EUROPEAN ASSESSMENT DOCUMENT

EAD 330232-00-0601

MECHANICAL FASTENERS FOR USE IN CONCRETE

October 2016

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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 may 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 fasteners are described by the manufacturer by reference to dimensions (external/internal diameter, thread length, diameter of shaft, neck, cone etc.) and mechanical properties (tensile and yield strength, fracture elongation) including possible tolerances.

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 dimensions:

- minimum thread size of 6 mm (M6).
- minimum fastening depth min h_{ef} of 40 mm. In special cases, e.g. in anchoring structural components which are statically indeterminate (such as light-weight suspended ceilings) and subject to internal exposure conditions only, min h_{ef} may be reduced to 30 mm and these required restrictions have to be clearly stated in the ETA.

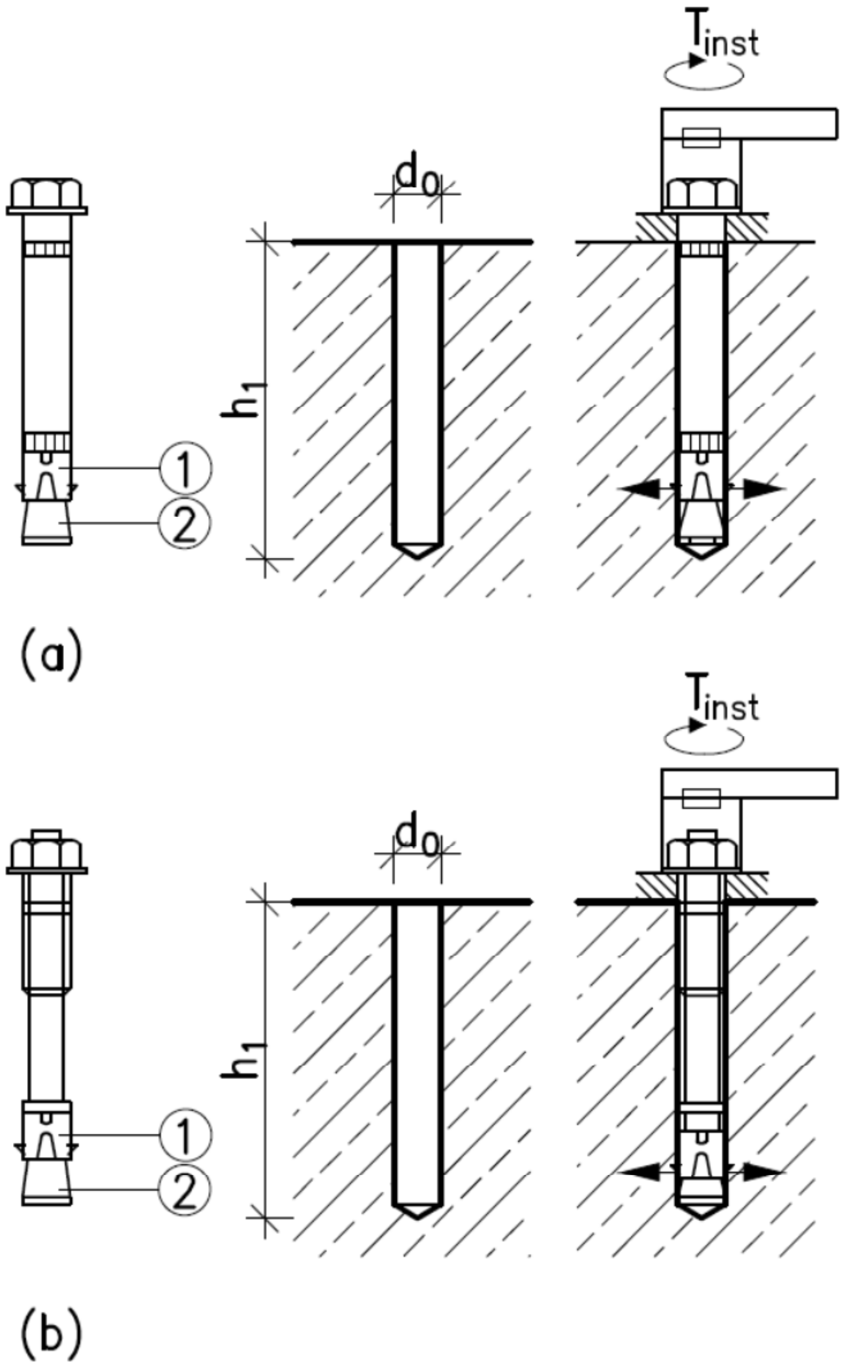
For concrete screws the diameter of the shaft applies and the requirement for the minimum embedment depth is fulfilled with the condition (h_{nom} - h_s) ≥ 40 mm according to Figure 1.14. The above mentioned reduction for statically indeterminate structures does not apply to concrete screws.

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.

Torque-controlled expansion fasteners (TC)

The operating principle is shown in Figure 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 a)
- Bolt type (Figure 1.1 b)



1 Expansion sleeve
2 Cone

(a) Sleeve type

1 Expansion sleeve
2 Cone

(b) Bolt type

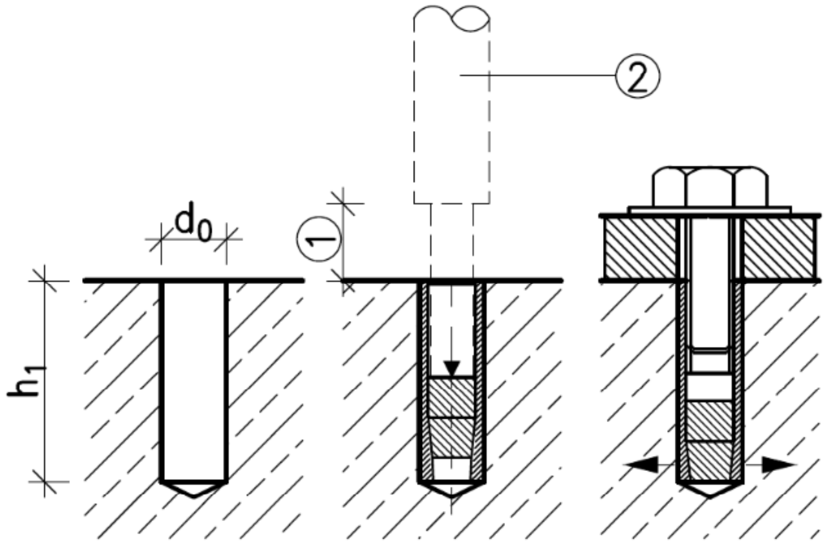
Figure 1.1 Example of torque-controlled expansion fasteners

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 1.2)
- shank-down type fastener (stud fastener, Figure 1.3)
- sleeve-down type fastener (Figure 1.4)
- sleeve-down type fastener (stud version, Figure 1.5)

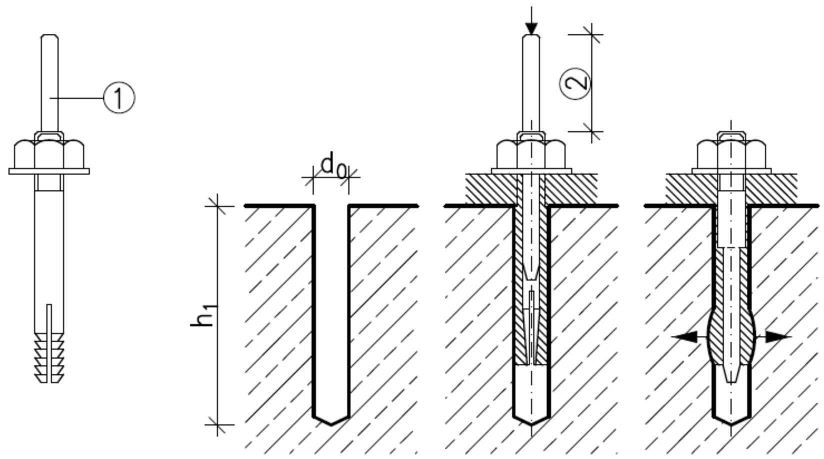
For the cone-down type the sleeve is expanded by driving in a cone. The fastening is controlled by the length of travel of the cone. A sleeve is driven over an expansion element in the case of sleeve-down type fasteners. The fastening is controlled by the travel of the sleeve over the expansion element.



1 controlled installation depth

2 Setting tool

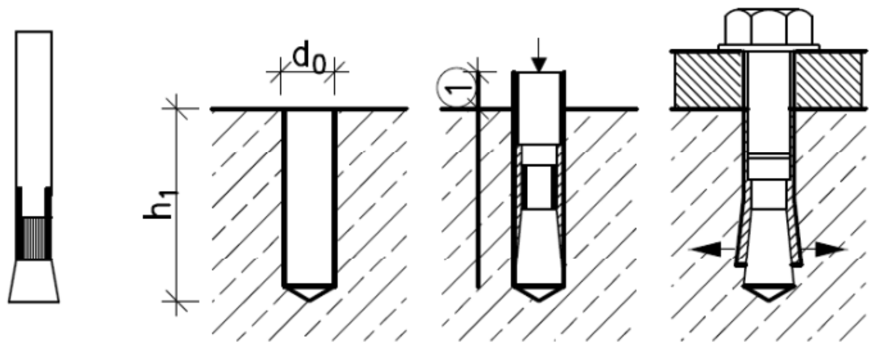
Figure 1.2 Cone-down type fastener (drop-in fastener)



1 Expansion nail

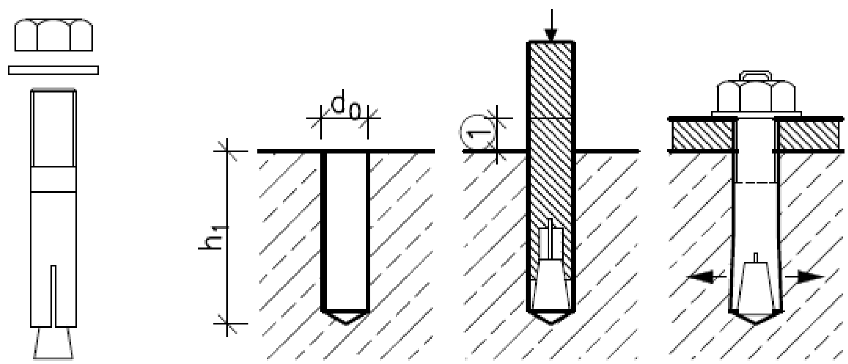
2 Controlled installation depth

Figure 1.3 Shank-down type fastener (stud fastener)



1 controlled installation depth

Figure 1.4 Sleeve-down type fastener; drilling with stop drill



1 controlled installation depth

Figure 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 1.6) 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 1.9).

This EAD covers displacement-controlled and torque-controlled undercut fasteners. In case of displacement controlled installation for fasteners according to Figure 1.6, Figure 1.7, Figure 1.9 and Figure 1.10 the depth of the drill hole h_1 needs to be ensured (e.g. by means of a stop-drill) The undercut may 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 1.6 to Figure 1.8.

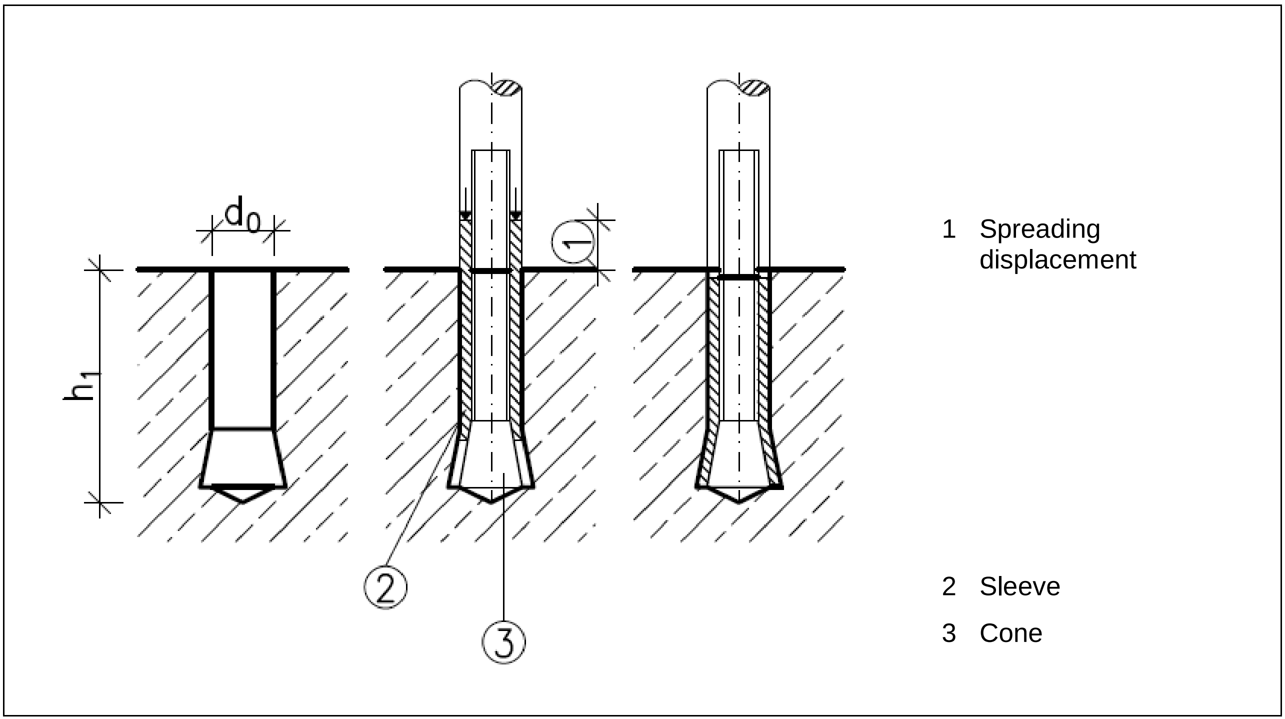
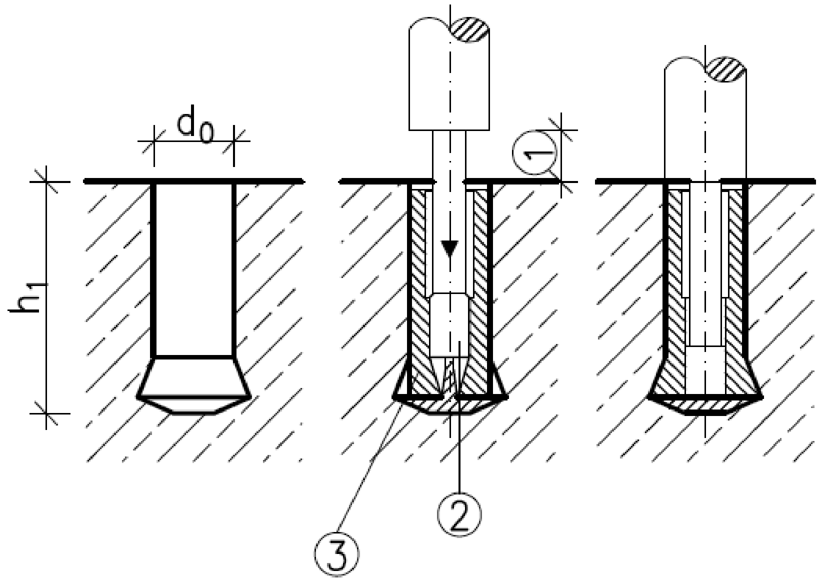


