EUROPEAN ASSESSMENT DOCUMENT

EAD 330232-01-0601

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# MECHANICAL FASTENERS FOR USE IN CONCRETE

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

**Contents**

# 1 SCOPE OF THE EAD

## 1.1 Description of the construction product

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

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

The product is not fully covered by EAD 330232-00-0601 [21] [1].

In addition to EAD 330232-00-0601 [21], the following new assessments/essential characteristics are added:

- New definition of minimum diameter, effective embedment depth and minimum thickness of the concrete member
- Further specification for ductility of concrete screw in groups of fasteners
- Former TR 048 and TR 049 are included (without technical changes in the assessment methods)
- Editorial revision without technical changes in the assessment methods

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

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

This EAD applies to fasteners with the following minimum dimensions:

**Table 1.1 Minimum fastener dimensions**

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

*) For concrete screws (CS) the nominal core diameter of the main load bearing section as Figure 2.8 applies.

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

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

**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)

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

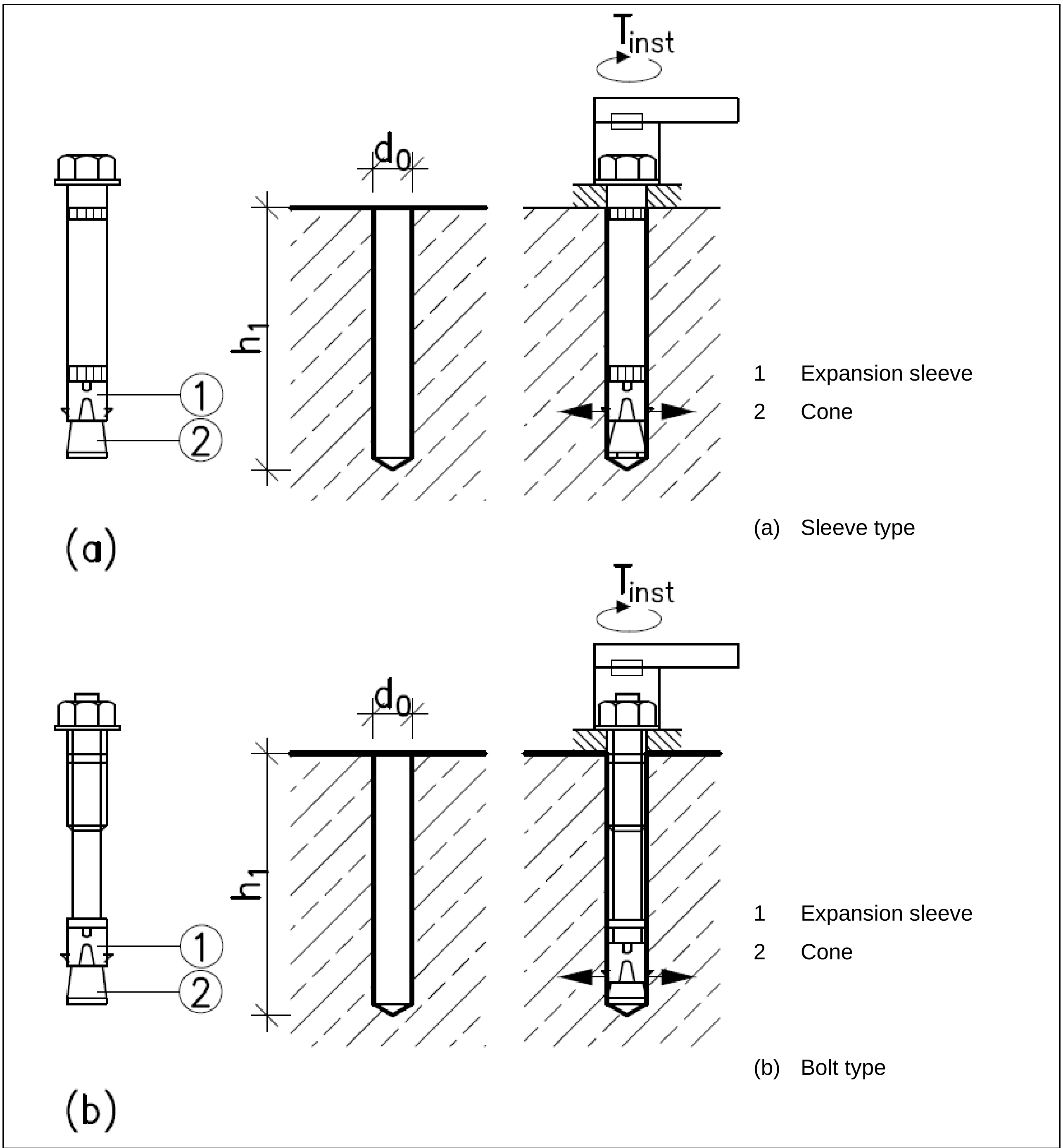


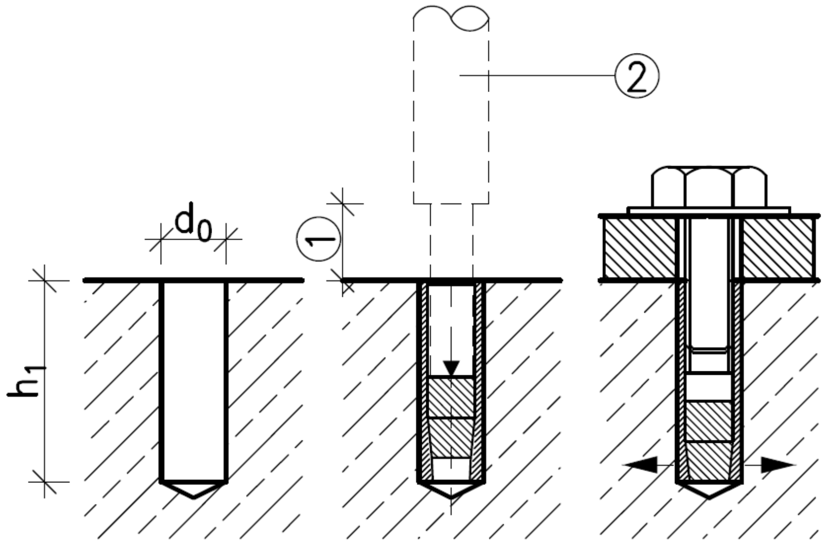

**Figure 1.1 Example of torque-controlled expansion fasteners**

**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)

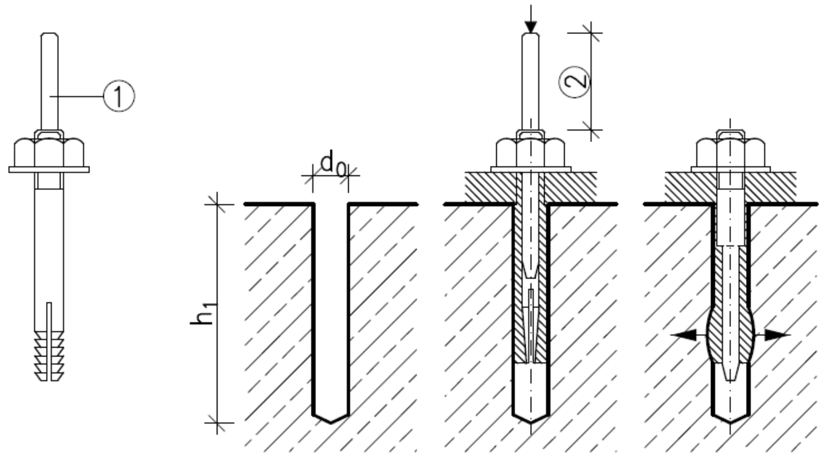
For the cone-down type the sleeve is expanded by driving in a cone. The fastening is controlled by the length of travel of the cone. A sleeve is driven over an expansion element in the case of sleeve-down type fasteners. The fastening is controlled by the travel of the sleeve over the expansion element.




1 controlled installation depth

2 Setting tool

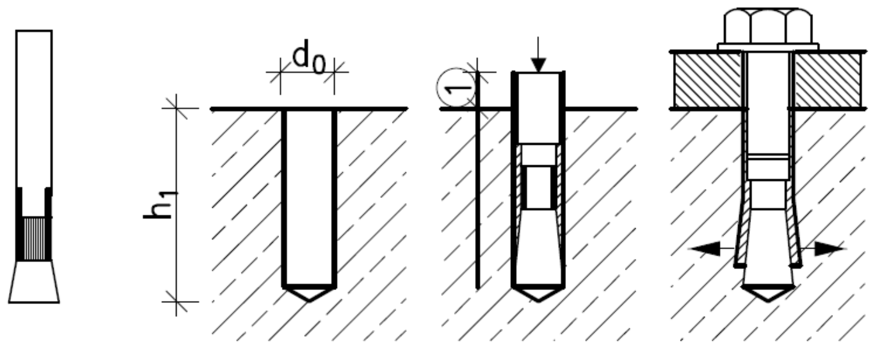
**Figure 1.2 Cone-down type fastener (drop-in fastener)**




1 Expansion nail

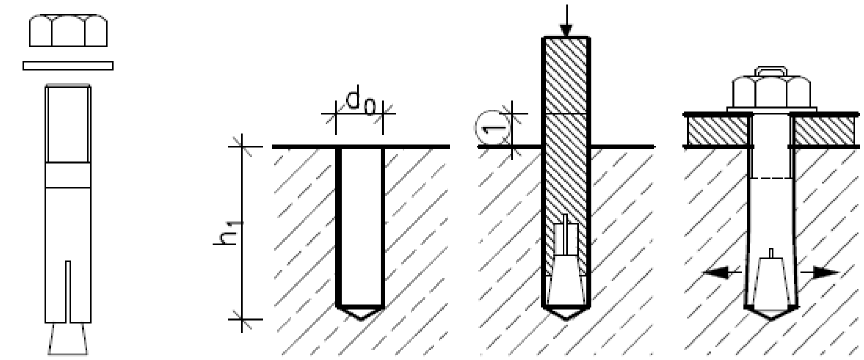
2 Controlled installation depth

**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**

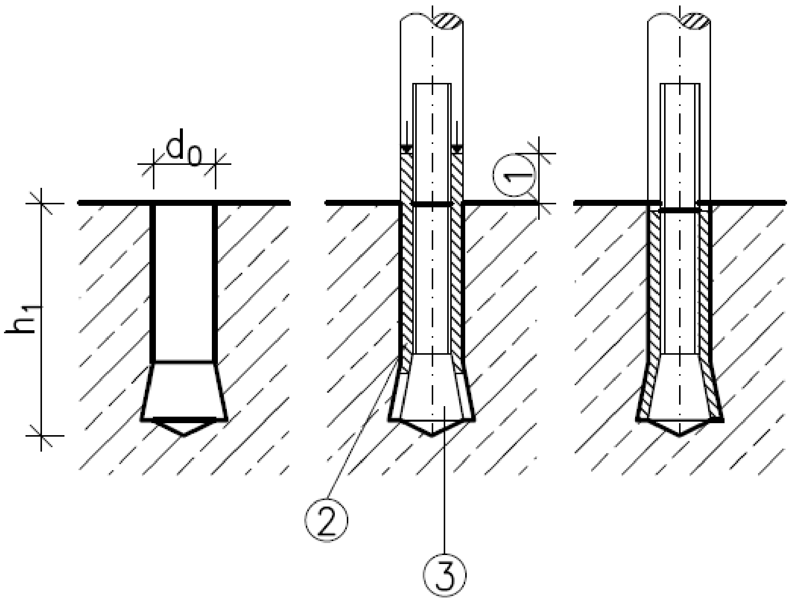
### Undercut fasteners (UC)

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.

