 % (cv > 15 %), determine the reduction factor for large scatter $ß_{cv}$ in accordance with Clause A.2.2.
- Determine the reduction factor α in accordance with A.2.4. The following test series shall be used as corresponding reference test series:
  - For fasteners for use in cracked concrete use test series A3.
  - For fasteners for use in uncracked concrete use test series A1.
- Use the reduction factor α_1 together with rqd. $\alpha = 0{,}90$.

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load N_{Sl} [kN] in accordance with Clause A.2.5.
- Where the requirement given in Equations (A.2.5.1) and (A.2.5.2) is not met in a test, meaning $N_{sl,t} < 0{,}7\, N_{Ru,t}$ and $N_{sl,t} < 0{,}8\, N_{Ru,t}$, respectively, the reduction factor α_1 shall be determined according to Equation (A.2.5.3).
- Use the reduction factor α_1 together with rqd. $\alpha_1 = 0{,}7$ (in cracked concrete) and $\alpha_1 = 0{,}8$ (in uncracked concrete) in Equation (A.2.5.3).
- Determine the displacements at 50 % of the mean failure load $\delta_{0,5Num}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50 % of the mean failure load cv($\delta_{0,5Num}$) [%] in accordance with A.2.6. If the displacements at 50 % of the failure load are greater than 0,4 mm the cv($\delta_{0,5Num}$) shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

Expression of results

$N_{Rk,0}$ [N], $ß_{cv}$, α_1 [-], α/rqd. α to be used in Clause 2.2.2.10.

2.2.20.1.3 General assessment of coating

The durability of the coating that ensures the functioning and the bearing behaviour of the fastener shall be shown.

The following environmental conditions shall be taken into account in assessing durability of coatings:

dry internal conditions
  - high alkalinity (pH ≥ 13.2)
  - temperature in range -5°C to +40°C

other environmental conditions

- high alkalinity (pH ≥ 13.2)
- temperature in range -40°C to +80°C
- condensed water
- chlorides
- sulphur dioxide
- nitrogen oxide
- ammonia

Zinc coatings (electroplated or hot dip galvanized) need not be subjected to testing if used under dry internal conditions only.

2.2.20.2 Durability of zinc-based coatings for TC in uncracked concrete only for variable working life

Purpose of the assessment

If torque-controlled expansion fasteners TC in accordance with Figure 1.1.1 with zinc-based coating are intended to be used in other environmental conditions than given in 2.2.20 (1), the durability (corrosion resistance) shall be assessed for a reduced working live (less than or equal to 50 years) for corrosivity categories as given in EN ISO 9223 [26] Table C.1.

Assessment method

A reduced working life of a zinc based coated fastener, e.g., hot dipped galvanized fasteners in accordance with EN ISO 10684 [13] shall be calculated based on the minimum thickness of the zinc-based coating according to the technical specification of the torque-controlled fastener TC using the corrosion rate r_{corr} for a given corrosivity category in accordance with EN ISO 9223 [26].

Often fasteners with a thickness of the zinc-based coating of 50 μm are used. Therefore, an example is given in Table 2.2.20.2.1.

Table 2.2.20.2.1 Corrosion rates for zinc-based coated coatings for different corrosivity categories

Corrosivity category in accordance with EN ISO 9223 [26] Table C.1	Corrosion rate r_{corr} in μm/a (based on EN ISO 9223 [26] Table 2)	Example of reduced working life for a zinc-based coating of minimum 50 μm in years
C1	0,1	500 a $^{1)}$
C2	0,7	75 a $^{1)}$
C3	2,0	25 a
C4	4,0	12,5 a
C5	8,4	5 a
CX	25	2 a

$^{1)}$ Limited by the working life in accordance with Clause 1.2.2

Expression of results

The working life shall be stated in the ETA depending on the thickness of the coating and the corrosivity category in accordance with EN ISO 9223 [26].

3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

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

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

The system is 1.

3.2 Tasks of the manufacturer

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

Table 3.2.1 Control plan for the manufacturer; cornerstones

No	Subject/type of control *(product, raw/constituent material, component - indicating characteristic concerned)*	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC) [including testing of samples taken at the factory in accordance with a prescribed test plan]					
1	Dimensions (outer diameter, inner diameter, thread length, etc.)	Calliper 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 [24], EN ISO 3506-1 [25]		3	
3	Yield strength *)	EN ISO 6892-1 [23], EN ISO 898-1 [24], EN ISO 3506-1 [25]		3	
4	Core hardness and Surface hardness (at specified functioning relevant points of the product) – where relevant	Tests in accordance with EN ISO 6507 [21] or EN ISO 6508 [22]		3	
5	Roughness of cone - where relevant	profile method: EN ISO 12085 [14] Software measurement standards: EN ISO 5436 [20] calibration : EN ISO 12179 [15]		3	
6	Zinc plating - where relevant	x-ray measurement according EN ISO 3497 [19], magnetic method according EN ISO 2178 [16], Phase-sensitive eddy-current method according EN ISO 21968 [17]		3	
7	Fracture elongation - where relevant	EN ISO 6892-1 [23] EN ISO 898-1 [24]		3	
8	Hard metal tip of fastener made of stainless steel - where relevant	Check of material, geometry, position and fixing to stainless steel		3	

*) Tests in accordance with this standard, however, however are, if necessary, performed on the finished product with the corresponding adaptations agreed with the TAB (e.g., geometrical aspects)

**) The lower control interval is decisive

3.3 Tasks of the notified body

The cornerstones of the actions to be undertaken by the notified body in the procedure of assessment and verification of constancy of performance for mechanical fasteners are laid down in Table 3.3.1.

Table 3.3.1 Control plan for the notified body; cornerstones

No	Subject/type of control *(product, raw/constituent material, component - indicating characteristic concerned)*	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control					
1	Notified Body will ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the "mechanical ***fastener***".	Verification of the complete FPC as described in the control plan agreed between the TAB and the manufacturer	According to Control plan	According to Control plan	When starting the production or a new line
Continuous surveillance, assessment and evaluation of factory production control					
2	The Notified Body will ascertain that the system of factory production control and the specified manufacturing process are maintained taking account of the control plan.	Verification of the controls carried out by the manufacturer as described in the control plan agreed between the TAB and the manufacturer with reference to the raw materials, to the process and to the product as indicated in Table 3.2.1	According to Control plan	According to Control plan	1/year

4 REFERENCE DOCUMENTS

[1] EAD 330232-01-0601 Mechanical fasteners for use in concrete

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

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

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

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

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

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

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

[9] EN 1990:2023 Eurocode - Basis of structural and geotechnical design

[10] EN 1992-4:2018 Design of concrete structures — Part 4: Design of fastenings for use in concrete

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

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

[13] EN ISO 10684:2004 + AC:2009 Fasteners – Hot dip galvanized coatings (ISO 10684:2004 + Cor. 1:2008)

[14] EN ISO 12085:1997/AC:2008 Geometrical Product Specifications (GPS) - Surface texture: Profile method - Motif parameters (ISO 12085:1996); German version EN ISO 12085:1997, Corrigendum to DIN EN ISO 12085:1998-05;

[15] EN ISO 12179:2022 Geometrical product specifications (GPS) - Surface texture: Profile method - Calibration of contact (stylus) instruments (ISO 12179:2021)

[16] EN ISO 2178:2016 Non-magnetic coatings on magnetic substrates - Measurement of coating thickness - Magnetic method

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

[18] EN ISO 22479:2022 Corrosion of metals and alloys - Sulfur dioxide test in a humid atmosphere (fixed gas method)

[19] EN ISO 3497:2000 Metallic coatings - Measurement of coating thickness - X-ray spectrometric methods

[20] EN ISO 5436-1:2000 Geometrical Product Specifications (GPS) - Surface texture: Profile method; Measurement standards - Part 1: Material measures

[21] EN ISO 6507-1:2023 Metallic materials - Vickers hardness test - Part 1: Test method (ISO 6507-1:2023)

[22] EN ISO 6508-1:2023 Metallic materials - Rockwell hardness test - Part 1: Test method (ISO 6508-1:2023)

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

[24] 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
[25] EN ISO 3506-1:2020	Fasteners - Mechanical properties of corrosion-resistant stainless-steel fasteners - Part 1: Bolts, screws and studs with specified grades and property classes (ISO 3506-1:2020)
[26] EN ISO 9223:2012	Corrosion of metals and alloys - Corrosivity of atmospheres - Classification, determination and estimation (ISO 9223:2012)
[27] EN ISO/IEC 17025:2017	General requirements for the competence of testing and calibration laboratories.
[28] EAD 330011-00-0601	Adjustable concrete screws

For further information

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

ANNEX A TEST PROGRAMME AND GENERAL ASPECTS OF ASSESSMENT

A.1 Test programme

The test programme for the assessment consists of

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

Table A.1.1 Test programme

N°	Purpose of test	Concrete	Crack width	Size	d_{cut}	n_{min}	rqd. α	Required for	Clause
Resistance to steel failure under tension load									
N1	Steel capacity	-	0	All	-	5	-	All	2.2.1.1
N2	Maximum torque	C50/60	0	All	$d_{cut,m}$	5		TC, UC, DC	2.2.1.2
N3	Hydrogen induced embrittlement	C50/60	0	All	$d_{cut,m}$	5	0,90	CS	2.2.1.3
Basic tension tests									
A1	Basic tension tests	C12/15 C20/25	0	All	$d_{cut,m}$	5 14)	-	Option 1-12	2.2.2.1
A2		C50/60 max	0	All		5 14)		CS: all options as reference for N3, All other: Option 7, 9, 11 1)	
A3		C12/15 C20/25	0,30	All		5 14)		Option 1-6	
A4		C50/60 max	0,30	All		5 14)		Option 1, 3, 5 1)	
Resistance to pull-out failure									
F1	Maximum crack width and large hole diameter	C12/15 C20/25	0	s/m/l	$d_{cut,max}$	5 3)	0,80	Option 7-12	2.2.2.2
		C12/15 C20/25	0,50	All				Option 1-6	
F2	Maximum crack width and small hole diameter	C50/60 max	0	s/m/l	$d_{cut,min}$	5 3)	1,00	Option 7-12	2.2.2.3
		C50/60 max	0,50	All			0,80	Option 1-6	
F3	crack cycling under load	C12/15 C20/25	0,10-0,30	All	$d_{cut,max}$	5 3)	0,90	TC, DC Option 1-6	2.2.2.4
		C12/15 C20/25			$d_{cut,m}$			UC, CS Option 1-6	
F4	repeated loads	C12/15 C20/25	0	m	$d_{cut,m}$	3	1,00	DC, TC, UC Option 1-12	2.2.2.5
		C12/15 C20/25		All		5		CS Option 1-12	
		C50/60 max		m		3		DC, TC, Option 7-12	
F5	Robustness of sleeve down type fasteners	C12/15 C20/25	0	All	$d_{cut,m}$	5	0,80	DC	2.2.2.6
		C12/15 C20/25	0,50						

N°	Purpose of test	Concrete	Crack width	Size	d_{cut}	n_{min}	rqd. α	Required for	Clause
F6	Torquing in low strength concrete	C12/15 C20/25	0	All	$d_{cut,max}$	10		CS	2.2.2.7
F7	Torquing in high strength concrete	C50/60 max	0	All	$d_{cut,min}$	10		CS	2.2.2.8
F8	Impact screw driver	C12/15 C20/25 (C50/60)	0	All	$d_{cut,max}$ ($d_{cut,min}$)	15		CS	0
F9	Robustness to variation in use conditions	C12/15	0	s/m/l 5)	4)	5 3)	0,95	Option 7-12	2.2.4.1
		C20/25							
		(C50/60) 4)	0,30	All			0,80	UC, DC, CS Option 1-6	
		max							
		C50/60					0,70	TC Option 1-6	
		max							
F10	Robustness to contact with reinforcement	C20/25	0,30	s/m 2)	$d_{cut,m}$ $d_{cut,max}$	5 3)	0,85 0,70 0,60	UC: Option 1-6 CS: Option 1-6	2.2.4.2
F11	Minimum edge distance and spacing	C12/15 C20/25	0	All	$d_{cut,m}$	5	-	Option 1-12	2.2.5
F12	Edge distance to prevent splitting under load	C20/25	0	All	$d_{cut,m}$	4	-	Option 1-12	2.2.6
Characteristic Resistance to shear load									
V1	Characteristic resistance to steel failure-under shear load	C12/15 C20/25	0	All	$d_{cut,m}$	5	-	Option 1-12	2.2.7.1
V2	Characteristic resistance to pry-out failure	C20/25	0	All		5		Option 1-12 7)	2.2.8
V3	Group of fasteners	C20/25	0	All	$d_{cut,m}$	5	-	CS 8)	2.2.7.2
Characteristic Resistance for seismic performance category C1									
C1.1	Functioning under pulsating tension load 3)	C20/25	0,5 9)	All	$d_{cut,m}$	5 10)	-	Option 1-6	2.2.12
C1.2	Functioning under alternating shear load 4)	C20/25	0,5 9)	All	$d_{cut,m}$	5 10)	-	Option 1-6	2.2.13
Characteristic Resistance for seismic performance category C2									
C2.1a	Reference tension tests in low strength concrete	C20/25	0,8 9)	All	$d_{cut,m}$	5 11)	-	Option 1-6	2.2.14.1
C2.1b	Tension tests in high strength concrete	C50/60	0,8 9)	All	$d_{cut,m}$	5 11)	-	Option 1-6	2.2.14.1
C2.2 3)	Reference shear tests	C20/25	0,8 9)	All	$d_{cut,m}$	5 11)	-	Option 1-6	2.2.15.1
C2.3	Functioning under pulsating tension load	C20/25	0,5 / 0,8	All	$d_{cut,m}$	5 11)	-	Option 1-6	2.2.14.2
C2.4	Functioning under alternating shear load	C20/25	0,8 9)	All	$d_{cut,m}$	5 11)	-	Option 1-6	2.2.15.2
C2.5	Functioning with tension load under varying crack width 13)	C20/25	Δ_{w1}=0,0 Δ_{w2}=0,8	All	$d_{cut,m}$	5 11)	-	Option 1-6	2.2.14.3
Resistance to Fire									
Fi1	Fire resistance to steel failure under tension load	C20/25	0	s/m	$d_{cut,m}$	5	-	Option 1-6	2.2.17
Fi2	Fire resistance to pull-out failure	C20/25	0,1-0,25	s/m	$d_{cut,m}$	5	-	Option 1-6	2.2.18
Fi3	Fire resistance to steel failure under shear load	C20/25	0	s/m	$d_{cut,m}$	5	-	Option 1-6	2.2.19

1) The tests shall be performed, if in the reference tension tests in concrete strength class C20/25 pull-out or concrete failure is observed.

[2] Necessary only for undercut fasteners and concrete screws with h_{ef} < 80 mm to be used in ~~test~~ members with a spacing of reinforcement a < 150 mm.

[3] If fewer than three sizes of the fastener are tested together and/or the different sizes are not similar in respect of geometry, friction between cone and sleeve (internal friction) and friction between sleeve and concrete (external friction), then the number of tests shall be increased to 10 for all sizes of the fastener.

[4] Test conditions are detailed in Clause 2.2.4.1.

[5] For fasteners that are not similar in respect of geometry and/or friction aspects all sizes shall be tested.

[6] Test conditions are detailed in Clause 0.

[7] Tests shall be omitted, if default values are used, see Clause 2.2.8.

[8] Tests shall be omitted, see Clause 2.2.7.2.

[9] Crack width added to the hairline crack width after fastener installation but before loading of fastener.

[10] Test all fastener diameters to be assessed for use in seismic applications. For different fastener types to be tested see A.5.2.

[11] Test all fastener diameters for which the fastener shall be assessed for use in seismic applications. For fasteners with different steel types, steel grades, production methods, head configurations (mechanical fasteners), types of inserts, multiple embedment depths and drilling methods see A.4.

[12] 0,5 ($\leq 0{,}5 \cdot N/N_{max}$); 0,8 ($> 0{,}5 \cdot N/N_{max}$). The tests may also be conducted in Δw = 0,8 mm at all load levels (N/N_{max}).

[13] Δw_1 = 0,0 mm is defined in 2.2.14.3.

[14] The assessment for effectiveness factors requires tests in at least 2 batches, see 2.2.3.

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

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

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

Note: The surface roughness of the drill hole is assumed to be comparable between the reference hammer drilling and hollow drilling. But depending for hollow drill bits, the diameter of drilled holes may be different compared to the standard drilling method. Therefore, tests with hollow drill bits are required in accordance with A.4 to show equivalence between the reference drilling method and hollow drilling. The tested drill bit diameter ($d_{cut,max}$) shall be stated in the ETA as upper limit for this drilling method, if it is different to the tolerances in accordance with Table A.3.1.4.1.

Note: The surface roughness of the drill hole is less rough with diamond core drilling than with hammer drilling.

Note: Depending on the type of diamond drill bit, the diameter of drilled holes may be smaller or larger. Therefore the tested drill bit diameter ($d_{cut,max}$) shall be stated in the ETA as upper limit for this drilling method if it is different to the tolerances in accordance with Table A.3.1.4.1.

For fasteners assessed for variable embedment depth, the required embedment depth for the test programme is given in Table A.1.3. This table represents the overview for the minimum required testing. Depending on the selected options tests at additional embedment depths may be performed.

Test series F10 shall be performed with the given h_{ef} if embedment depths less than 80 mm are requested by the applicant.

Test series N2 shall be performed with an embedment depth associated to the largest value of T_{inst}.

Table A.1.3 Required embedment depth for the minimum required test programme

Embedment depth to be tested for given diameter	Test series performed for embedment depths
$h_{ef,min}$	N3, A1, A2, A3, A4, F1[a)b)], F2 [a)b)], F3 [a)], F6, F8[c)], F9, F10 (CS), F11, F12, V1, V2, C1.1 [a)], C1.2, C2.1a [a)], C2.1b [a)], C2.2, C2.3 [a)], C2.4, C2.5 [a)]
$h_{ef,max,t}$	N1, N2, N3, A1, A2, A3, A4, F1, F2, F3, F4, F7, F8[d)], F9, F10 (CS;UC), F12, V3, C1.1, C1.2 [e)], C2.1a, C2.1b, C2.3, C2.5

[a)] This test series is required for concrete screws (CS) only.

[b)] tests in cracked concrete are required for the assessment for seismic performance category C2.

[c)] applies to tests in concrete C20/25.

[d)] applies to tests in concrete C50/60.

[e)] The tests with $h_{ef,max}$ shall be performed, if pull-out or concrete failure with $h_{ef,min}$ occurs.

Provisions for all test series

As far as applicable the Annex A shall be followed for the test members, test setup and performance of the tests. The tension tests shall be performed with unconfined test setup.

Handling of tests and calibration items shall be performed in accordance with EN ISO/IEC 17025 [27].

If the fastener bolts are intended to be installed with more than one embedment depth, in general, the tests shall be carried out with all embedment depths. In special cases, e.g., when steel failure occurs, the number of tests shall be reduced.

As reference drilling and cleaning method only one method shall be defined, for which the complete test programme in accordance with Table A.1.1 has been conducted. This also applies to assessments of seismic category C1 and fire resistance in accordance with 2.2.17, 2.2.18 and 2.2.19. Current practice is to take the rotary hammer drilling method with hard-metal drill bit as reference method. If more than one drilling method is used, Clause A.4 describes the supplementary test programme. It differentiates between hollow drilling and the additional drilling method diamond core drilling. A reduced test programme shall be executed (Table A.4.1 for hollow drilling, Table A.4.2 for additional drilling method diamond core drilling), if equivalence can be shown in these series with the reference drilling. If equivalence cannot be shown, more test series shall be performed (Table A.4.3).