Figure 1.6 Fastener installation by hammering the fastener sleeve onto the cone

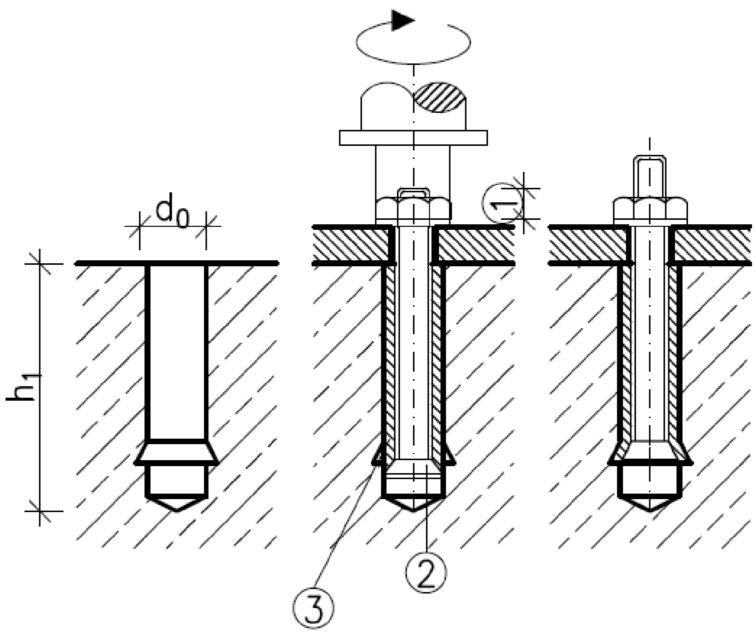


1 Spreading displacement

2 Expansion element

3 Sleeve

Figure 1.7 Fastener installation by hammering the expansion element (cone) into the fastener sleeve



1 Spreading displacement

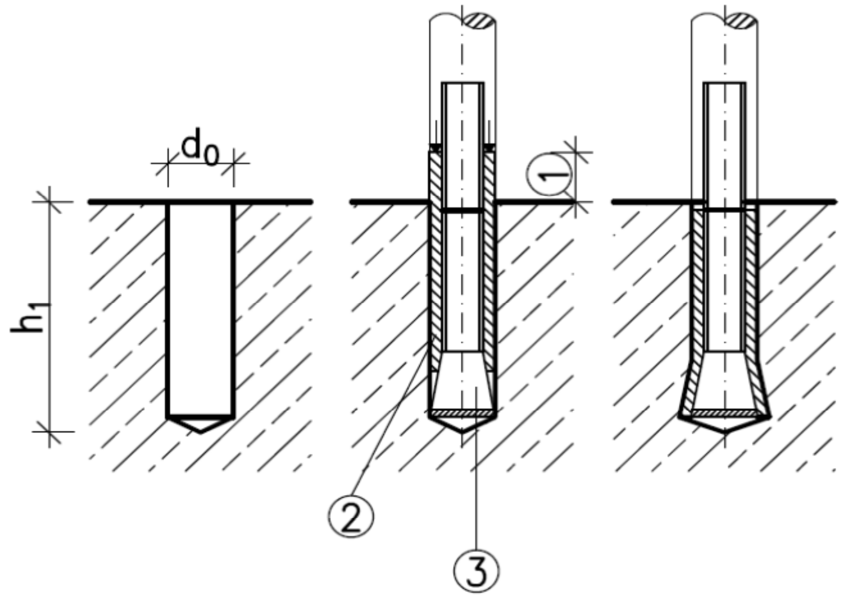
2 Sleeve

3 Cone

Figure 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 1.9 to Figure 1.14. A combination of Figure 1.9 and Figure 1.10 is also possible.



1 Spreading displacement

2 Sleeve

3 Cone

Figure 1.9 Fastener installation by hammering the sleeve over the cone; e.g. by using a drilling machine

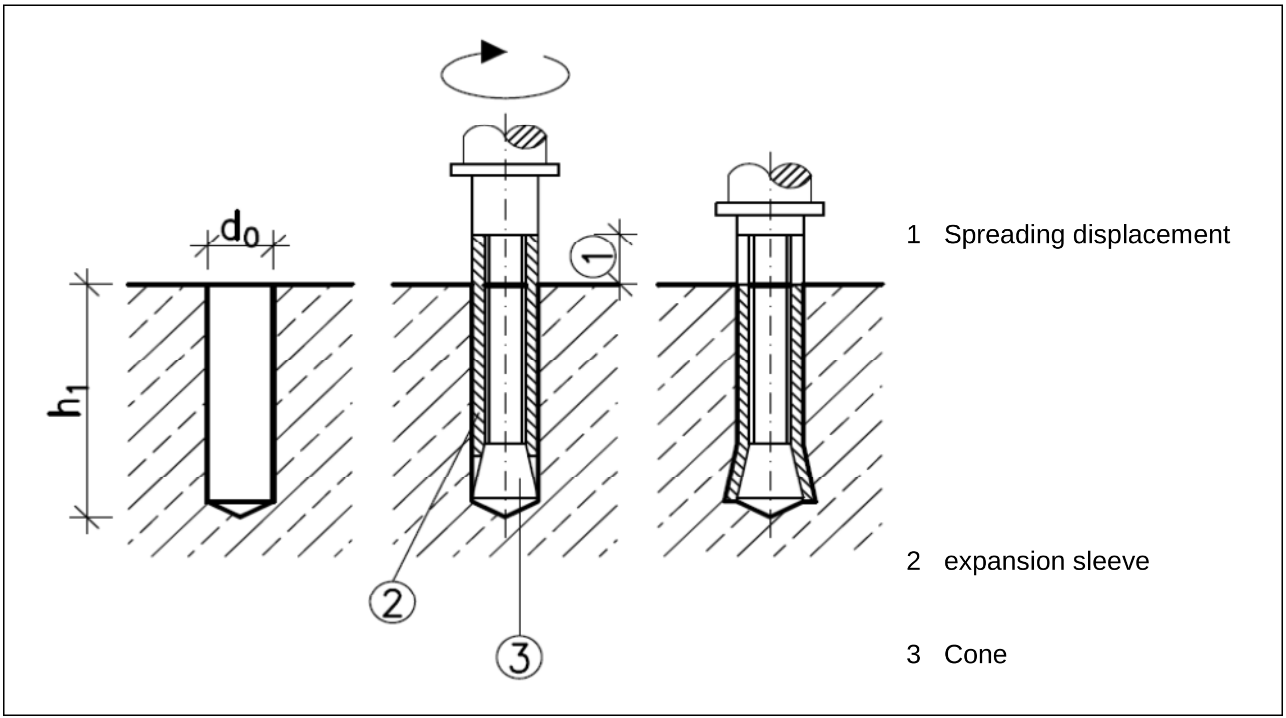


Figure 1.10 Fastener installation by rotating the fastener sleeve, e.g. by means of the drilling machine; thereby undercutting the concrete and forcing the sleeve over the cone. To facilitate the undercutting, the end of the fastener sleeve can be specially designed (e.g. with cutting pins)

c) Torque-controlled installations

The different types of fastener installation are shown in Figure 1.11 and Figure 1.12.

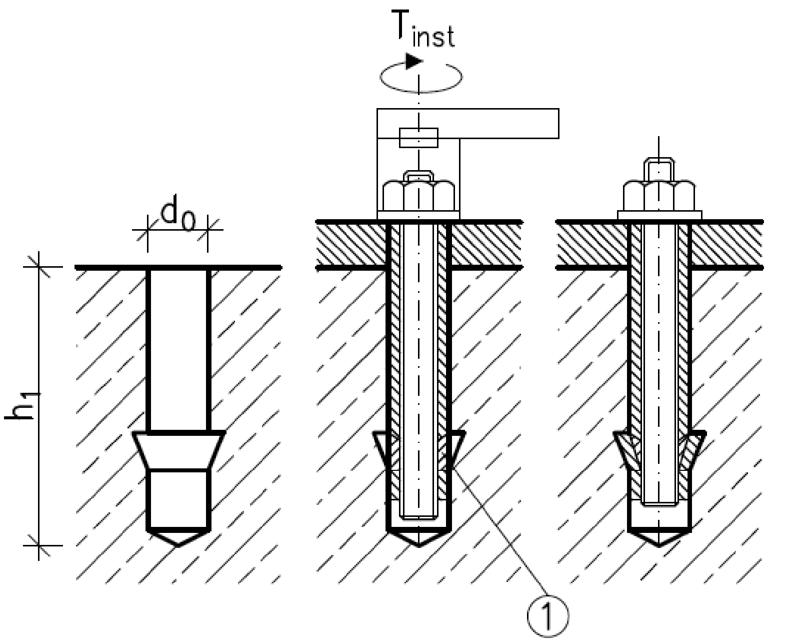


Figure 1.11 Fastener installation by forcing the expansion elements against the undercut by applying a defined torque moment

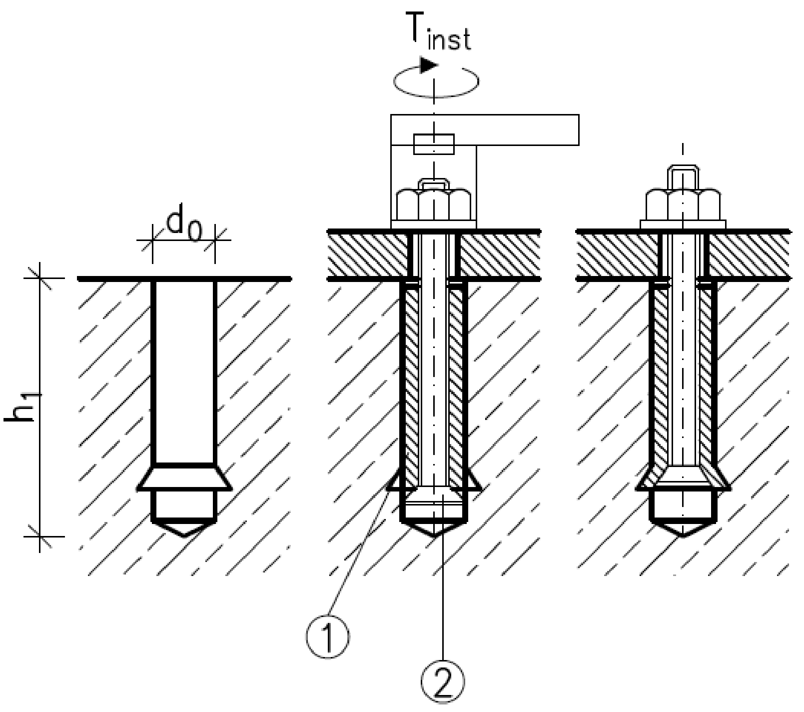


Figure 1.12 Fastener installation by pulling the cone into the fastener sleeve by applying a defined torque moment

Concrete screws (CS)

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

Note 1: Concrete screws may be 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 may 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 2: 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 [4].

The products addressed in this EAD are not covered by a harmonised European standard (hEN).

Concerning product packaging, transport, storage, maintenance, replacement and repair it is the responsibility of the manufacturer to undertake the appropriate measures and to advise his clients on the transport, storage, maintenance, replacement and repair of the product as he considers necessary.

It is assumed that the product will be installed according to the manufacturer's instructions or (in absence of such instructions) according to the usual practice of the building professionals.

Relevant manufacturer's stipulations having influence on the performance of the product covered by this European Assessment Document shall be considered for the determination of the performance and detailed in the ETA.

1.2 Information on the intended use of the construction product

1.2.1 Intended use

In this EAD the assessment is made to determine characteristic values of the mechanical fastener for design according to prEN 1992-4 [16].

Note 3: 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 without fibres with strength classes in the range C20/25 to C50/60 all in accordance with EN 206 [12].

The fastener is intended to be used

- in uncracked concrete only (Table 1.1, option 7 – 12)
- in cracked and uncracked concrete (Table 1.1, option 1 – 6: max w = 0,3 mm)
- under static or quasi-static actions
- under seismic actions (category C1: max w = 0,5 mm; category C2: max w = 0,8 mm; with C1 and C2 according to TR 049)
- with requirements related to resistance to fire (only for fasteners in cracked concrete, Table 1.1, option 1-6)

loaded in tension, shear or combined tension and shear.

Note 4: The loading on the fastener resulting from actions on the fixture (e. g. tension, shear, bending or torsion moments or any combination thereof) will generally be axial tension and/or shear. When the shear force is applied with a lever arm, a bending moment on the fastener will arise. It is presumed, that compressive forces acting in the axis of the fastener are transmitted by the fixture directly to the concrete without acting on the fastener's load transfer mechanism.

The 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.

The thickness of the concrete member in which the fastener is installed is $h \geq 2\ h_{ef}$ and $h \geq 100$ mm.

Note 5: If the thickness of the concrete member is smaller than required above, aspects such as e.g. bending of the concrete 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 concrete members are not covered in this EAD.

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

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

- ✓ Intended use covered by the assessment option
- × Intended use not covered by the assessment option

Table 1.1 Assessment options covered by this EAD

<table>
<tr><th>Option</th><th>Cracked concrete</th><th>Non cracked concrete</th><th>One value for all concrete strength classes</th><th>Different values for C20/25 to C50/60</th><th>One value for load direction</th><th>Separate values for tension and shear capacity</th><th>c_{cr} / s_{cr}</th><th>$c_{min} < c_{cr}$ / $s_{min} < s_{cr}$</th><th>Design method acc. to prEN 1992-4 [16]</th></tr>
<tr><td>1</td><td rowspan="6">✓</td><td rowspan="6">✓</td><td>×</td><td>✓</td><td rowspan="2">×</td><td rowspan="2">✓</td><td rowspan="4">✓</td><td rowspan="4">✓</td><td rowspan="2">A</td></tr>
<tr><td>2</td><td>✓</td><td>×</td></tr>
<tr><td>3</td><td>×</td><td>✓</td><td rowspan="4">✓</td><td rowspan="4">×</td><td rowspan="2">B</td></tr>
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<tr><td>5</td><td>×</td><td>✓</td><td rowspan="2">✓</td><td rowspan="2">×</td><td rowspan="2">C</td></tr>
<tr><td>6</td><td>✓</td><td>×</td></tr>
<tr><td>7</td><td rowspan="6">×</td><td rowspan="6">✓</td><td>×</td><td>✓</td><td rowspan="2">×</td><td rowspan="2">✓</td><td rowspan="4">✓</td><td rowspan="4">✓</td><td rowspan="2">A</td></tr>
<tr><td>8</td><td>✓</td><td>×</td></tr>
<tr><td>9</td><td>×</td><td>✓</td><td rowspan="4">✓</td><td rowspan="4">×</td><td rowspan="2">B</td></tr>
<tr><td>10</td><td>✓</td><td>×</td></tr>
<tr><td>11</td><td>×</td><td>✓</td><td rowspan="2">✓</td><td rowspan="2">×</td><td rowspan="2">C</td></tr>
<tr><td>12</td><td>✓</td><td>×</td></tr>
</table>

1.2.2 Working life/Durability

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

When assessing the product, the intended use as foreseen by the manufacturer shall be taken into account. The real working life may be, in normal use conditions, considerably longer without major degradation affecting the basic requirements for works[1].