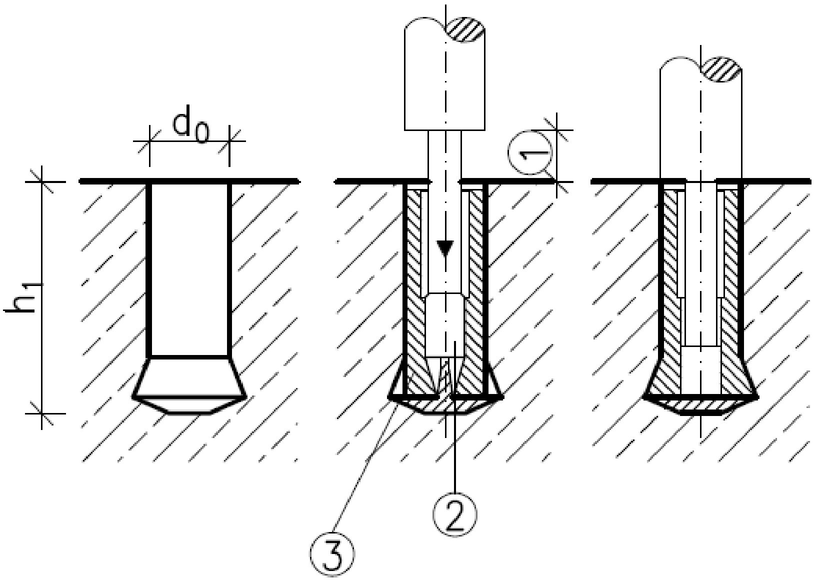



1 Spreading displacement

2 Sleeve

3 Cone

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

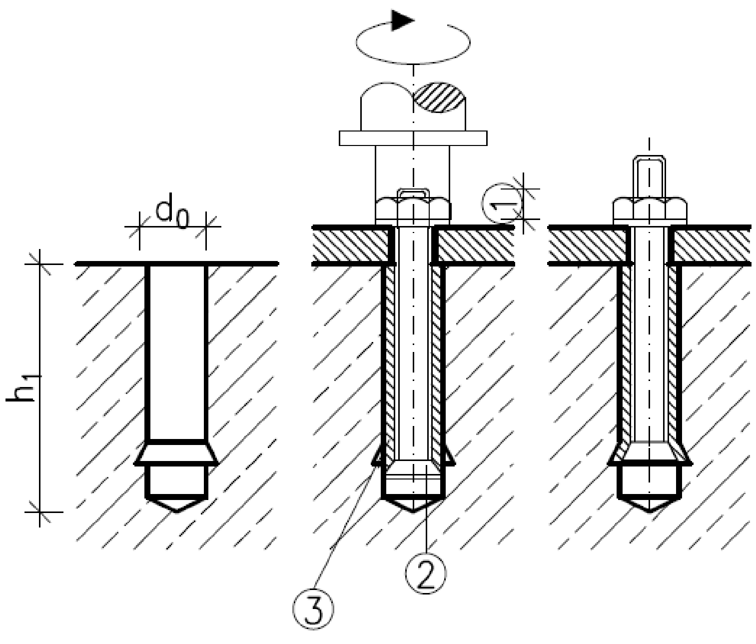



1 Spreading displacement

2 Expansion element

3 Sleeve

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




1 Spreading displacement

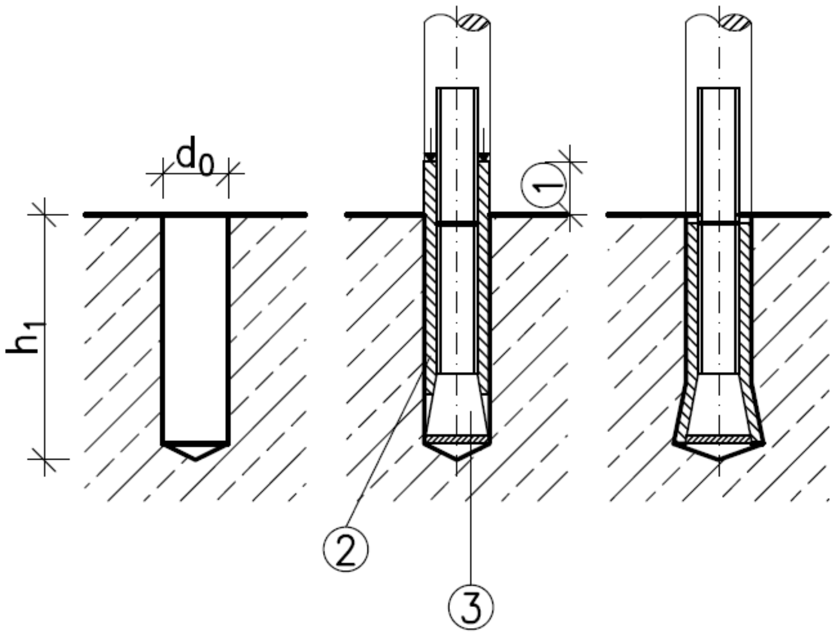
2 Sleeve

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.

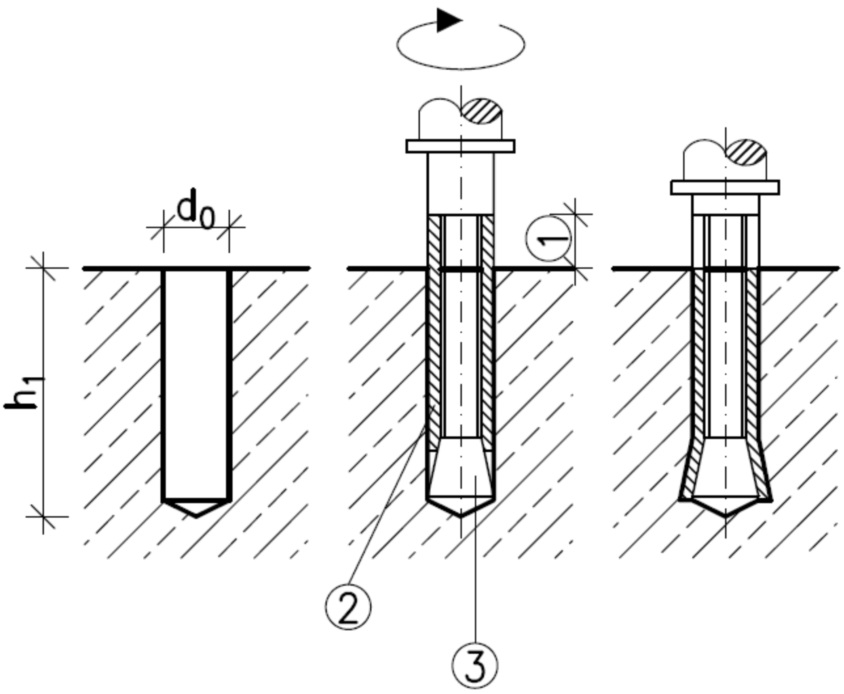



1 Spreading displacement

2 Sleeve

3 Cone

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




1 Spreading displacement

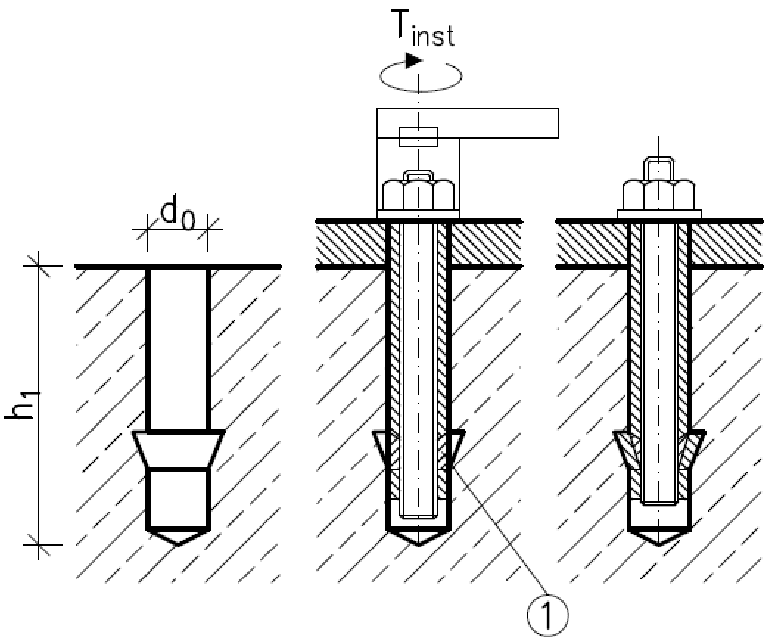
2 expansion sleeve

3 Cone

**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)**

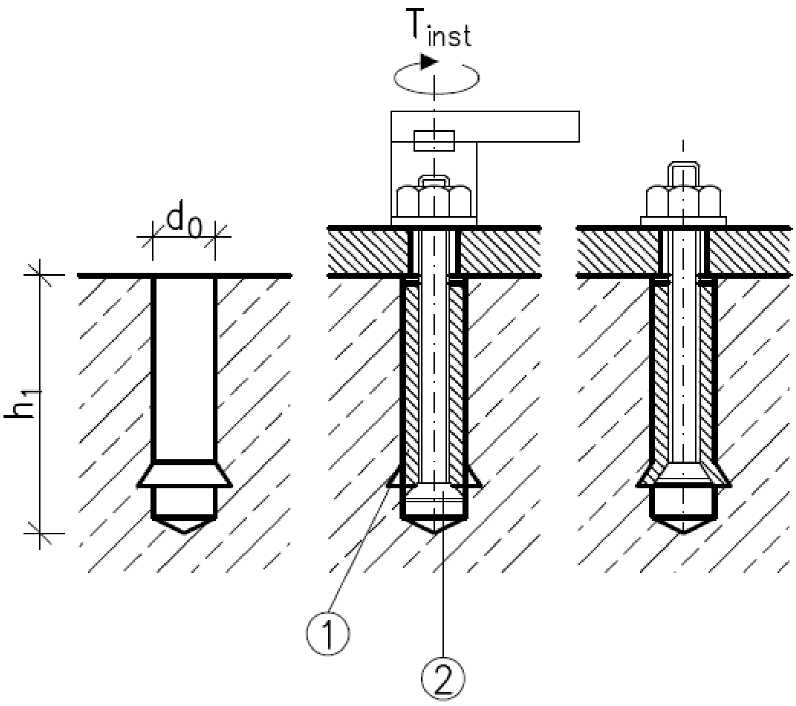
**c) Torque-controlled installations**

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




1 Expansion elements

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




1 Sleeve

2 Cone

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

**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 [1].*

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 calculation according to EN 1992-4 [4].

*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 [2].

The fastener is intended to be used

- in uncracked concrete only (Table 1.2, option 7 – 12)
- in cracked and uncracked concrete (Table 1.2, option 1 – 6)
- under static or quasi-static actions
- under seismic actions (category C1, category C2 according to Annex C)
- with requirements related to resistance to fire (only for fasteners in cracked concrete, Table 1.2, 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 moment or torsion or any combination thereof) will generally be axial tension and/or shear. When the shear force is applied with a lever arm, a bending moment on the fastener will arise. It is presumed, that compressive forces acting in the axis of the fastener are transmitted by the fixture directly to the concrete without acting on the fastener’s load transfer mechanism.*

The hardened concrete is at least 21 days old.

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

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

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

*Note 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) shall be reported in the ETA.

**Options for intended use**

According to the intended use the manufacturer may choose one of the options given in Table 1.2.

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

**Table 1.2 Options for intended use covered by this EAD**

<table>
<tr><th>Option</th><th>Cracked concrete</th><th>Uncracked concrete</th><th>One value for all concrete strength 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>Method according to EN 1992-4 [4]</th></tr>
<tr><td>1</td><td rowspan="6">✓</td><td rowspan="6">✓</td><td>×</td><td>✓</td><td rowspan="2">×</td><td rowspan="2">✓</td><td rowspan="4">✓</td><td rowspan="4">✓</td><td rowspan="2">A</td></tr>
<tr><td>2</td><td>✓</td><td>×</td></tr>
<tr><td>3</td><td>×</td><td>✓</td><td rowspan="4">✓</td><td rowspan="4">×</td><td rowspan="2">B</td></tr>
<tr><td>4</td><td>✓</td><td>×</td></tr>
<tr><td>5</td><td>×</td><td>✓</td><td rowspan="2">✓</td><td rowspan="2">×</td><td rowspan="2">C</td></tr>
<tr><td>6</td><td>✓</td><td>×</td></tr>
<tr><td>7</td><td rowspan="6">×</td><td rowspan="6">✓</td><td>×</td><td>✓</td><td rowspan="2">×</td><td rowspan="2">✓</td><td rowspan="4">✓</td><td rowspan="4">✓</td><td rowspan="2">A</td></tr>
<tr><td>8</td><td>✓</td><td>×</td></tr>
<tr><td>9</td><td>×</td><td>✓</td><td rowspan="4">✓</td><td rowspan="4">×</td><td rowspan="2">B</td></tr>
<tr><td>10</td><td>✓</td><td>×</td></tr>
<tr><td>11</td><td>×</td><td>✓</td><td rowspan="2">✓</td><td rowspan="2">×</td><td rowspan="2">C</td></tr>
<tr><td>12</td><td>✓</td><td>×</td></tr>
</table>

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

Mechanical fasteners are intended for use in fastener groups as defined in EN 1992-4 [4]. Fasteners covered by this EAD can be used in fastener groups, only when criteria for load-displacement behaviours specified in clauses 2.2.2 and 2.2.5 are met.