A.2 General assessment methods

A.2.1 Conversion of failure loads to nominal strength

The conversion of failure loads shall be done in accordance with Equation (A.2.1.1) to (A.2.1.8) depending on the failure mode.

Concrete failure	$N_{u,m}(f_{ck}) = N_{u,m,test} \cdot \left(\frac{f_{ck}}{f_{c,test}}\right)^{0.5}$	[N]	for $f_{ck} < f_{c,test}$	(A.2.1.1)
Pull-out failure	$N_{u,m}(f_{ck}) = N_{u,m,test} \cdot \left(\frac{f_{ck}}{f_{c,test}}\right)^{m}$	[N]	for $f_{ck} < f_{c,test}$	(A.2.1.2)
	$m_{ucr} = \frac{log\left(\frac{N_{u,m,A2}}{N_{u,m,A1}}\right)}{log\left(\frac{f_{c,t,A2}}{f_{c,t,A1}}\right)} \leq 0{,}50$			(A.2.1.3)
	$m_{cr} = \frac{log\left(\frac{N_{u,m,A4}}{N_{u,m,A3}}\right)}{log\left(\frac{f_{c,t,A4}}{f_{c,t,A3}}\right)} \leq 0{,}50$			(A.2.1.4)
	$\psi_{c,xx} = \left(\frac{f_{ck,xx}}{f_{ck,20}}\right)^{m}$	1)		(A.2.1.5)
Steel failure	$N_{u,m}(f_u) = N_{u,m,test} \cdot \left(\frac{f_u}{f_{u,test}}\right)$	[N]		(A.2.1.6)
	$V_{u,m}(f_u) = V_{u,m,test} \cdot \left(\frac{f_u}{f_{u,test}}\right)$	[N]		(A.2.1.7)
	For fasteners with a sleeve in the shear plane: $V_{u,m}(f_u) = V_{u,m,test} \cdot \left(\frac{f_u}{f_{u,test}} \cdot \frac{A_{s,bol}}{A_{s,fas}} + \frac{f_{u,sle}}{f_{u,sle,test}} \cdot \frac{A_{s,sle}}{A_{s,fas}}\right)$ [N]			(A.2.1.8)

1) If no distinction is made for cracked and uncracked conditions, the factor m shall be determined as the minimum of Equations (A.2.1.3) and (A.2.1.4).

where

$A_{s,bol}$ = [mm^2] - effective cross section of bolt;
$A_{s,sle}$ = [mm^2] - effective cross section of sleeve;
$A_{s,fas}$ = [mm^2] - $A_{s,bol}$ + $A_{s,sle}$.
$N_{u,m}$ = [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_{ck} = [N/mm^2] - mean compressive strength of concrete to which the capacity shall be normalized;
$f_{c,test}$ = [N/mm^2] - mean compressive strength of concrete used at the time of testing;
f_u = [N/mm^2] - mean ultimate steel strength of bolt, threaded rod or insert to which the capacity shall be normalized;
$f_{u,sle}$ = [N/mm^2] - mean ultimate steel strength of the sleeve to which the capacity shall be normalized;
$f_{u,sle,test}$ = [N/mm^2] - ultimate steel strength of the sleeve of fasteners used in the tests;
$f_{u,test}$ = [N/mm^2] - ultimate mean steel strength of bolt, threaded rod or insert of fasteners used in the tests;
m = normalization exponent in accordance with Equations (A.2.1.3) and (A.2.1.4).

Adjustment for different steel strengths in Equation (A.2.1.6) 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.

A.2.2 Criteria regarding scatter of failure loads

If the coefficient of variation of the failure load in any basic test series exceeds 15 % and is not greater than 30 %, the following reduction shall be taken into account:

$$\beta_{cv} = \frac{1}{1+0{,}03(cv_F - 15)} \le 1{,}0 \qquad \text{(A.2.2.1)}$$

If the coefficient of variation of the failure load in any other test series exceeds 20 % and is not greater than 30 %, the following reduction shall be taken into account:

$$\beta_{cv} = \frac{1}{1+0{,}03(cv_F - 20)} \le 1{,}0 \qquad \text{(A.2.2.2)}$$

If the maximum limit for the coefficient of variation of the failure loads of 30 % is exceeded the number of tests shall be increased to meet this limit. This EAD does not cover fasteners for which this limit cannot be achieved.

If the coefficient of variation is smaller than the criteria mentioned above, $\beta_{cv} = 1{,}0$.

The smallest result of $ß_{cv}$ shall be taken for assessment.

A.2.3 Establishing 5 % fractile

The 5 % fractile of the ultimate loads measured in a test series shall be calculated according to statistical procedures for a confidence level of 90 %. If a precise verification does not take place, a normal distribution and an unknown standard deviation of the population shall be assumed.

$$F_{u,5\%} = F_{u,m}(1 - k_s \cdot cv_F) \qquad \text{(A.2.3.1)}$$

$$F_{u,95\%} = F_{u,m}(1 + k_s \cdot cv_F) \qquad \text{(A.2.3.2)}$$

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

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

Note 1: The confidence level of 90 % is defined for characteristic resistance of fasteners in EN 1992-4 [10] and is therefore used for the assessment in this EAD.

A.2.4 Determination of reduction factors α

For all any other test series the mean failure loads and 5 % fractile of failure loads shall be compared with the corresponding reference test series of basic tension tests:

$$\alpha = min\left\{\frac{F_{u,m,t}}{F_{u,m,r}};\frac{F_{u,5\%,t}}{F_{u,5\%,r}}\right\} \qquad \text{(A.2.4.1)}$$

If the number of tests in both series is n ≥ 10, the comparison of the 5 % fractile of failure loads shall be done under assumption of a k-value of 1,645 for the determination of the factor α only.

The comparison of the 5 % fractile shall 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 %.

For tests for robustness to variation in use conditions and robustness to contact with reinforcement the reduction factor α is used to determine the factor γ_{inst}.

For all other test series, the following references shall be used for the comparison in accordance with Equation (A.2.4.1):

- $F_{u,m,r} = N_{Rk,c} / 0{,}75$
- $F_{u,5\%,r} = N_{Rk}$ (characteristic resistance given in the ETA)

A.2.5 Criteria for uncontrolled slip under tension loading

The load/displacement curves shall show a steady increase (see Figure A.2.5.1). A reduction in load and/or a horizontal part in the curve caused by uncontrolled slip of the fastener is not acceptable up to a load of:

Tests in cracked concrete: $N_{sl} = 0{,}7\ N_{Ru}$ (A.2.5.1)

Tests in uncracked concrete $N_{sl} = 0{,}8\ N_{Ru}$ (A.2.5.2)

Where the criteria given in Equations (A.2.5.1) and (A.2.5.2) is not met in a test, meaning $N_{sl,t} < 0{,}7\ N_{Ru,t}$ and $N_{sl,t} < 0{,}8\ N_{Ru,t}$, respectively, the reduction factor α_1 shall be determined in accordance with Equation (A.2.5.3)

$\alpha_1 = N_{sl,t} / N_{Ru,t}$ (A.2.5.3)

Where

$N_{sl,t}$ = load level where uncontrolled slip occurs in the test

$N_{Ru,t}$ = ultimate load in the test

This reduction shall be omitted if, within an individual series of tests, not more than one test shows a load/displacement curve with a short plateau below the value determined by Equation (A.2.5.1), provided all of the following conditions are met:

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

The lowest value for α_1 / rqd. α_1, with rqd. $\alpha_1 = 0{,}7$ for tests in cracked concrete and rqd. $\alpha_1 = 0{,}8$ for tests in uncracked concrete, in all tests is inserted into Equation (2.2.2.10.1) and (2.2.2.10.2).

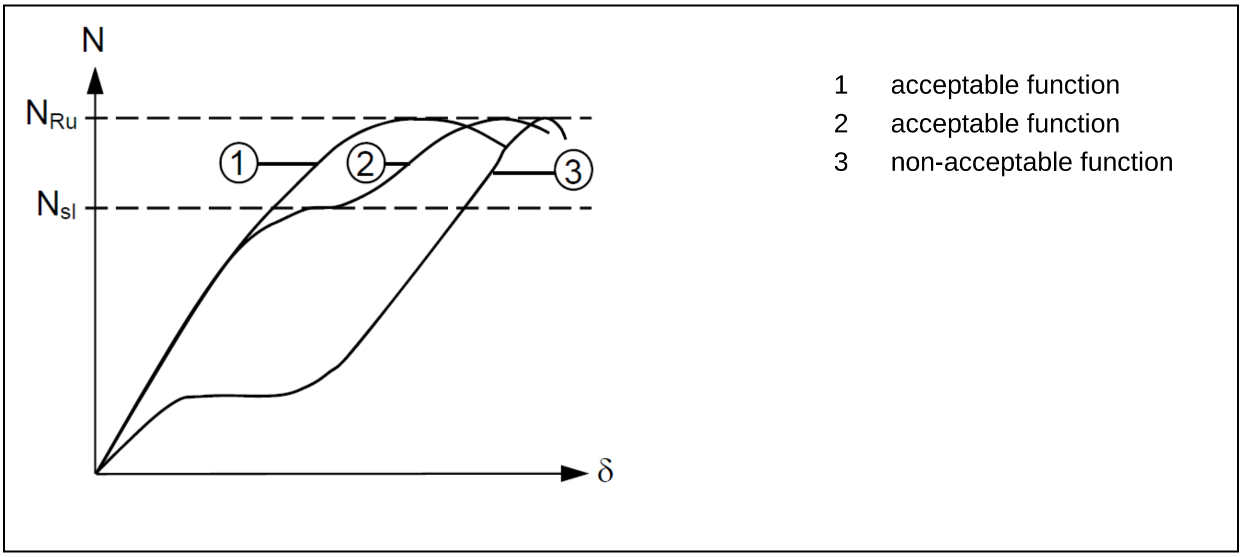


Figure A.2.5.1 Examples for load/displacement curves

Uncontrolled slip is defined for the different types of fasteners as follows:

<u>Torque-controlled fasteners (TC)</u>

Uncontrolled slip of the fastener occurs if the expansion sleeve is moving in the drilled hole. This can be recognized by a reduction in load and/or a horizontal or nearly horizontal part in the load/displacement curve (compare Figure A.2.5.1). If in doubt about the fastener behaviour, the displacement of the expansion sleeve relative to its position in the drilled hole shall be recorded during or after the tension tests.

<u>Undercut fasteners (UC) / Concrete screws (CS)</u>

Uncontrolled slip of the fastener occurs if the expansion sleeve or expansion elements are significantly moving in the drilled hole. This can be caused by failure of the highly loaded concrete in the region of the undercut. This slip can be recognized by a reduction in load and/or a horizontal or nearly horizontal part in the load/displacement curve with a corresponding displacement of > 0,5 mm.

<u>Deformation-controlled fasteners (DC)</u>

With deformation-controlled expansion fasteners the sleeve can slip in the hole. The differences in static friction and sliding friction can lead to fluctuations in the load/displacement curve as shown in Figure A.2.5.2 (2) and (5). Furthermore, in cracked concrete after overcoming the friction resistance the tension load is transferred by mechanical interlock of the expanded fastener, resulting in a much lower fastener stiffness. This also leads to a reduction of the load taken up by the fastener over a rather short displacement interval as shown in Figure A.2.5.2 (4) and (5). This cannot be considered as uncontrolled slip.

The ultimate load is the maximum load recorded in the test independently of the displacement.

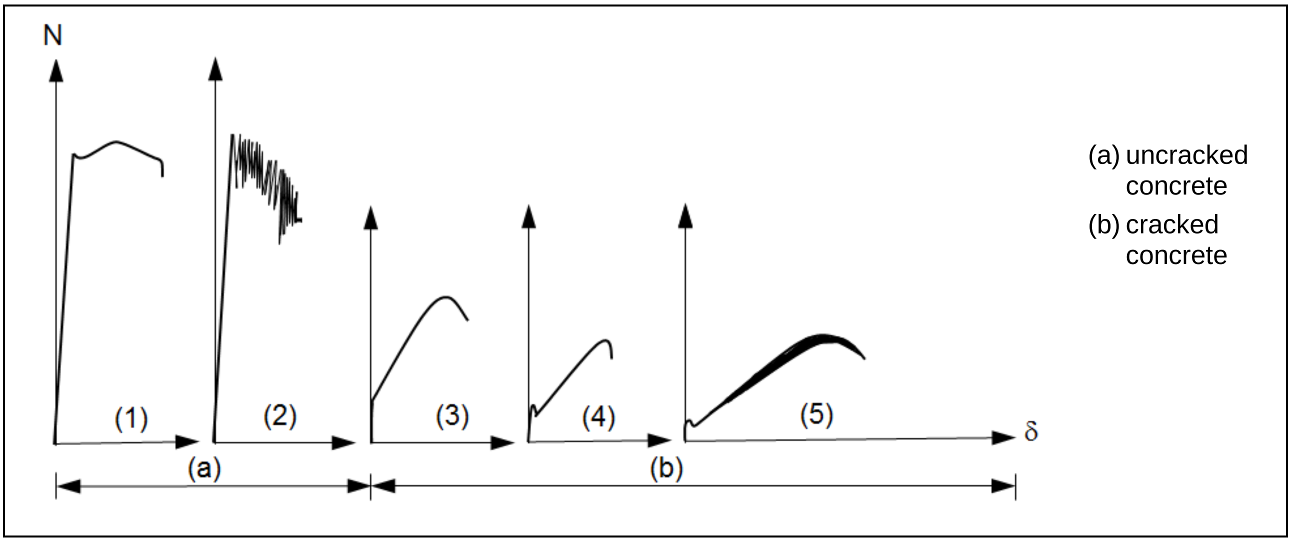


Figure A.2.5.2 Typical load/displacement behaviour

Uncontrolled slip of a fastener occurs under sliding friction conditions, when an increase of the load is only generated by inaccuracies of the drilled hole (e.g., change in diameter over its length, off centre over its length).

This can be recognized when the extension of the load/displacement curve is cutting the displacement axis at displacements $\delta \geq 0$ (see Figure A.2.5.3). The load N_{sl} is defined by the horizontal branch of the load/displacement curve.

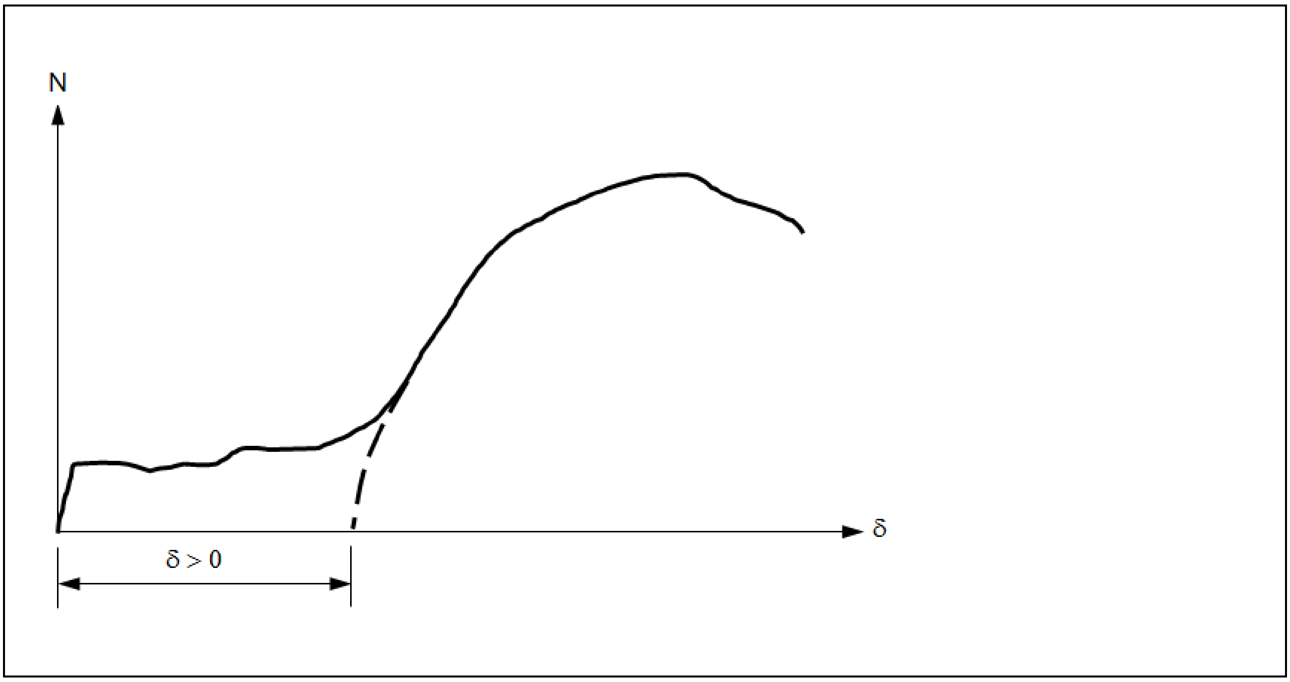


Figure A.2.5.3 Load/displacement behaviour with uncontrolled slip

The following simplification shall be used.

It is an indication of uncontrolled slip if the load/displacement curve falls below the linear connection between the peak load (ultimate load) and the zero point in any area (see Figure A.2.5.4).

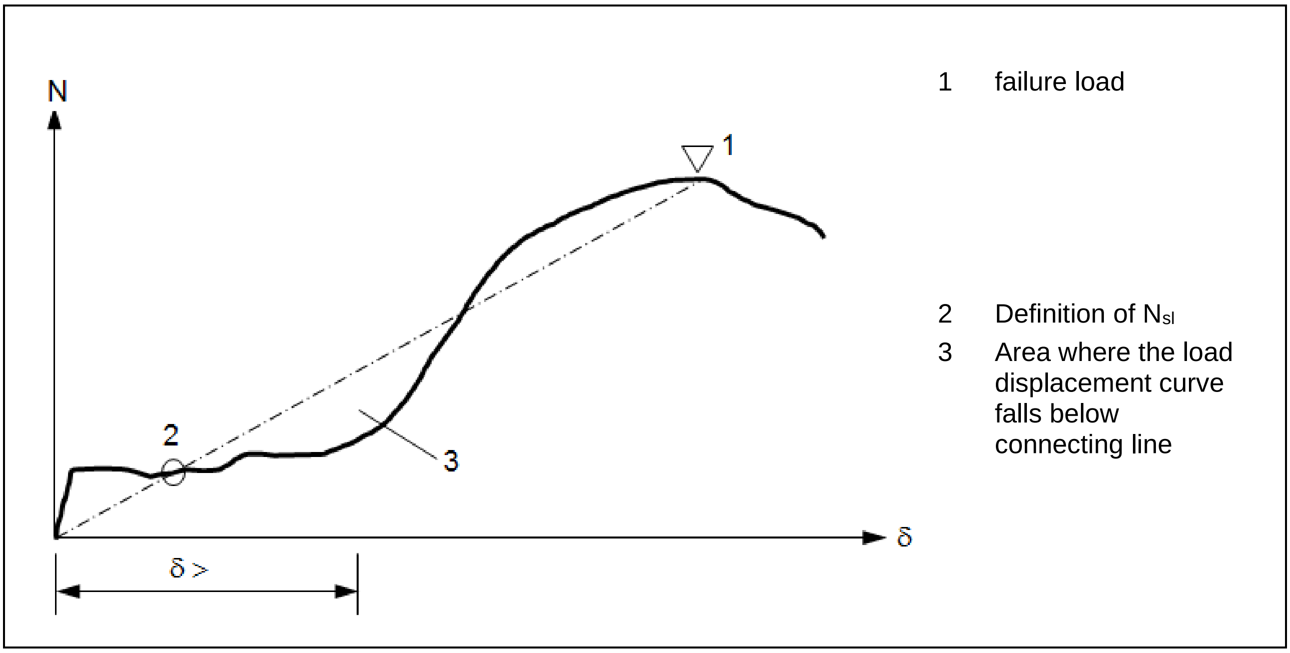


Figure A.2.5.4 Load/displacement behaviour with uncontrolled slip

The load N_{sl} as given above shall be defined as the lower interclause point of the straight line with the load/displacement curve.