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

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

1.3 Specific terms used in this EAD

1.3.1 Abbreviations

C1	=	seismic performance category C1 (use in design according to prEN 1992-4 [16])
C2	=	seismic performance category C2 (use in design according to prEN 1992-4 [16])
CS	=	concrete screw
DC	=	deformation-controlled expansion fastener
DM-A	=	design method A according to prEN 1992-4 [16]
DM-B	=	design method B according to prEN 1992-4 [16]
DM-C	=	design method A according to prEN 1992-4 [16]
MPII	=	manufacturer’s product installation instructions
TC	=	torque-controlled expansion fastener
UC	=	undercut fastener
X1	=	subject to dry internal conditions
X2	=	subject to dry internal conditions or external atmospheric exposure including industrial and marine environment or permanently damp internal condition, if no particular aggressive conditions exist
X3	=	subject to dry internal conditions or external atmospheric exposure including industrial and marine environment or permanently damp internal condition or permanently damp internal condition and in other particular aggressive conditions *Particular aggressive conditions are e. g. permanent, alternating immersion in seawater or the splash zone of seawater, chloride atmosphere of indoor swimming pools or atmosphere with extreme chemical pollution (e. g. in desulphurization plants or road tunnels where de-icing materials are used).*

1.3.2 Notation

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_s	=	stressed cross-section of the fastener used for determining the tensile capacity
A_5	=	fracture elongation
b	=	width of concrete member
c_1	=	edge distance in direction 1
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

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 Technical Report 048 [9] Figure 3.5)

$d_{cut,max}$ = cutting diameter at the upper tolerance limit (see Technical Report 048 [9] Figure 3.5) (maximum diameter bit)

$d_{cut,min}$ = cutting diameter at the lower tolerance limit (see Technical Report 048 [9] Figure 3.5) (minimum diameter bit)

d_f = diameter of clearance hole in the fixture

d_{nom} = outside diameter of fastener

d_1 = diameter of undercutting hole

d_2 = diameter of expanded undercut fastener

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

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

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)

$F_{u,m,t}$ = 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

$F_{u,5\%,20}$ = 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)

$f_{u,test}$ = steel ultimate tensile strength in the test

f_{uk} = nominal characteristic steel ultimate strength

$f_{y,test}$ = steel tensile yield strength in the test

f_{yk}	=	nominal characteristic steel yield strength
h	=	thickness of the concrete member
h_{ef}	=	effective embedment depth
h_{min}	=	minimum thickness of concrete member
h_{nom}	=	overall fastener embedment depth in the concrete
h_o	=	depth of cylindrical drill hole at shoulder
h_1	=	depth of drilled hole to deepest point
k	=	factor for required torque moment in Equation (2.9)
L	=	largest size of the complete product range of each fastener type as supplied to the market
M	=	medium size of the complete product range of each fastener type as supplied to the market
N	=	normal force (+N = tension force)
N_{sl}	=	load at which uncontrolled slip of the fastener occurs (see Figure A.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	=	number of tests of a test series
n_{min}	=	minimum number of tests for a test series
$p_1 – p_5$	=	fitting parameter
$rqd.\ \alpha$	=	required value of α according to Table A.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 an fastener group in direction 1
s_2	=	spacing of fasteners in an fastener group in direction 2
T	=	torque moment
T_{inst}	=	required or maximum recommended setting torque specified by the manufacturer for expansion or pre-stressing of fastener

$max\ T_{fix}$	=	maximum setting torque moment for attachment of the fixture for prepositioned fasteners
t_{fix}	=	thickness of fixture
t_u	=	time to failure in tests under fire exposure
V	=	shear force
α	=	reduction factor for load according to A2.4
α_1	=	reduction factor for uncontrolled slip according to A2.5
$ß_{cv}$	=	reduction factor for large scatter according to A2.2
γ_M	=	recommended material partial safety factor according to prEN 1992-4 [16] of the corresponding failure mode
γ_{inst}	=	factor accounting for the sensitivity to installation of post-installed fasteners according to prEN 1992- [16]
$\delta_{0,5Nu,m}$	=	displacement of the fastener at 50% 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 Technical Report 048 [9]); the larger value is decisive
$\delta_{N\infty}$	=	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
Δw	=	required crack width, in addition to the initial hairline crack width as measured after the installation of the fastener
$\Delta\sigma_s$	=	working stroke of action in repeated load tests

1.3.3 Indices

cr	=	cracked concrete
fi	=	fire
r	=	reference tests
t	=	tested result
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

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
installation expansion	=	expansion achieved by applying a specified expansion energy which is reduced in relation to reference expansion (see TR 048); installation expansion is used in the tests for installation factor
reference expansion	=	expansion achieved by applying specified expansion energy (see TR 048); reference expansion is used in any other tests
test member	=	concrete member in which the fastener is tested

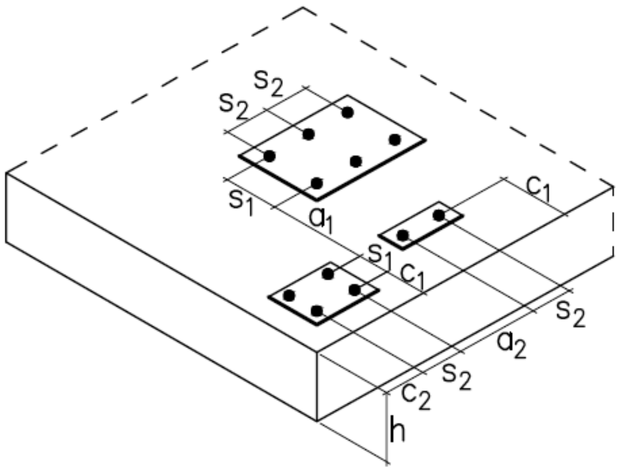


Figure 1.13 Definitions - concrete member, fastener spacing and edge distance

The effective fastening depth of concrete screws shall be determined according to Figure 1.14.

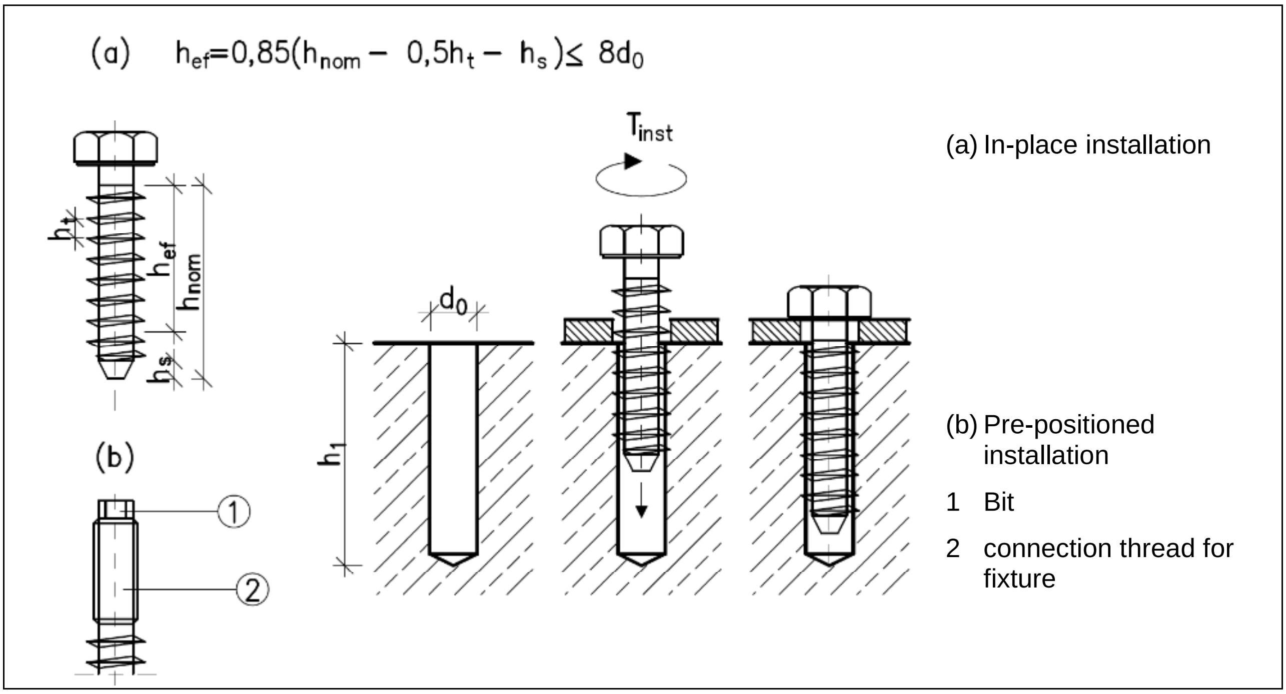


Figure 1.14 Installation by driving the concrete screw with a self-cutting special thread with wrench or impact screw driver into a predrilled cylindrical hole.

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1 shows how the performance of mechanical fasteners is assessed in relation to the essential characteristics.

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

No	Essential characteristic	Assessment methods	Type of expression of product performance *(level, class, description)*
Basic Works Requirement 1: Mechanical resistance and stability			
Characteristic resistance to tension load (static and quasi-static loading)			
1	Resistance to steel failure	2.2.1	$N_{Rk,s}$ [kN], E_s [N/mm²]
2	Resistance to pull-out failure	2.2.2	$N_{Rk,p}$ [kN], ψ_c
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	$N^0_{Rk,sp}$ [kN], $c_{cr,sp}$ [mm]
Characteristic resistance to shear load (static and quasi-static loading)			
7	Resistance to steel failure under shear load	2.2.7	$V^0_{Rk,s}$ [kN], $M^0_{Rk,s}$ [Nm], k_7 [-]
8	Resistance to pry-out failure	2.2.8	k_8 [-]
9	Resistance to concrete edge failure	2.2.9	d_{nom}, ℓ_f
10	Displacements under static and quasi-static loading	2.2.10	δ_{N0}, $\delta_{N\infty}$ δ_{V0}, $\delta_{V\infty}$ [mm]
11	Durability	2.2.12	Description
Characteristic resistance and displacements for seismic performance categories C1 or C2 (optional)			
12	Resistance to steel failure	TR 049	$N_{Rk,s,eq}$, $V_{Rk,s,eq}$ [kN]
13	Resistance to pull-out		$N_{Rk,p,eq}$ [kN]
14	Fracture elongation		A_5 [%]
15	Factor for annular gap		α_{gap} [-],
16	Displacements		$\delta_{N,eq}$, $\delta_{V,eq}$ [mm]
Basic Works Requirement 2: Safety in case of fire			
17	Reaction to fire	-	Class (A1) according to EN 13501-1 [19]
Resistance to fire (optional)			
18	Fire resistance to steel failure (tension load)	2.2.13	$N_{Rk,s,fi}$ [kN]
19	Fire resistance to pull-out failure (tension load)	2.2.14	$N_{Rk,p,fi}$ [kN]
20	Fire resistance to steel failure (shear load)	2.2.15	$V_{Rk,s,fi}$ [kN], $M^0_{Rk,s,fi}$ [Nm]

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

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

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

2.2.1 Resistance to steel failure under tension load

2.2.1.1 Steel capacity (test series N1)

Purpose of the test

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

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

If the steel strength differs along the length of the element, calculate the design steel capacity for the specified steel strengths and the corresponding nominal stressed cross sections according to Equation (2.1) taking into account the recommended partial factor for steel resistance $\gamma_{M,s}$ according to prEN 1992-4 [16], Table 4.1. Take the minimum of these design steel capacities and determine the characteristic resistance to steel failure. The characteristic resistance and the corresponding partial factor $\gamma_{M,s}$ shall be stated in the ETA.

Tests are needed only if 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.

The modulus of elasticity for steel can be taken as E_s = 210 000 N/mm².

Test conditions

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

Assessment

Determine the 5%-fractile of the failure loads. This value shall be normalized to account for over-strength of tested samples according to equation (A.6).

2.2.1.2 Maximum torque moment (test series N2)

Purpose of the test

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.

Test conditions

The tests shall be performed according to Technical Report 048 [9], 3.5

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

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Technical Report 048 [9], Figure 3.5. The diameter of the clearance hole in the fixture shall correspond to the values given in Table 2.5.

Deformation controlled expansion fasteners (DC):

Deformation controlled expansion fasteners (DC) shall be set with reference expansion according to TR 048.

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.

Assessment

Failure loads

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

Criteria

All following criteria shall be fulfilled.

1. The 95 %-fractile of the tension force generated in the torque tests at a torque moment $T = 1{,}3\ T_{inst}$ shall be smaller than the nominal yield force ($A_s \cdot f_{yk}$) of the bolt or screw.
2. The tension force generated in the torque test shall be smaller than the concrete cone capacity for concrete C20/25 according to prEN 1992-4 [16].
3. At the end of the test, the connection shall be capable of being unscrewed.
4. For deformation controlled expansion fasteners (drop-in fasteners) it shall be shown that the screw is not in contact with the cone by applying a torque moment of $T = 1{,}3\ T_{inst}$ when using the longest screw.

2.2.1.3 Hydrogen embrittlement (CS, test series N3)

Purpose of the test:

The tests are only required for concrete screws (see Figure 1.14).

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 sample is kept under constant and defined electrochemical conditions (at constant potential of –955 mV vs. normal hydrogen electrode (NHE)) by potentiostatic control or by other appropriate means. The potential is controlled by means of a reference electrode. The test setup is shown schematically in Figure 2.1.

This test for concrete screws may be omitted if

- concrete screws are made of stainless steel
- it is 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 according to EN ISO 6507 [21]; < 36 HRC according to EN ISO 6508 [22].

Preparation of samples:

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 must be removed without damaging the surface of the screw; scratch and other induced irregularity of the surface must be carefully avoided during removal of the coating. If a chemical process is used to remove the coating, expertise is required to demonstrate that such method do not add or remove diffused atoms of hydrogen in the steel subject to the process.

Test conditions:

The tests are 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.

The temperature range is between 20°C and 25°C.

Test solution:

Saturated solution (in distilled or deionizated water with a conductivity not higher 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 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 2.1). During the test the head of the concrete screw shall be submerged in the fluid.

Sustained load:

$$N_{HE} = \min \{0{,}5\ N_{st,m};\ 0{,}7\ N_{u,m}\} \qquad (2.2)$$

In Equation (2.2) 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 2.1.

Electrochemical conditions:

<u>Potential:</u> -955 mV vs. NHE.

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

<u>Counter electrode:</u> 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.