Concrete screws

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

### 1.2.2 Working life/Durability

The assessment methods included or referred to in this EAD have been written based on the manufacturer's request to take into account a 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[2].

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

## 1.3 Specific terms used in this EAD

### 1.3.1 Abbreviations

C1 = seismic performance category C1 (use in design according to EN 1992-4 [4])

C2 = seismic performance category C2 (use in design according to EN 1992-4 [4])

CS = concrete screw

DC = deformation-controlled expansion fastener

DM-A = design method A according to EN 1992-4 [4]

DM-B = design method B according to EN 1992-4 [4]

DM-C = design method C according to EN 1992-4 [4]

MPII = manufacturer's product installation instructions

TC = torque-controlled expansion fastener

UC = undercut fastener

### 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

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

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

$c_{min}$ = minimum allowable edge distance

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

$cv_F$ = coefficient of variation [%] related to loads

$cv_\delta$ = 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 Annex B Figure B.4)

$d_{cut,max}$ = cutting diameter at the upper tolerance limit (see Annex B Figure B.4) (maximum diameter bit)

$d_{cut,min}$ = cutting diameter at the lower tolerance limit (see Annex B Figure B.4) (minimum diameter bit)

$d_f$ = diameter of clearance hole in the fixture

$d_{nom}$ = outside diameter of fastener. For concrete screws (CS) the nominal core diameter of the main load bearing section as in Figure 2.4 applies

$d_1$ = 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) |
| $f_{u,t}$ | = | mean ultimate tensile steel strength of the batch for the tested fastener |
| $f_{uk}$ | = | nominal characteristic steel ultimate strength as specified in the technical specification of the manufacturer for the fastener |
| $f_{yk}$ | = | nominal characteristic steel yield strength as specified in the technical specification of the manufacturer for the fastener |
| $h$ | = | thickness of the 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 |
| $h_s$ | = | non-load bearing tip of a concrete screw according to Figure 1.14 |
| $h_t$ | = | pitch of the thread of a concrete screw according to Figure 1.14 |
| $h_1$ | = | depth of drilled hole to deepest point |
| $k$ | = | factor for required torque in Equation (2.11) |
| $L$ | = | largest size of the complete product range of each fastener type as supplied to the market |
| $l_f$ | = | effective length of the fastener for transfer of shear load |
| $M$ | = | medium size of the complete product range of each fastener type as supplied to the market |
| $N$ | = | normal force (+N = tension force) |
| $N_{Rk,c}$ | = | characteristic concrete cone resistance in cracked concrete given in the ETA for static loading |
| $N_{Rk,p}$ | = | characteristic tension pull-out resistance given in the ETA for static loading |
| $N_{Rk,s}$ | = | characteristic steel tension resistance given in the ETA for static loading |
| $N_{sl}$ | = | 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 a fastener group in direction 1 |
| $s_2$ | = | spacing of fasteners in a fastener group in direction 2 |
| $T$ | = | torque |
| $T_{inst}$ | = | required setting torque specified by the manufacturer for expansion, installation or pre-stressing of fastener |
| $t_{fix}$ | = | thickness of the fixture |
| $t_u$ | = | time to failure in tests under fire exposure |
| $V$ | = | shear force |
| $V^0_{Rk,s}$ | = | characteristic steel shear resistance given in the ETA for static loading |
| $\alpha$ | = | reduction factor for load according to A.2.4 |
| $\alpha_1$ | = | reduction factor for uncontrolled slip according to A.2.5 |
| $ß_{cv}$ | = | reduction factor for large scatter according to A.2.2 |
| $\gamma_M$ | = | recommended material partial factor according to EN 1992-4 [4] of the corresponding failure mode |
| $\gamma_{inst}$ | = | factor accounting for the sensitivity to installation of post-installed fasteners according to EN 1992-4 [4] |
| $\delta_{0,5Nu,m}$ | = | displacement of the fastener at 50% of the mean failure load in a test series |
| $\delta_{m1}$ | = | mean fastener displacement after $10^3$ crack movements |
| $\delta_{m2}$ | = | mean displacement in the repeated load tests after $10^5$ load cycles or the sustained load tests after terminating the tests (see Annex B); 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 |
| $\Delta w$ | = | 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 Annex B); installation expansion is used in the tests for installation factor |
| reference expansion | = | expansion achieved by applying specified expansion energy (see Annex B); reference expansion is used in any other tests |
| test member | = | concrete member in which the fastener is tested |
| impact screw driver | = | electric tool with sudden rotational force for setting and loosening screws |
| non-structural element | = | Building element, the failure of which results in medium consequence for loss of human life and considerable economic, social or environmental consequences, but does not result in the failure of the structure or part of the structure; examples: façade element, piping |
| structural element | = | Building element, the failure of which may result in the failure of the structure or part of the structure; examples: column, beam, slab |

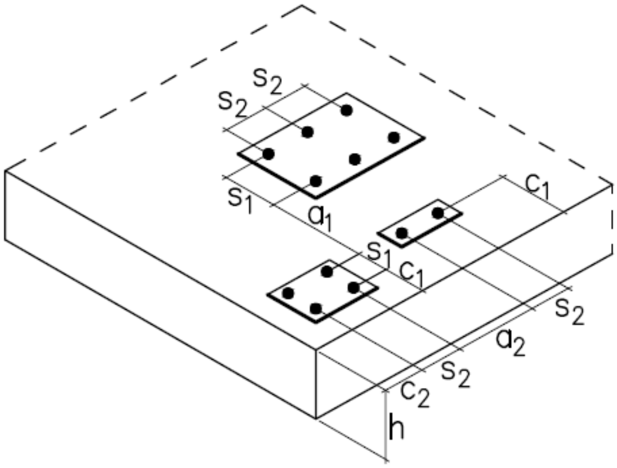



**Figure 1.13 Definitions - concrete member, fastener spacing and edge distance**

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

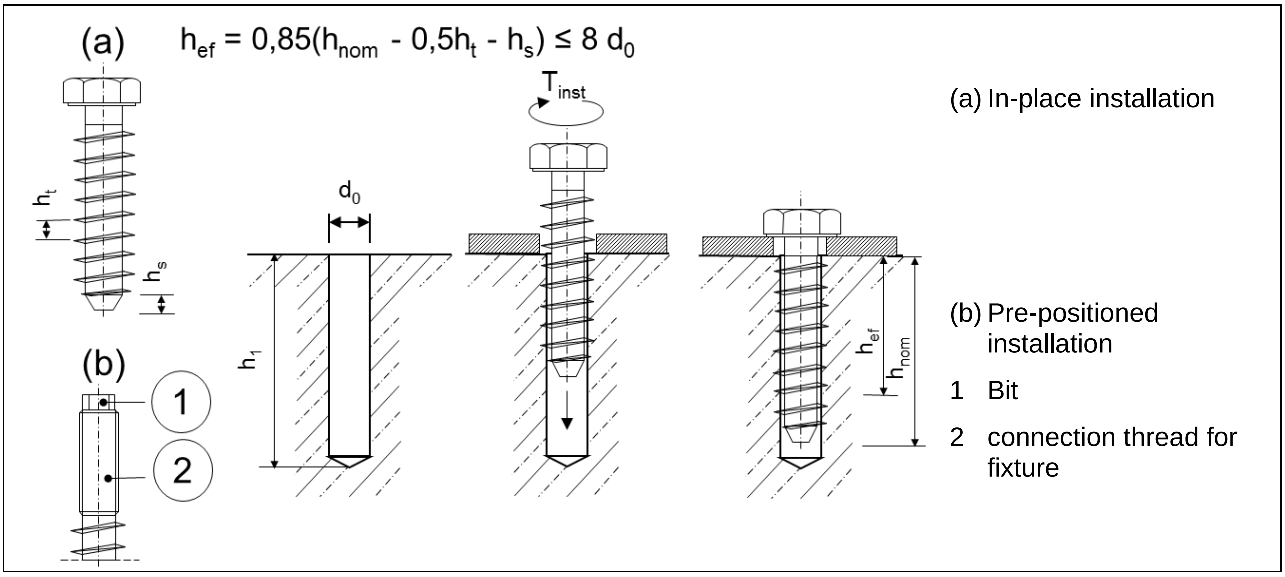



**Figure 1.14 Installation by driving the concrete screw with a self-cutting special thread with wrench or impact screw driver into a predrilled cylindrical hole.**

# 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 for use in concrete is assessed in relation to the essential characteristics.

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

| No | Essential characteristic | | Assessment methods | Type of expression of product performance |
|---|---|---|---|---|
| Basic Works Requirement 1: Mechanical resistance and stability | | | | |
| Characteristic resistance to tension load (static and quasi-static loading) Method A | | | | |
| 1 | Resistance to steel failure | | 2.2.1 | Level<br>$N_{Rk,s}$ [kN], |
| 2 | Resistance to pull-out failure | | 2.2.2 | Level<br>$N_{Rk,p}$ [kN], $\psi_c$ [-] |
| 3 | Resistance to concrete cone failure | | 2.2.3 | Level<br>$k_{cr,N}$, $k_{ucr,N}$ [-], $h_{ef}$, $c_{cr,N}$ [mm] |
| 4 | Robustness | | 2.2.4 | Level<br>$\gamma_{inst}$ [-] |
| 5 | Minimum edge distance and spacing | | 2.2.5 | Level<br>$c_{min}$, $s_{min}$, $h_{min}$ [mm] |
| 6 | Edge distance to prevent splitting under load | | 2.2.6 | Level<br>$N^0_{Rk,sp}$ [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 | Level<br>$V^0_{Rk,s}$ [kN], $M^0_{Rk,s}$ [Nm], $k_7$ [-] |
| 8 | Resistance to pry-out failure | | 2.2.8 | Level<br>$k_8$ [-] |
| Characteristic resistance for simplified design | | | | |
| 9 | Method B | | 2.2.9.1 | Level<br>$F^0_{Rk}$ [kN], $M^0_{Rk,s}$ [Nm], $\psi_c$ [-], $c_{cr}$, $s_{cr}$, $s_{min}$, $c_{min}$, $h_{min}$ [mm] |
| 10 | Method C | | 2.2.9.2 | Level<br>$F_{Rk}$ [kN], $M^0_{Rk,s}$, [Nm], $c_{cr}$, $s_{cr}$, $h_{min}$ [mm] |
| Displacements | | | | |
| 11 | Displacements under static and quasi-static loading | | 2.2.10 | Level<br>$\delta_{N0}$, $\delta_{N\infty}$, $\delta_{V0}$, $\delta_{V\infty}$ [mm] |
| Characteristic resistance and displacements for seismic performance categories C1 and C2 | | | | |
| 12 | Resistance to tension load, displacements | C1 | 2.2.11 | Level<br>$N_{Rk,s,C1}$, $N_{Rk,p,C1}$ [kN] |
| | | C2 | 2.2.12 | Level<br>$N_{Rk,s,C2}$, $N_{Rk,p,C2}$ [kN], $\delta_{N,C2}$, [mm] |
| 13 | Resistance to shear load, displacements | C1 | 2.2.13 | Level<br>$V_{Rk,s,C1}$, [kN] |

| No | Essential characteristic | | Assessment methods | Type of expression of product performance |
|---|---|---|---|---|
| | | C2 | 2.2.14 | Level<br>$V_{Rk,s,C2}$, [kN], $\delta_{V,C2}$ [mm] |
| 14 | Factor for annular gap | | 2.2.15 | Level<br>$\alpha_{gap}$ [-] |
| Basic Works Requirement 2: Safety in case of fire | | | | |
| 15 | Reaction to fire | | 2.2.16 | Class (A1) |
| Resistance to fire | | | | |
| 16 | Fire resistance to steel failure (tension load) | | 2.2.17 | Level<br>$N_{Rk,s,fi}$ [kN] |
| 17 | Fire resistance to pull-out failure (tension load) | | 2.2.18 | Level<br>$N_{Rk,p,fi}$ [kN] |
| 18 | Fire resistance to steel failure (shear load) | | 2.2.19 | Level<br>$V_{Rk,s,fi}$ [kN], $M^0_{Rk,s,fi}$ [Nm] |
| Aspects of durability | | | | |
| 19 | Durability | | 2.2.20 | Description |

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

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

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.

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

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

Tests are needed only if calculation of the characteristic resistance to steel failure is not reasonable because the distribution of the steel strength of the finished product along the length of the fastener is not known or cannot easily be determined.

**Test conditions**

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

**Assessment**

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

#### 2.2.1.2 Maximum torque (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 Annex B, B.3.5

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

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Annex B, Figure B.4. The diameter of the clearance hole in the fixture shall correspond to the values given in Table 2.5.