In comparing results of assessments in accordance with Figure A.2.5.3 and Figure A.2.5.4, the type given in Figure A.2.5.3 will govern.

A.2.6 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 displacements at the load level of 0,5 $N_{u,m}$ in basic tension tests shall fulfil the limit given in Equation (A.2.6.1) and for any other tests the limit given in Equation (A.2.6.2)) shall be kept.

$cv_{\delta} \leq 0,25$ (basic tension tests) (A.2.6.1)

$cv_{\delta} \leq 0,40$ (any other tests) (A.2.6.2)

The load displacement curves shall be shifted according Figure A.2.6.1 for determination of the displacement at 0,5 $N_{u,m}$.

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

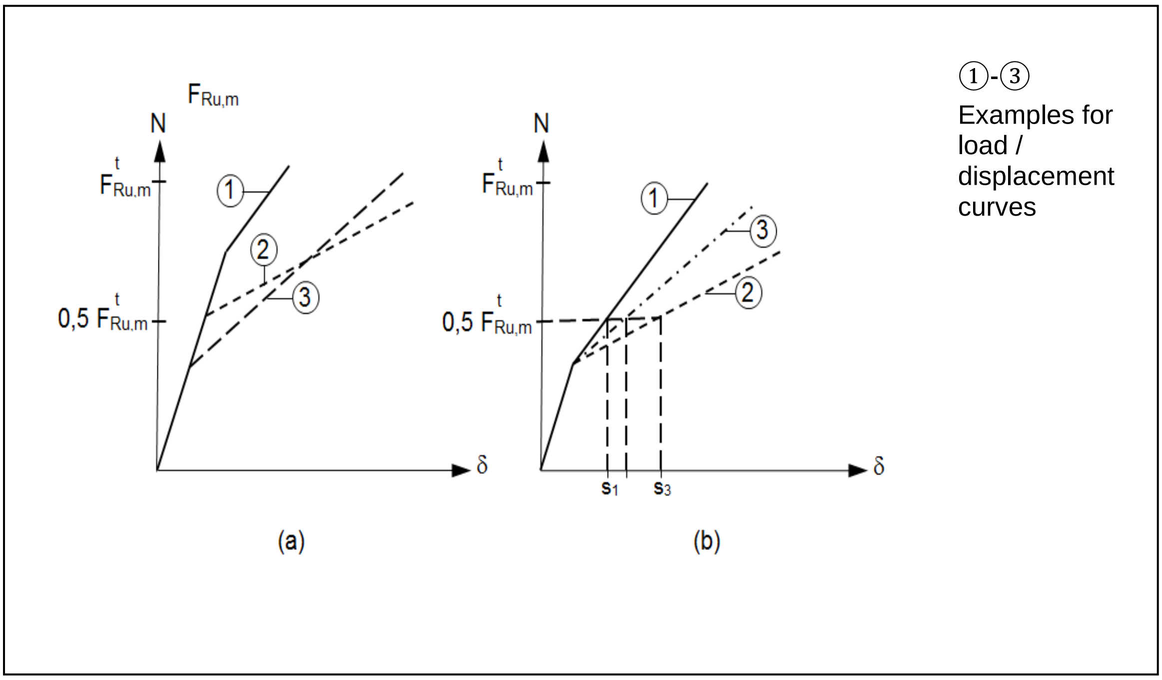


Figure A.2.6.1 Influence of pre-stressing on load/displacement curves

(a) original curves

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

A.2.7 Tests minimum concrete strength class lower than C20/25

If the fastener is intended to be used in concrete strength classes smaller than C20/25 (≥ C12/15), in addition to tests in C20/25, the required number of tests n_{min} in accordance with Table A.1.1 shall be performed, each in test members of minimum concrete class for which the assessment is requested by the manufacturer in tests series A1, A3, F1, F3 to F6, F8, F9, F11 to F12 and V1.

For assessment of test series F1, F3 to F6, F8, F9, F11 to F12 and V1, determine the reduction factor α in accordance with Equation (A.2.4.1) in the corresponding test series A1 (uncracked concrete) or A3 (cracked concrete) separately for minimum concrete strength class and C20/25.

Note: The assessments for seismic performance and fire exposure do not apply for concrete strength classes smaller than C20/25.

A.2.8 Tests in maximum concrete strength class greater than C50/60

If the fastener is intended to be used in concrete strength classes greater than C50/60 (≤ C90/105), the required number of tests n_{min} in accordance with Table A.1.1 tests series A2, A4, F2, F4, F7 to F9 shall be performed, each in high strength concrete C50/60 and in the highest requested concrete strength class (not greater than C90/105).

In accordance with EN 1992-4 [10]], Clause 7.1 (2), it is sufficient to show that the performance in high strength concrete > C50/60 meets the displacements and characteristic resistance for concrete strength class C50/60. Therefore, failure loads in tests in concrete strength classes > C50/60 shall not be normalized in accordance with Clause A.2.1.

For assessment of test series F2, F4, F7, to F9, the reduction factor α in accordance with Equation (A.2.4.1), shall be determined in the corresponding test series A2 (uncracked concrete) or A4 (cracked concrete) separately for C50/60 and the maximum concrete strength class (≤ C90/105).

Note: The assessment for seismic performance and fire exposure do not apply for concrete strength classes greater than C50/60.

A.3 Details of tests for static and quasi-static loading

A.3.1 Test specimen, test members, test setup, installation and test equipment

A.3.1.1 Test specimen

Fasteners with inner threads shall 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 is 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.

A.3.1.2 Test members

A.3.1.2.1 General

This Annex is valid for fasteners tested in test members using compacted normal weight concrete without fibres with strength classes in the range of C20/25 - C50/60 in accordance with EN 206 [12]. The fastener performance is only valid for the range of tested concrete.

The test members shall comply with the following:

A.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 A.3.1.2.2.1. The maximum aggregate size shall be 16 mm or 20 mm. The aggregate density shall be between 2,0 and 3,0 t/m^3 (see EN 206 [12]).

The boundaries reported in Figure A.3.1.2.2.1 are valid for aggregate with a maximum size of 16 mm. For different values of maximum aggregate sizes, different boundaries are adopted, if previously agreed with the responsible TAB.

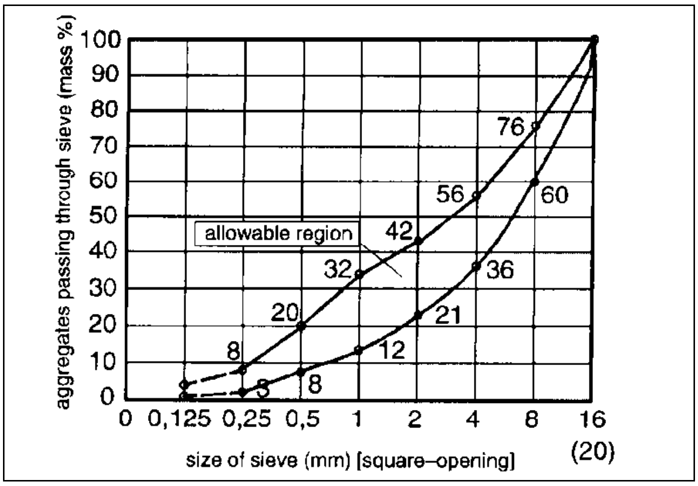


Figure A.3.1.2.2.1 Admissible region for the grading curve

A.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 [8])

A.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.

A.3.1.2.5 Concrete strength

The mean compressive strengths at the time of testing fasteners shall not exceed the nominal concrete strength + 10 N/mm².

The concrete compressive strength shall be measured 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 shall be used:

C20/25 $$f_c = \frac{1}{1{,}25} f_{cube} \qquad \text{(A.3.1.2.5.1)}$$

C50/60 $$f_c = \frac{1}{1{,}20} f_{cube} \qquad \text{(A.3.1.2.5.2)}$$

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

$$f_{cube100} = \frac{1}{0{,}95} f_{cube} \qquad \text{(A.3.1.2.5.3)}$$

$$f_{cube} = \frac{1}{0{,}95} f_{cube200} \qquad \text{(A.3.1.2.5.4)}$$

$f_{cube} = f_{core100}$ (in accordance with EN 13791 [4], Clause 7.1) (A.3.1.2.5.5)

Note: Additional literature for conversion is given by R. Lewandowski [29].

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 are doubts whether the strength of the control specimens represents the concrete strength of the test members, at least three cores of 100 mm diameter shall be taken from the test members outside the zones where the concrete has been damaged in the tests, and tested in compression. The cores shall be cut to a height equal to their diameter, and the surfaces to which the compression loads are applied shall be ground or capped. The compressive strength measured on these cores shall be converted into the strength of cubes in accordance with A.3.1.2.5.

A.3.1.2.6 Test members for tests with varying crack opening (F3, C2.5)

The tests shall be carried out on test members with unidirectional cracks. To control cracking, so-called ‘crack-formers’ shall be built into the member, provided they are not situated near the anchorage zone. An example for a test member is given in Figure A.3.1.2.6.1.

In the test with variable crack width the reinforcement ratio (top and bottom reinforcement) shall be $\mu = 0{,}01$ ($\mu = A_s / (b \cdot h)$ when rounding tolerance $\mu = 0{,}005$ to $0{,}014$ is acceptable and the spacing of the bars ≤ 400 mm along the outbreak cone.

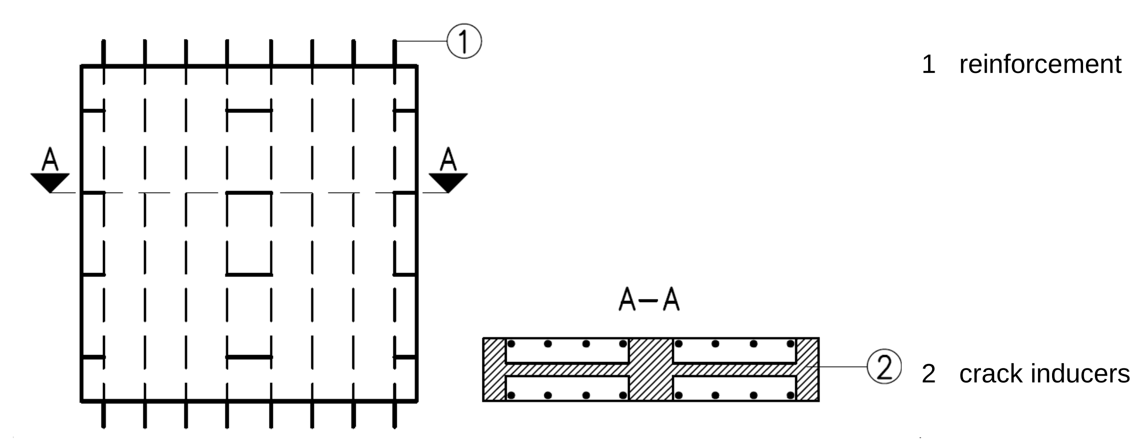


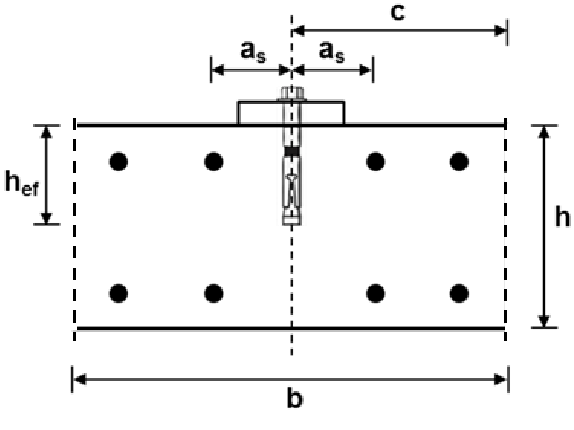
Figure A.3.1.2.6.1 Example of a test member for fasteners tested in cracked concrete

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 criterion 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 greater than Δw_{hef} for $\Delta w_{hef} \geq 0{,}3$ mm.

The reinforcement shall be of equal size and placed symmetrically (see Figure A.3.1.2.6.2). 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 A.3.1.2.6.3) shall be large enough to introduce the tension force into the concrete.

To facilitate the opening of the crack a bond breaker shall be applied at both sides of the crack (see Figure A.3.1.2.6.3). A plastic pipe with an inner diameter of ≈ 1,2 d_s shall be used for this purpose, where the rebar size d_s denotes the diameter of the reinforcing bar. When using bond breakers, the de-bonding length ℓ_{db} shall 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 A.3.1.2.6.2 Example cross section of test member

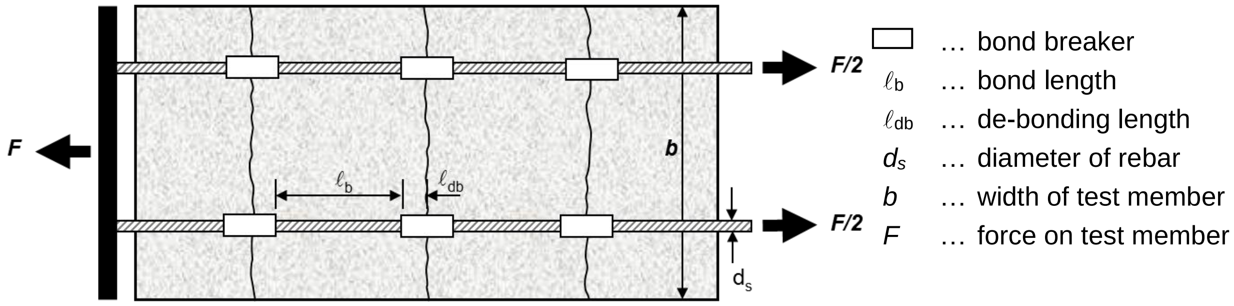


Figure A.3.1.2.6.3 Example for test member with bond breaking pipes on rebar (plan view)

The criterion 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 (see EN 1992-4 [10] Figure 7.1 b) does not intersect with an edge or the edge distance of the fastener in all directions is $c \geq 2{,}0\ h_{ef}$.

The criterion 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 A.3.1.2.6.2) is $a_s \geq \max(75\ \text{mm};\ 0{,}60\ h_{ef})$. If for large embedment depths this distance criterion and the spacing criterion 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.

> *Note: The above criterion 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 not less than 150 mm.*

The fulfilment of the criteria 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 A.1.1). 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 given in the test report. There are two options for the assessment shown in Figure A.3.1.2.6.4 a) and b). These two options are equivalent.

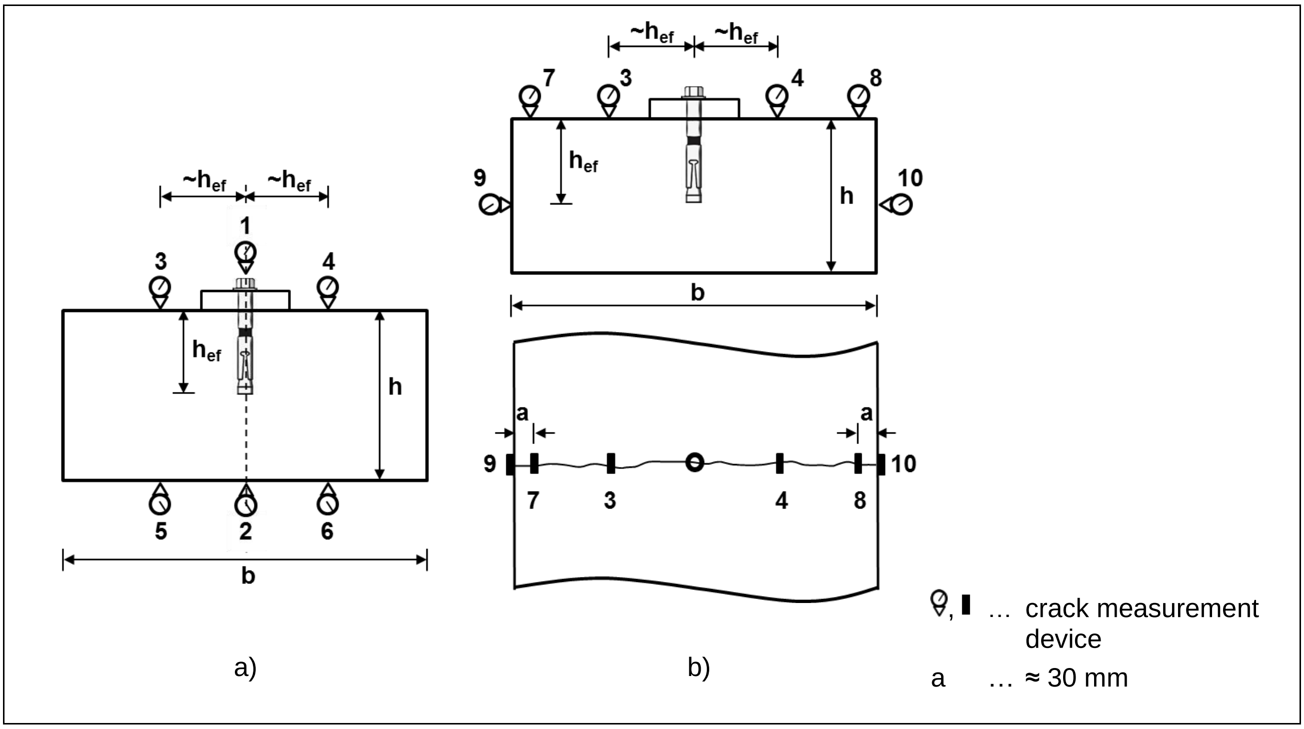


Figure A.3.1.2.6.4 Measurements to show fulfilment of the constant crack width criteria

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.

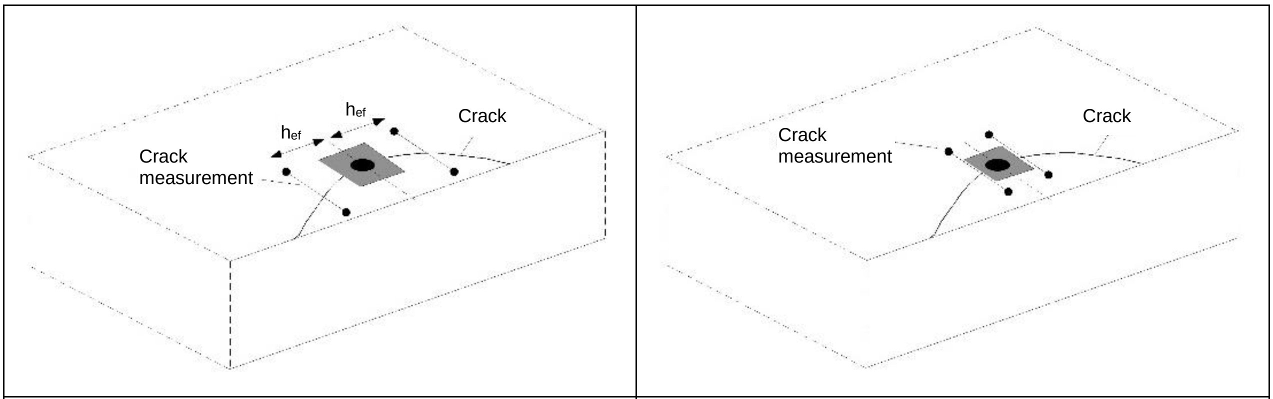
In tension tests the crack width Δw_{hef} shall be determined by either one of the following two approaches:

a) Linear interpolation of crack measurements at the top Δw_{top} and bottom Δw_{bot} of the test member (see Figure A.3.1.2.6.4 a). In this case the crack width shall be measured either at the location of the fastener (i.e., locations 1 (Δw_{top}) and 2 (Δw_{bot}) in Figure A.3.1.2.6.4 a) or on both sides of the fastener (i.e., locations 3 & 4 (for Δw_{top}) and 5 & 6 (for Δw_{bot}) in Figure A.3.1.2.6.4 a) with the two mean values of the measurements at the top and bottom representing Δw_{top} and Δw_{bot}, respectively.

b) Measuring the crack width at the side of the test member at the embedment depth level h_{ef} (i.e., locations 9 & 10 in Figure A.3.1.2.6.4 b). In this case the mean value of the measurements at the side of the test member shall be determined to represent Δw_{hef}.