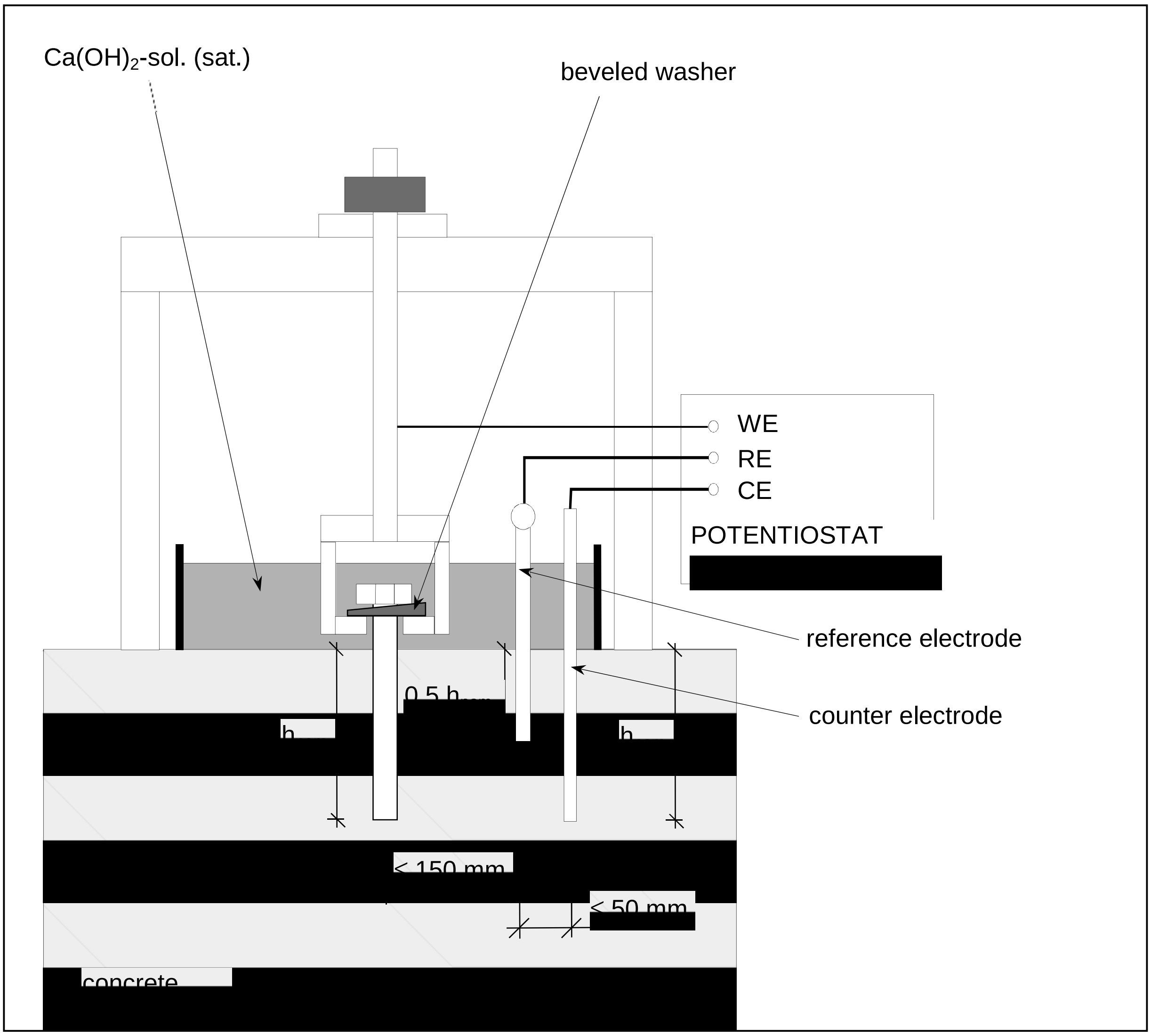


Figure 2.1 Test setup (schematic) for sensitivity to brittle fracture

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:

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20% (cv_F > 20%), determine the reduction factor for large scatter $ß_{cv}$ according to A2.2.
- Determine the reduction factors α according to Annex A comparing the test results with reference test series according to Table A.1 line A2.
- Use this reduction factor α together with rqd. α = 0,9 in equation (2.8)

2.2.2 Resistance to pull-out failure

2.2.2.1 Reference tension tests (test series A1 to A4)

Purpose of the test

These tests 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 test series is also needed for the determination of the displacements δ_{N0} in 2.2.9.

Test conditions

The tests shall be performed according to Technical Report 048 [9], 3.3.1.

The tests are performed in uncracked and cracked concrete with strength classes C20/25 and C50/60 as given in Annex A, Table Table A.1, lines A1 to A4.

If the manufacturer applies for intended use in uncracked concrete only, the test series in cracked concrete according to Table A.1 lines A3 and A4 may be omitted.

If the manufacturer applies for one tension resistance for all concrete strength classes in uncracked concrete only, the tests in high strength concrete according to Table A.1 line A2 may be omitted.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Technical Report 048 [9], Figure 3.5. Deformation controlled expansion fasteners (DC) shall be set with full expansion according to TR 048.

Assessment

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

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine $N_{Rk,0}$ from the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 15% (cv_F > 15%), determine the reduction factor for large scatter $ß_{cv}$ according to A2.2.
- Determine the reduction factor α_1 according to Annex A.
- Use the reduction factor α_1 together with rqd. α_1 = 0,7 (in cracked concrete) and rqd. α_1 = 0,8 (in uncracked concrete) in Equation (2.8).

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [kN] according to A2.5.
- Determine the mean value of the failure loads $N_{u,m}$ [kN] of the test series.
- Determine the displacements at 50% of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50% of the mean failure load cv_δ [%]. If the displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed
  - ~~40 % in tests according to Table A.1 lines F2 to F5, F9 and F10~~
  - 25 % in tests according to Table A.1 lines A1 to A4 and V1 to V2.

Note 6: The design according to prEN 1992-4 [16] for groups of fasteners is only valid if the scatter of displacements under load does not exceed 40% with respect to the distribution of the load to all fasteners of the group. This may be neglected for fasteners with very small displacements δ < 0,4 mm.

2.2.2.2 Maximum crack width and large hole diameter (test series F1)

Purpose of the test

These tests are performed to evaluate the sensitivity to low strength concrete and large hole diameter drilled with $d_{cut,max}$.

Test conditions

The tests shall be performed according to Technical Report 048 [9], 3.3.1.

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

The holes shall be drilled with a cutting diameter $d_{cut,max}$ of the drill bit according to Technical Report 048 [9], Figure 3.5. Deformation controlled expansion fasteners (DC) shall be set with reference expansion according to TR 048.

Assessment

<u>Failure loads</u>

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20% (cv_F > 20%), determine the reduction factor for large scatter $ß_{cv}$ according to A2.2.
- Determine the reduction factors α and α_1 according to Annex A comparing the test results with reference test series according to Table A.1 line A3 (cracked concrete) or test series A1 (uncracked concrete only, respectively) with a rqd. α = 0,8.

<u>Load displacement behaviour:</u>

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [kN] according to A2.5.
- Determine the mean value of the failure loads $N_{u,m}$ [kN] of the test series.
- Determine the displacements at 50% of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test
- Determine the coefficient of variation of the displacements at 50% of the mean failure load cv_δ [%]. If the displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

2.2.2.3 Maximum crack width and small hole diameter (test series F2)

Purpose of the test

These tests are performed to evaluate the sensitivity to high strength concrete and small hole diameter drilled with $d_{cut,min}$..

Test conditions

The tests shall be performed according to Technical Report 048 [9], 3.3.1.

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

The holes shall be drilled with a cutting diameter $d_{cut,min}$ of the drill bit according to Technical Report 048 [9], Figure 3.5. Deformation controlled expansion fasteners (DC) shall be set with reference expansion according to TR 048.

Assessment

<u>Failure loads</u>

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal concrete strength.

- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20% (cv_F > 20%), determine the reduction factor for large scatter $ß_{cv}$ according to A2.2.
- Determine the reduction factors α and α_1 according to Annex A. 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 according to Table A.1 line A4 (cracked concrete) with a rqd. α = 0,8.
  - For fasteners with intended use in uncracked concrete only compare the test results with test series according to Table A.1 line A2 (uncracked concrete) with rqd. α = 1,0.

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [kN] according to A2.5.
- Determine the mean value of the failure loads $N_{u,m}$ [kN] of the test series.
- Determine the displacements at 50% of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test
- Determine the coefficient of variation of the displacements at 50% of the mean failure load cv_δ [%]. If the displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

2.2.2.4 Crack cycling under load (test series F3)

Purpose of the test

Fasteners intended for use in cracked concrete, in the long term, shall continue to function effectively when the width of the crack is subject to changes in the range covered by this EAD.

Test conditions

The tests shall be performed according to Technical Report 048 [9], 3.3.3.

The tests shall be performed for all diameter sizes of the fastener. The tests are performed in concrete C20/25.

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 according to Technical Report 048 [9], Figure 3.5.

The tensile load Np applied to the fastener during the crack cycling test is defined in Equation (2.3).

$$N_p = 0,50\ N_{Rk} / \gamma_{inst} \qquad (2.3)$$

where

N_{Rk} = characteristic tensile resistance in cracked concrete C20/25 as evaluated to be provided in the ETA.

This test series may be omitted for fasteners which are intended to be used in uncracked concrete only.

Deformation controlled expansion fasteners (DC) shall be set with reference expansion according to TR 048.

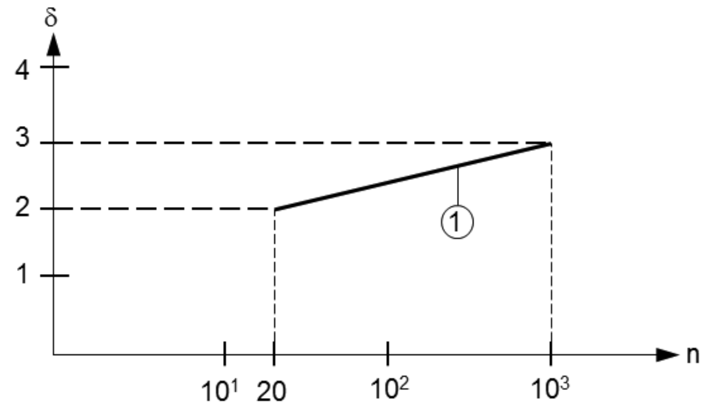
Assessment

Displacements during crack cycles

In each test the rate of increase of fastener displacements, plotted in a half-logarithmic scale (see Figure 2.2), 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:	δ_{20} ≤ 2 mm and δ_{1000} ≤ 3 mm
10 to 20 tests:	δ_{20} ≤ 2 mm; one tests is allowed to 3 mm
	δ_{1000} ≤ 3 mm; one tests is allowed to 4 mm
> 20 tests:	δ_{20} ≤ 2 mm; 5% of tests are allowed to 3 mm
	δ_{1000} ≤ 3 mm; 5% of tests are allowed to 4 mm

Note 7: 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

Figure 2.2 Criteria for results of tests with variable crack width

If in the tests the above given requirements on the displacement behaviour, i.e. rate of increase and allowable displacements, are not fulfilled, the test series shall be repeated with a reduced tension load $N_{p,red}$ until the requirements are fulfilled. The characteristic resistance shall be reduced by applying the reduction factor $\alpha_p = N_{p,red}/N_p$ in Equation (2.8).

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

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20% (cv_F > 20%), determine the reduction factor for large scatter $ß_{cv}$ according to A2.2.
- Determine the reduction factor α according to Annex A comparing the test results with reference test series according to Table A.1 line A3.
- Use the reduction factor α together with rqd. α = 0,9 in Equation (2.8).
- Determine the reduction factor α_1 according to Annex A.
- Use the reduction factor α_1 together with rqd. α_1 = 0,7 (in cracked concrete) in Equation (2.8)

Load displacement behaviour in the residual load tests:

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [kN] according to A2.5.
- Determine the mean value of the failure loads $N_{u,m}$ [kN] of the test series.
- Determine the displacements at 50% of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test
- Determine the coefficient of variation of the displacements at 50% of the mean failure load cv_δ [%]. If the displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

2.2.2.5 Repeated loads (test series F4)

Purpose of the test

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

Test conditions

The tests shall be performed according to Technical Report 048 [9], 3.3.4.

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

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.

For concrete screws the tests are to be performed on bevelled washers (inclined angle ≥ 4°) with all diameter sizes of the fastener.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Technical Report 048 [9], Figure 3.5. Deformation controlled expansion fasteners (DC) shall be set with reference expansion according to TR 048.

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

$$\max N = \text{smaller value of } 0{,}6\ N_{Rk,ucr} \text{ and } 0{,}8 \cdot A_s \cdot f_{yk}\ [N] \qquad (2.4)$$

$$\min N = \text{higher value of } 0{,}25\ N_{Rk,ucr} \text{ and } \max N - A_s \cdot \Delta\sigma_s\ [N] \qquad (2.5)$$

where:

$N_{Rk,ucr}$ = characteristic value of the failure load in tension in uncracked concrete for the concrete strength of the test member. This value is determined from the reference tension tests A1 or A2 (see 2.2.2.1) depending on the concrete strength for the test

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

Assessment

During the repeated load portion of the test no failure is allowed to occur and the increase of displacements during the cycling shall stabilize in a manner that failure is unlikely to occur after some additional cycles. If these requirements are not met, repeat the test with load values max N and min N determined based on a reduced value $N_{RK,ucr,red}$ until the requirements are met. The characteristic resistance shall be reduced by applying the reduction factor $\alpha_p = N_{Rk,ucr,red}/N_{Rk,ucr}$ in Equation (2.8).

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

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20% ($cv_F > 20\%$), determine the reduction factor for large scatter β_{cv} according to A2.2.
- Determine the reduction factor α according to Annex A. The following test series are used as corresponding reference test series:
    - For tests performed in concrete C20/25 use the test results of test series according to Table A.1 line A1
    - For tests performed in concrete C50/60 use the test results of the test series according to Table A.1 line A2
- Use the reduction factor α together with rqd. $\alpha = 1{,}0$ in Equation (2.8).
- Determine the reduction factor α_1 according to Annex A.
- Use the reduction factor α_1 together with rqd. $\alpha_1 = 0{,}8$ (in uncracked concrete) in Equation (2.8).

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load N_{sl} [kN] according to A2.5.
- Determine the mean value of the failure loads $N_{u,m}$ [kN] of the test series.
- Determine the displacements at 50% of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test
- Determine the coefficient of variation of the displacements at 50% of the mean failure load cv_δ [%]. If the displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

2.2.2.6 Robustness of sleeve down type fasteners (DC test series F5)

Purpose of the test

For sleeve down type deformation controlled fasteners the position of the sleeve in relation to the cone is not visible after installation. This test determines the robustness of sleeve down type fasteners.

Test conditions

The tests are 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 1.4 and Figure 1.5).

After achieving full expansion of the fastener two more blows shall be applied with the impact device according to Technical Report 048 [9].

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Technical Report 048 [9], Figure 3.5.

Assessment

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20% (cv_F > 20%), determine the reduction factor for large scatter $ß_{cv}$ according to A2.2.
- Determine the reduction factor α according to Annex A. The following test series are used as corresponding reference test series:
  - For fasteners for use in cracked and uncracked concrete use test series according to Table A.1 line A3.
  - For fasteners for use in uncracked concrete only use test series according to Table A.1 line A1.
- Use the reduction factor α together with rqd. α = 0,8 in Equation (2.8).
- Determine the reduction factor α_1 according to Annex A.
- 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 (2.8).

2.2.2.7 Torqueing in low strength concrete (CS test series F6)

Purpose of the test

The tests are only required for concrete screws according to Figure 1.14. The tests are performed to check if failure occurs during setting (turn-through of the concrete screw), which would then reduce the performance of the fastener.

Test conditions

Perform 10 tests with each size of the fastener in uncracked concrete C20/25. The holes shall be drilled with a cutting diameter $d_{cut,max}$ of the drill bit according to Technical Report 048 [9], Figure 3.5.

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 1.14). Afterwards the torque shall be increased up to failure. The ultimate torque moments (T_u) and the 5%-fractile of the ultimate torque ($T_{u,5\%}$) of the test series shall be determined.