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

Deformation-controlled expansion fasteners (DC) shall be set with reference expansion according to Annex B.

<u>Undercut fastener (UC):</u>

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**

<u>Failure loads</u>

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 $T_{inst}$.

<u>Criteria</u>

All following criteria shall be fulfilled.

1. The 95 %-fractile of the tension force generated in the torque tests at a torque T = 1,3 $T_{inst}$ shall be smaller than the nominal yield force ($A_s \cdot f_{yk}$) of the bolt or screw.
2. At the end of the test, the connection shall be capable of being unscrewed.
3. For sleeve-down type deformation-controlled expansion fasteners (drop-in fasteners) according to Figure 1.4 it shall be shown that the screw is not in contact with the cone by applying a torque of T = 1,3 $T_{inst}$ when using the longest screw.

#### 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. 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 $N/mm^2$ and hardness is smaller than 350 HV referring to the total cross section for both surface and core hardness according to EN ISO 6507 [8]; < 36 HRC according to EN ISO 6508 [9].

**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 shall be removed without damaging the surface of the screw; scratch and other induced irregularity of the surface shall be carefully avoided during removal of the coating. If a chemical process is used to remove the coating, 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 deionized 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:**

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

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.

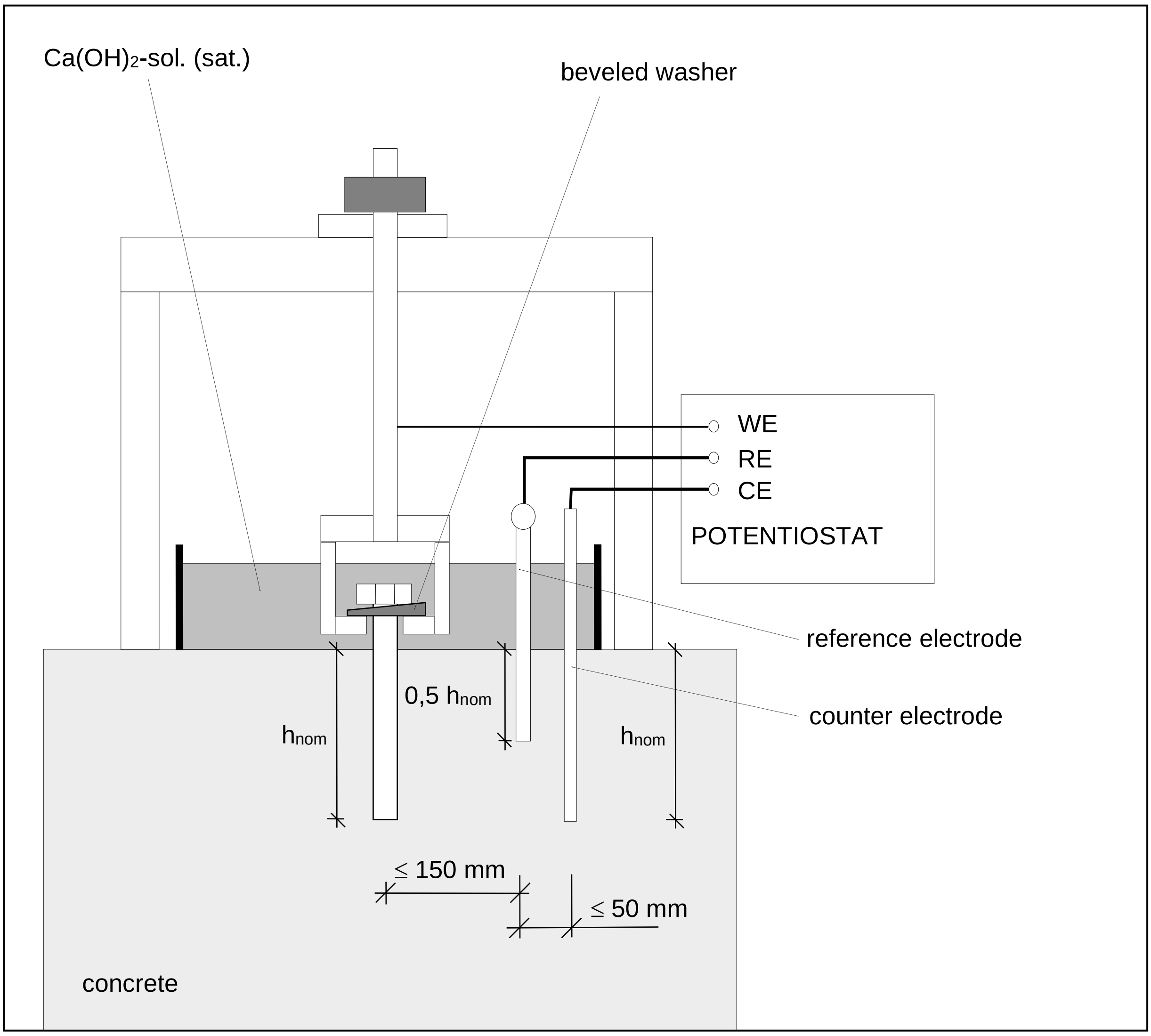



**Figure 2.1 Test setup (schematic) for sensitivity to brittle fracture**

**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 strength in accordance with A2.1, accounting for the relevant failure mode.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- Determine the reduction factor $\alpha$ according to Equation (A.11) comparing the test results with reference test series according to Table A.1 line A2.

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

### 2.2.2 Resistance to pull-out failure

#### 2.2.2.1 Basic 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 $\delta_{N0}$ in 2.2.10.

**Test conditions**

The tests shall be performed according to Annex B, B.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 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 Annex B, Figure B.4. Deformation-controlled expansion fasteners (DC) shall be set with full expansion according to B.3.7 a).

**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 strength in accordance with A2.1, accounting for the relevant failure mode.
- Determine $N_{Rk,0}$ from the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- 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 A.2.2.

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load $N_{sl}$ [kN] according to A2.5.
- Determine the reduction factor $\alpha_1$ according to Equation (A.14).
- Use the reduction factor $\alpha_1$ together with rqd. $\alpha_1$ = 0,7 (in cracked concrete) in Equation (2.9) and rqd. $\alpha_1$ = 0,8 (in uncracked concrete) in Equation (2.8).
- 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 $cv_\delta$ [%]. If the mean value of displacements at 50% of the failure load are larger than 0,4 mm, $cv_\delta$ shall not exceed 25 %.

#### 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 Annex B, B.3.3.

If the fastener is intended to be used in cracked concrete (option 1 – 6), the influence of increased crack width $\Delta w$ = 0,50 mm in combination with drill bits at the upper limit of tolerances (large hole diameter) 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 Annex B, Figure B.4. Deformation-controlled expansion fasteners (DC) shall be set with reference expansion according to Annex B.

**Assessment**

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- 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 $\alpha$ according to Equation (A.11) comparing the test results with reference test series according to Table A.1 line A3 (cracked concrete) or test series A1 (uncracked concrete only with a rqd. $\alpha$ = 0,8.

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load $N_{sl}$ [kN] according to A2.5.
- Determine the reduction factor $\alpha_1$ according to Equation (A.14).
- Use the reduction factor $\alpha_1$ together with rqd. $\alpha_1$ = 0,7 (cracked concrete) in Equation (2.9) and rqd. $\alpha_1$ = 0,8 (uncracked concrete) in Equation (2.8).
- 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 $cv_\delta$ [%]. If the mean value of displacements at 50% of the failure load are larger than 0,4 mm, $cv_\delta$ 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 Annex B, B.3.3.1.

If the fastener is intended to be used in cracked concrete, the influence of increased crack width $\Delta w$ = 0,5 mm in combination with drill bits at the lower limit of tolerances (small hole diameter) 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 Annex B, Figure B.4. Deformation-controlled expansion fasteners (DC) shall be set with reference expansion according to Annex B.

**Assessment**

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- 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 $\alpha$ according to Equation (A.11). 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. $\alpha$ = 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. $\alpha$ = 1,0.

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load $N_{sl}$ [kN] according to A2.5.
- Determine the reduction factor $\alpha_1$ according to Equation (A.14).

- Use the reduction factor $\alpha_1$ together with rqd. $\alpha_1$ = 0,7 (cracked concrete) in Equation (2.9) and rqd. $\alpha_1$ = 0,8 (uncracked concrete) in Equation (2.8).
- 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 $cv_\delta$ [%]. If the mean value of displacements at 50% of the failure load are larger than 0,4 mm, $cv_\delta$ 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 Annex B, B.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 Annex B, Figure B.4.

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

$$N_p = 0{,}50\ N_{Rk,A3} / \gamma_{inst} \qquad (2.3)$$

where

$N_{Rk,A3}$ = characteristic tensile resistance as evaluated in test series A3 converted to $f_c$ = 20 N/mm² according to Annex A2.1.

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 Annex B.

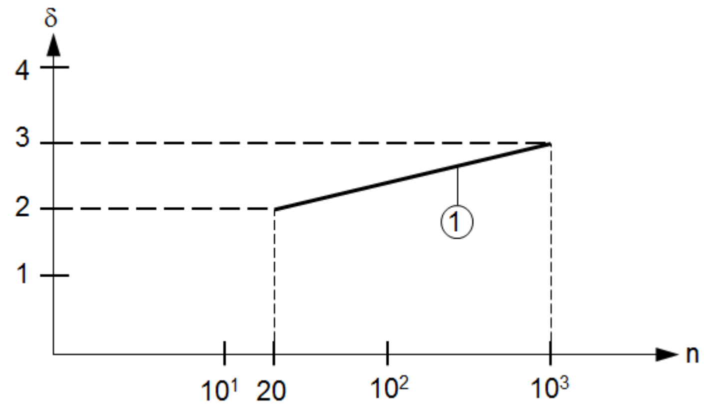
**Assessment**

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 ($\delta_{20}$) and 1000 ($\delta_{1000}$) cycles of crack opening are graduated as a function of the number of tests as follows:

| | |
|---|---|
| 5 to 9 tests: | $\delta_{20} \leq$ 2 mm and $\delta_{1000} \leq$ 3 mm |
| 10 to 20 tests: | $\delta_{20} \leq$ 2 mm; one tests is allowed to 3 mm |
| | $\delta_{1000} \leq$ 3 mm; one tests is allowed to 4 mm |
| > 20 tests: | $\delta_{20} \leq$ 2 mm; 5% of tests are allowed to 3 mm |
| | $\delta_{1000} \leq$ 3 mm; 5% of tests are allowed to 4 mm |

*Note 6: The displacements are considered to be stabilized if the increase of displacements during cycles 750 to 1000 is smaller than the displacement during cycles 500 to 750.*




1 maximum allowable displacement

n number of crack cycles

δ displacement of the fastener in [mm]

**Figure 2.2 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 strength in accordance with A2.1, accounting for the relevant failure mode.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- 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 $\alpha$ according to Equation (A.11) comparing the test results with reference test series according to Table A.1 line A3.
- Use the reduction factor $\alpha$ together with rqd. $\alpha$ = 0,9 in Equation (2.9).

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 reduction factor $\alpha$1 according to Equation (A.14).
- Use the reduction factor $\alpha_1$ together with rqd. $\alpha_1$ = 0,7 (cracked concrete) in Equation (2.9)
- 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 $cv_\delta$ [%]. If the mean value of displacements at 50% of the failure load are larger than 0,4 mm, $cv_\delta$ 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 Annex B, B.3.3.4.

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

For concrete screws the bending effect of an inclination angle of the drilling hole (max 5° according to 1.1) shall be reflected. Drill the hole perpendicular to the concrete surface and install the concrete screw on bevelled washers (inclined angle 4 to 5°, see Annex B Figure B.11). An alternative test setup ensuring the inclination angle during testing is considered equivalent.

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

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Annex B, Figure B.4. Deformation-controlled expansion fasteners (DC) shall be set with reference expansion according to Annex B.

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

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

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

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 basic 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 max $N_{red}$ until the requirements are met. The characteristic resistance shall be reduced by applying the reduction factor $\alpha_p$ = max $N_{red}$ / 0,6 $N_{Rk,ucr}$ 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 strength in accordance with A2.1, accounting for the relevant failure mode.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- 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 $\alpha$ according to Equation (A.11). 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 $\alpha$ together with rqd. $\alpha$ = 1,0 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 reduction factor $\alpha_1$ according to Equation (A.14).
- Use the reduction factor $\alpha_1$ together with rqd. $\alpha_1$ = 0,8 (in uncracked concrete) in Equation (2.8).
- 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 $cv_\delta$ [%]. If the mean value of displacements at 50% of the failure load are larger than 0,4 mm, $cv_\delta$ 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 according to B.3.7. a), two more blows shall be applied with the impact device according to Figure B.13.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Annex B, Figure B.4.