For both approaches in unconfined tension tests the measurement devices shall be placed as shown in Figure A.3.1.2.6.4.

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 (see Figure A.3.1.2.6.5).



Crack measurement within the distance 1,0 h_{ef} in front of and behind the fastener

Crack measurement directly located at the fastener

Figure A.3.1.2.6.5 **Examples for measuring points of crack width**

The mean of the measured crack widths Δw_{hef} for each test series determined for each fastener shall be equal to or greater than the specified crack width for the test series. Individual crack widths shall be within the following tolerance:

Table A.3.1.2.6.1 Tolerances for Individual crack widths

Nominal value Δw	Maximum allowed deviation	
[mm]	[%]	[mm]
0,1	20 %	± 0,02
0,2	20 %	± 0,04
0,3	20 %	± 0,06
0,35	20 %	± 0,07
0,4	10 %	± 0,04
0,5	10 %	± 0,05
0,6	10 %	± 0,06
0,7	10 %	± 0,07
0,8	10 %	± 0,08

A.3.1.2.7 Test members for tests in uncracked concrete

Generally, the tests shall be 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 criterion will be met if the reinforcement is located outside the zone of concrete cones having a vertex angle of 120°.

A.3.1.2.8 Casting and curing of test members

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

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

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

A.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 A.3.1.3.1.

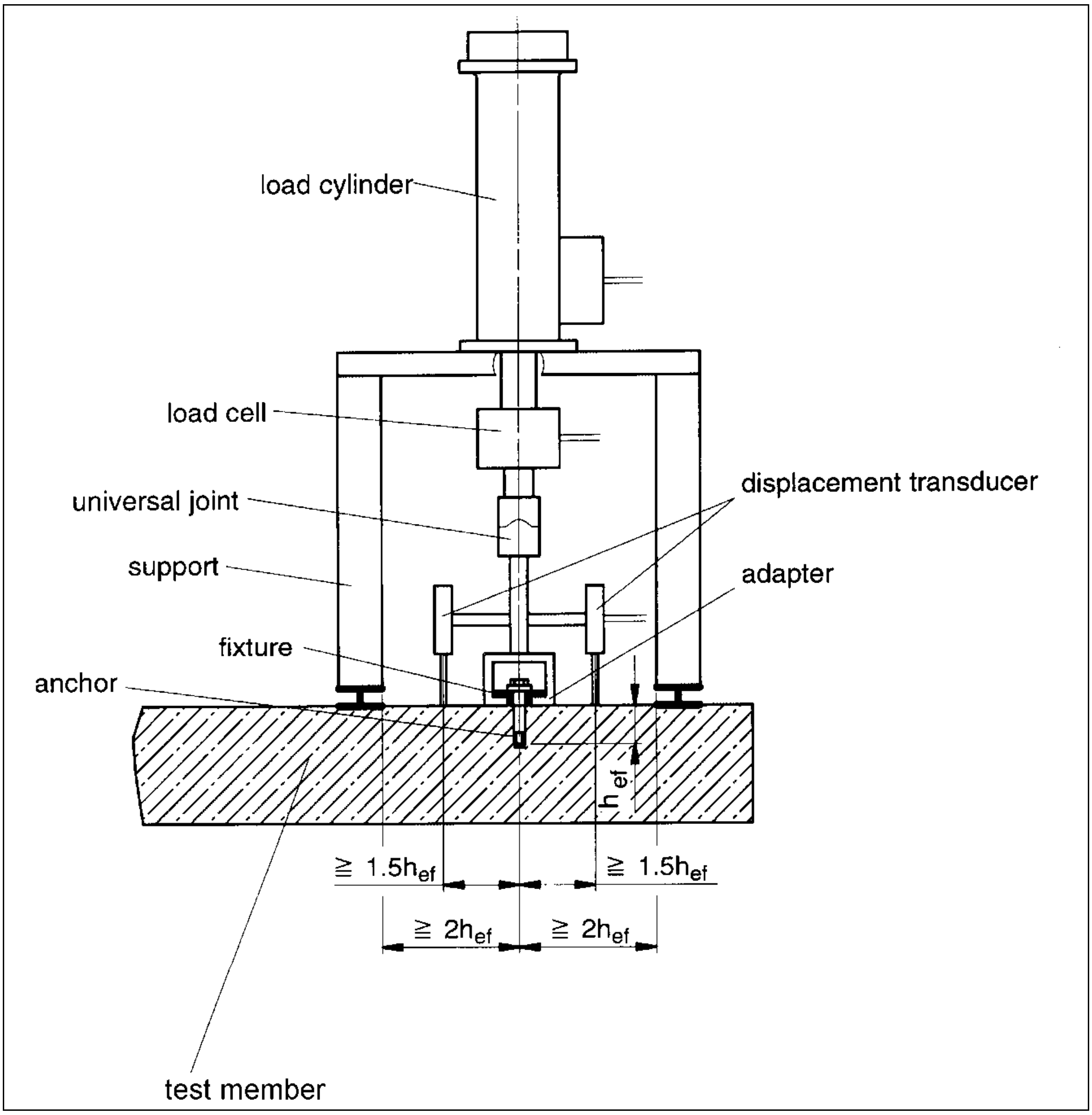


Figure A.3.1.3.1 Example of a tension test rig for unconfined tests

A.3.1.4 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.

Torques, where necessary, 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 fasteners, about 10 minutes after torquing the fasteners with the torque T_{inst} required by the manufacturer, the 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 torque (e.g., deformation-controlled expansion fasteners, many types of undercut fasteners) 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 shall be inserted between washer and fixture (see Figure A.3.1.5.3).

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

Note: In the test with variable crack width the crack may be opened for the verification of the crack in the hole. This can be documented by a picture in the test report. After drilling the hole, before opening the crack, the crack measurement shall be set to $\Delta w=0$. Before installation of the fastener, the crack shall be closed back to $\Delta w=0$.

The holes for fasteners shall be perpendicular (± 5° deviation) to the surface of the test member.

In the tests the drilling tools specified by the manufacturer for the fasteners shall be used.

The diameter of the cutting edges as a function of the nominal drill bit diameter is given in Table A.3.1.4.1.

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

If additional drilling bits like stop-drills, hollow drill bits or diamond core drill bits are required no standards on the specification of these products are available. In this case, the specifications given for the fastener with regard to the dimensions and tolerances of the bits and tests shall be taken into account. The definition of a required or corresponding diameter shall be laid down by the responsible TAB. The drill bit with the largest d_{cut} shall be tested. Tolerances in accordance with Table A.3.1.4.1 shall be added to the tested drill bit as upper limit $d_{cut,max}$ stated in the ETA, but not exceed the maximum of Table A.3.1.4.1.

Note 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 Furthermore, the diamond drilling tool may have an influence on the performance of mechanical fasteners (e.g., expansion 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.

For concrete screws the reduction of the torque is not required.

Install the fastener in accordance with the MPII in a hairline crack. For tests with tension load and varying crack width (test series C2.5, see 2.2.14.3), a compression load is applied to the test member before installation of the fastener. Use drill bits with a diameter $d_{cut,m}$ (medium).

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 torque shall be reduced to 0,5 T_{inst} to account for relaxation of the pre-stressing force with time. This reduction of the installation torque does not apply to concrete screws.

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.

Table A.3.1.4.1 Tolerances of cutting diameter of hard metal hammer drill bits

d_{nom}	$d_{cut,min}$		$d_{cut,m}$		$d_{cut,max}$	
	from	**to**	**from**	**to**	**from**	**to**
5	5,05	5,15	5,20	5,30	5,35	5,40
6	6,05	6,15	6,20	6,30	6,35	6,40
7	7,05	7,20	7,25	7,35	7,40	7,45
8	8,05	8,20	8,25	8,35	8,40	8,45
10	10,05	10,20	10,25	10,35	10,40	10,45
11	11,10	11,20	11,25	11,35	11,45	11,50
12	12,10	12,20	12,25	12,35	12,45	12,50
13	13,10	13,20	13,25	13,35	13,45	13,50
14	14,10	14,20	14,25	14,35	14,45	14,50
15	15,10	15,20	15,25	15,35	15,45	15,50
16	16,10	16,20	16,25	16,35	16,45	16,50
18	18,10	18,20	18,25	18,35	18,45	18,50
19	19,10	19,20	19,30	19,40	19,50	19,55
20	20,10	20,20	20,30	20,40	20,50	20,55
22	22,10	22,20	22,30	22,40	22,50	22,55
24	24,10	24,20	24,30	24,40	24,50	24,55
25	25,10	25,20	25,30	25,40	25,50	25,55
28	28,10	28,20	28,30	28,40	28,50	28,55
30	30,10	30,20	30,30	30,40	30,50	30,55
32	32,15	32,25	32,35	32,50	32,60	32,70
34	34,15	34,25	34,35	34,50	34,60	34,70
35	35,15	35,25	35,35	35,50	35,60	35,70
37	37,15	37,25	37,35	37,50	37,60	37,70
40	40,15	40,25	40,40	40,60	40,70	40,80
44	44,15	44,25	44,40	44,60	44,70	44,80
48	48,15	48,25	48,40	48,60	48,70	48,80
52	52,15	52,25	52,40	52,60	52,80	52,95

A.3.1.5 Test equipment

Tests shall be carried out using measuring equipment having a documented calibration in accordance with 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 A.3.1.3.1 or 2 c_1 (shear test at the edge with load applied towards the edge, with c_1 = edge distance in load direction) as shown in Figure A.3.1.5.2. Only in shear tests without edge influence where steel failure is expected this distance shall 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. An example of a tension test rig is illustrated in Figure A.3.1.3.1.

In shear tests (see A.3.4), the load shall be applied parallel to the concrete surface. A plate with interchangeable sleeves shall be used for testing the different sizes of fasteners (see Figure A.3.1.5.1). The sleeves shall be made of quenched steel and have radiused edges (0,4 mm) where in contact with the fastener. The height of the sleeves shall correspond 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 A.3.1.5.2. As there is a lever arm between the applied load and the support reaction, the test member is stressed by torsion. This shall be taken up by additional reaction forces placed sufficiently far away from the fastener.

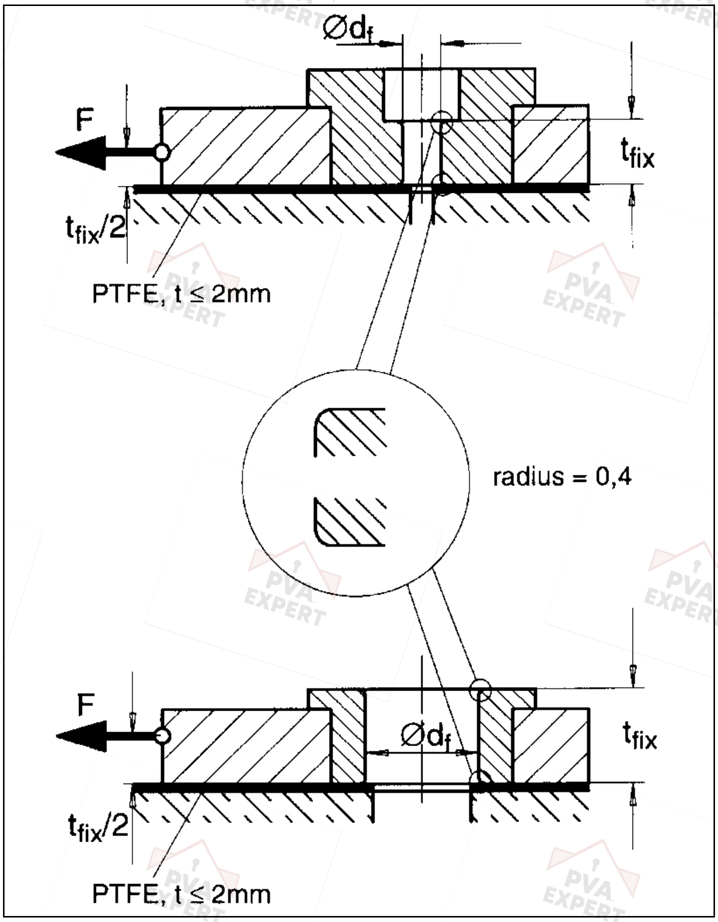
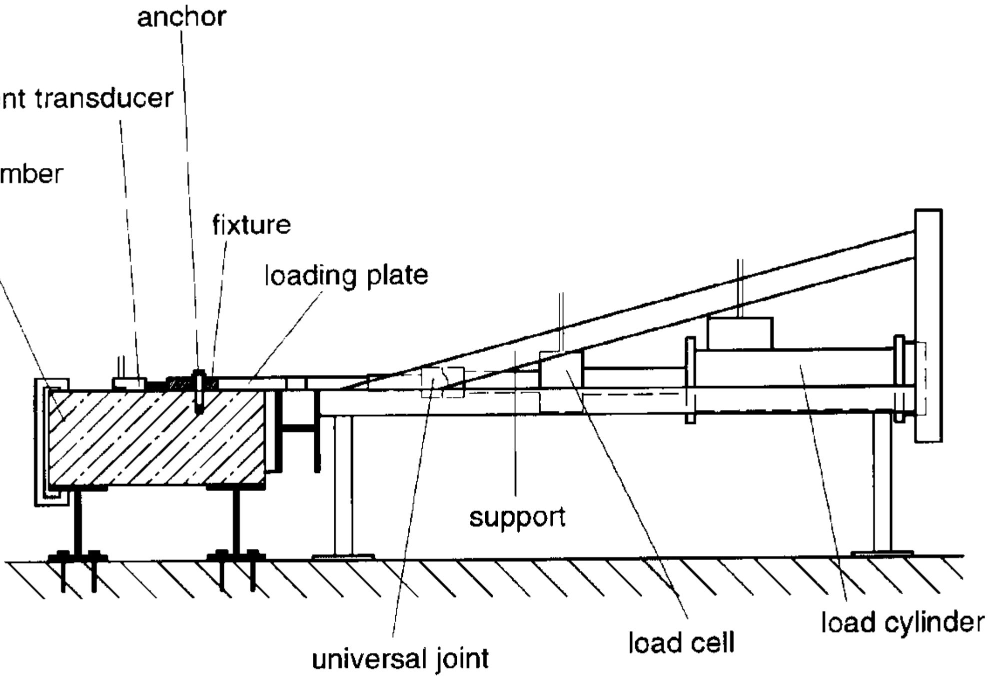


Figure A.3.1.5.1 Examples of shear test sleeves

Side view:



Top view:

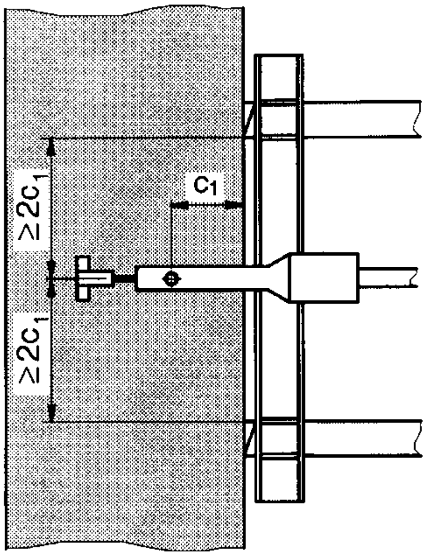


Figure A.3.1.5.2 Example of a shear test rig

In torque tests the relation between the applied 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 A.3.1.5.3).

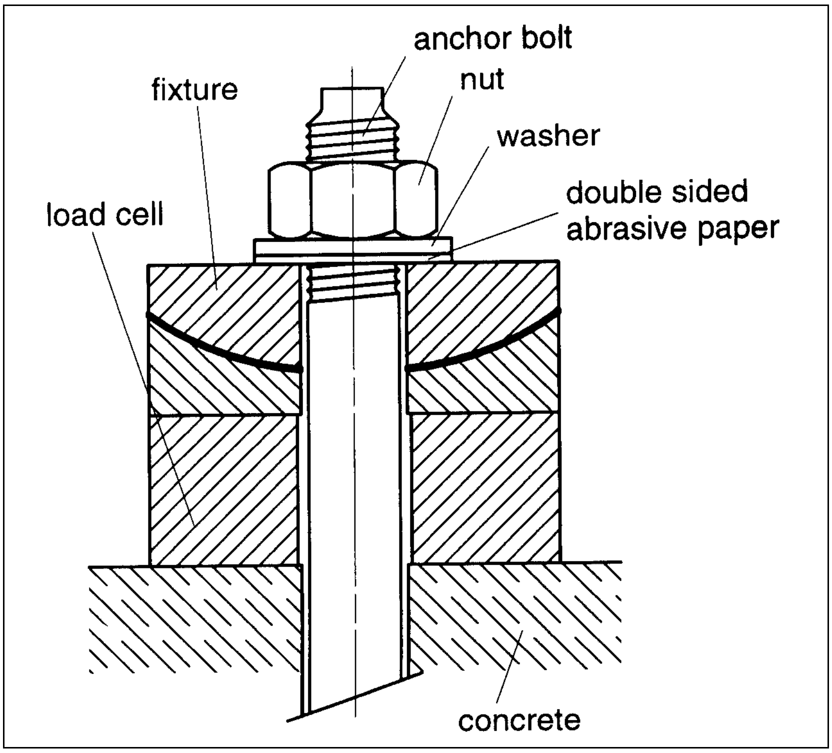


Figure A.3.1.5.3 Example for torque test (schematic)

Any rotation of the spherical part of the fixture shall be prevented.

A.3.2 Test procedure – general aspects

The fasteners shall be installed in accordance with the MPII, except where special conditions are specified in Clause A.3.1.4 for the test series.

The tests in cracked concrete shall be undertaken in unidirectional cracks. The required crack width Δw is given in Table A.1.1 and Clause 2. 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 shall be 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 shall be 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 shall be installed be maintained at a value greater 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 shall 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 a displacement-controlled test setup the speed shall be kept constant.

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

A.3.3 Tension tests

A.3.3.1 Robustness to contact with reinforcement (F10)

For tests with robustness to contact with reinforcement the specimen shall be reinforced with smooth bars (bar diameter ϕ = 25 mm, spacing a > 150 mm). The concrete cover shall correspond to the value $h_{ef} - \phi / 2$ (so that the effective embedment depth is at the same depth as the axis of the bar).

When drilling the cylindrical hole, the drilling tool shall be mounted in a drilling stand and positioned such that the reinforcing bar is clearly cut. On the average the depth of the notch cut shall be 1 mm. Apart from the contact with reinforcement the fastener shall be installed according to the MPII. Then a tension test shall be performed.