Assessment

The following conditions shall be met:

(1) It shall be possible to properly set the fastener. The maximum torque moment to set the fastener with the designated setting depth and the torque moment 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 according to 2.2.2.8. In case of scatter larger than cv = 15% but not larger than 30%, the factor β_{cv} shall be determined according to Equation (A.7). For cv ≤ 15% the factor β_{cv} = 1,0.

(2) Tests with steel failure:

$$T_{u,5\%} \geq 1{,}5 \cdot T_{inst} (f_{u,t} / f_{u,nom}) / ß_{cv} \quad (2.6)$$

(3) Tests with concrete failure

$$T_{u,5\%} \geq 2{,}1 \cdot T_{inst} (f_{c,t} / f_{c,nom})^{0,5} / ß_{cv} \quad (2.7)$$

where

$f_{c,nom}$ = nominal concrete strength required for the test (e.g. 20 N/mm^2 measured on cylinders for concrete C20/25)

Note 8: The factor 1,5 in Equation (2.6) was established to take into account the scatter of steel failure due to torque moment. The factor 2,1 in Equation (2.6) was established to take into account the scatter of concrete failure due to torque moment.

If the scatter is larger than 30% more tests shall be performed to reduce the scatter. If the scatter is not reduced to a value lower than 30% the fastener cannot be assessed according to this EAD.

If in all tests steel failure occurs, Equation (2.7) may be omitted. If Equation (2.7) is fulfilled, Equation (2.6) may be omitted.

2.2.2.8 Torqueing in high strength concrete (CS, test series F7)

Purpose of the test

The tests are only required for concrete screws according to Figure 1.14. The tests are performed to check if steel failure occurs due to the torsion during setting.

Test conditions

Perform 10 tests with each size of the fastener in uncracked concrete C50/60. The holes shall be drilled with a cutting diameter $d_{cut,min}$ of the drill bit according to Technical Report 048 [9], Figure 3.5.

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 1.14). The maximum value of the required torque moment shall be measured. Afterwards the torque shall be increased up to failure. The ultimate torque moments (T_u) and the 5%-fractile of the ultimate torque ($T_{u,5\%}$) of the test series shall be determined.

Assessment

The following test criteria shall be met:

(1) It shall be possible to properly set the fastener. The maximum torque moment to set the fastener with the designated setting depth and the torque moment to tighten the fixture shall be $\leq T_{inst}$. 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 larger than cv = 15% but not larger than 30%, the factor β_{cv} shall be determined according to Equation (A.7). For cv ≤ 15% the factor β_{cv} = 1,0.

(2) Tests with steel failure: see Equation (2.6).

(3) Tests with concrete failure: see Equation (2.7).

If the scatter is larger than 30% more tests shall be performed to reduce the scatter. If the scatter is not reduced to a value lower than 30% the fastener cannot be assessed according to this EAD.

2.2.2.9 Impact screw driver (CS, test series F8)

Purpose of the test

The tests are only required for concrete screws according to Figure 1.14. The tests are performed to check if steel failure of the concrete screw occurs while setting with impact screw drivers.

Test conditions

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.

The following test conditions shall be kept:

- Non-cracked concrete C20/25;
- Cutting diameter of drill bits $d_{cut} = d_{cut,max}$;
- 15 tests with each fastener size;
- Impact screw driver with maximum power output specified in the MPII for the fastener size. Because the power output given by the manufacturer of the screw driver may not be valid for setting the TAB shall select the screw driver with maximum power output for this application from the screw drivers on the market fulfilling the specifications of the fastener.
- The fastener shall be set up to the designated depth; afterwards 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.

Assessment

In all 15 tests no failure shall occur. If the test number is increased to n = 30, one test failure may occur.

2.2.2.10 Characteristic resistance to pull-out failure

The initial value $N_{Rk,0}$ is taken as the 5% fractile of failure loads in the reference tension test series for uncracked concrete according to Table A.1 line A1 and A2 and for cracked concrete line A3 and A4.

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

(1) Load/displacement behaviour, tension loading
If the requirements on uncontrolled slip according to A2.5 are not fulfilled by the tension tests, the characteristic resistance shall be reduced according to Equation (2.8). The smallest value for α_1 applies.

(2) Crack cycling and repeated load tests
If, in the crack movement, and repeated load tests the criteria on the displacement behaviour given in 2.2.2.4 and 2.2.2.5 are not fulfilled, the characteristic resistance shall be reduced and the tests repeated until the requirements are fulfilled.

(3) Ultimate load in any other tests
If the requirements on the ultimate load in test series according to Table A.1 line N3, F1 to F5, F9 and F10, are not fulfilled in one or more test series, the characteristic resistance shall be reduced according to Equation (2.8). The smallest value of α applies. If not all sizes of fasteners have been tested, the smallest reduction factor for the size of fasteners shall be applied for all neighbour sizes which were not tested.

$$N_{Rk,p} = N_{Rk,0} \bullet \min \alpha_p \bullet \min\left(\frac{\alpha_1}{rqd.\alpha_1}\right) \bullet \min\left(\frac{\alpha}{rqd.\alpha}\right) \bullet \min ß_{cv} \leq N^0_{Rk,c} \quad (2.8)$$

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

The characteristic resistance shall be rounded down accounting for increments as given in Table 2.2.

Table 2.2 Values of characteristic resistance $N_{Rk,p}$

Range of $N_{Rk,p}$ [kN]	Increment [kN]	example
≤ 10	0,5	3,0 / 3,5 / 4,0 … 9,5 / 10,0
≤ 20	1,0	11,0 / 12,0 … 19,0 / 20,0
≤ 50	2,0	22,0 / 24,0 … 48,0 / 50,0
> 50	5,0	55,0 / 60,0 / 65,0 / …

The characteristic resistance of a fastener in case of pull-out failure in concrete of strength > C20/25 is determined by multiplying the characteristic value for concrete C20/25 by a factor ψ_c according to A2.1.

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 according to prEN 1992-4 [16] requires the factors $k_{ucr,N}$ and $k_{cr,N}$. The following 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, 3.1.28 and Figure 1.14

2.2.4 Robustness

2.2.4.1 Robustness to variation in use conditions (test series F9)

Purpose of the test

These tests are performed to determine the sensitivity of the performance to foreseeable and unavoidable variations in the use conditions.

Test conditions

The tension tests are performed according to Technical Report 048 [9], 3.3.1.

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 are 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 according to Technical Report 048 [9], Figure 3.5. The fastener is installed with an applied torque T = 0,5 T_{inst}.

Deformation-controlled expansion fasteners (DC)

The tests are performed in low strength concrete C20/25. The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Technical Report 048 [9], Figure 3.5. The fastener shall be set with installation expansion according to Technical Report 048 [9], 2.6.1.

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.

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 according to Figure 1.6

- 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 2.3 Diameter of drill bits d_0 and d_1

Fastener installation according to Figure 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 or as a combination of both.

Fastener installation according to Figure 1.8

- Diameter of drill bit for cylindrical hole d_0: $d_{cut,max}$
- Diameter of drill bit for undercutting d_1: $d_{cut,max}$
- Expansion displacement depends on the installation tools. If the expansion can be done only with a special installation tool and the required expansion displacement can easily be recognized, then the actual expansion displacement shall reflect the possible tolerances.

Installation according to Figure 1.9 and Figure 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 moment, then the fastener shall be torqued with T = 1,0 T_{inst}, after about 10 minutes the torque moment shall be reduced to T = 0,5 T_{inst}. If no defined torque moment shall be applied, then the fastener shall not be torqued before testing (T = 0).

Torque-controlled installation

For undercut fasteners which are installed by torque control according to Figure 1.11 and Figure 1.12 the test conditions in the installation safety 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 according to Figure 1.11 only)
- Torque moment T = 0,5 T_{inst}
- Concrete strength C20/25 and C50/60

Concrete screws (CS)

The tests are 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 $d_{cut,max}$ according to Technical Report 048 [9] increased by the difference in the main load bearing section of the fastener between the thread diameter in the test and the lower limit of the thread diameter according to the specification of the manufacturer, i.e.

  $d_0 \geq d_{cut,max} + (d_{th,t} - d_{th,low})$

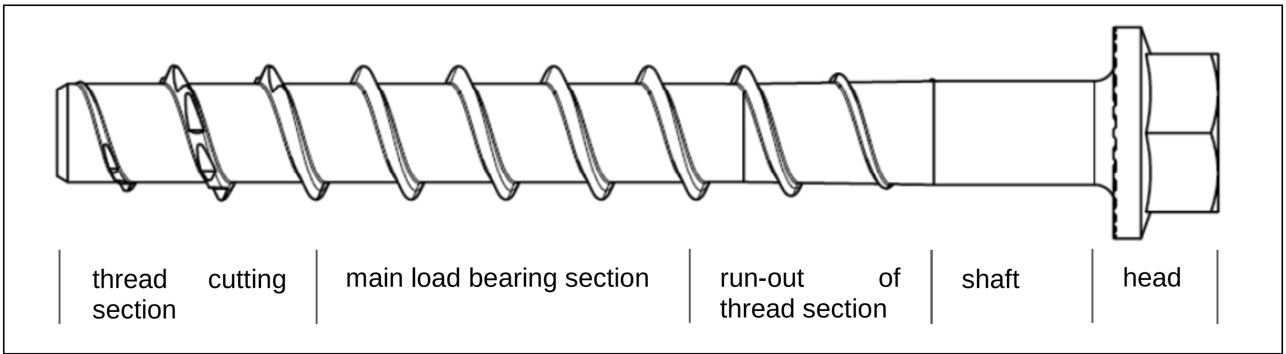


Figure 2.4 Possible sections of a concrete screw

Assessment

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20% (cv_F > 20%), determine the reduction factor for large scatter $ß_{cv}$ according to A2.2.
- Determine the reduction factors α according to Annex A. 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 according to Table 2.3. Depending on which level of rqd. α the factor α fulfils the corresponding value of γ_{inst} is taken.
- 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} [kN] according to A2.5.
- Determine the mean value of the failure loads $N_{u,m}$ [kN] of the test series.
- Determine the displacements at 50% of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test
- Determine the coefficient of variation of the displacements at 50% of the mean failure load cv_δ [%]. If the displacements at 50% of the failure load are larger than 0,4 mm, cv_δ shall not exceed 40 %.

Table 2.3 Values of rqd. α for robustness to variation in use conditions

Factor γ_{inst}	rqd. α
1,0	≥ 0,95
1,2	≥ 0,80
1,4	≥ 0,70

2.2.4.2 Robustness to contact with reinforcement (UC, CS, test series F10)

Purpose of the test

These tests are 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.

Test conditions

The tests shall be performed according to Technical Report 048 [9], 3.3.2.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Technical Report 048 [9], Figure 3.5.

These tests are required only 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 Technical Report 048 [9], 2.2.3.

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 according to Technical Report 048 [9].

Assessment

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal concrete strength.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal concrete strength.
- Verify the coefficient of variation of failure loads. If the coefficient of variation exceeds 20% (cv_F > 20%), determine the reduction factor for large scatter β_{cv} according to A2.2.
- Determine the reduction factors α according to Annex A. Test series A3 is used as the corresponding reference test series.

- Determine the factor to account for the sensitivity to installation γ_{inst} according to Table 2.4. Depending on which level of rqd. α the factor α fulfils the corresponding value of γ_{inst} is taken.
- 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} [kN] according to A2.5.
- Determine the mean value of the failure loads $N_{u,m}$ [kN] of the test series.
- Determine the displacements at 50% of the mean failure load $\delta_{0,5Nu,m}$ [mm] in each test
- Determine the coefficient of variation of the displacements at 50% of the mean failure load cv_{δ} [%]. If the displacements at 50% of the failure load are larger than 0,4 mm, cv_{δ} shall not exceed 40 %.

Table 2.4 Values of rqd. α for contact with reinforcement

Factor γ_{inst}	rqd. α
1,0	≥ 0,85
1,2	≥ 0,70
1,4	≥ 0,60

2.2.5 Minimum edge distance and spacing (test series F11)

Purpose of the test

The tests are performed to check that splitting of the concrete does not occur during the installation of the fastener.

Test conditions

The tests shall be performed according to Technical Report 048 [9], 3.4.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Technical Report 048 [9], Figure 3.5.

Test fasteners in uncracked concrete C20/25. Use a drill bit of diameter $d_{cut,m}$ for drilling the holes in which the fasteners are installed. Install two fasteners at minimum edge distance c_{min} and minimum spacing s_{min} in a test member with the minimum thickness h_{min} applied for the fastener.

The minimum edge distance c_{min} and minimum spacing s_{min} of the fasteners are specified by the manufacturer. Edge distance and axial spacing shall be rounded to at least 5 mm. They shall not be smaller than 4 d_0 and 35 mm.

Deformation controlled expansion fasteners

Set double fastener group at the edge with minimum edge distance and minimum spacing in a slab with minimum thickness of member ($s = s_{min}$, $c = c_{min}$, $h = h_{min}$). Install the fastener with full expansion. If cracks occur while setting repeat the test with enlarged edge distance or spacing.

Assessment:

After setting enlarge the projected splitting area $A_{sp,t} = (3\ c_{min} + s_{min})(1{,}5\ c_{min} + h_{ef})$ with a factor of 1,3 (cracked) and 1,7 (uncracked concrete).

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

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

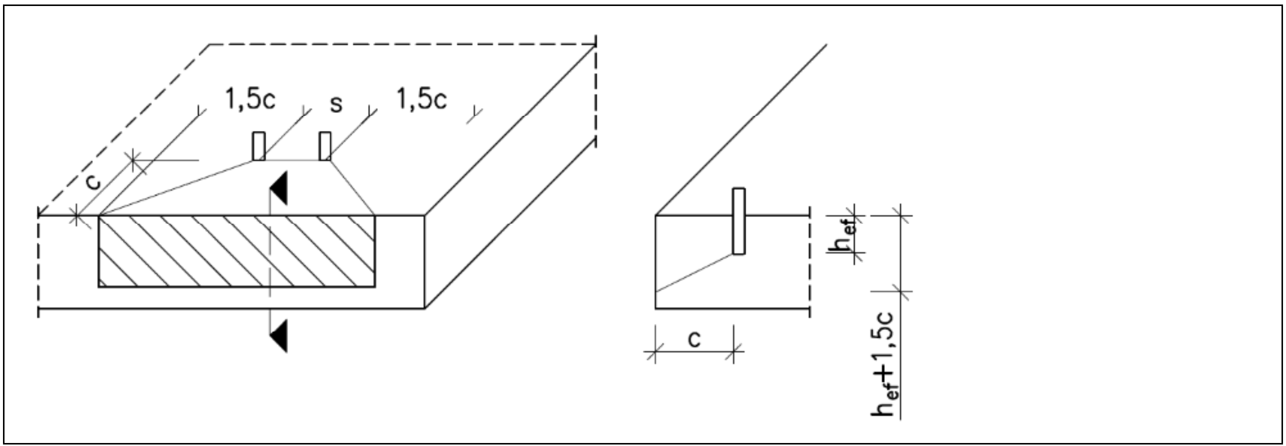


Figure 2.5 Projecting Area A_{sp}

Undercut fasteners

In addition to the tests to derive the minimum edge distance and minimum spacing, tension tests according to Technical Report 048 [9] shall be performed with double fastener group parallel to the edge ($s = s_{min}$, $c = c_{min}$, $h = h_{min}$) if the mean pre-stressing force at the maximum torque moment given by the manufacturer is smaller than the characteristic failure load for concrete failure according to prEN 1992-4 [16].