**Assessment**

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- 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 $\alpha$ according to Equation (A.11). 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 $\alpha$ together with rqd. $\alpha = 0{,}8$ in Equation (2.8) and (2.9).

Load displacement behaviour:

- Verify the criteria for uncontrolled slip and determine the load $N_{sl}$ [kN] according to A2.5.
- Determine the reduction factor $\alpha_1$ according to Equation (A.14).
- Use the reduction factor $\alpha_1$ together with rqd. $\alpha_1 = 0{,}7$ (in cracked concrete) in Equation (2.9) and $\alpha_1 = 0{,}8$ (in uncracked concrete) in Equation (2.8).
- 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 $cv_\delta$ [%]. If the mean value of displacements at 50% of the failure load are larger than 0,4 mm, $cv_\delta$ shall not exceed 40 %.

#### 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.

The tests may be omitted if the MPII specify setting with an impact screw driver only.

**Test conditions**

Perform 10 tests with each size of the fastener in uncracked concrete C20/25. If the MPII allow different embedment depths, the tests shall be performed with minimum embedment depth. The holes shall be drilled with a cutting diameter $d_{cut,max}$ of the drill bit according to Annex B, Figure B.4.

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 ($T_u$) 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 to set the fastener with the designated setting depth and the torque to tighten the fixture shall be ≤ $T_{inst}$. $T_{inst}$ is the installation torque recommended by the manufacturer. If no installation torque is specified by the manufacturer, $T_{inst}$ shall be determined in high strength concrete, where $T_{inst}$ is the maximum torque required to completely set the fastener in tests according to 2.2.2.8. In case of scatter larger than cv = 15% but

not larger than 30%, the factor $\beta_{cv}$ shall be determined according to Equation (A.7). For cv ≤ 15% the factor $\beta_{cv}$ = 1,0.

(2) Tests with steel failure:

$$T_{u,5\%} \geq 1,5 \cdot T_{inst} \, (f_{u,t} \; / \; f_{uk}) \; / \; \beta_{cv} \tag{2.6}$$

(3) Tests with concrete failure

$$T_{u,5\%} \geq 2,1 \cdot T_{inst} \, (f_{c,t} \; / \; f_{ck})^{0,5} \; / \; \beta_{cv} \tag{2.7}$$

*where*

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

*Note 7: The factor 1,5 in Equation (2.6) was established to take into account the scatter of steel failure due to torque. The factor 2,1 in Equation (2.7) was established to take into account the scatter of concrete failure due to torque.*

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.

The tests may be omitted if the MPII specify setting with an impact screw driver only.

**Test conditions**

Perform 10 tests with each size of the fastener in uncracked concrete C50/60. If the MPII allow different embedment depths, the tests shall be performed with maximum embedment depth. The holes shall be drilled with a cutting diameter $d_{cut,min}$ of the drill bit according to Annex B, Figure B.4.

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

**Assessment**

The following test criteria shall be met:

(1) It shall be possible to properly set the fastener. The maximum torque to set the fastener with the designated setting depth and the torque to tighten the fixture shall be ≤ $T_{inst}$. $T_{inst}$ is the installation torque recommended by the manufacturer. If no installation torque is specified by the manufacturer, $T_{inst}$ shall be taken as the maximum torque required to completely set the fastener. In case of scatter larger than cv = 15% but not larger than 30%, the factor $\beta_{cv}$ shall be determined according to Equation (A.7). For cv ≤ 15% the factor $\beta_{cv}$ = 1,0.

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

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

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.

#### 2.2.2.9 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.

The tests may be omitted if the MPII do not allow setting with an impact screw driver.

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

**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:

- Uncracked concrete C20/25 (in addition, also in C50/60, if test series F7 was omitted);
- Cutting diameter of drill bits C20/25: $d_{cut} = d_{cut,max}$; for C50/60: $d_{cut} = d_{cut,min}$;
- If the MPII allow different embedment depths, the tests shall be performed in C20/25 with minimum embedment depth and in C50/60 with maximum embedment depth.
- 15 tests with each fastener size;
- Impact screw driver with maximum power output as given by the manufacturer in MPII or, if not, as recommended by the TAB based on experiences and stated in the ETA.
- The fastener shall be 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 one failure occurs, the TAB may increase the test number to n = 30 with one failure allowed. If more than 1 failure occurs, then the manufacturer cannot declare suitability of the product for the impact screw driver used in the test.

#### 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 normalized to concrete strength C20/25.

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). For the tension test series, the factor $\alpha_1$ is determined. The smallest value for the ratio $\alpha_1$/(rqd.$\alpha_1$) applies.

(2) Applied load in repeated load tests $\alpha_{p,ucr}$
For characteristic resistance in uncracked concrete $\alpha_p$ according to section 2.2.2.5 (tests with repeated loads) is accounted for in Equation (2.8).

(3) Applied load in crack cycling tests $\alpha_{p,cr}$
For characteristic resistance in cracked concrete $\alpha_p$ according to section 2.2.2.4 (tests with crack cycling) is accounted for in Equation (2.9).

(4) 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 are not fulfilled in one or more test series, the characteristic resistance shall be reduced according to Equation (2.8). The smallest value of the ratio $\alpha$/(rqd. $\alpha$) 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.

Characteristic resistance in uncracked concrete

$$N_{Rk,p,ucr} = N_{Rk,0} \cdot min\, \beta_{cv} \cdot min \left\{ \alpha_{p,ucr}; \min \left( \frac{\alpha_1}{rqd.\alpha_1} \right); min \left( \frac{\alpha}{rqd.\alpha} \right) \right\} \quad (2.8)$$

Characteristic resistance in cracked concrete

$$N_{Rk,p,cr} = N_{Rk,0} \cdot min\, \beta_{cv} \cdot min \left\{ \alpha_{p,cr}; \min \left( \frac{\alpha_1}{rqd.\alpha_1} \right); min \left( \frac{\alpha}{rqd.\alpha} \right) \right\} \quad (2.9)$$

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 / … |

For reasons of consistency with existing ETA the characteristic resistance may also be rounded down to 25 and 35 kN.

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 $\psi_c$ 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 EN 1992-4 [4] 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, 3.1.26; for concrete screws: $h_{ef}$ shall be determined according to 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 and to determine the factor $\gamma_{inst}$ for the sensitivity to installation.

If the manufacturer applies for several embedment depths of one fastener size, the tests shall be performed at minimum embedment depth and at the maximum embedment which does not create steel failure.

If in tests with minimum embedment depth steel failure occurs, tests at maximum embedment depth may be omitted.

**Test conditions**

The tension tests are performed according to Annex B, B.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.

<u>Torque-controlled expansion fasteners (TC)</u>

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 Annex B, Figure B.4. The fastener is installed with an applied torque T = 0,5 $T_{inst}$.

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

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 Annex B, Figure B.4. The fastener shall be set with installation expansion according to Annex B, B.3.7.

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

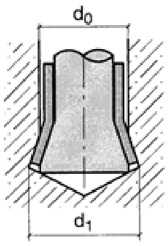



**Figure 2.3 Diameter of drill bits $d_0$ and $d_1$**

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 according to B.3.7 a) 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 $d_1$: $d_{cut,max}$

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

*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 robustness tests are defined as follows:

- Diameter of drill bit for cylindrical hole $d_0$: $d_{cut,max}$
- Diameter of drill bit for undercutting $d_1$: $d_{cut,max}$ and $d_{cut,min}$ (fastener according to Figure 1.11 only)
- Torque $T = 0,5\ T_{inst}$
- 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 Annex B 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.

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

  $d_{t,t}$ outer diameter of thread according to Figure 2.8 of the concrete screw in the main load bearing section measured on the concrete screw used in the test

  $d_{t,low}$ lower limit outer diameter of thread according to Figure 2.8 of the concrete screw in the main load bearing section according to the specification of the manufacturer

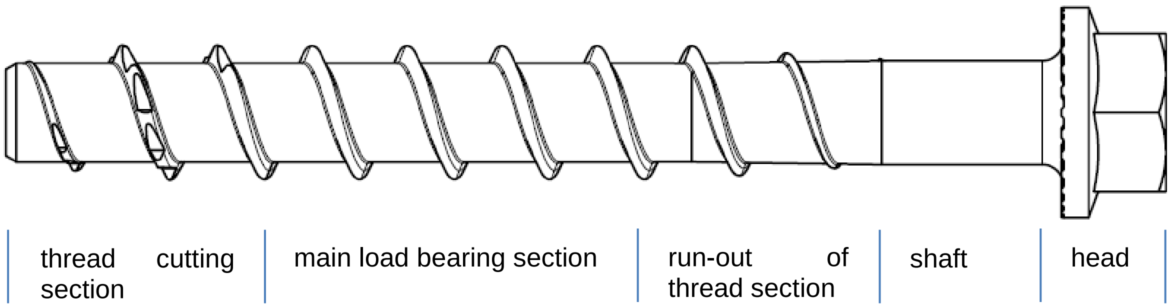



**Figure 2.4 Possible sections of a concrete screw**

**Assessment**

<u>Failure loads</u>

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- 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 $\alpha$ according to Equation (A.11). 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. $\alpha$ the factor $\alpha$ fulfils the corresponding value of $\gamma_{inst}$ is taken.
- For UC and CS compare the factor $\gamma_{inst}$ with the result of test series “robustness to contact with reinforcement”. The larger value governs.

<u>Load displacement behaviour:</u>

- Verify the criteria for uncontrolled slip and determine the load $N_{sl}$ [kN] according to A2.5.
- Determine the reduction factor $\alpha_1$ according to Equation (A.14).
- Use the reduction factor $\alpha_1$ together with rqd. $\alpha_1$ = 0,7 (in cracked concrete) in Equation (2.9) and rqd. $\alpha_1$ = 0,8 (in uncracked concrete) in Equation (2.8).
- 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 $cv_\delta$ [%]. If the mean value of displacements at 50% of the failure load are larger than 0,4 mm, $cv_\delta$ shall not exceed 40 %.

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

**Table 2.3 Values of $\gamma_{inst}$ for robustness to variation in use conditions**

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

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

### 2.2.4.2 Robustness to contact with reinforcement (UC, CS, 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 $\gamma_{inst}$ for the sensitivity to installation.

**Test conditions**

The tests shall be performed according to Annex B, B.3.3.2.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Annex B, Figure B.4.

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 $\Delta w$ = 0,30 mm and a position of the reinforcement relative to the fastener as given in Annex B, B.3.3.2.

If the manufacturer applies for several embedment depths of one diameter of the fastener, only the largest embedment depth $h_{ef}$ which is smaller than 80 mm shall be tested.

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 B.3.3.2.

**Assessment**

Failure loads

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- Determine the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- 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 $\alpha$ according to Equation (A.11). Test series A3 is used as the corresponding reference test series.
- Determine the factor to account for the sensitivity to installation $\gamma_{inst}$ according to Table 2.4.
- Depending on which level of rqd. $\alpha$ the factor $\alpha$ fulfils the corresponding value of $\gamma_{inst}$ is taken.
- Compare the factor $\gamma_{inst}$ 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 $cv_\delta$ [%]. If the mean value of displacements at 50% of the failure load are larger than 0,4 mm, $cv_\delta$ shall not exceed 40 %.

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

**Table 2.4 Values of $\gamma_{inst}$ for contact with reinforcement**

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

If $\alpha < 0,60$ the fastener is not covered by this EAD.

### 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 Annex B, B.3.4.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Annex B, Figure B.4.

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 $h_{min}$ as applied for the fastener.

If the manufacturer does not specify $c_{min}$ and $s_{min}$ and no experience for the fastener exist, $c_{min}$ = 1,5 $h_{ef}$ and $s_{min}$ = 3 $h_{ef}$ are recommended for the test lab.

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.

Undercut fasteners

In addition to the tests to derive the minimum edge distance and minimum spacing, tension tests according to Annex B 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 as applied for by the manufacturer is smaller than the characteristic failure load for concrete failure according to EN 1992-4 [4].

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 according to B.3.7 a).

Concrete screws

Set double fastener group at the edge with the requested minimum edge distance and minimum spacing in a slab with minimum thickness of the concrete member ($s=s_{min}$, $c=c_{min}$, $h=h_{min}$).