A fastener after installation in contact with reinforcement is shown in Figure A.3.3.1.1.

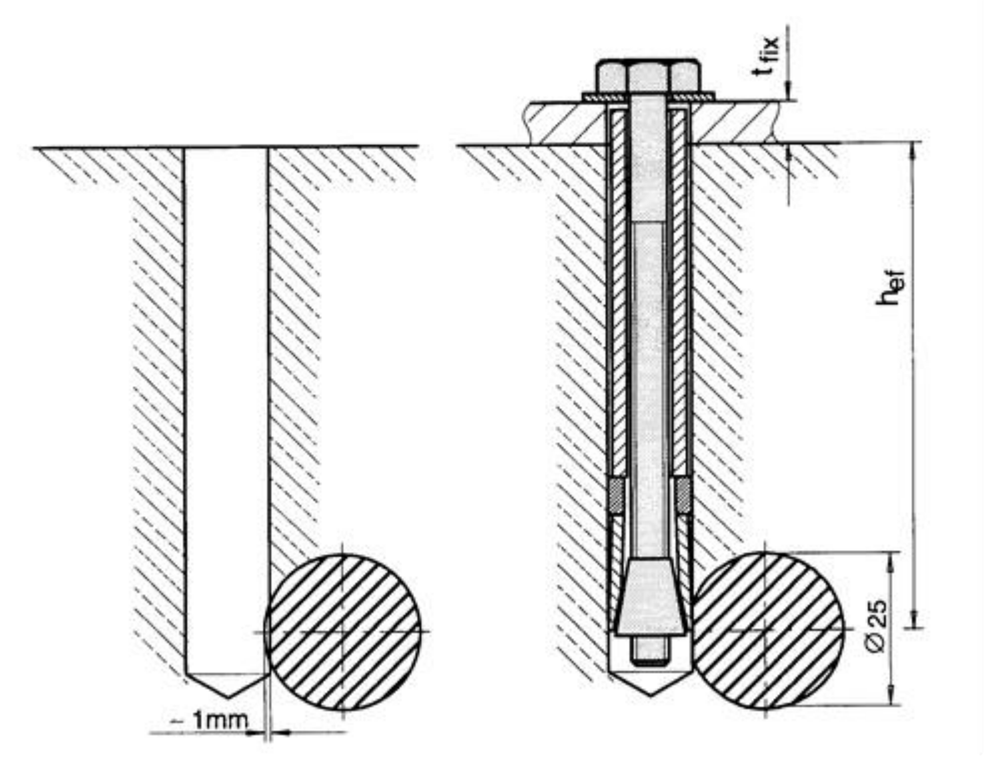


Figure A.3.3.1.1 Position of fastener when tested in contact with reinforcement

A.3.3.2 Single fastener under tension load (A1 to A4, F1 to F10, F12)

After installation, the fastener shall be 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 an uncracked test member, the test rig shall be placed such that an unrestricted concrete failure towards the corner is possible (see Figure A.3.3.2.1). It is necessary to support the test rig outside the test member.

When testing in cracked concrete, the crack width shall be regularly measured 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.

For the evaluation of stiffness characteristics see Clause 2.2.11.

For the determination of the load-displacement curves, the measuring frequency shall be not less than 10 Hz for load and displacement. The data pairs shall be recorded in the ascending branch, plateau and descending branch. The displacement rate shall be selected such that the maximum load is reached after 60 to 180 seconds.

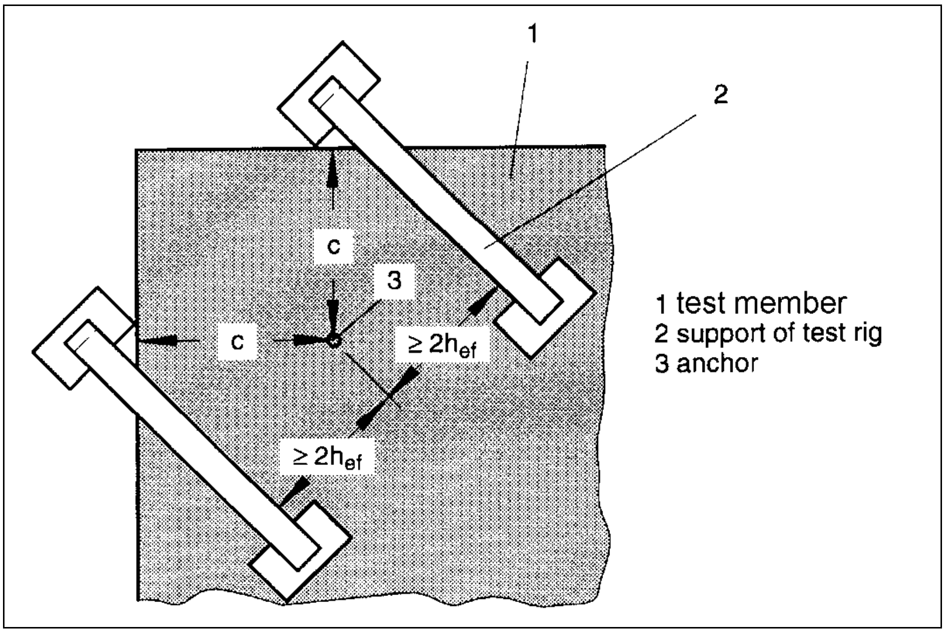
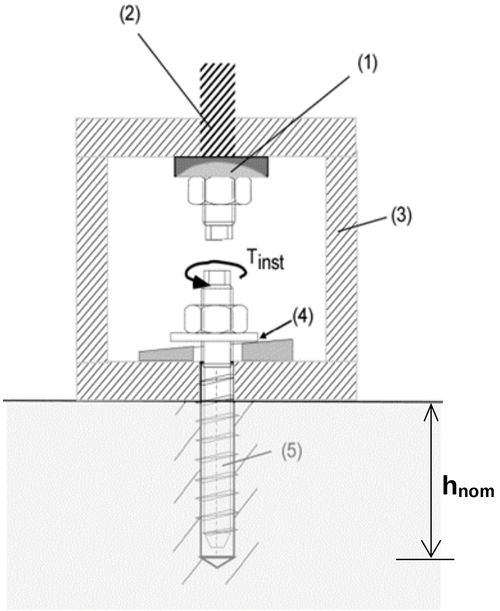


Figure A.3.3.2.1 Example of the test rig for tension tests on fasteners at a corner (test series F12)



(1)	Washer for centric tension load
(2)	Threaded rod
(3)	Adapter for load application (shall not be weak point of the assembly)
(4)	Point of contact
(5)	Concrete screw

Figure A.3.3.2.2 Example of load application to concrete screws via adapter in tests F4 with repeated loads

A.3.3.3 Crack cycling under load (F3)

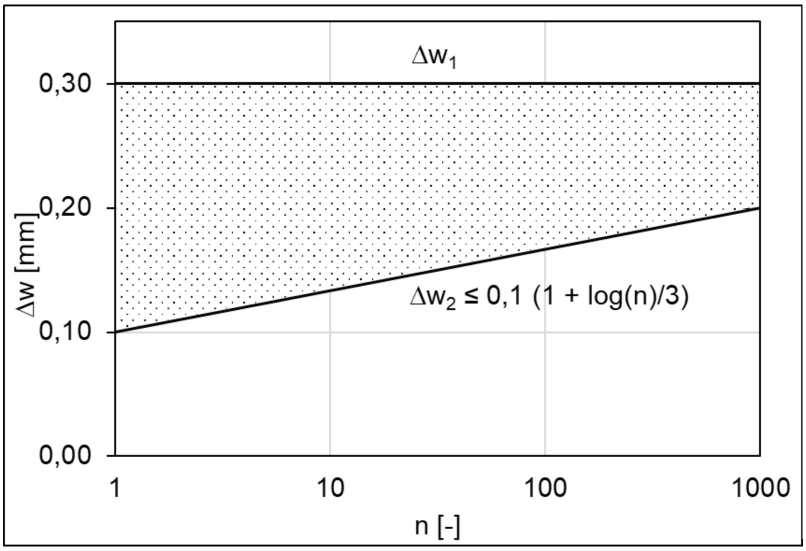
After installation of the fastener the maximum (max N_s) and minimum (min N_s) loads applied to the test member shall be determined such that the crack width under max N_s is $\Delta w_1 = 0{,}3$ mm and under min N_s is $\Delta w_2 = 0{,}1$ mm. To stabilize crack formation, up to 10 load changes varying between max N_s and min N_s shall be applied. Then a tensile load N_p (Equation (2.2.2.4.1)) is applied to the fastener after opening the crack to $\Delta w_1 = 0{,}3$ mm.

N_p shall remain constant during the test (variation ± 5 %). Then the crack is opened and closed 1000 times (frequency approximately 0,2 Hz).

During opening of the cracks, the upper crack width Δw_1 is kept constant with minimum 0,3 mm and the lower crack width Δw_2 shall comply with limits in Figure A.3.3.3.1. If the lower crack width exceeds the values of Figure A.3.3.3.1, the test can be continued under the condition that upper crack width must be increased, in such case, the crack width difference ($\Delta w1 - \Delta w2$) in accordance with Figure A.3.3.3.1 shall be kept.

The load/displacement behaviour shall be recorded up to the load N_p. Afterwards under N_p, the displacements of the fastener and the crack widths Δw_1 and Δw_2 shall be recorded 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 fastener shall be unloaded, the displacement recorded and a tension test to failure performed with $\Delta w = 0{,}3$ mm.



Δw_1 minimum upper crack width

Δw_2 maximum lower crack width

Figure A.3.3.3.1 Allowable crack opening variations during the crack movement test

Table A.3.3.3.1 minimum crack cycling width during the crack movement test

Cycle	Minimum crack cycling width $\Delta w_1 - \Delta w_2$ [mm]
20	0,16
50	0,14
100	0,13
200	0,12
500	0,11
750	0,10
≥ 1000	0,10

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 concrete screw, over 1,5 times the length of the interaction zone h_{iz} of a torque-controlled expansion fastener or undercut fastener see Figure A.3.3.3.2).

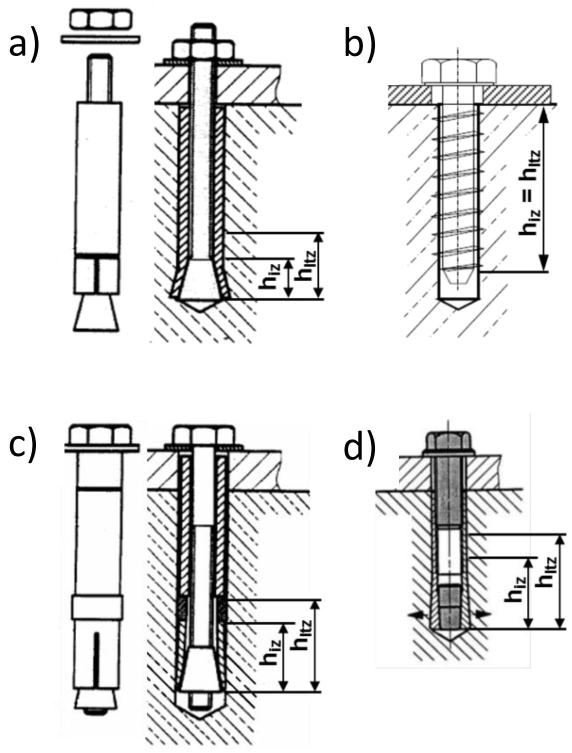
Note: One way to achieve this, at least for larger fastener diameters, is to drill the fastener hole at the desired position prior to initiating the cracking.

It shall be verified that the fastener is located in the crack over the length defined above, e.g., by use of a borescope.

In accordance with Figure A.3.1.2.6.4 a) the crack widths shall be measured at the top and bottom of the test member either at the fastener location (locations 1 and 2 in Figure A.3.1.2.6.4 a) or at a distance of approximately h_{ef} on both sides of the fastener (locations 3 & 4 and 5 & 6 in Figure A.3.1.2.6.4 a). The mean value of the crack width measurements at locations 3 and 4 represents Δw_{top} and the mean value of the crack width measurements at locations 5 and 6 represents Δw_{bot}. The crack width Δw_{hef} is obtained by linear interpolation of the top and bottom crack widths, i.e., Δw_{top} and Δw_{bot}, respectively.

Equally, the approach shown in Figure A.3.1.2.6.4 b) shall 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.



a) undercut fastener
b) concrete screw
c) torque-controlled expansion fastener
d) deformation-controlled expansion fastener

Figure A.3.3.3.2 Effective load transfer zone

Control of crack width

In the tests to failure (monotonic tests and residual capacity tests) the fastener is subjected to load while the crack width is controlled, either

a) at a constant width taking into account the criteria given in A.3.1.2.6, for example, by means of a servo system, or
b) limited to a width close to the specified value by means of the reinforcement and test member dimensions (see A.3.1.2.6).

A.3.4 Tests under shear load

A.3.4.1 Single fastener (V1)

After installation, the fastener is connected to the test rig without gap (d_f = d, a tolerance + 3/10 mm is acceptable) 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 recorded 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 A.3.1.5.2).

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 shall be tested.

In shear tests, the uplift of the fixture (steel plate) shall be restrained in a way that no significant friction forces are induced. Such friction forces are avoided if for example a setup as shown in Figure A.3.4.1.1 is used, which prevents the uplift, limits friction by roller bearing and does not actively apply a compression force. Furthermore, the maximum allowed annular gap of the clearance hole (see Table 2.2.7.1.1) shall be selected in the shear tests.

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

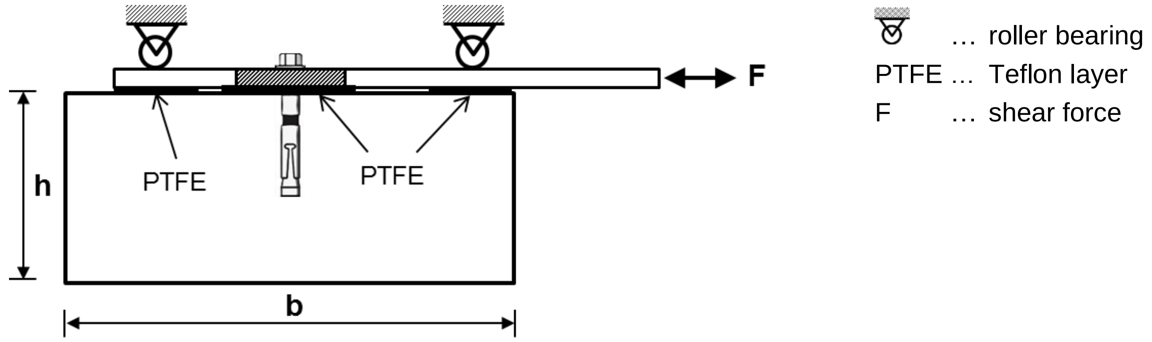


Figure A.3.4.1.1 Sketch of example for shear test setup with no significant friction forces in seismic shear tests

A.3.4.2 Quadruple fastener group (V2)

Fasteners shall be installed according to clause A.3.1.4 and according to MPII with prescribed T_{inst}. For concrete screws and clearance holes in the fixture greater than the clearance holes given in Table 6.1 of EN 1992-4 [10] the setting position is given in Figure 2.2.7.2.4 with setting position CS1 = CS3 and CS2 = CS4.

To ensure the setting positions in general the holes may be drilled though the fixture or a dummy fixture (e.g., made of timber) to ensure that the position of the holes is as requested.

To ensure the position CS1 to CS2 for concrete screws where the hole cannot be drilled through the fixture, a dummy fixture with larger holes shall be used.

After installation, the 4 fasteners shall be connected by a rigid fixture with the dimension given in Figure A.3.4.2.1.

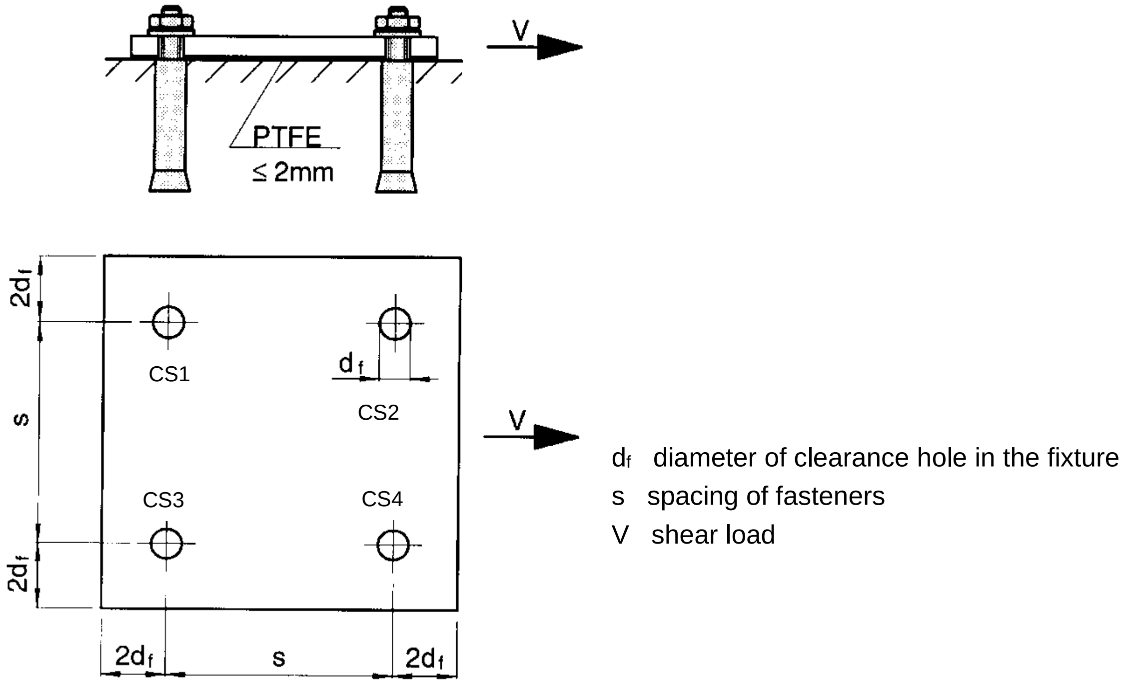


Figure A.3.4.2.1 Dimensions of fixture

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

A.3.5 Degree of expansion for deformation-controlled expansion fasteners

In order to achieve reproducible results for deformation-controlled expansion fasteners, defined conditions for the expansion shall be defined.

The fastener behaviour can be sensitive to the effectiveness of expansion. The effectiveness of fastener expansion depends on:

- energy of blows either by hand or machine, including setting tool
- material, geometry, tolerances, etc. of the fastener and the setting tool
- diameter of the drilled hole
- concrete strength class

The influence of these parameters on the fastener behaviour is covered by tests with reference expansion.

Test conditions

The tests shall be performed with single fasteners, without edge and spacing effects.

The tests shall be performed with at least 5 fasteners of every size in concrete with a strength class of C50/60, using a drill bit with a diameter of the cutting edge $d_{cut,m}$ in the cast side of an uncracked test member. Prior to expansion the fasteners are installed according to the manufacturer's product installation specification MPII.

The expansion of the fasteners is achieved by an impact device. The principle, test setup is shown in Figure A.3.5.1. The impact device is kept perpendicular to the fastener and the setting tool. The drop mass of the impact device generates the expansion by impacting on the setting tool. Impact device, setting tool and fastener shall be in line to prevent energy losses due to additional friction, e.g., by shortening of the setting device outside the concrete and/or by use of a special device to keep the setting tool in line with the fastener axis.

Before the first blow and at least after the number of blows in accordance with Table A.3.5.1, lines 5 and 6, the fastener expansion shall be recorded.