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

The minimum spacing s_{min} and minimum edge distance c_{min} shall be evaluated from the results of installation tests with double fastener groups ($c = c_{min}$, $s = s_{min}$). The 5 %-fractile of the torque moments, $T_{5\%}$, calculated according to Equation (A.9) at which a hairline crack has been observed at one fastener of the double fastener group, shall fulfil Equation (2.9).

$$T_{5\%} \geq k \cdot \text{rqd. } T_{inst} \, (f_{c,t} / f_{ck})^{0,5} \quad \text{(for concrete failure)} \tag{2.9}$$

The following values for k shall be taken:

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

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

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

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

The choice of (a) or (b) in the assessment has to be reflected in the FPC.
The splitting forces at the required or recommended torque moment respectively depend on the pre-stressing force generated during torqueing and the ratio splitting force to pre-stressing force. Pre-stressing force and splitting force may be measured in appropriate tests (see Technical Report 048 [9]).

Note 9: 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.

Undercut fasteners

If tension tests shall be performed, the characteristic failure load shall be equal to or larger than the value calculated for concrete cone failure. The largest value for c_{min} derived from the two types of tests governs.

2.2.6 Edge distance to prevent splitting under load (test series F12)

Purpose of the test

The tests are performed to check determine the characteristic edge distance at which splitting is not decisive.

Test conditions

Test fasteners in uncracked concrete C20/25. Use a drill bit of diameter $d_{cut,m}$ for drilling the holes in which the fasteners are installed. 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 and minimum thickness of the concrete are proposed by the manufacturer. Perform a tension test according to Technical Report 048 [9], 3.3.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Technical Report 048 [9], Figure 3.5. Deformation controlled expansion fasteners (DC) shall be set with full expansion according to TR 048.

Assessment

The characteristic edge distance $c_{cr,sp}$ is evaluated from the results of tension tests on single fasteners at the corner ($c_1 = c_2 = c_{cr,sp}$). The mean failure load in the tests with fasteners at the corner shall be statistically equivalent the same as for a fastener without edge and spacing effects (Table A.1 line A1) for the same concrete strength. If this condition is not fulfilled, the edge distance shall be increased accordingly.

The characteristic resistance to splitting $N^0_{Rk,sp}$ shall be determined by Equation (2.10). It is the lower result of either characteristic resistance to pull-out failure ($N_{Rk,p}$ according to Equation (2.8) or to concrete failure ($N_{Rk,c}$ according to prEN 1992-4 [16]).

$$N^0_{Rk,sp} = \min \{N_{Rk,c}; N_{Rk,p}\} \quad (2.10)$$

2.2.7 Resistance to steel failure under shear load

2.2.7.1 Single fastener (test series V1)

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

$$V_{Rk,s} = \alpha_v \cdot A_s \cdot f_{uk} = 0,5 \cdot A_s \cdot f_{uk} \quad [N] \quad (2.11)$$

$$M^0_{Rk,S} = 1,2 \cdot W_{el} \cdot f_{uk} \quad [Nm] \quad (2.12)$$

Note 10: The value $\alpha_V = 0,5$ is recommended for carbon steel with an ultimate steel tensile strength up to 1000 N/mm^2. For ultimate steel strength smaller than 500 N/mm^2 this value is considered conservative. The design provisions prEN 1992-4 [16] are valid for fasteners with a nominal steel tensile strength of $f_{uk} \leq 1000$ N/mm^2, with the exception of concrete screws where this limit does not apply.

If Equation (2.11) is not applicable, the characteristic resistance to steel failure $V_{Rk,S}$ shall be determined by tests.

Purpose of the test

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

Test conditions

The tests shall be performed according to Technical Report 048 [9], 3.6.1.

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 may be determined according to Equations (2.11) and (2.12).

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Technical Report 048 [9], Figure 3.5.

Table 2.5 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

<u>Deformation controlled expansion fasteners (DC)</u>

Deformation controlled expansion fasteners (DC) shall be set with full expansion according to TR 048.

<u>Concrete screws (CS):</u>

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

Assessment

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

<u>Failure loads</u>

- Determine the mean value of failure loads $V_{u,m}$.
- Determine $V_{Rk,s} = V_{u,5\%}$ as the 5% fractile of the failure loads $V_{u,5\%}$ [kN], converted to the nominal steel strength, according to A2.3.

<u>Displacements:</u>

- The test series is also needed for determination of the displacements δ_{V0} in 2.2.9.

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 prEN 1992-4 [16].

The factor k_7 may be assumed as follows:

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

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

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

Purpose of the test

The test series is performed to determine the k_8 factor for design according to prEN 1992-4 [16] for pry-out failure. The test series is optional. If the tests are not performed, the default values for k_8 according to Table 2.6 apply.

Table 2.6 Default values for k_8

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

Test conditions

The tests shall be performed according to Technical Report 048 [9], 3.6.2.

The test series is performed with a group of 4 fasteners in uncracked concrete C20/25 according to Technical Report 048 [9]. The spacing is selected as $s = s_{cr,N}$ and the edge distance $c \geq c_{cr,N}$. If steel failure occurs, the spacing may be reduced.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Technical Report 048 [9], Figure 3.5. Deformation controlled expansion fasteners (DC) shall be set with full expansion according to TR 048.

Assessment

As an option the pry-out performance may be derived by tests according to Table A.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 $N_{Rk,ucr}$ according to Equations (2.13) and (2.14).

$$k_8 = \frac{V_{u,5\%,t}}{N_{Rk,ucr}} \qquad (2.13)$$

$$N_{Rk,ucr} = k_{ucr} \cdot h_{ef}^{1,5} \cdot \sqrt{f_{c,t}} \, \frac{(s + 3h_{ef})^2}{9h_{ef}^2} \qquad (2.14)$$

2.2.9 Concrete edge failure

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

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

ℓ_f effective length of the fastener for transfer of shear load

2.2.10 Characteristic resistance for simplified design method

2.2.10.1 Method B

F^0_{Rk} and corresponding γ_M is the decisive failure mode for all load directions:

$$F^0_{Rk} / \gamma_M = \min (N_{Rk,S} / \gamma_{Ms}; N_{Rk,c} / \gamma_{Mc}; N_{Rk,p} / \gamma_{Mp}; V_{Rk,S} / \gamma_{Ms}) \qquad (2.15)$$

$$c_{cr} = c_{cr,N} \qquad (2.16)$$

$$s_{cr} = s_{cr,N} \qquad (2.17)$$

In absence of National regulations recommended values for γ_{Ms}, γ_{Mc}, γ_{Mp} are given in EN 1992-4 Table 4.1.

2.2.10.2 Method C

F_{Rk} and corresponding γ_M is the decisive failure mode for all load directions:

$$F_{Rk} / \gamma_M = \min (N_{Rk,S} / \gamma_{Ms}; N_{Rk,c} / \gamma_{Mc}; N_{Rk,p} / \gamma_{Mp}; V_{Rk,S} / \gamma_{Ms}) \qquad (2.18)$$

In absence of National regulations recommended values for γ_{Ms}, γ_{Mc}, γ_{Mp} are given in EN 1992-4 Table 4.1.

2.2.11 Displacements

The displacements under short and long term tension and shear loading shall be given in the ETA for a load F which corresponds approximately to the value according to Equation (2.19)

$$F = \frac{F_{Rk}}{1{,}4 \cdot \gamma_M} \qquad (2.19)$$

The displacements under short term tension and shear loading (δ_{NO} and δ_{VO}) are evaluated from the tests on single fasteners without edge or spacing effects according to Table A.1 lines A1 to A4 and V1. The value derived shall correspond to the maximum value obtained in the test series for the given load level.

The short term tension and shear displacements δ_{NO} and 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.

Under shear loading, the displacements might increase due to a gap between fixture and fastenerIt shall be stated clearly in the ETA if this gap is taken into account in the assessment.

For fasteners assessed for use in uncracked and cracked concrete the long term displacements under tension loading, $\delta_{N\infty}$, shall be calculated from the results of crack movement tests (see Table A.1line F3) according to Equation (2.20)

$$\delta_{N\infty} = \frac{\delta_{m1}}{1,5} \tag{2.20}$$

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 line F4) according to Equation (2.21)

$$\delta_{N\infty} = \frac{\delta_{m2}}{2,0} \tag{2.21}$$

The long term shear displacements $\delta_{V\infty}$ may 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.

2.2.12 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). Furthermore, those parts of fasteners that are intended to move against each other during installation (e.g. nut on thread or cone in sleeve) or in use (e.g. cone in sleeve) shall not be subject to jamming so that the behaviour is not impaired when the fastener is loaded to failure.

In the context of the assessment of durability of the construction product the following shall be considered:

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

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

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

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

b) Coating

The durability of the coating that ensures the functioning and the bearing behaviour of the fastener shall be shown.

No special test conditions can be given in this EAD for checking the durability of any coating because they depend on the type of coating. Any appropriate tests shall be decided on by the responsible TAB based on the specific type of coating and the intended conditions of use (i.e. dry internal or external conditions).

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.

c) Jamming

No special test conditions are given to show compliance with the requirement given in the first paragraph above, because they depend on the specific measures taken to prevent jamming and shall be decided by the responsible TAB.

Assessment of the risk of jamming with stainless steel fasteners is based on the consideration of the grade(s) and surface finish of steel used in relation to existing experience of jamming in appropriate cases.

2.2.13 Fire resistance to steel failure (tension load)

Purpose of the test

The tests are performed to determine the resistance to steel failure of the fasteners under tension load and fire exposure. The determination of the duration of the fire resistance is according to the conditions given in EN 1363-1 [13] using the “Standard Temperature/Time Curve” (STC).

Test conditions

The tests are carried out according to Technical Report 048 [9]. The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Technical Report 048 [9], Figure 3.5.

Assessment

The tests shall be performed according to Technical Report 048 [9], 3.8.1.

From the fire tests pair of variates [test load F / duration of failure t_u] shall be determined (existing test results in cracked concrete shall be taken into account for the evaluation, if the failure appeared after more than 60 min). 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 2.6). By linear regression of the pair of variates σ_s / $(1/t_u)$ (see Figure 2.7) the formula (mean value curve) according to Equation (2.22) shall be determined.

The test results shall represent the regression curve according to Figure 2.6. Clouds of similar test results cannot be used for the determination of the regression curve. If the fastener does not fail during the test, the result cannot be used for determination of the regression curve according to Figure 2.6.

$$\sigma_{s1} = p_1 + p_2 / t_u \qquad (2.22)$$

The mean value curve according to Equation (2.22) shall be reduced with an additional 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 according to Equation (2.23) is obtained.

$$\sigma_{s2} = p_3\,(p_1 + p_2 / t_u) \qquad (2.23)$$

The characteristic steel stress for the duration of fire resistance of 60 min, 90 min and 120 min shall be calculated using Equation (2.23) as follows:

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

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

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

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:

$$\sigma_{s3} = p_4 - p_5 \cdot t_u \qquad (2.24)$$

The characteristic steel stress for a duration of fire resistance of 30 min shall be calculated using Equation (2.24) as follows:

$$\sigma_{Rk,s,fi(30)} = p_4 - p_5 \cdot 30\text{ min} \qquad (2.25)$$

$$N_{Rk,s,fi} = \sigma_{Rk,s,fi} \cdot A_s \qquad (2.26)$$

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 2.8), if the ratio of the steel strength $\sigma_{Rk,s,d2}$ is not larger 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.