Install the two concrete screws (CS1 and CS2) according to the following sequence:

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

**Assessment:**

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

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

Deformation-controlled expansion fasteners

After the successful test setting enlarge the projected splitting area $A_{sp,t}$ according to Equation (2.10) with a factor of 1,3 (cracked) and 1,7 (uncracked concrete) to obtain rqd. $A_{sp}$:

$$A_{sp,t} = (3\ c_{min,t} + s_{min,t})(1{,}5\ c_{min,t} + h_{ef}) \quad \text{when } h > (1{,}5\ c_t + h_{ef}) \tag{2.10}$$

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

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

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

Use Equation (2.10) to determine $c_{min} \ge c_{min,t}$ and $s_{min} \ge s_{min,t}$ such that the Equation rqd $A_{sp}$ is fulfilled.

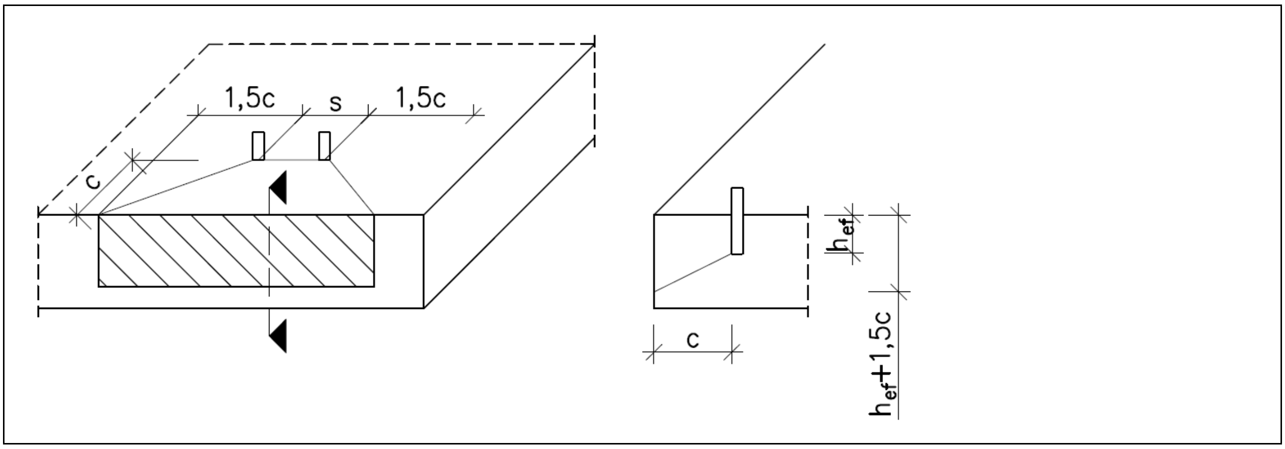



**Figure 2.5 Projecting Area $A_{sp}$**

All other fasteners

The minimum spacing $s_{min}$ and minimum edge distance $c_{min}$ shall be evaluated from the results of installation tests with double fastener groups ($c = c_{min,t}$, $s = s_{min,t}$). The 5 %-fractile of the torque, $T_{5\%}$, calculated according to Equation (A.9) at which a hairline crack has been observed at one fastener of the double fastener group, shall fulfil Equation (2.11).

$$T_{5\%} \ge k \cdot \text{rqd. } T_{inst}\ (f_{c,t} / f_{ck})^{0,5} \quad \text{(for concrete failure)} \tag{2.11}$$

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 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 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 respectively depend on the pre-stressing force generated during torqueing and the ratio splitting force to pre-stressing force.

*Note 8: 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 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 TAB or specified by the manufacturer. Perform a tension test according to B.3.3.1.

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Figure B.4. Deformation-controlled expansion fasteners (DC) shall be set with full expansion according to B.3.7 a).

**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 to the result of the test series with 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.

<u>Failure loads:</u>

- Determine the mean value of failure loads $N_{u,m}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- Determine $N_{Rk,sp}$ from the 5% fractile of the failure loads $N_{u,5\%}$ [kN], converted to the nominal strength in accordance with A2.1, accounting for the relevant failure mode.
- 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.

<u>Load displacement behaviour:</u>

- Verify the criteria for uncontrolled slip and determine the load $N_{sl}$ [kN] as well as the factor $\alpha_1$ in accordance with A2.5.
- Use the reduction factor $\alpha_1$ together with rqd. $\alpha_1 = 0{,}8$ (in uncracked concrete) in Equation (2.8).
- 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 $cv_\delta$ [%]. If the mean value of displacements at 50% of the failure load are larger than 0,4 mm, $cv_\delta$ shall not exceed 25 %.

The characteristic resistance to splitting $N^0_{Rk,sp}$ shall be determined by Equation (2.12). 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 $N^0_{Rk,c}$ according to EN 1992-4 [4], Equation (7.2).

$$N^0_{Rk,sp} = \min \{N^0_{Rk,c}; N_{Rk,p}\} \qquad (2.12)$$

### 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.

$$V^0_{Rk,s} = \alpha_v \cdot A_s \cdot f_{uk} = 0{,}5 \cdot A_s \cdot f_{uk} \quad [N] \qquad (2.13)$$

$$M^0_{Rk,s} = 1{,}2 \cdot W_{el} \cdot f_{uk} \quad [Nm] \qquad (2.14)$$

If Equation (2.13) is not applicable, the characteristic resistance to steel failure $V^0_{Rk,s}$ shall be determined by tests.

**Purpose of the test**

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

**Test conditions**

The tests shall be performed according to B.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 (2.13) and (2.14).

The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Figure B.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 B.3.7 a)

<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 $V^0_{Rk,s} = V_{u,5\%}$ as the 5% fractile of the failure loads $V_{u,5\%}$ [kN], converted to the nominal steel strength, according to A2.1.

<u>Displacements:</u>

- The test series is also needed for determination of the displacements $\delta_{V0}$ in 2.2.10.

<u>Load displacement behaviour:</u>

- Determine the mean value of the failure loads $V_{u,m}$ [kN] of the test series.
- Determine the displacements at 50% of the mean failure load $\delta_{0,5Vu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50% of the mean failure load $cv_\delta$ [%]. If the mean value of displacements at 50% of the failure load are larger than 0,4 mm, $cv_\delta$ shall not exceed 25 %.

### 2.2.7.2 Group of fasteners

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

The factor $k_7$ may be assumed as follows:

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

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

The factor $k_7$ may be taken as equal to 1,0 without further testing, if the MPII prescribe to fill the annular gap with an effective material (e.g., with a minimum compressive strength of 30 MPa). The TAB shall check if for a group of fasteners, the annular gap can be filled with the respective filling material according to the MPII.

**Concrete screws (CS, Test series V3)**

For concrete screws, which do not comply with the standard hole clearance requirements given in Table 6.1 of EN 1992-4 [4] and/or for which the rupture elongation $A_5$ cannot readily be determined, the characteristic resistance of a group may be determined based on tests.

**Purpose of the test**

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

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

The test is performed to determine the shear resistance of a group of concrete screws, which do not comply with the standard hole clearance given in Table 6.1 of EN 1992-4 and/or for which the rupture elongation $A_5$ cannot be readily determined. The test accounts for the larger hole clearance as well as the ductility of the fastener.

The hole clearance is defined as the difference between the diameter of the clearance hole in the fixture $d_f$ and the relevant diameter of the fastener $d_r$. For concrete screws the relevant diameter $d_r$ is shown in Figure 2.6. The relevant diameter of the fastener $d_r$ may be the diameter of the shaft $d_s$ (see Figure 2.6 a), c) and e)), the diameter of the threaded head (see Figure 2.6 d)) or the diameter of the thicker portion right below the head, if this thicker portion bears against the fixture for at least 0,5 $t_{fix}$ (see Figure 2.6 b)).

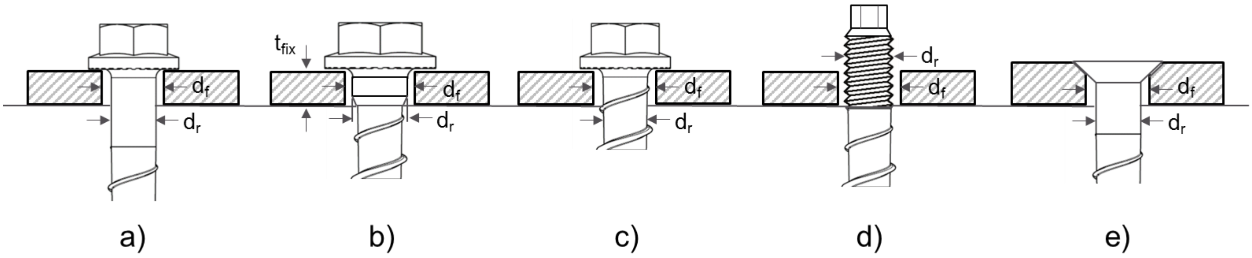



**Figure 2.6 Clearance hole for concrete screws**

**Description of the test**

The test is performed for the most unfavourable condition, i.e. resulting in the largest annular gap, with a group of 2 fasteners (concrete screws) in uncracked concrete C20/25 (see Figure 2.7).

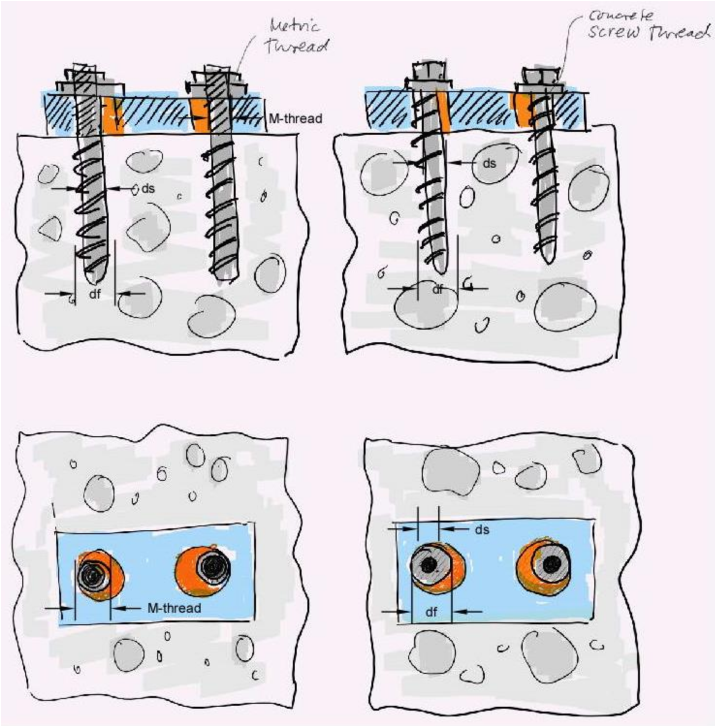
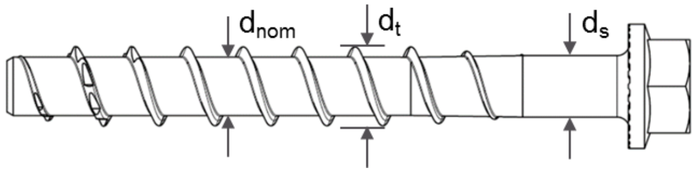


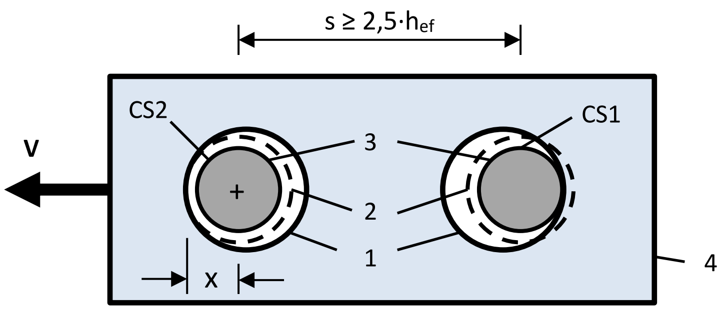

**Figure 2.7 Most unfavourable condition - largest annular gap**

For concrete screws with a smooth shaft (see Figure 2.8) a test setup to determine the shear capacity of groups of concrete screws is shown in Figure 2.9 and the installation steps are given below. For concrete screws with other shaft/head configuration (see Figure 2.6 b) to e)) the installation needs to be adapted ensuring a resulting largest annular gap.