This shall be undertaken by measuring the distance between the outer end of the sleeve and the surface of the cone / nail for cone down type fasteners (drop-in fastener), shank-down type fastener (stud fastener) and sleeve-down type fasteners. For the stud version of sleeve-down type fasteners this can be done by measuring the displacement of the stud in relation to the concrete surface or by measuring the distance of the marking on the fastener to the concrete surface.

Three different expansion conditions a), b) and c) are distinguished:

a) Full expansion:

Expansion achieved when setting the fastener according to the MPII.

b) Reference expansion:

Expansion achieved by applying specified expansion energy (see Table A.3.5.1, line 5). The reference expansion is defined as the mean expansion achieved in tests with the number of applied blows in accordance with Table A.3.5.1, line 5.

c) Installation expansion:

Expansion achieved by applying a specified expansion energy which is reduced in relation to reference expansion. The installation expansion is defined as the mean expansion achieved with the number of applied blows in accordance with Table A.3.5.1, line 6.

The degree of expansion is characterized by the displacement of the cone in the sleeve (See Figure 1.1.2). This displacement shall be measured for full expansion, reference expansion and installation expansion. For the test series, the mean value of the displacements of the cones shall be determined for a), b) and c).

If the reference expansion and/or installation expansion is less than full expansion, the mean displacement of the cone for full expansion, reference expansion or installation expansion shall be ensured in the relevant test series.

Machine setting:

If a manufacturer recommends in the written installation instructions setting by machine, then it shall be shown that the installation and reference expansion achieved in the machine setting test shall be at least equal to the corresponding expansion in the setting test by impact device in accordance with Figure A.3.5.1.

The machine setting tests shall be performed with at least 5 fasteners of every size in concrete of strength class C50/60, using a drill bit with a diameter of the cutting edge $d_{cut,m}$ in the cast side of a uncracked test member. The setting shall be undertaken vertically upwards by the setting machine with the smallest energy output of the range of machines defined in the manufacturer's installation specifications. Care shall be taken to hold the machine in line with the fastener axis. Before the first blow and after a maximum of 10 and 15 seconds of setting time the expansion shall be recorded.

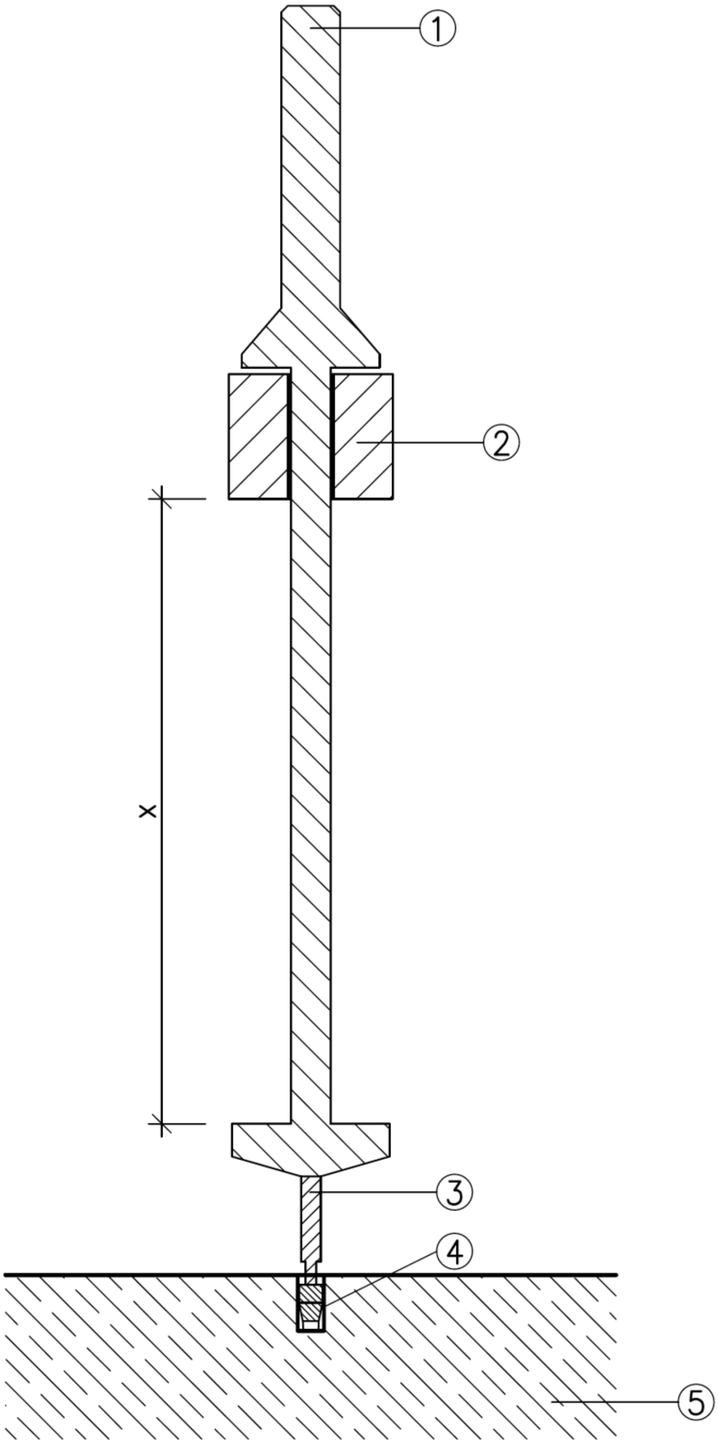
The installation expansion is achieved in the setting test by the impact device. In setting tests, using a machine, this expansion shall be achieved on average after a setting time of at maximum 10 seconds.

The reference expansion is achieved in the setting test by the impact device. In setting tests, using a machine, this expansion shall be achieved on average after a setting time of at maximum 15 seconds.

Table A.3.5.1 Test conditions

1	fastener size		M6	M8	M10	M12	M16	M20
2	impact device, type		B	B	B	B	C	C
3	Mass	[kg]	4,5	4,5	4,5	4,5	15	15
4	height of fall	[mm]	450	450	450	450	600	600
5	number of blows 1) for evaluation of reference expansion.	-	3	5	6	7	4	5
6	number of blows 1) for evaluation of installation expansion.	-	2	3	4	5	3	4

1) The tests shall be carried out with a standardized device applying a constant energy per blow. In practice, the energy applied during setting of the fastener by a hand hammer depends on the fastener size. Therefore, the number of blows is different for the different fastener sizes.



1 Bubble level

2 Drop weight

x Height of fall

3 Setting tool

4 Fastener

5 Test member

Figure A.3.5.1 **Arrangement for tests to determine the degree of expansion (schematic) – example of setting a drop-in fastener**

A.3.6 Fire exposure

A.3.6.1 Tests for steel failure under tension load under fire exposure (Fi1)

Test set-up:

The tests for the determination of the carrying capacity under steel failure shall be carried out in uncracked concrete using an unloaded slab. The principle, test set-up can be seen in Figure A.3.6.1.1.

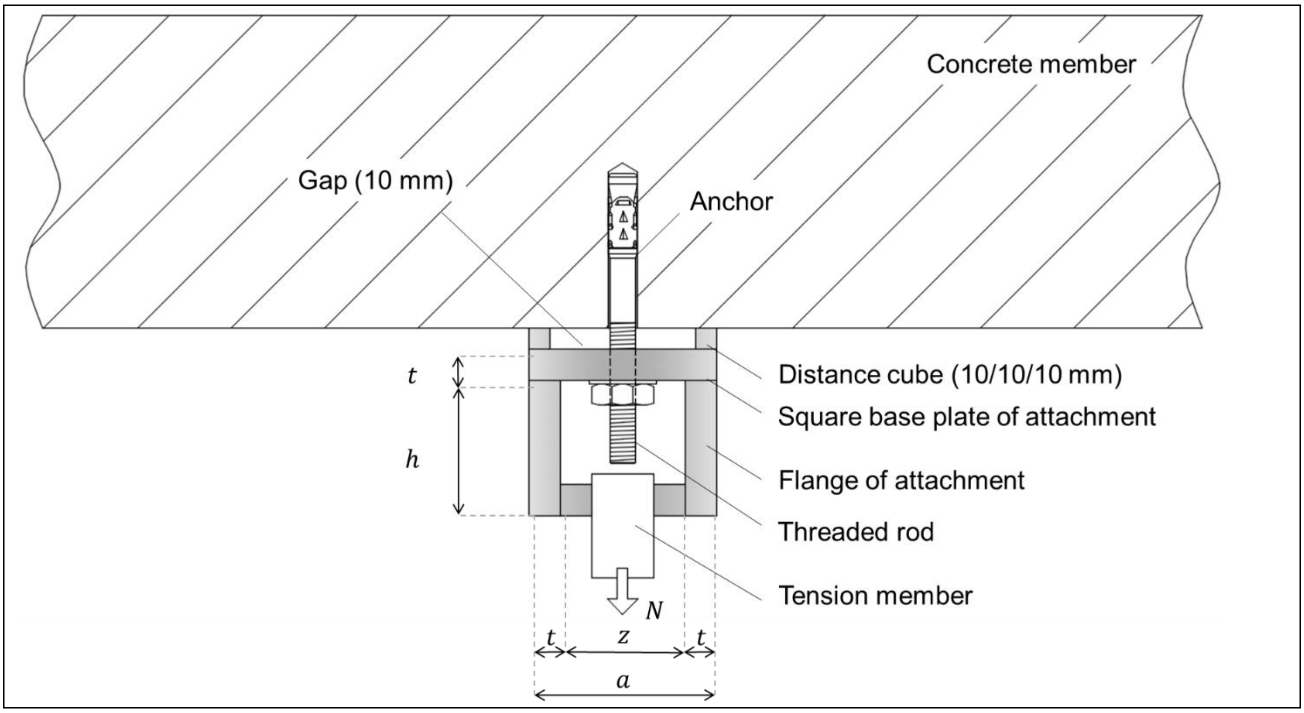


Figure A.3.6.1.1 Test setup for the determination of the steel failure under fire exposure

The dimensions of attachment shall be chosen depending on the load categories in accordance with Table A.3.6.1.1. The attachment has to provide a steel stress of 2 – 4 N/mm^2 in the relevant parts. Ordinary perforated sheet metal tapes can be used for the tests up to a load of 1,0 kN.

For fasteners with sleeve with internal thread (e.g., given in Figure 1.1.2 and Figure 1.1.4):

Fastening screws, threaded rods and nuts of the minimum strength according to the specifications given in the ETA shall be used. It is proven by experience that failure of nuts on threaded rods is decisive and shall be used for the tests. If commercial standard screws or rods are specified in the ETA, they shall not be delivered by the manufacturer.

Table A.3.6.1.1 Dimensions of the fixture during the test under fire exposure

Type of adapter	Load categories	Length of the square base plate	flange height/ width	thickness of attachment parts	distance between the flanges
	$N_{Rk,s,fi}$ [kN]	a = b [mm]	h / b [mm]	t [mm]	z [mm]
I	> 1 - ≤ 3	90	100 / 90	15	60
	> 3 - ≤ 5	90	100 / 90	15	60
II	> 5 - ≤ 7	110	120 / 110	20	70
	> 7 - ≤ 9	110	120 / 110	20	70
III	> 9 - ≤ 11	120	120 / 120	25	70
	> 11 - ≤ 13	120	120 / 120	25	70

Test procedure:

The fastener shall be loaded in tension during the test under fire exposure via the fixture which is defined in Table A.3.6.1.1. The fire tests shall be carried out in accordance with EN 1363-1 [3].

At least 5 tests each using the smallest size d_1 and the medium size d_2 ($\leq$ M12) of the fastener shall be carried out. The duration of fire resistance shall be more than 60 min in at least 4 tests per fastener size.

For each test record the test load and the corresponding duration to failure.

A.3.6.2 Tests for pull-out failure under tension load under fire exposure (Fi2)

Test setup:

The tests shall be carried out in reinforced concrete slabs (C20/25) with a reinforcement of ϕ = 12 mm / a = 150 mm and a degree of reinforcement of A_S / (b · d) of approximately 0,4 %. Steel failure shall not occur. Hence the fixation including the fastener shall be lagged or protected. The fixation shall be more compact than in the tests in accordance with ClauseA.3.6.2. The reinforced concrete slab shall be at least designed for the desired duration of fire resistance. The thickness of the slab shall be $\geq 2\ h_{ef}$ and at least be 250 mm. The test set-up can be seen in principle in Figure A.3.6.2.1.

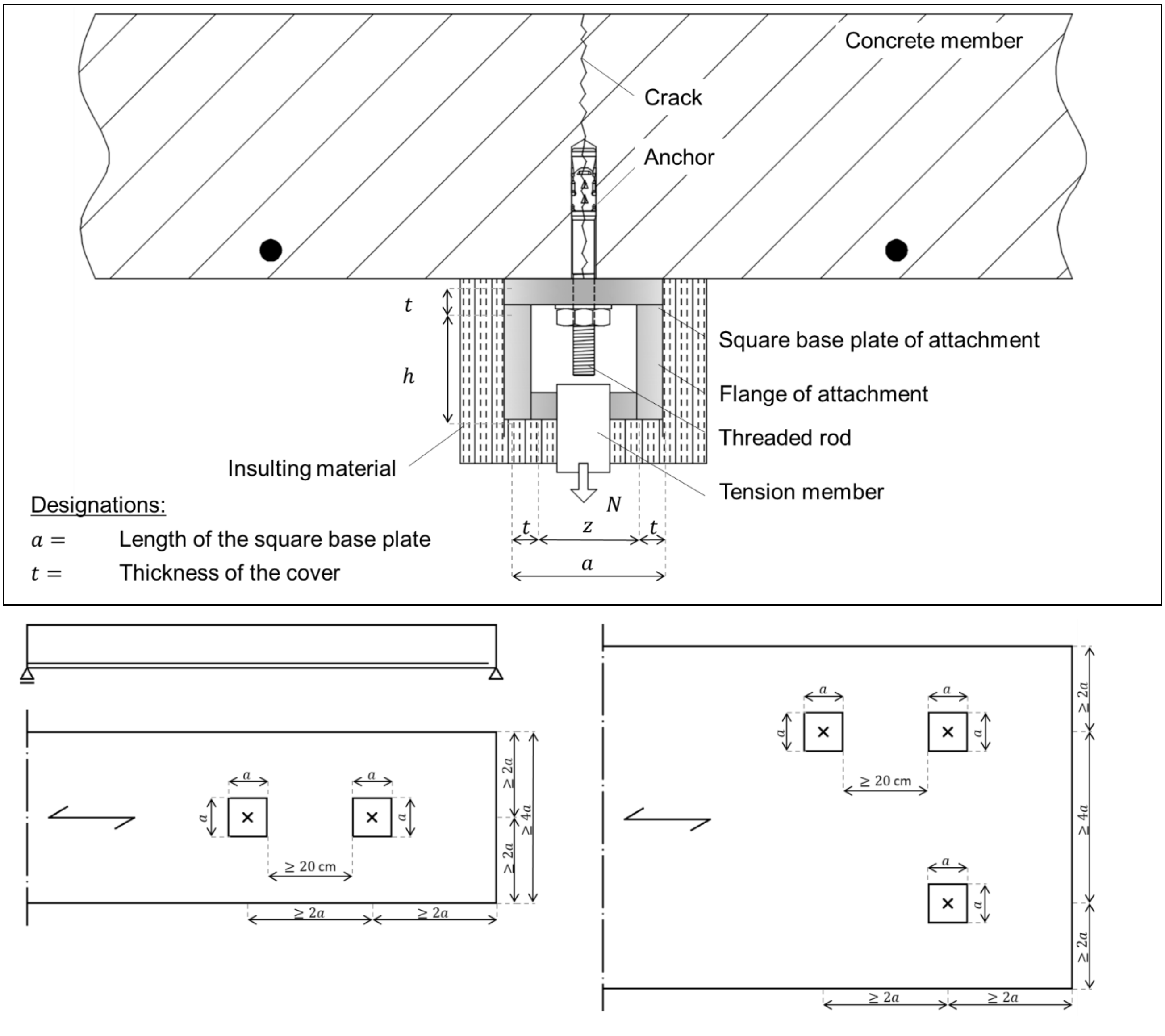


Figure A.3.6.2.1 Test setup for the determination of the characteristic resistance under fire exposure to pull-out failure

Test procedure:

The reinforced concrete slab shall be loaded until cracks appear. The fastener shall be set directly into the crack after the load release. Afterwards the slab shall be loaded again; up to a calculated reinforcement stress of 270 N/mm^2 ± 20 N/mm^2 in the area of the fastener. This will lead to crack widths of 0,10 to 0,25 mm. Next the fastener has to be loaded with the designated load for the fire test in accordance with EN 1363-1 [3]. The steel stress of the reinforcement shall be held constant during the test.

At least 5 tests using fastener with the smallest size, which have an effective embedment depth h_{ef} of approximately 60 mm to 70 mm, shall be carried out for the determination of the limit value curve. The duration of the fire resistance shall be more than 60 min in at least 4 tests.

For each test record the test load and the corresponding duration to failure.

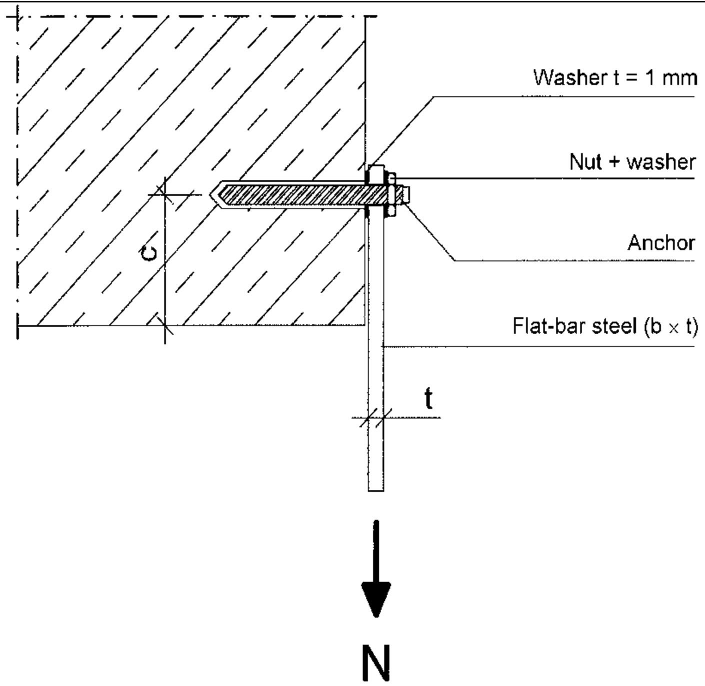
A.3.6.3 Tests for steel failure under shear load under fire exposure (Fi3)

The test procedure shall be done in accordance with Clause A.3.6.1. The shear load shall be applied via flat-bar steel, which is adequate for a steel stress of 2 to 4 N/mm^2.

The test set-up can be seen in principle in Figure A.3.6.3.1.

The flat bar shall not fail under fire. Therefore, the dimensions shall be selected according to this condition such that the failure occurs in the fastener, not in the flat bar. The stresses given in clause 2.2.17 are determined for the fastener, not for the fixture.

For each test record the test load and the corresponding duration to failure.



Designations:

c = edge distance

t = thickness of the flat-bar steel
$10 \text{ mm} \leq t \leq 20 \text{ mm}$

b = width of the flat-bar steel
$b = N / (t \times \sigma_{Rk,s,fi})$ with
$2 \text{ N/mm}^2 \leq \sigma_{Rk,s,fi} \leq 4 \text{ N/mm}^2$

Figure A.3.6.3.1 Test setup for the determination of the characteristic resistance under fire exposure to steel failure due to shear loads

A.4 Reduced test programme for different drilling methods

This clause provides information for the assessment of mechanical fasteners for use with different drilling methods. The provided tests are required for every method being different in drilling from the standard drilling and defined by the manufacturer in the MPII.