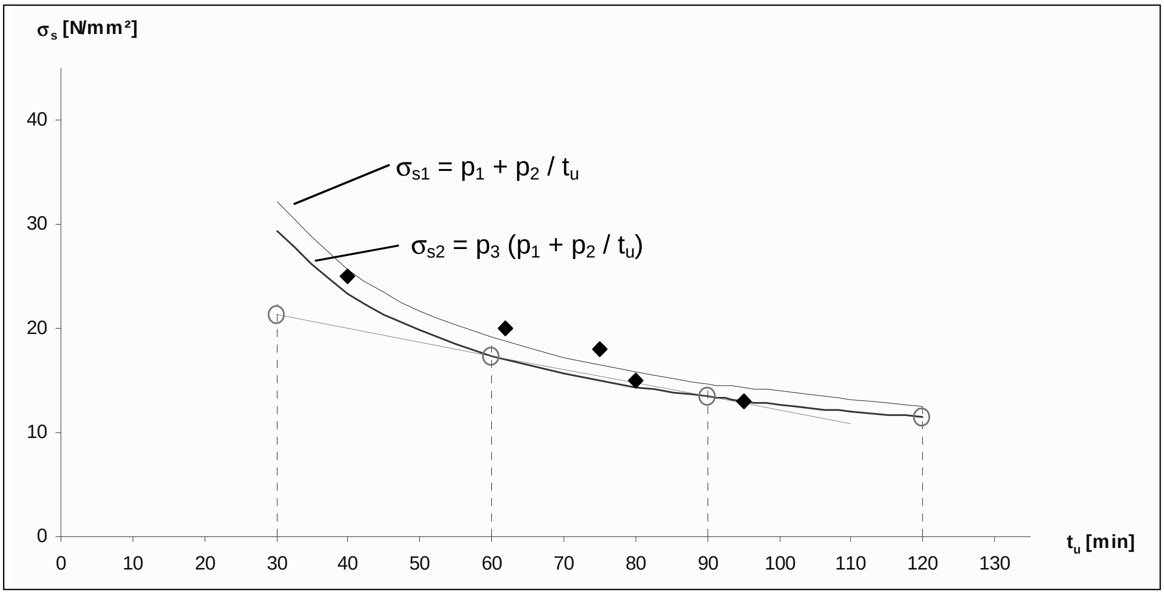


Figure 2.6 Determination of the characteristic steel stress

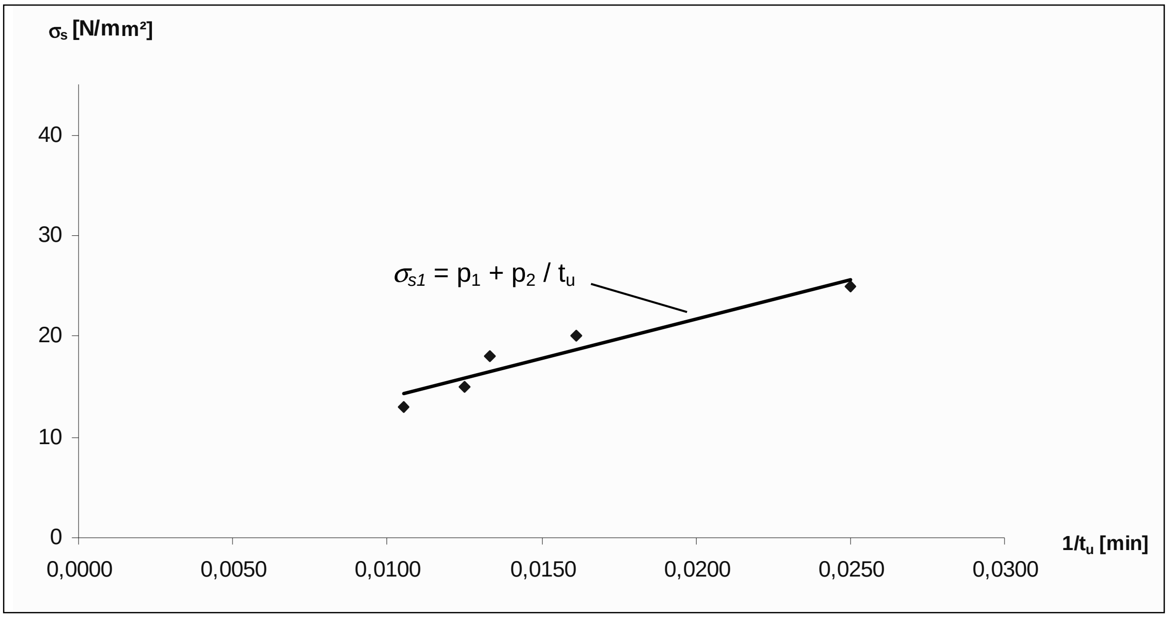


Figure 2.7 Determination of the regression equation

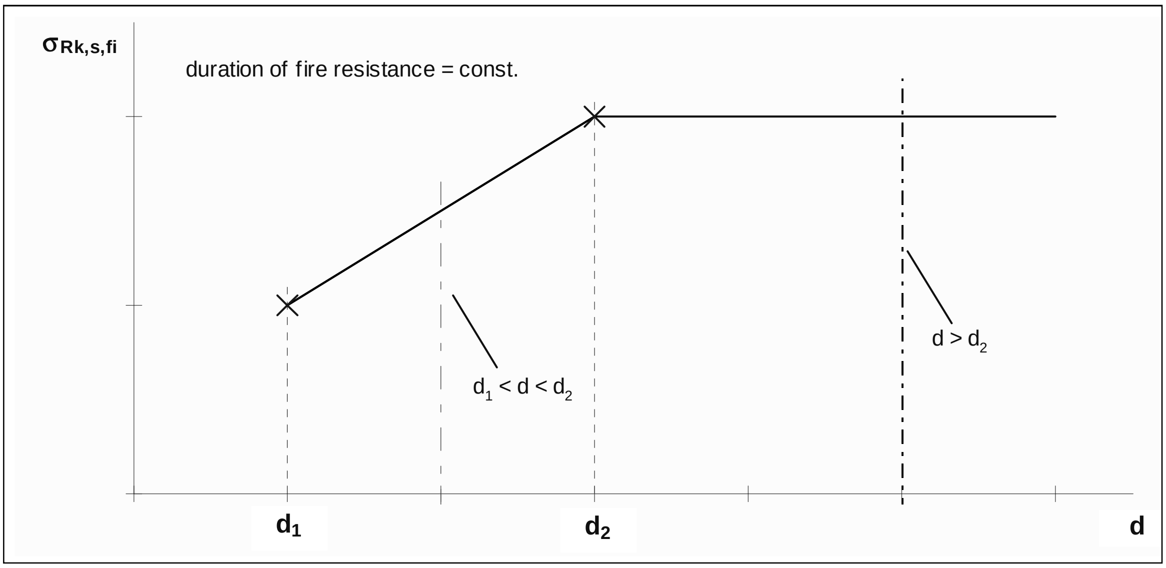


Figure 2.8 Interpolation of intermediate sizes for constant duration of fire resistance

2.2.14 Fire resistance to pull-out failure (tension load)

Purpose of the test

The tests are 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 according to the conditions given in EN 1363-1 [13] using the “Standard Temperature/Time Curve” (STC).

Test conditions

The tests shall be performed according to Technical Report 048 [9], 3.8.2. The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Technical Report 048 [9], Figure 3.5.

Assessment

The assessment shall be carried out in the same way as for steel failure under tension load (see 2.2.13). 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 and 120 min and the characteristic resistance for pull-out $N_{Rk,p}$ for cracked concrete C20/25 according to 2.2.2 may be used for all fastener sizes of the evaluated system.

2.2.15 Fire resistance to steel failure (shear load)

Purpose of the test

The tests are performed to determine the resistance to steel failure of the fasteners under shear load and fire exposure. The determination of the duration of the fire resistance is according to the conditions given in EN 1363-1 [13] using the “Standard Temperature/Time Curve” (STC). The ultimate strength of fasteners at fire exposure under tension load may be used for shear load as a conservative assumption. In this case the tests in this section may be omitted.

Test conditions

The tests shall be performed according to Technical Report 048 [9], 3.8.3. The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Technical Report 048 [9], Figure 3.5.

Assessment

The assessment shall be carried out according to 2.2.13.

$$V_{Rk,s,fi} = \sigma_{Rk,s,fi} \cdot A_s \qquad (2.27)$$

$$M^0_{Rk,s,fi} = 1{,}2\ \sigma_{Rk,s,fi} \cdot W_{el} \qquad (2.28)$$

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 in this EAD the applicable European legal act is: Decision 1996/582/EC.

The system is: **1**

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of the mechanical fastener in the procedure of assessment and verification of constancy of performance are laid down in Table 3.1.

The manufacturer shall ensure that the product placed on the market is consistent with the assessed product e.g. by showing consistency of results of factory production control.

Table 3.1 Control plan for the manufacturer; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC) [**including testing of samples taken at the factory in accordance with a prescribed test plan**]*					
1	Dimensions (outer diameter, inner diameter, thread length, etc.)	Caliper and/or gauge	Laid down in control plan	3	Every manufacturing batch or 100.000 elements or when raw material batch has been changed **)
2	Tensile Load or tensile strength *)	EN ISO 6892-1 [29], EN ISO 898-1 [25], EN ISO 3506-1 [20]		3	
3	Yield strength *)	EN ISO 6892-1 [29], EN ISO 898-1 [25], EN ISO 3506-1 [20]		3	
4	Core hardness and Surface hardness (at specified functioning relevant points of the product) – where relevant	Tests acc. to EN ISO 6507 [20] or EN ISO 6508 [22]		3	
5	Roughness of cone - where relevant	profile method: EN ISO 12085 Software measurement standards: EN ISO 5436 [31] calibration: EN ISO 12179 EN ISO 1302 [30]		3	
6	Zinc plating - where relevant	x-ray measurement according EN ISO 3497 [32], magnetic method according EN ISO 2178 [33], Phase-sensitive eddy-current method according EN ISO 21968 [34]		3	
7	Fracture elongation - where relevant	EN ISO 6892-1 [29] EN ISO 898-1 [25]		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 according to this standard, 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 3.2.

Table 3.2 Control plan for the notified body; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Initial inspection of the manufacturing plant and of factory production control					
1	Ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the mechanical fastener.	-	Laid down in control plan	-	1
Continuous surveillance, assessment and evaluation of factory production control					
2	Verifying that the system of factory production control and the specified automated manufacturing process are maintained taking account of the control plan.	-	Laid down in control plan	-	1/year

4 REFERENCE DOCUMENTS

As far as no edition date is given in the list of standards thereafter, the standard in its current version at the time of issuing the European Technical Assessment is of relevance.

[1] ASTM E2935, Standard practice for conducting equivalence testing in laboratory applications
[2] BS 1377-4:1990, Methods of test for soils for civil engineering purposes. Compaction-related tests
[3] DIN 18127:2012, Soil, Investigation and testing – Proctor-test
[4] EAD 330011-00-0601, Adjustable concrete screws
[5] EAD 330076-00-0604, Metal injection anchors for use in masonry
[6] EAD 330087-00-0601, Systems for post-installed rebar connections with mortar
[7] EAD 330499-00-0601, Bonded fasteners for use in concrete
[8] EAD 330747-00-0601, Fasteners used in redundant non-structural systems
[9] Technical Report 048:2016-08 "Details of tests for post-installed fasteners in concrete"
[10] Technical Report 049:2016-08 "Assessment of metal fasteners under seismic action"
[11] EN 197-1, Cement - Part 1: Composition, specifications and conformity criteria for common cements.
[12] EN 206, Concrete: Specification, performance, production and conformity
[13] EN 1363-1, Fire resistance tests – Part 1: General requirements
[14] EN 1992-1-1, Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings
[15] EN 1992-1-2, Eurocode 2: Design of concrete structures – Part 1-2: General rules – Structural fire design
[16] FprEN 1992-4:2016, Eurocode 2: Design of concrete structures – Part 4: Design of fastenings for use in concrete
[17] EN 1993-1-1, Design of steel structures, Part 1-1: General rules and rules for buildings
[18] EN 10088-3, Stainless steels - Part 3: Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes
[19] EN 13501, Fire classification of construction products and building elements; Part 1: Classification using data from reaction to fire tests; Part 2: Classification using data from fire resistance tests, excluding ventilation services
[20] EN ISO 3506, Mechanical properties of corrosion-resistant stainless steel fasteners, Part 1: Bolts, screws and studs; Part 2: Nuts
[21] EN ISO 6507, Metallic materials – Vickers hardness test
[22] EN ISO 6508, Metallic materials – Rockwell hardness test
[23] EN ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories.
[24] ISO 273, Fasteners - clearance holes for bolts and screws
[25] ISO 898, 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
Part 2: Nuts with specified property classes – Coarse thread and fine pitch thread
[26] ISO 5468, Rotary and rotary impact masonry drill bits with hard metal tips – Dimensions
[27] ISO 5922, Malleable cast iron.
[28] ISO 6783, Coarse aggregates for concrete - determination of particle density and water absorption - hydrostatic balance method
[29] EN ISO 6892-1, Metallic materials – Tensile testing – Part 1: Method of test at room temperature
[30] EN ISO 1302, Geometrical Product Specifications (GPS) - Indication of surface texture in technical product
[31] ISO 5436-1, Geometrical Product Specifications (GPS) - Surface texture: Profile method; Measurement standards - Part 1: Material measures
[32] ISO 3497, Metallic coatings - Measurement of coating thickness - X-ray spectrometric methods
[33] ISO 2178, Non-magnetic coatings on magnetic substrates - Measurement of coating thickness - Magnetic method
[34] ISO 21968, Non-magnetic metallic coatings on metallic and non-metallic basis materials - Measurement of coating thickness - Phase-sensitive eddy-current method
[35] EN ISO 14638, Geometrical product specifications (GPS)- Matrix model
[36] EN ISO 4288 - Geometrical Product Specifications (GPS) -- Surface texture: Profile method -- Rules and procedures for the assessment of surface texture

A ANNEX A TEST PROGRAM AND GENERAL ASPECTS OF ASSESSMENT

A1 Test program

The test program 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 Test program

N°	Purpose of test	Concrete	Crack width	Size	d_{cut}	n_{min}	rqd. α	Required for	Section
Resistance to steel failure under tension load									
N1	Steel capacity	-	0	All	-	5	-	All	2.2.1.1
N2	Maximum torque moment	C50/60	0	All	$d_{cut,m}$	5		TC, UC, DC	2.2.1.2
N3	Hydrogen induced embrittlement	C50/60	0	All	-	5	0,90	CS	2.2.1.3
Basic tension tests									
A1	Reference tension tests	C20/25	0	All	$d_{cut,m}$	5	-	Option 1-12	2.2.2.1
A2		C50/60	0	All		5		CS: all options as reference for N3 All other: Option 7, 9, 11 [1)]	
A3		C20/25	0,30	All		5		Option 1-6	
A4		C50/60	0,30	All		5		Option 1, 3, 5 [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	Option 1-6	2.2.2.4
					$d_{cut,m}$			UC, CS Option 1-6	
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	Torqueing in low strength concrete	C20/25	0	All	$d_{cut,max}$	10		CS	2.2.2.7
F7	Torqueing 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
F9	Robustness to variation in use conditions	C20/25	0	s/m/l	$d_{cut,m}$	$5^{3)}$	0,95	Option 7-12	2.2.4.1
		C20/25	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	Option 1-6 UC, CS	2.2.4.2

N°	Purpose of test	Concrete	Crack width	Size	d_{cut}	n_{min}	rqd. α	Required for	Section
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 to shear load									
V1	Characteristic resistance to steel failure-under shear load	C20/25	0	All	$d_{cut,m}$	5	-	All	2.2.7.1
V2	Characteristic resistance to pry-out failure	C20/25	0	All		5		Optional test	2.2.8

1) The tests may be omitted, if in the reference tension tests in concrete strength class C20/25 the failure is caused by rupture of steel.

2) Necessary only for undercut fasteners and concrete screws with h_{ef} < 80 mm to be used in concrete members with a spacing of reinforcement s < 150 mm as well as for concrete screws.

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.

For certain test series according to Table A.1 a reduced range of tested sizes, indicated by “s/m/l”, may be used. The number of diameters to be tested in this case depends on the number of requested sizes and is given in Table A.2.

Table A.2 Reduced range of tested sizes s/m/l

Number of requested sizes	Number of diameters to be tested
≤ 5	3
≤ 8	4
≤ 11	5
> 11	6

Provisions for all test series

As far as applicable the Technical Report 048 [9] shall be followed for the test members, test setup and performance of the tests. Modifications are addressed in the following sections, which overrule conflicting provisions in the Technical Report 048 [9]. The tension tests are performed with unconfined test setup.

It is recommended that handling of tests and calibration items are performed in accordance with EN ISO/IEC 17025 [23].

If the fastener bolts are intended to be installed with more than one embedment depth, in general, the tests have to be carried out with all embedment depths. In special cases, e.g. when steel failure occurs, the number of tests may be reduced.

A2 General assessment methods

A2.1 Conversion of failure loads to nominal strength

The conversion of failure loads shall be done according to Equation (A.1) to (A.6) depending on the failure mode.

Concrete failure	$F_{u,c} = F_{u,t} \cdot \left(\frac{f_c}{f_{c,t}} \right)^{0,5}$ with $\frac{f_c}{f_{c,t}} \leq 1,0$	(A.1)
Pull-out failure	$F_{u,c} = F_{u,t} \cdot \left(\frac{f_c}{f_{c,t}} \right)^{n}$ with $\frac{f_c}{f_{c,t}} \leq 1,0$	(A.2)
	$\psi_{c,50} = \min\left\{ \frac{N_{u,m,A2}}{N_{u,m,A1}}; \frac{N_{u,m,A4}}{N_{u,m,A3}} \right\} \leq 1{,}55$	(A.3)
	$n = \log(\Psi_{c,50}) / \log(50/20)$	(A.4)
	$\psi_{c,xx} = \left(\frac{f_{ck,xx}}{f_{ck,20}} \right)^{n}$	(A.5)
Steel failure	$F_{u,s} = F_{u,t} \frac{f_u}{f_{u,t}}$	(A.6)

A2.2 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 larger than 30%, the following reduction shall be taken into account:

$$\beta_{cv} = \frac{1}{1 + 0{,}03(cv_F - 15)} \leq 1{,}0 \quad \text{(A.7)}$$

If the coefficient of variation of the failure load in any other test series exceeds 20% and is not larger than 30%, the following reduction shall be taken into account:

$$\beta_{cv} = \frac{1}{1 + 0{,}03(cv_F - 20)} \leq 1{,}0 \quad \text{(A.8)}$$

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, β_{cv} = 1,0.

The smallest result of $ß_{cv}$ shall be taken for assessment.