Key
$d_s$ diameter of shaft
$d_t$ outer diameter of thread

**Figure 2.8 Concrete screw with a smooth shaft**




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

**Figure 2.9 Test condition for group of concrete screws**

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

- drill the hole for the concrete screw CS1;
- position the fixture (which has pre-drilled clearance holes of diameter $d_f$ in accordance with the manufacturer specifications at a spacing of $s \geq 2{,}5 \cdot h_{ef}$ to avoid pry-out during the test);

- install the concrete screw CS1; before the head of the concrete screw touches the fixture, move the fixture such that the clearance hole touches the shaft of the concrete screw (see position of CS1 in Figure 2.9); finish installation of the concrete screw;
- drill the hole and install the second concrete screw CS2 such that, once CS2 is installed, the maximum clearance between the fixture and the shaft of the concrete screw is not greater than half of the difference between the maximum outer diameter of the thread $d_t$ and the diameter of the shaft $d_s$ (see Figure 2.8), taking into account possible tolerances; hence, the distance x given in Figure 2.9 shall fulfil Equation (2.15)

$$x \leq \frac{d_t}{2} + \frac{d_t - d_s}{2} \qquad (2.15)$$

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

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

Perform a shear test in accordance with Annex B (B.3.1, including thickness of fixture as given in B.3.1.5 and B.3.2) with the loading direction as shown in Figure 2.9. Where feasible, uplifting of the fixture may be avoided during the test, which, if executed, applies for both the group test and the test with a single fastener.

The hardness of the fixture should be higher than that of the concrete screw to avoid damage of the fixture.

For the shear test of a single concrete screw and the shear test of the group of two concrete screws, concrete screws from the same batch in one batch of concrete should be used.

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

**Assessment**

Determine the mean value of the failure loads $V_{u,m}$ [kN] and the corresponding coefficient of variation cv [%]. If the concrete screws used for the test series according Table A.1, line V1 and this test series are not taken from the same batch, normalization of the failure loads in accordance with A2.1, Equation (A.6) shall be applied. The performance of a group of concrete screws is determined accounting for the ductility of the fastener.

*Note 9: For fasteners complying with the hole clearance requirements in Table 6.1 of EN 1992-4 [4] the characteristic resistance in case of steel failure of a group of fasteners loaded in shear is determined based on two values of $k_7$ as given above. For reasons of consistency the same distinction is made for the assessment of the test results.*

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

$$\alpha_{ag} = \frac{V_{u,m}}{2 \cdot V_{u,m,single}} \qquad (2.16)$$

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

$V_{u,m,single}$ is the mean failure load of the test series according to Table A.1, line V1 with a single fastener

If the concrete screws in the single fastener test and the group test are not from the same batch and the strength of concrete screws used in the group test is larger than that of the single fastener test, normalize failure loads down to the strength of the single fastener in accordance with A2.1, Equation (A.6).

The coefficient of variation of the failure load $cv(V_u)$ shall not be larger than 20% for the current test series as well as for the test series in accordance with Table A.1, line V1. If the coefficient of variation is in the range $10\% < cv(V_u) \leq 20\%$, the factor $\beta_{df}$ shall be determined in accordance with Equation (2.17).

$$\beta_{df} = \frac{1}{1 + (cv(V_u) - 10) \cdot 0{,}03} \leq 1{,}0 \qquad (2.17)$$

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

$k_7 = 1{,}0 \cdot \beta_{df}$ for $\alpha_{ag} \geq 0{,}95$ (2.18)

$k_7 = 0{,}8 \cdot \beta_{df}$ for $\alpha_{ag} \geq 0{,}8$ (2.19)

$k_7 = \alpha_{ag} \cdot \beta_{df}$ for $0{,}7 \leq \alpha_{ag} < 0{,}8$ (2.20)

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

Hence, if the tests are carried out and the factor $k_7$ is evaluated based on these tests the following text shall be stated in the ETA:

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

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

The test series may be omitted if the default values for $k_8$ according to Table 2.6 apply.

**Purpose of the test**

The test series is performed to determine the $k_8$ factor for design according to EN 1992-4 [4] for pry-out failure.

**Table 2.6 Default values for $k_8$**

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

Other factors $k_8$ may be determined by tests.

**Test conditions**

The tests shall be performed according to Annex B, B.3.6.2.

The test series is performed with a group of 4 fasteners in uncracked concrete C20/25 according to Annex B. 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 Annex B, Figure B.4. Deformation-controlled expansion fasteners (DC) shall be set with full expansion according to B.3.7 a).

**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 (2.21) and (2.22).

$$k_8 = \frac{V_{u,5\%,t}}{N_{Rk,ucr}} \qquad (2.21)$$

$$N_{Rk,ucr} = k_{ucr} \cdot h_{ef}^{1,5} \cdot \sqrt{f_{c,t}} \, \frac{(s + 3h_{ef})^2}{9h_{ef}^{\,2}} \qquad (2.22)$$

<u>Load displacement behaviour:</u>

- Determine the mean value of the failure loads $V_{u,m}$ [kN] of the test series.
- Determine the displacements at 50% of the mean failure load $\delta_{0,5Vu,m}$ [mm] in each test.
- Determine the coefficient of variation of the displacements at 50% of the mean failure load $cv_\delta$ [%]. If the mean value of displacements at 50% of the failure load are larger than 0,4 mm, $cv_\delta$ shall not exceed 25 %."

### 2.2.9 Characteristic resistance for simplified design method

#### 2.2.9.1 Method B

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

$$F^0_{Rk} / \gamma_M = \min (N_{Rk,s} / \gamma_{Ms}; N_{Rk,c} / \gamma_{Mc}; N_{Rk,p} / \gamma_{Mp}; V^0_{Rk,s} / \gamma_{Ms}) \quad (2.23)$$

$$c_{cr} = c_{cr,N} \quad (2.24)$$

$$s_{cr} = s_{cr,N} \quad (2.25)$$

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

#### 2.2.9.2 Method C

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

$$F_{Rk} / \gamma_M = \min (N_{Rk,s} / \gamma_{Ms}; N_{Rk,c} / \gamma_{Mc}; N_{Rk,p} / \gamma_{Mp}; V^0_{Rk,s} / \gamma_{Ms}) \quad (2.26)$$

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

### 2.2.10 Displacements

The displacements under short-term and long-term tension and for shear loading shall be given in the ETA for a load F which corresponds approximately to the value according to Equation (2.27)

$$F = \frac{F_{Rk}}{1{,}4 \cdot \gamma_M} \quad (2.27)$$

The displacements under short-term tension $\delta_{NO}$ and for shear loading $\delta_{VO}$ 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 displacements under short-term tension $\delta_{NO}$ and under short-term shear $\delta_{VO}$ 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 fastener. It 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.1 line F3) according to Equation (2.28)

$$\delta_{N\infty} = \frac{\delta_{m1}}{1{,}5} \quad (2.28)$$

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 (2.29)

$$\delta_{N\infty} = \frac{\delta_{m2}}{2{,}0} \quad (2.29)$$

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

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.

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

**Purpose of the test**

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

**Test conditions**

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

**Assessment**

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

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

**Purpose of the test**

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

**Test conditions**

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

The general test conditions are given in section C.3.1. Explanations for fastener types to be tested are given in section C.3.2. Specific test conditions are given in section C.3.4.1 for reference test series C.2.1, in section C.3.4.2 for tests under pulsating tension loading (test series C2.3) and in section C.3.4.4 for tests with tension load and varying crack width (test series C2.5).

**Assessment**

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

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

**Purpose of the test**

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

**Test conditions**

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

**Assessment**

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

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

**Purpose of the test**

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

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

**Test conditions**

The general test conditions are given in section C.3.1. Explanations for fastener types to be tested are given in section C.3.2. Specific test conditions are given in section C.3.4.1 for the reference test series C2.2 and in section C.3.4.3 for test series under alternating shear load (series C2.4).

**Assessment**

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

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

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

### 2.2.16 Reaction to fire

Fasteners made of steel are considered to satisfy the requirements for performance class A1 of the characteristic reaction to fire in accordance with the EC Decision 96/603/EC without the need for testing on the basis of it fulfilling the conditions set out in that Decision and its intended use being covered by that Decision.

Therefore, the performance of such fasteners is class A1.

### 2.2.17 Fire resistance to steel failure (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 [3] using the "Standard Temperature/Time Curve" (STC).

The tests may be omitted if resistance to steel failure is calculated in according with 1992-4 [4], Annex D.4.2.1.

**Test conditions**

The tests are carried out according to Annex B. The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Annex B, Figure B.4.

**Assessment**

The tests shall be performed according to Annex B, B.3.8.1.

From the fire tests pair of variates [test load F / duration of failure $t_u$] shall be determined. The test loads F shall be converted into steel stresses $\sigma_s$ and drawn for each fastener size in a diagram depending on the determined fire resistance duration $t_u$ (see Figure 2.10). The tests shall be performed with different load levels such that the obtained results are reasonably distributed along the $t_u$-axis within the interval [30min, 120min]. Clouds of similar test results cannot be used for the assessment. For the determination of the mean trend line, the data are displayed in terms of $\sigma_s$ vs. $1/t_u$ (see Figure 2.11). By linear regression of the pair of variates $\sigma_s$ / $(1/t_u)$ (see Figure 2.11) the formula (mean value curve) according to Equation (2.30) shall be determined. The regression curve shall represent the test results as shown in Figure 2.10. If the fastener does not fail during the test, the result cannot be used for determination of the regression curve according to Figure 2.10.

$$\sigma_{s1} = p_1 + p_2 / t_u \qquad (2.30)$$

where $p_1$ is the value where the regression line cuts the y-axis (Figure 2.11)

$p_2$ is the gradient of the regression line (Figure 2.11)

The mean value curve according to Equation (2.30) shall be reduced with an additional shift factor $p_3 < 1$ in such a way, that the curve runs through the pair of variates of the most unfavourable test result. As a result, the lower limit value curve according to Equation (2.31) is obtained.

$$\sigma_{s2} = p_3 (p_1 + p_2 / t_u) \qquad (2.31)$$

The characteristic steel stress for the duration of fire resistance of 60 min, 90 min and 120 min shall be calculated using Equation (2.31) 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:

$$\sigma_{s3} = p_4 - p_5 \cdot t_u \quad (2.32)$$

where $p_4$ is the value where the straight line (red line in Figure 2.10) cuts the y-axis

$p_5$ is the gradient of the straight line (red line in Figure 2.10)

The characteristic steel stress for duration of fire resistance of 30 min shall be calculated using Equation (2.32) as follows:

$$\sigma_{Rk,s,fi(30)} = p_4 - p_5 \cdot 30 \text{ min} \quad (2.33)$$

$$N_{Rk,s,fi} = \sigma_{Rk,s,fi} \cdot A_s \quad (2.34)$$

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 2.12), 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.