The assessment is made to verify the validity of the performance of the mechanical fasteners system combined with different drilling methods as assessed for use in compacted normal weight concrete with or without fibres of different strength classes and loading.

The essential characteristics of mechanical fasteners combined with different drilling methods assessed in accordance with this Annex shall be used for design in accordance with EN 1992-4 [10].

For the assessment of the additional drilling methods either one of the following 2 approaches applies:

1 Same performance for reference and additional drilling methods shall be given in ETA:

   a) Statistical equivalence of the mean values and 5 % fractile values of the ultimate loads is proven. Verify that $N_{u,m}$ [N] and the 5 % fractile of the failure loads $N_{5\,\%}$ [N] of test series shall be at least 95 % of the corresponding parameters of the same test series with the reference drilling method. The comparison of the 5 % fractile shall be omitted for any number of tests in a test series if 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 %.
   b) The results of tests carried out using additional drilling methods show higher values for the ultimate loads for mean value or 5 % fractile value (item a) not fulfilled) in one or more series; also in this case, the values of the reference drilling method remain decisive.
   c) The applicable test programme is given in Table A.4.1 (hollow drilling) or in Table A.4.2 (additional drilling method diamond core drilling). The proof in accordance with item a) or b) applies to all series with different drilling methods given in these tables.

With the assessment of equivalency for test series F1, also the optional assessments of seismic category C1 and fire resistance in accordance with 2.2.17, 2.2.18 and 2.2.19 are covered. The assessment for diamond coring can be applied to steel fibre reinforced concrete (SFRC), if equivalency is shown.

2 Differentiation of performance in ETA for special method:

- If the validation for equivalency or better in accordance with items 1. a) or b) cannot be fulfilled for all series with the different drilling method, the test programme in accordance with Table A.4.3 applies.
- The assessment of the performance of additional drilling method shall be performed separately. For the series given in Table A.4.3. the results assessment shall be performed as given in the corresponding clauses. For series not required as per Table A.4.3 that are only performed with the reference drilling method, the reduction factors applicable for the reference method shall be adopted.

Test conditions

The test programme for hollow drilling is given in Table A.4.1 and for the use of additional drilling method diamond core drilling is given in Table A.4.2.

The tests shall be performed with each additional drilling method of the MPII.

If the tested diameter falls below the required sizes of Table A.3.1.4.1 this reduced tested diameter shall be stated in the ETA as maximum upper limit $d_{cut,max}$. The tolerance for $d_{cut.max}$ given in Table A.3.1.4.1 for this diameter shall be added to the tested diameter.

Table A.4.1 **Reduced test programme for mechanical fasteners with hollow drilling for same performance as reference drilling method (proof of equivalency)**

N°	Purpose of test	Concrete	crack width [mm]	size	d_{cut}	Required for	n_{min}	Clause
A1	Reference tension tests	C20/25	0	All	$d_{cut,m}$ 2)	All	5	2.2.2.1
A2		C50/60	0	All	$d_{cut,m}$		5	
A3 7)		C20/25	0,3	All	$d_{cut,m}$	Option 1-6	5	
A4 7)		C50/60	0,3	All	$d_{cut,m}$	Option 1, 3, 5 1)	5	
F1 3)	Maximum crack width and large hole diameter	C20/25	0	s/m/l	$d_{cut,max}$ 1)	Option 7-12	5	2.2.2.2
			0,5	All		Option 1-6		
F1F 4)	Maximum crack width and large hole diameter	C20/25 20 kg/m³	0	s/m/l 6)	$d_{cut,max}$ 1)	Option 7-12	5	2.2.2.2
			0,5			All		
F3	Crack cycling under load	C20/25	0,10-0,30	All	$d_{cut,m}$	Option 1-6, CS only	5	2.2.2.4
C2.1a 5)	Seismic C2 Reference tension tests in low strength concrete	C20/25	0,8	All	$d_{cut,m}$	Option 1-6	5	2.2.14.1

1) The hollow drill bit with the largest d_{cut} shall be tested as $d_{cut,max}$.

2) For fasteners intended to be used in uncracked concrete test series F1 shall be omitted if the tests are performed with $d_{cut,max,}$.

3) Valid for assessment of equivalency of in cracked concrete, seismic performance and fire resistance.

4) For assessment in SFRC in accordance with Annex B

5) For assessment of seismic category C2 (see 2.2.14)

6) For fasteners that are not similar in respect of geometry and/or friction aspects all sizes shall be tested

7) Tests are required only for improved efficiency factors k_{cr} in accordance with Clause 2.2.3

Table A.4.2 Test programme for mechanical fasteners combined with diamond core drilling for same performance as reference drilling method (proof of equivalency)

N°	Purpose of test	Concrete	crack width [mm]	size	d_{cut} [1]	Required for	**n_{min}**	Clause
A1	Reference tension tests	C20/25	0	All	$d_{cut,m}$	All	5	2.2.2.1
A2		C50/60	0	All	$d_{cut,m}$	CS: as reference for N3	5	
						All		
A3 [2]		C20/25	0,3	All	$d_{cut,m}$	Option 1-6	5	
A4 [2]		C50/60	0,3	All	$d_{cut,m}$	Option 1, 3, 5 [1]	5	
F1	Maximum crack width and large hole diameter	C20/25	0	s/m/l	$d_{cut,max}$	Option 7-12	5	2.2.2.2
			0,5	All	$d_{cut,max}$	Option 1-6		
F2	Maximum crack width and small hole diameter	C50/60	0	s/m/l	$d_{cut,min}$	Option 7-12	5	2.2.2.3
			0,5	All	$d_{cut,min}$	Option 1-6		
F3	Crack cycling under load	C20/25	0,10-0,30	All	$d_{cut,max}$	Option 1-6	5	2.2.2.4
					$d_{cut,m}$	CS, UC	5 [1]	
F8	Impact screw driver	C20/25	0	All	$d_{cut,max}$	CS	5	2.2.2.9
F9	Robustness to variation in use conditions	C20/25	0	s/m/l	$d_{cut,m}$	Option 7-12	5	2.2.4.1
		C20/25	0,3	All		UC, DC		
		C50/60	0,3	All		Option 1-6		
C2.1a	Seismic C2 Reference tension tests in low strength concrete	C20/25	0,8	All	$d_{cut,m}$	Option 1-6	5	2.2.14.1
C2.1b	Seismic C2 Reference tension tests in low strength concrete	C50/60	0,8	All	$d_{cut,m}$	Option 1-6	5	2.2.14.1
C2.5	Seismic C2 functioning with tension load under varying crack width	C20/25	$\Delta w1$ = 0,0 $\Delta w2$ = 0,8	All	$d_{cut,m}$	Option 1-6	5	2.2.14.3

[1] The diamond drill bit with the largest d_{cut} shall be tested as $d_{cut,max}$.

[2] Tests are required only for improved efficiency factors k_{cr} in accordance with Clause 2.2.3

Table A.4.3 Test programme for mechanical fasteners combined with additional drilling for different performance in ETA as reference drilling method (no proof of equivalency)

N°	Purpose of test	Concrete	Crack width	Size	d_{cut}	n_{min}	rqd. α	Required for	Clause
Basic tension tests									
A1	Basic tension tests	C20/25	0	All		5		All	2.2.2.1
A2		C50/60	0	All		5		CS: as reference for N3 All other Option 7-12 $^{1)}$	
Resistance to pull-out failure									
F1	Maximum crack width and large hole diameter	C20/25	0	s/m/l	$d_{cut,max}$	$5^{3)}$	0,80	Option 7-12	2.2.2.2
			0,50	All				Option 1-6	
F2	Maximum crack width and small hole diameter	C50/60	0	s/m/l	$d_{cut,min}$	$5^{3)}$	1,00	Option 7-12	2.2.2.3
			0,50	All			0,80	Option 1-6	
F3	Crack cycling under load	C20/25	0,10-0,30	All	$d_{cut,max}$	$5^{3)}$	0,90	TC, DC Option 1-6	2.2.2.4
					$d_{cut,m}$			UC, CS cr and ucr	
F4	Repeated loads	C20/25	0	m	$d_{cut,m}$	3	1,00	DC, TC, UC Option 1-12	2.2.2.5
		C20/25		All		5		CS Option 1-12	
		C50/60		m		3		DC, TC, Option 7-12	
F5	Robustness of sleeve down type fasteners	C20/25	0	All	$d_{cut,m}$	5	0,80	DC	2.2.2.6
			0,50						
F6	Torquing in low strength concrete	C20/25	0	All	$d_{cut,max}$	10		CS	2.2.2.7
F7	Torquing in high strength concrete	C50/60	0	All	$d_{cut,min}$	10		CS	2.2.2.8
F8	Impact screw driver	C20/25	0	All	$d_{cut,max}$	15		CS	2.2.2.9
		(C50/60)$^{6)}$			($d_{cut,min}$)				
F9	Robustness to variation in use conditions	C20/25	0	s/m/l $^{5)}$	$^{4)}$	$5^{3)}$	0,95	Option 7-12	2.2.4.1
		C20/25 (C50/60)$^{4)}$	0,30	All			0,80	UC, DC, CS Option 1-6	
		C50/60					0,70	TC Option 1-6	
F10	Robustness to contact with reinforcement	C20/25	0,30	s/m $^{2)}$	$d_{cut,m}$	$5^{3)}$	0,85 0,70 0,60	UC Option 1-6	2.2.4.2
					$d_{cut,max}$			CS Option 1-6	
F11	Minimum edge distance and spacing	C20/25	0	All	$d_{cut,m}$	5	-	All	2.2.5
F12	Edge distance to prevent splitting under load	C20/25	0	All	$d_{cut,m}$	4	-	Option 1-12	2.2.6
Characteristic Resistance for seismic performance category C1									
C1.1	Functioning under pulsating tension load $^{3)}$	C20/25	0,5 $^{9)}$	All	$d_{cut,m}$	5 $^{10)}$	-	Option 1-6	2.2.12

N°	Purpose of test	Concrete	Crack width	Size	d_{cut}	n_{min}	rqd. α	Required for	Clause
Characteristic Resistance for seismic performance category C2									
C2.1a	Reference tension tests in low strength concrete	C20/25	0,8 9)	All	$d_{cut,m}$	5 11)	-	Option 1-6	2.2.14.1
C2.1b	Tension tests in high strength concrete	C50/60	0,8 9)	All	$d_{cut,m}$	5 11)	-	Option 1-6	2.2.14.1
C2.3	Functioning under pulsating tension load	C20/25	0,5 / 0,8	All	$d_{cut,m}$	5 11)	-	Option 1-6	2.2.14.2
C2.5	Functioning with tension load under varying crack width 13)	C20/25	Δ_{w1}= 0,0 Δ_{w2}= 0,8	All	$d_{cut,m}$	5 11)	-	Option 1-6	2.2.14.3

Explanation of Footnotes is given in Table A.1.1
The results of tests also apply for concrete strength classes lower than C20/25 and greater than C50/60.

A.5 Tests for seismic performance

The tests 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 criteria 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 uncracked concrete.

The compressive strength of concrete $f_{c,test}$ used in the various equations in this document shall consistently represent the value measured with standard cylinders or standard cubes, unless specifically required otherwise. The concrete compressive strength shall be converted accordingly.

A.5.1 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 [10].

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 test member after fastener installation but before fastener loading.

The assessment of fasteners for category C1 comprises tests under pulsating tension load and tests under alternating shear load. The assessment of fasteners for category C2 includes reference tests up to failure, tests under pulsating tension load, tests under alternating shear load as well as tests under crack cycling. 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.

A.5.2 Fastener types to be tested

Seismic tests shall be performed with all fastener diameters, embedment depths, steel types (galvanized 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) as well as drilling methods to be assessed for use in seismic applications. The number of variants to be tested shall 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.

Embedment depth:

a) Fasteners under category C1 (test series C1.1):
If multiple embedment depths are specified, in general, minimum and maximum embedment depths shall be tested. However, only the maximum embedment depth needs to be tested if the factor for seismic loading $\alpha_{N,C1}$ in accordance with Equation (2.2.12.5) is accepted for all embedment depths.

b) Fasteners under category C2 (test series C2.1, C2.3 and C2.5):
If multiple embedment depths are specified, it is allowed to only perform tests at the maximum embedment depth. If only the maximum embedment depth is tested, the factors $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ in accordance with Equations (2.2.14.4.1) and (2.2.14.4.2), respectively, for the maximum embedment depth shall be applied to fasteners with shallower embedment depths and the displacements measured for fasteners with the maximum embedment shall be applied to fasteners with shallower embedment depths.

A.5.2.1 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.

A.5.2.2 Tension tests

A.5.2.2.1 Torque-controlled expansion fasteners TC

If all of the following conditions a) to c) are fulfilled, and the eventual reduction factor is accepted for all fasteners, 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, the fasteners of different production methods shall be tested.

a) The fasteners have the same geometry.
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} shall be different for different steel types and steel grades.
c) The friction between cone and sleeve (internal friction) and the friction between sleeve and concrete (external friction) are identical 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, and any functional coatings are the same, and the surface roughness and hardness of the cone and the sleeve are 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 functional coating is identical, and the internal friction between cone and sleeve depends mainly on the functional coating, and the surface roughness and hardness of the cone and the sleeve are statistically equivalent.

*Note: for definition of functional coating see 1.3.4; zinc coating to prevent corrosion is not considered as a functional coating in this context. I*n this context “fast 1“is the fastener for which the tests have been performed and “fast 2” is the fastener for which the tests are omitted.

- The geometrical data of the two fasteners, i.e., “fast 1” and “fast 2”, are compared with each other and the comparison including the identified differences are documented and submitted for the assessment.
- The fastener “fast 2” has an ETA for cracked concrete for static loading conditions.

- The performance of “fast 2” is better or equal to the performance of “fast 1”, which shall be shown in terms of
  - $N_{Rk,p,fast\ 2} \geq N_{Rk,p,fast\ 1}$ (where $N_{Rk,p}$ is the characteristic value given in the ETA);
  - reference tension tests in cracked concrete C20/25 and C50/60 in accordance with Table A.1.1, series A3 and A4: performance of fastener “fast 2” ≥ performance of fastener “fast 1”;
  - tests for “maximum crack width and large hole diameter” and “maximum crack width and small hole diameter” in accordance with Table A.1.1, series F1 and F2: performance of fastener “fast 2” ≥ performance of fastener “fast 1”;
  - tests for “crack cycling under load” in accordance with Table A.1.1, series F3: sustained load for which fastener “fast 2” passes the criteria is greater than or equal to the corresponding load for fastener “fast 1”;
  - in the load/displacement curves fasteners “fast 1” and “fast 2” show the same stiffness
  - the ductility in terms of the A_5-value of fastener “fast 2” ≥ ductility for fastener “fast 1”.
- The seismic resistance for “fast 2” shall be determined as min ($N_{Rk,p,fast\ 1} \cdot \alpha_{N,Cx,fast\ 1}$; $N_{Rk,p,fas\ 2} \cdot \alpha_{N,Cx,fast\ 1}$).

Note: *In case the highest steel grade is tested pull-out failure might be decisive and steel failure does not occur. For lower steel grades steel failure may become decisive and the corresponding seismic performance may be relevant.*

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

A.5.2.2.2 Undercut fasteners UC

If the undercut of the concrete is identical in all models for full expansion in accordance with A.3.5 a) and partial expansion during the tests for “robustness to variation in use conditions” in accordance with Table A.1.1 series F9, only fasteners of one steel type, the highest steel grade and one production method need to be tested. The measured displacements shall be applied to all steel types, steel grades and production methods. If this condition is not fulfilled, test all fasteners; however, only fasteners with the minimum undercut for full expansion in accordance with A.3.5 a) need to be tested if the reduction factor due to simulated seismic tension testing $\alpha_{N,C1}$ in accordance with Equation (2.2.12.5) and $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ in accordance with Equation (2.2.14.4.1) and Equation (2.2.14.4.2), respectively, are accepted for all fasteners.

In addition, an undercut fastener that shows a follow-up expansion during loading shall comply with the criteria for torque-controlled expansion fasteners in A.5.2.2.

A.5.2.2.3 Concrete screws CS

The seismic tests for the other steel type, steel grade or production method shall be omitted if all of the following criteria are met. In this context “fast 1“is the fastener for which the tests have been performed and “fast 2” is the fastener for which the tests are omitted.

- The fastener “fast 2” has an ETA for cracked concrete for static loading conditions.
- The performance of fastener “fast 2” is better or equal to the performance of fastener “fast 1”, which shall be shown in terms of
  - $N_{Rk,p,fast\ 2} \geq N_{Rk,p,fast\ 1}$ (where $N_{Rk,p}$ is the characteristic value given in the ETA);
  - tests for “crack cycling under load” in accordance with Table A.1.1 series F3: sustained load for which fastener “fast 2” passes the criteria is higehr than or equal to the corresponding load for fastener “fast 1”;
  - the ductility in terms of the A_5-value of fastener “fast 2” ≥ ductility for fastener “fast 1”;
  - the seismic resistance for fastener “fast 2” shall be determined as min($N_{Rk,p,fast\ 1} \cdot \alpha_{N,Cx,fast\ 1}$; $N_{Rk,p,fast\ 2} \cdot \alpha_{N,Cx,fast\ 1}$).

A.5.2.3 Shear tests

A.5.2.3.1 Torque-controlled expansion fasteners TC and undercut fasteners UC

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 [24] 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.

Embedment depth:

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 shall be omitted if the reduction factor $\alpha_{V,C1}$ in accordance with Equation (2.2.13.6) is applied to all embedment depths.

b) Fasteners under category C2 (test series C2.2, C2.4):
Only the minimum embedment depth needs to be tested if the reduction factor for seismic loading $\alpha_{V,C2}$ in accordance with Equation (2.2.15.3.1) 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.

If for a specified embedment depth deeper setting is allowed, the embedment depth for the tests shall be selected such that the most unfavourable position with regard to the shear plane is accounted for. For example, fasteners consist of a smooth shaft and a threaded part. Depending on the thickness of the fixture the shear plane shall pass through the smooth portion or the threaded part (see Figure A.5.2.3.1.1).

Note *For mechanical fasteners a single embedment depth h_{ef} is frequently specified for each diameter (e.g., M12, h_{ef} = 70 mm). Different lengths of the fastener for the same diameter may account for different thicknesses of the fixture t_{fix}. Therefore, it is allowed to set the fastener deeper than the specified value (as long as all other criteria such as for example h_{min} are met) for ease of use to avoid extensive projection of the fastener above the fixture. This results in an unfavourable position with regards to shear loading.*

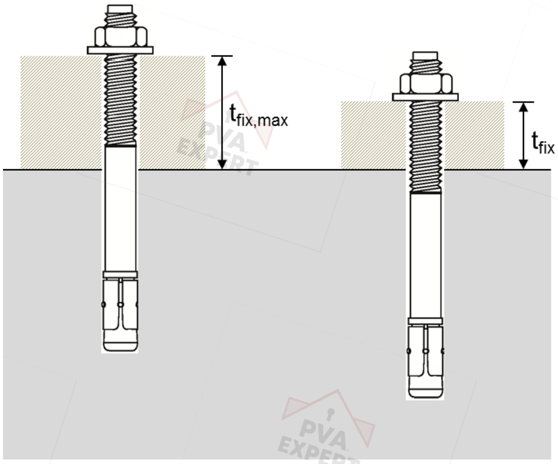


Figure A.5.2.3.1.1 Shear test with unfavourable position with regard to shear plane

A.5.2.3.2 Concrete screws CS

A reduction of number of variants to be tested is only allowed for shear tests with respect to the embedment depth as given in A.5.2.