A2.3 Establishing 5 % fractile

The 5 %-fractile of the ultimate loads measured in a test series is to be calculated according to statistical procedures for a confidence level of 90 %. If a precise verification does not take place, a normal distribution and an unknown standard deviation of the population shall be assumed.

$$F_{u,5\%} = F_{u,m}(1 - k_s \cdot cv_F) \quad \text{(A.9)}$$

$$F_{u,95\%} = F_{u,m}(1 + k_s \cdot cv_F) \quad \text{(A.10)}$$

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

n = 10 tests: k_s = 2,57

Note 11: The confidence level of 90% is defined for characteristic resistance of fasteners in prEN 1992-4 and is therefore used for the assessment in this EAD.

A2.4 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:

$$\alpha = min\left\{\frac{F_{u,m,t}}{F_{u,m,r}};\frac{F_{u,5\%,t}}{F_{u,5\%,r}}\right\} \quad \text{(A.11)}$$

If the number of tests in both series is $n \geq 10$, the comparison of the 5% - fractile of failure loads may 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 may be omitted for any number of tests in a test series when the coefficient of variation of the test series is smaller than or equal to the coefficient of variation of the reference test series or if the coefficient of variation in both test series is smaller than 15 %.

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 may be used for the comparison according to Equation (A.11):

- $F_{u,m,r} = N_{Rk,c} / 0,75$
- $F_{u,5\%,r} = N_{Rk}$ (characteristic resistance given in the ETA)

A2.5 Criteria for uncontrolled slip under tension loading

The load/displacement curves shall show a steady increase (see Figure A.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.12)

Tests in uncracked concrete $N_{sl} = 0,8\ N_{Ru}$ (A.13)

Where the requirement given in Equations (A.12) and (A.13) 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.14)

$\alpha_1 = N_{sl,t} / N_{Ru,t}$ (A.14)

where

$N_{sl,t}$ = load level where uncontrolled slip occurs in the test

$N_{Ru,t}$ = ultimate load in the test

This reduction may 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.12), 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 (2.8).

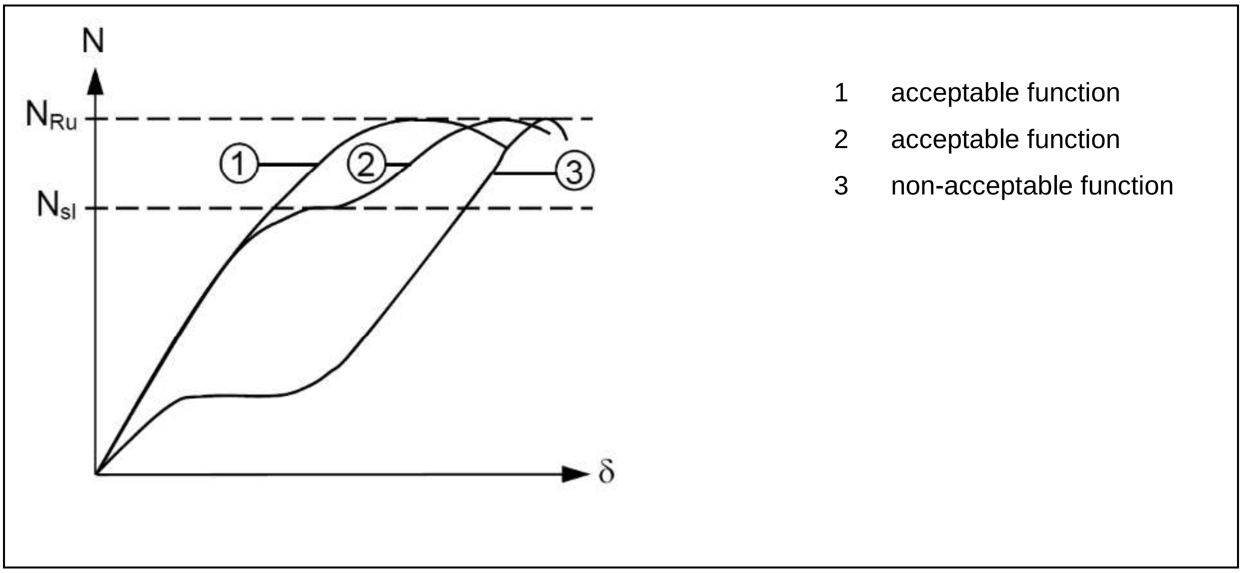


Figure A.1 Requirements for the load/displacement curve

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.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 (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 may also lead to a reduction of the load taken up by the fastener over a rather short displacement interval as shown in Figure A.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.

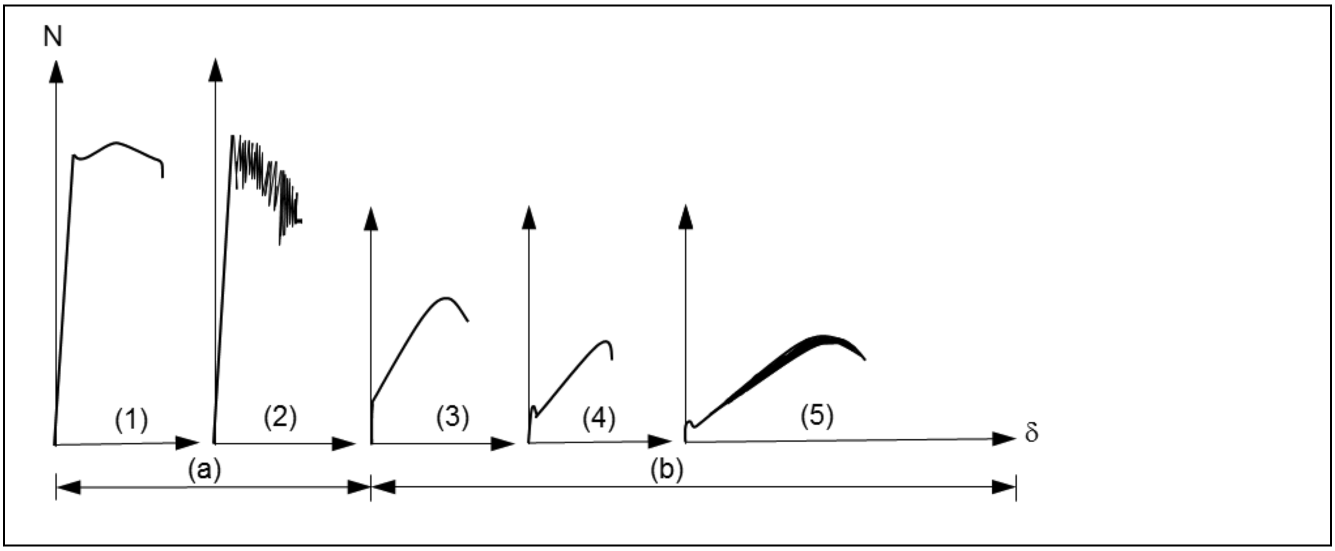


Figure A.2 Typical load/displacement behaviour

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.3). The load N_{sl} is defined by the horizontal branch of the load/displacement curve.

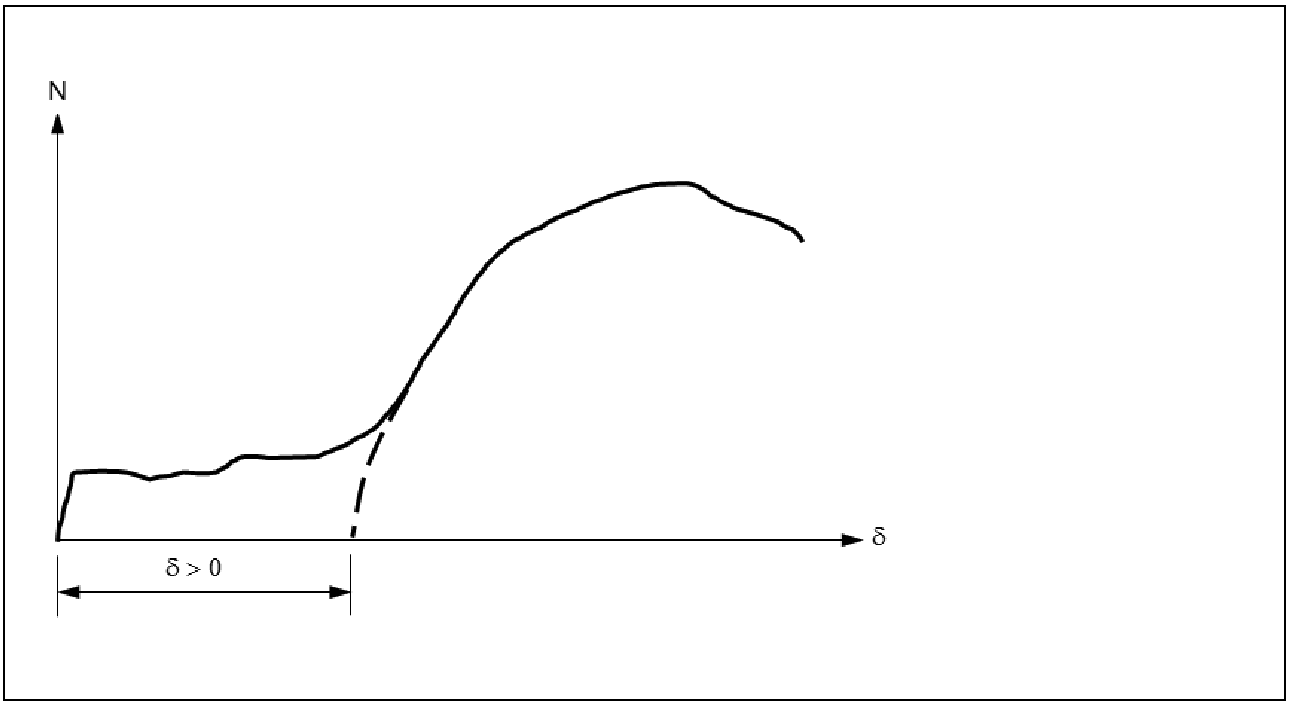


Figure A.3 Load/displacement behaviour with uncontrolled slip

Because it may be difficult to draw an extension to a curved line the following simplification may 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.4).

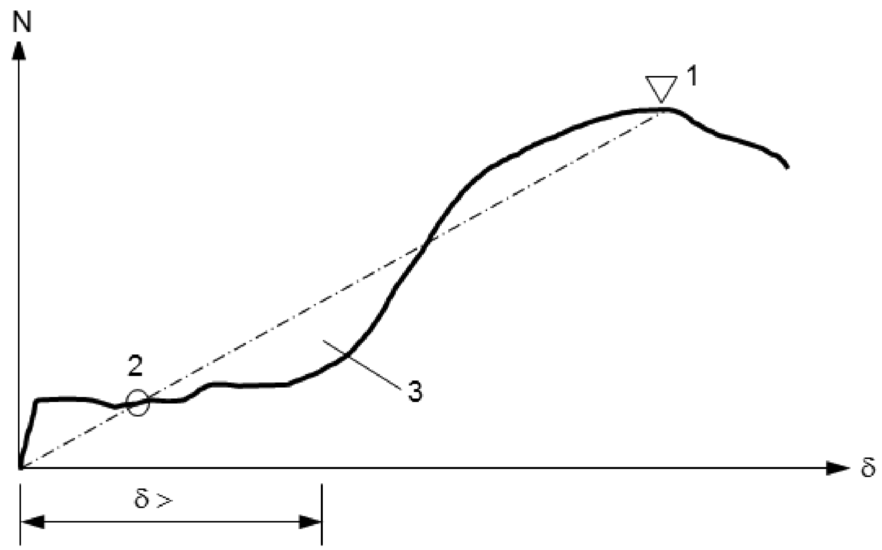


Figure A.4 Load/displacement behaviour with uncontrolled slip

The load N_{sl} as given above may be defined as the lower intersection point of the straight line with the load/displacement curve.

In comparing results of assessments according to Figure A.3 and Figure A.4, the type given in Figure A.3 will govern.

A2.6 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 mean displacement at the load level of 0,5 $N_{u,m}$ in basic tension tests shall fulfil the limit given in Equation (A.15) and for any other tests the limit given in Equation (A.16) shall be kept.

$cv_{\delta} \leq 0,25$ (basic tension tests) (A.15)

$cv_{\delta} \leq 0,40$ (any other tests) (A.16)

The load displacement curves may be shifted according Figure A.5 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 all displacements at a load of 0,5 $N_{u,m}$ are smaller than or equal to 0,4 mm.

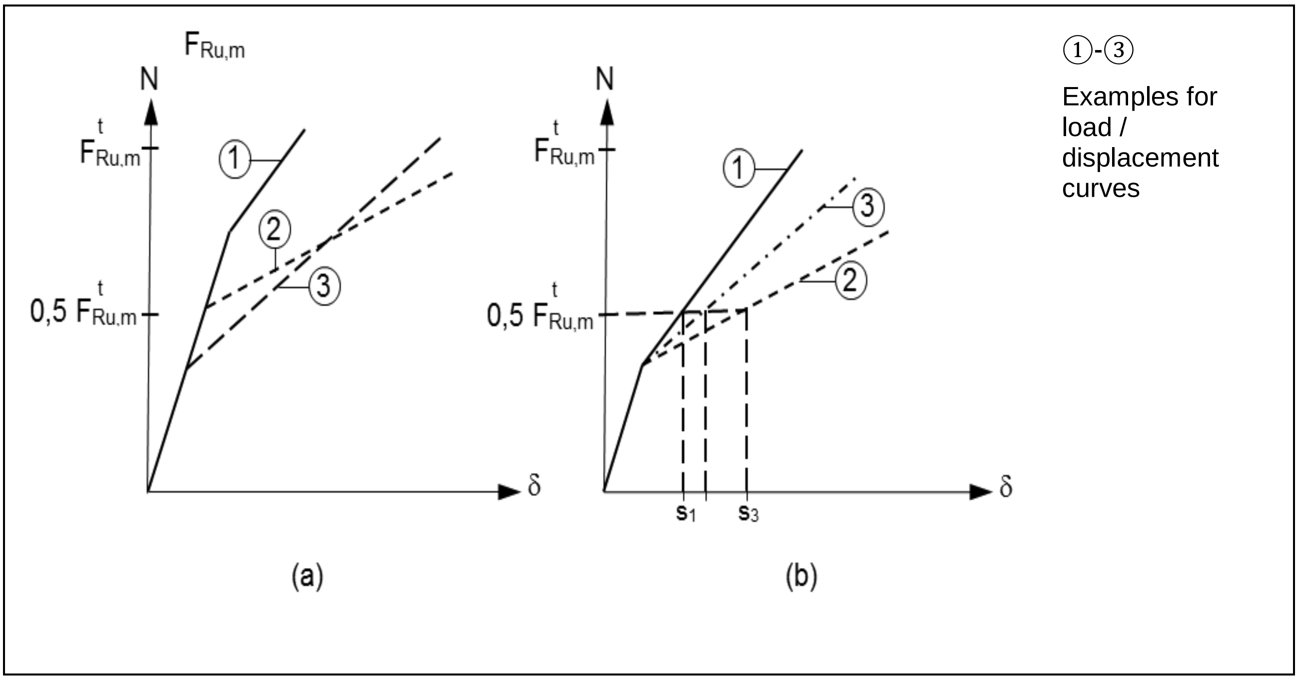


Figure A.5 Influence of pre-stressing on load/displacement curves

(a) original curves

(b) shifted curves for evaluation of scatter at N = 0,5 $N_{u,m}$