A.5.2.4 Deformation-controlled expansion fasteners DC

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

A.5.3 Load/displacement behaviour

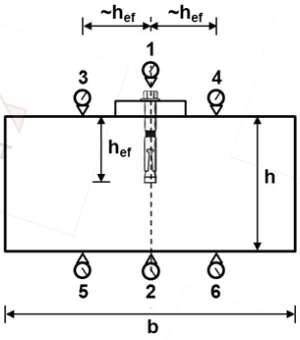
In the load/displacement curve for each fastener tested, a load plateau with a corresponding slip greater than 10 % of the displacement at ultimate load, and/or a temporary drop in load of more than 5 % of the ultimate load is not acceptable up to a load of 70 % of the ultimate load in the single test. An example of uncontrolled slip is shown in Figure A.2.5.4.

This criterion 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 criterion is not fulfilled, the ETA shall include a sentence: " Significant decrease of resistance to tension load of fasteners may occur.”.

A.6 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 at least 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		
Drawing of test member (including dimensions and position of reinforcement)		sketch according to "examples cross section " and "example for test member with bond breaking pipes"
Dimensions		(l / w / h)
concrete mix		e.g., cement, aggregate type and content, w/c-ratio
curing conditions		
age of test 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 ration		
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		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
Test method for fastener being located in crack over required length	e.g., borescope (sketch of crack formation over load transfer zone)
Particulars concerning restraining uplift in shear tests (where applicable)	
Method of crack creation	
Verification of approximately constant crack width throughout thickness of test member (where applicable)	
4. Test parameter	
crack opening mechanism	Describe how the crack width in the area of the load transfer zone is ensured
Loading device	
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
type and position of crack measurement devices	
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)
(hairline) crack width before and after fastener installation	
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	
Crack width for residual capacity tests	
measuring uncertainty for crack width transducers	e.g., ±0,005 mm.
minimal frequency during the test	
maximal frequency during the test	
Particulars concerning restraining uplift in shear tests (where applicable)	

Alternating shear load cycling procedure	
Reduced load levels and reason for reduction (where applicable)	
Location of failure (e.g., in shaft portion, threaded part, neck of fastener)	
Particulars of tests for category C1 - Crack width Δw - Fastener displacement as a function of number of load cycles - Constant load levels N_{C1}, N_i and N_m on fastener and method of applying the load in test series C1.1 - Constant load levels V_{C1}, V_i and V_m on fastener and method of applying the load in test series C1.2	
Particulars of tests for category C2 - Maximum loads N_{max} and V_{max} in test series C2.3 and C2.4, respectively - Type of loading cycles (sinusoidal or triangular) in test series C2.3 - 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 Nw1 and Nw2 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.	
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 are 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 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 (for shallow embedment)
Torque at failure (torque tests only)	
Diagram with displacement over time of testing (long-term tests only)	

ANNEX B ASSESSMENT FOR MECHANICAL FASTENERS IN STEEL FIBRE REINFORCED CONCRETE OF STRENGTH CLASS C20/25 TO MAXIMUM CONCRETE STRENGTH CLASS

B.1 Scope

This Annex provides information for the assessment of mechanical fasteners for use in steel fibre reinforced concrete (SFRC) in accordance with EN 206 [12], to which steel fibres in accordance with EN 14889-1 [7] are included into the concrete matrix.

The maximum content of steel fibres is 80 kg/m³ unless specified differently by the manufacturer. The volume of steel fibres shall be determined in accordance with EN 14721 [6].

The assessment is made to verify the validity of the performance of mechanical fasteners in SFRC as assessed for use in compacted normal weight concrete without fibres of strength classes C20/25 to maximum concrete strength class for static and quasi-static loading, seismic loading or resistance to fire.

If the validity (equivalence) cannot be verified, all tests in accordance with Table A.1.1 shall be performed under conditions given in Clause B.2 and the complete assessment in accordance with Clause 2.2 shall be done.

The essential characteristics of mechanical fasteners in steel fibre reinforced concrete assessed in accordance with this Annex can be used for design in accordance with EN 1992-4 [4].

B.2 Test programme and details of tests

The test programme for use in fibre reinforced concrete is given in Table B.3.1 for mechanical fasteners.

Concrete mix:

For steel fibre reinforced concrete, Table B.3.1 applies. The maximum aggregate size can be reduced to 8 mm. Figure B.2.1 shall be used as guidance.

Note: For better handling of the concrete mix, it is recommended to select aggregate sizes ≤ 2 mm close to the upper curve of Figure A.3.1.2.2.1 or Figure B.2.1 in SFRC.

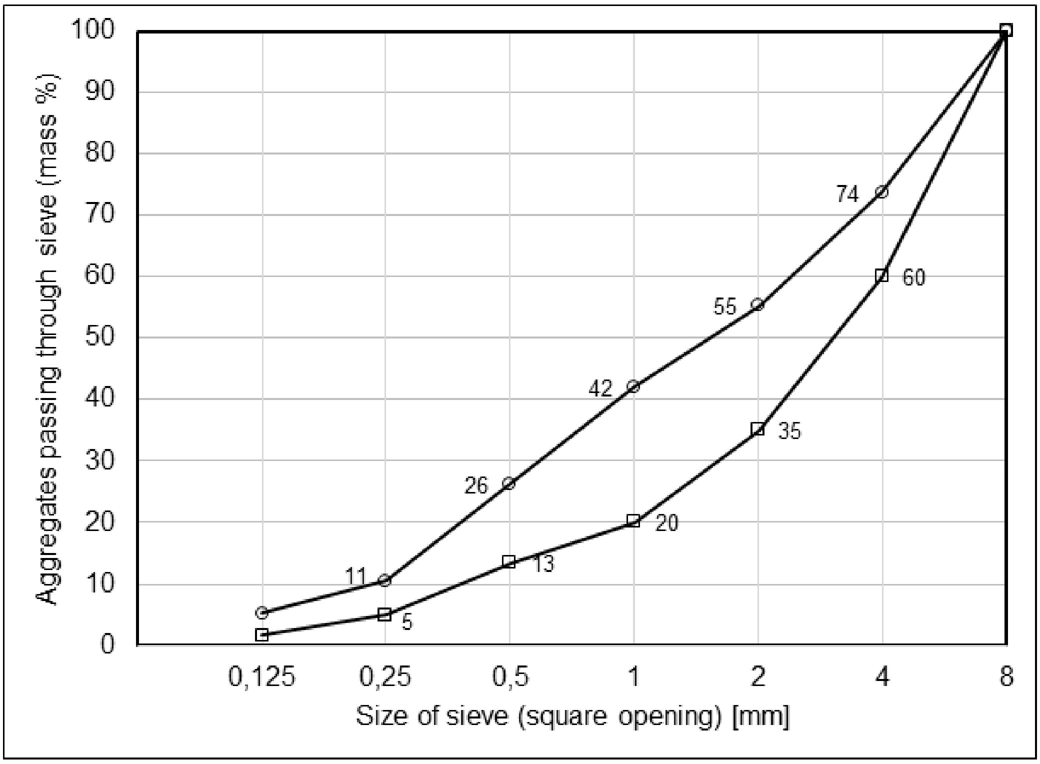


Figure B.2.1 **Grading curve for SFRC (Aggregate sizes shall be between both curves)**

Test members with steel fibres in accordance with EN 14889-1 [7], Clause 5 group I, with a length of 50-60 mm and a diameter between 0,75 and 1,05 mm shall be used (if not specified otherwise by the manufacturer of the fastener) in order to ensure the same test conditions in different labs.

The fibre content for each test series is given in Table B.3.1.

B.3 Test programme

The test programme for use in fibre reinforced concrete is given in Table B.3.1.

For all concrete batches used in this assessment, the following test procedure shall be carried out:

- Before addition of steel fibres, determine f_c or f_{cube} in concrete without fibres of the same concrete mix for comparison with the assessment in plain concrete without fibres at the time of performing the test series (see A.3.1.2.5). This concrete strength shall be used for the normalization in the assessment.
- Determine the residual flexural strength $f_{R,j}$ (j = 1, 3) of the final ae of the fibre reinforced concrete (C20/25 with 20 kg/m³ fibre content) in accordance with EN 14651 [5] at an age of the specimen of 28 days. The test specimens shall be at least six prisms conforming to EN 12390-1 [2]. The length of the steel fibres shall not be less than 1,5 times the maximum grain size. The characteristic values $f_{R1,k}$ and $f_{R3,k}$ shall be computed consistently with EN 1990 [9], Annex D, Clause D7.3 assuming a lognormal distribution. If the concrete composition is identical for all batches, the flexural strength shall be tested only once.

  Note: Both the cases 'V_X known' and 'V_X unknown' can be adopted. However, the former shall be applied only if prior knowledge is available from the evaluation of previous tests in comparable situations (e.g., if the specific concrete is produced under Factory Production Control and the coefficient of variation determined for the evaluated tests is lower or equal than the one previously determined through FPC tests).

Table B.3.1 Test programme for mechanical fasteners in steel fibre reinforced concrete

N°	Purpose of test	Concrete Steel fibre content	Crack width [mm]	Size	d_{cut}	Required for	n_{min}	Assessment clause
A1F	Basic tension tests	C20/25 20 kg/m³	0	s/m/l	$d_{cut,m}$	All	5	B.3.1
A2F		max 80 kg/m³	0	s/m/l			5	
F1F	Maximum crack width and large hole diameter	C20/25 20 kg/m³	0,50	s/m/l	$d_{cut,max}$	All	5	B.3.2
F2F	Maximum crack width and small hole diameter	max 80 kg/m³	0,50	s/m/l	$d_{cut,min}$	All	5	B.3.2
F7F	Torquing in high strength concrete	max 80 kg/m³	0	s/m/l	$d_{cut,min}$	(CS only)	10	B.3.3
F8F	Impact screw driver	C20/25 20 kg/m³	0	s/m/l	$d_{cut,max}$	(CS only)	15	B.3.3
F9F	Robustness to variation in use conditions	C20/25 20 kg/m³	0,30	s/m/l	4)	UC, DC, CS	5	B.3.2
		max 80 kg/m³				TC		
Seismic performance category C2								
C2.1aF	Reference tension tests in low strength concrete	C20/25 20 kg/m³	0,8	s/m/l	$d_{cut,m}$	All	5	B.3.6
C2.1bF	Tension tests in high strength concrete	max 80 kg/m³	0,8	s/m/l	$d_{cut,m}$	All	5	B.3.6

B.3.1 Assessment of test series A1F, A2F

Equivalence of performance accounting for the sensitivity of fibres in the concrete shall be evaluated with comparison of the results of the reference test series A1F and A2F of Table B.3.1. Determine the mean value of failure loads $N_{u,m}$ [N], converted to the nominal concrete strength in accordance with A.2.1.

- Determine the 5 % fractile of the failure loads $N_{5\%}$ [N], converted to the nominal concrete strength in accordance with Clause A.2.1.
- Verify the coefficient of variation of failure loads. If the coefficient of variation cv_F > 15 %, determine the reduction factor for large scatter β_{cv} in accordance with Clause A.2.2.
- Verify that the $N_{u,m}$ [N] and the 5 % fractile of the failure loads $N_{5\,\%}$ [N] of test series A1F and A2F are at least 95 % of the corresponding parameters of the reference tests A1 and A2 in accordance with Table A.1.1. The comparison of the 5 % fractile shall 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 %.

Load displacement behaviour

- 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 [%] in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm, cv_δ shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

B.3.2 Assessment of test series F1F, F2F, F9F

Equivalence of performance accounting for the sensitivity of fibres in the concrete shall be evaluated by comparison of the results of the test series F1F, F2F, F9F to the corresponding series in plain normal weight concrete in accordance with Table A.1.1.

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [N], converted to the nominal concrete strength in accordance with Clause A.2.1.
- Determine the 5 % fractile of the failure loads $N_{5\,\%}$ [N], converted to the nominal concrete strength. in accordance with Clause A.2.1.
- Verify the coefficient of variation of failure loads. If the coefficient of variation cv_F > 20 %, determine the reduction factor for large scatter $ß_{cv}$ in accordance with Clause A.2.2.
- Verify that the $N_{u,m}$ [N] and the 5 % fractile of the failure loads $N_{5\,\%}$ [N] are at least 95 % of the corresponding test series in normal weight concrete of the same strength in accordance with Table A.1.1. The comparison of the 5 % fractile shall 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 %.

Load displacement behaviour

- 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 [%] in accordance with A.2.6. If the mean value of displacements at 50 % of the failure load is greater than 0,4 mm, cv_δ shall not exceed 25 %. Otherwise, the ETA shall include a sentence: "The displacements of the fasteners are not similar. Significant decrease of resistance to tension load in groups of fasteners may occur."

B.3.3 Assessment of test series F7F, F8F (CS only)

For series F7F and F8F the assessment shall fulfil the provisions given in Clauses 2.2.2.8 and 2.2.2.9, respectively.

B.3.4 Assessment under fire exposure

The resistance under fire conditions in plain concrete covers application in SFRC.

B.3.5 Assessment of seismic performance category C1

The resistance for category C1 in accordance with Annex C in plain concrete covers application in SFRC for category C1 if tests in accordance with Table B.3.1 lines A1F to F9F are performed and the assessment shows equivalency.

B.3.6 Assessment for seismic performance category C2 test series C2.1aF and C2.1bF

Equivalence of performance accounting for the sensitivity of fibres in the concrete shall be evaluated by comparison of the results of the test series C2.1aF and C2.1bF to the corresponding series in plain normal weight concrete in accordance with Clause 2.2.14.1.

Failure loads

- Assessment in accordance with Clause 2.2.14.1.
- Verify that the $N_{u,m}$ [N] is at least 95 % of the corresponding test series in normal weight concrete of the same strength in accordance with Clause 2.2.14.1.

B.3.7 Expression of results

Specification of the intended use (Annex B of the ETA):

"• The fastener is intended to be used in fibre reinforced concrete in accordance with EN 206 [12] including steel fibres in accordance with EN 14889-1 [7], Clause 5, group xxx.

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

- The maximum content of steel fibres (give amount as tested)."

ANNEX C ADDITIONAL PROVISIONS FOR WORKING LIFE OF 100 YEARS

C.1 General

The assessment of fasteners shall be done in accordance with Clause 2.2, with the modifications as given in this Annex.

C.2 Crack cycling under load (test series F3)

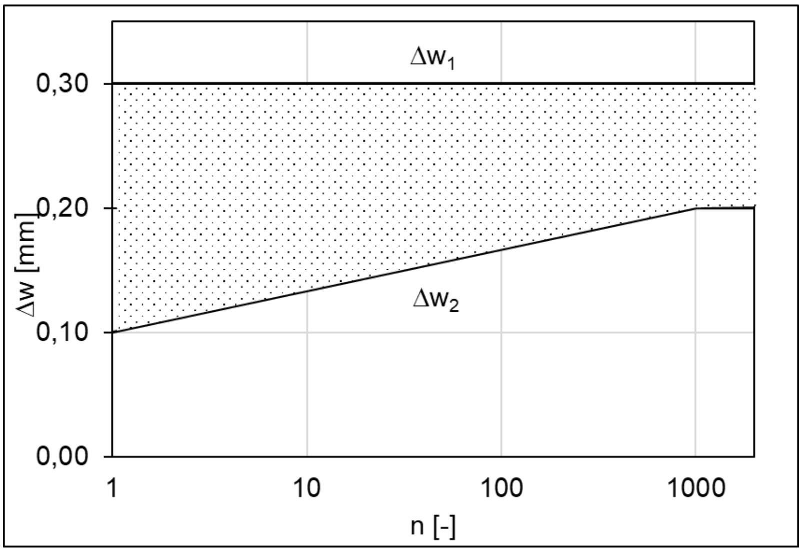
The methods for testing and assessment are the same as given in Clause 2.2.2.4, with the following exceptions:

- Perform 2000 crack cycles instead of 1000 crack cycles.
- The displacements during crack cycles after 20 (δ_{20}) and after 2000 (δ_{2000}) cycles shall fulfil the criteria specified below. Otherwise, the test series shall be repeated with a reduced test load N_p in accordance with Clause 2.2.2.4, and α_p shall be determined for assessment for 100 years working life.
- The displacements are considered to be stabilized if the increase of displacements during cycles 1500 to 2000 is smaller than or equal to the displacement during cycles 1000 to 1500.
- The lower crack width for the first 1000 cycles shall follow Figure A.3.3.3.1 and then shall not exceed 0,2 mm.

Displacements during crack cycles

In each test the rate of increase of fastener displacements, plotted in a half-logarithmic scale (see Figure 2.2.2.4.1), shall either decrease or be almost constant: the criteria of the allowable displacement after 20 (δ_{20}) and 2000 (δ_{2000}) cycles of crack opening are graduated as a function of the number of tests as follows:

During opening of the cracks, the upper crack width Δw_1 is kept constant with minimum 0,3 mm and the lower crack width Δw_2 shall comply with limits in Figure C.2.1. If the lower crack width exceeds the values of Figure C.2.1, the test can be continued under the condition that upper crack width shall be increased, in such case, the crack width difference ($\Delta w1$ - $\Delta w2$) in accordance with Figure C.2.1 shall be kept.



Δw_1 minimum upper crack width

Δw_2 maximum lower crack width

$\Delta w_2 = \min(0{,}1\ (1+\log(n)/3);0{,}2\ \text{mm})$

Figure C.2.1 **Allowable crack opening variations during the crack movement test for 2000 cycles**

Displacements during crack cycles

In each test the rate of increase of fastener displacements, plotted in a half-logarithmic scale (see Figure 2.2.2.4.1), shall either decrease or be almost constant: the criteria of the allowable displacement after 20 (δ_{20}) and 2000 (δ_{2000}) cycles of crack opening are graduated as a function of the number of tests as follows:

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

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

$\delta_{2000,mean} \leq 3$ mm and $\delta_{2000,max} \leq 4$ mm

Where

$\delta_{20,mean}$	mean displacement of all tests after 20 cycles
$\delta_{20,max}$	maximum displacement of all tests after 20 cycles
$\delta_{2000,mean}$	mean displacement of all tests after 2000 cycles
$\delta_{2000,max}$	maximum displacement of all tests after 2000 cycles

Expression of results:

Displacement $\delta_{2000,mean}$ to be used in 2.2.10

C.3 Repeated loads (test series F4)

The methods for testing and assessment shall be the same as given in Clause 2.2.2.5, with the following exceptions:

- Perform 200.000 load cycles instead of 100.000 load cycles.

Expression of results:

Displacement after 200.000 load cycles to be used in 2.2.10

C.4 Durability of functional coating for torque-controlled expansion fasteners

The methods for testing and assessment of durability of functional coatings for torque-controlled expansion fasteners is given in clause 2.2.20.1.1 and in clause 2.2.20.1.2, with following exceptions:

- Perform tests with 4000 h storage time instead of 2000 h storage time
- Perform tests with at least 160 weathering cycles instead of 80 cycles

Expression of results:

$N_{Rk,0,100}$ [N], $ß_{cv}$, α_1 [-], α/rqd. α to be used in clause 2.2.2.10.

C.5 Determination of the characteristic resistance

The determination of the characteristic to pull-out failure shall be done in accordance with Clause 2.2.2.10, taking into account the assessment given in C.2 to C.4.

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

Expression of results:

$N_{Rk,p,100}$ [kN]