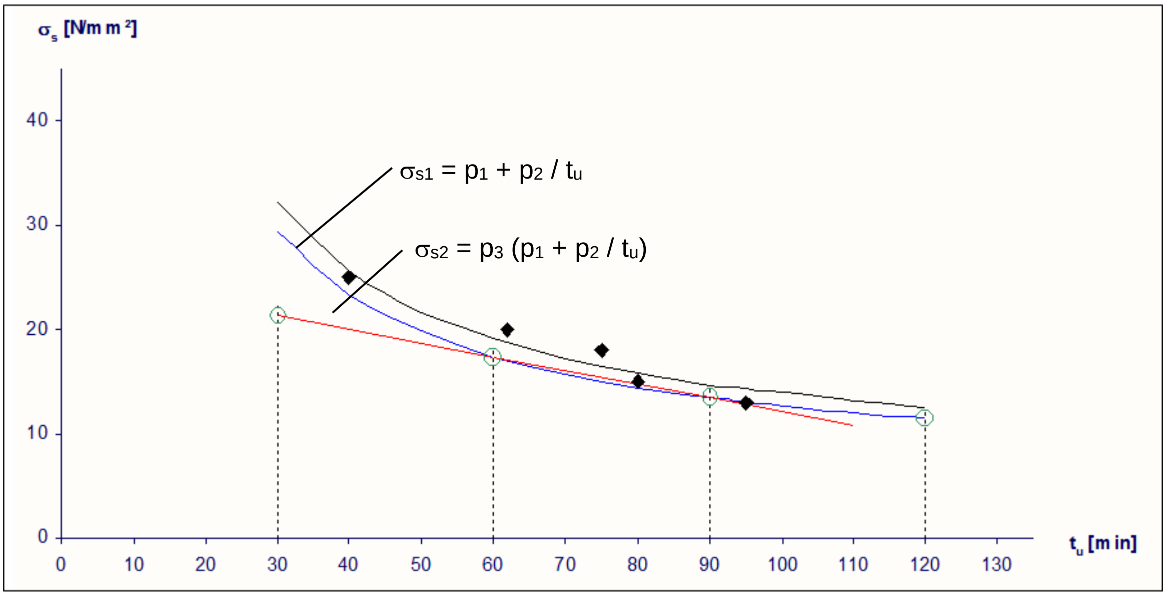



**Figure 2.10 Determination of the characteristic steel stress**

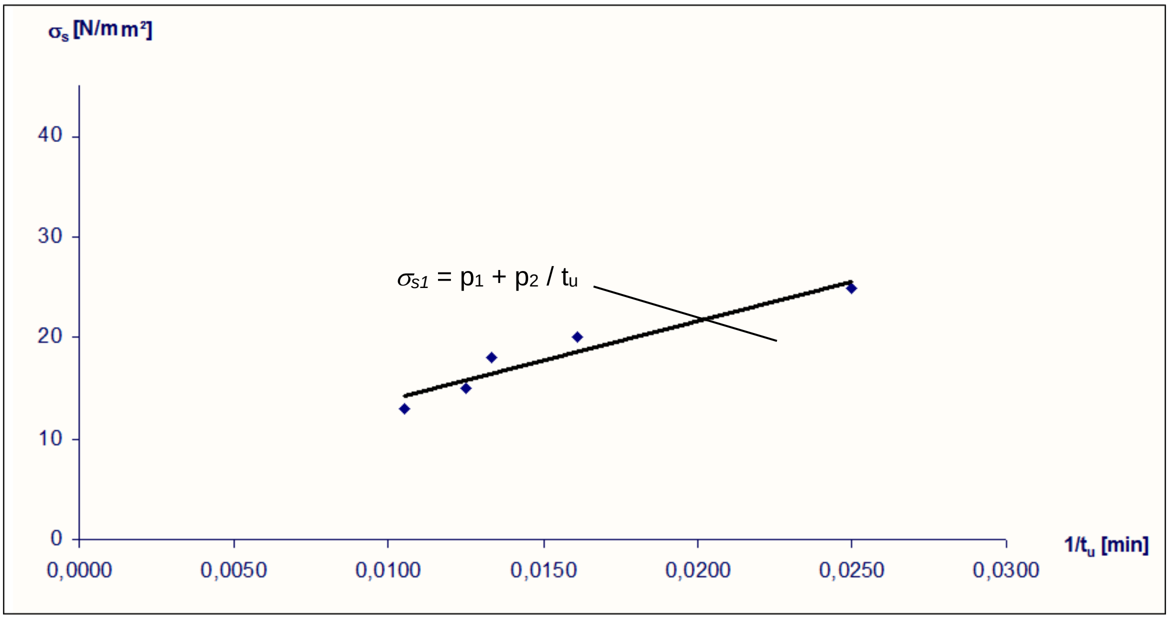



**Figure 2.11 Determination of the regression Equation**

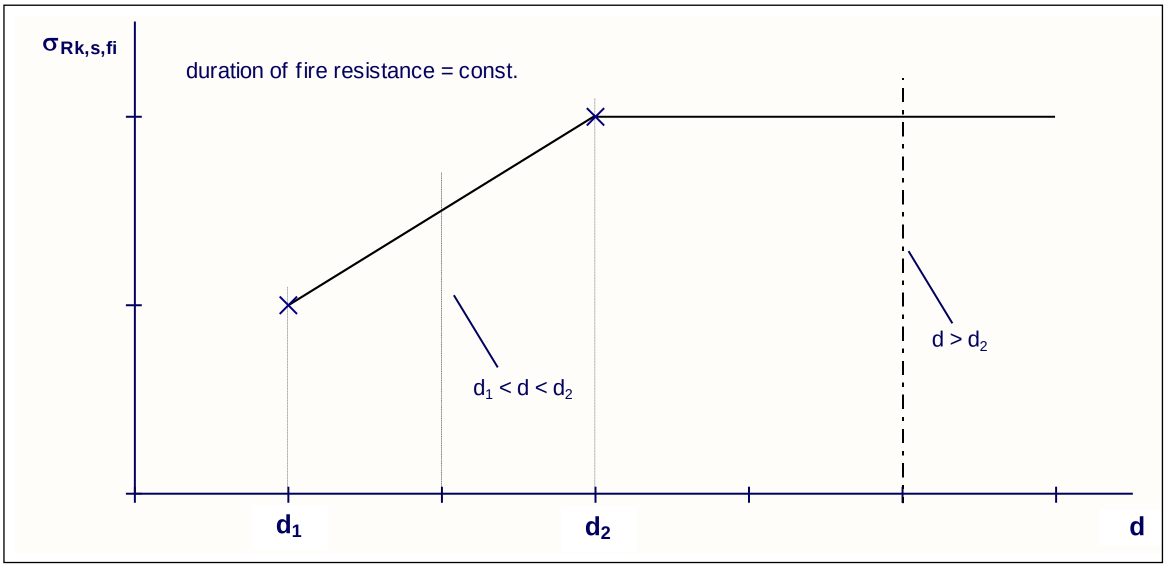



**Figure 2.12 Interpolation of intermediate sizes for constant duration of fire resistance**

### 2.2.18 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 [3] using the “Standard Temperature/Time Curve” (STC).

The tests may be omitted if resistance to pull-out failure is calculated in according with EN 1992-4 [4], Annex D.4.2.3.

**Test conditions**

The tests shall be performed according to Annex B, B.3.8.2. The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Annex B, Figure B.4.

**Assessment**

The assessment shall be carried out in the same way as for steel failure under tension load (see 2.2.17). The relation between the characteristic pull-out resistance $N_{Rk,p,fi}$ for the duration of fire resistance of 30 min, 60 min, 90 min, 120 min and the characteristic resistance for pull-out $N_{Rk,p}$ for cracked concrete C20/25 according to 2.2.2 may be used for all fastener sizes of the evaluated system.

### 2.2.19 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 Annex B, B.3.8.3. The holes shall be drilled with a cutting diameter $d_{cut,m}$ of the drill bit according to Annex B, Figure B.4.

**Assessment**

The assessment shall be carried out according to 2.2.17.

$$V_{Rk,s,fi} = \sigma_{Rk,s,fi} \cdot A_s \quad (2.35)$$

$$M^0_{Rk,s,fi} = 1{,}2\ \sigma_{Rk,s,fi} \cdot W_{el} \quad (2.36)$$

### 2.2.20 Durability

The fastener characteristics shall not change during the working life, therefore the mechanical properties on which the functioning and bearing behaviour of the fastener depends (e.g., material, coating) shall not be adversely affected by ambient physico-chemical effects such as corrosion and degradation caused by environmental conditions (e.g., alkalinity, moisture, pollution). 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) Fasteners for use according EN 1993-1-4 [5], Annex A:

Fasteners made of stainless steel according EN 1993-1-4 [5], Annex A, Tables A.3 and A.4 are considered to have sufficient durability for the corresponding Corrosion Resistance Class (CRC).

**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. 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.

# 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 for use in concrete in the procedure of assessment and verification of constancy of performance are laid down in Table 3.1.

**Table 3.1 Control plan for the manufacturer; 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)**<br>[**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 [12], EN ISO 898-1 [11], EN ISO 3506-1 [7] | | 3 | |
| 3 | Yield strength *) | EN ISO 6892-1 [12], EN ISO 898-1 [11], EN ISO 3506-1 [7] | | 3 | |
| 4 | Core hardness and Surface hardness (at specified functioning relevant points of the product) – where relevant | Tests according to EN ISO 6507 [8] or EN ISO 6508 [9] | | 3 | |
| 5 | Roughness of cone - where relevant | profile method: EN ISO 12085 [18]<br>Software measurement standards:<br>EN ISO 5436 [14]<br>calibration: EN ISO 12179 [19]<br>EN ISO 1302 [13] | | 3 | |
| 6 | Zinc plating - where relevant | x-ray measurement<br>according EN ISO 3497 [15], magnetic method according EN ISO 2178 [16], Phase-sensitive eddy-current method according EN ISO 21968 [17] | | 3 | |
| 7 | Fracture elongation - where relevant | EN ISO 6892-1 [12]<br>EN ISO 898-1 [11] | | 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


| | | |
|---|---|---|
| [1] | EAD 330011-00-0601:2014-07 | Adjustable concrete screws |
| [2] | EN 206:2013+A2:2021 | Concrete: Specification, performance, production and conformity |
| [3] | EN 1363-1:2012 | Fire resistance tests – Part 1: General requirements |
| [4] | EN 1992-4:2018 | Design of concrete structures — Part 4: Design of fastenings for use in concrete |
| [5] | EN 1993-1-4:2006 + A1:2015 | Eurocode 3: Design of steel structures, Part 1-4: General rules – Supplementary rules for stainless steels |
| [6] | EN 13501-1:2007+A1:2009 | 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 |
| [7] | EN ISO 3506-01:2009 | Mechanical properties of corrosion-resistant stainless-steel fasteners, Part 1: Bolts, screws and studs; Part 2: Nuts |
| [8] | EN ISO 6507-1:2018 | Metallic materials – Vickers hardness test |
| [9] | EN ISO 6508-1:2016 | Metallic materials – Rockwell hardness test |
| [10] | EN ISO/IEC 17025:2017 | General requirements for the competence of testing and calibration laboratories. |
| [11] | EN ISO 898-1:2013 | Mechanical properties of fasteners made of carbon steel and alloy steel.<br>Part 1: Bolts, screws and studs with specified property classes – Coarse thread and fine pitch thread |
| [12] | EN ISO 6892-1:2016 | Metallic materials – Tensile testing – Part 1: Method of test at room temperature |
| [13] | EN ISO 1302:2002 | Geometrical Product Specifications (GPS) - Indication of surface texture in technical product |
| [14] | EN ISO 5436-1:2000 | Geometrical Product Specifications (GPS) - Surface texture: Profile method; Measurement standards - Part 1: Material measures |
| [15] | EN ISO 3497:2000 | Metallic coatings - Measurement of coating thickness - X-ray spectrometric methods |
| [16] | EN ISO 2178:2016 | Non-magnetic coatings on magnetic substrates - Measurement of coating thickness - Magnetic method |
| [17] | EN ISO 21968:2005 | Non-magnetic metallic coatings on metallic and non-metallic basis materials - Measurement of coating thickness - Phase-sensitive eddy-current method |
| [18] | EN ISO 12085:2013 | Geometrical Product Specifications (GPS) - Surface texture: Profile method - Motif parameters (ISO 12085:1996); |
| [19] | EN ISO 12179:2000 | Geometrical Product Specifications (GPS) - Surface texture: Profile method - Calibration of contact (stylus) instruments |
| [20] | EN 13791:2007 | Assessment of in-situ compressive strength in structures and precast concrete components |
| [21] | EAD 330232-00-0601:2016-05 | Mechanical fasteners for use in concrete |
| [22] | EN 197-1:2014 | Cement - Part 1: Composition, specifications and conformity criteria for common cements |
| [23] | EN 1090-2:2011 | Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures |
| [24] | ISO 5468:2006 | Rotary and rotary impact masonry drill bits with hard metal tips - Dimensions |

| | | |
|---|---|---|
| [25] | EN 1993-1-1:2010 | Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings |
| [26] | EN 1993-1-4:2006+A1:2015 | Eurocode 3: Design of steel structures - Part 1-4: Supplementary rules for stainless steels |
| [27] | Lewandowski, R | Beurteilung von Bauwerksfestigkeiten an Hand von Betongütewürfeln und –bohrproben, Schriftenreihe der Institute für Konstruktiven Ingenieurbau der Technischen Universität Braunschweig, Heft 3, Werner Verlag, Düsseldorf, 1971 |
| [28] | EN 1363-1:1999 | Fire resistance tests - Part 1: General requirements |
| [29] | EN 1998-1:2004 + AC 2009 | Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings. |

# 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 | C50/60 | 0 | All | $d_{cut,m}$ | 5 | | TC, UC, DC | 2.2.1.2 |
| N3 | Hydrogen induced embrittlement | C50/60 | 0 | All | $d_{cut,m}$ | 5 | 0,90 | CS | 2.2.1.3 |
| **Basic tension tests** | | | | | | | | | |
| A1 | Basic tension tests | 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 | TC, DC 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 |
| | | (C50/60)$^{6)}$ | | | ($d_{cut,min}$) | | | | |
| F9 | Robustness to variation in use conditions | C20/25 | 0 | s/m/l $^{5)}$ | $^{4)}$ | 5$^{3)}$ | 0,95 | Option 7-12 | 2.2.4.1 |
| | | C20/25 (C50/60)$^{4)}$ | 0,30 | All | | | 0,80 | UC, DC, CS Option 1-6 | |
| | | C50/60 | | | | | 0,70 | TC Option 1-6 | |
| F10 | Robustness to contact with reinforcement | C20/25 | 0,30 | s/m $^{2)}$ | $d_{cut,m}$ | 5$^{3)}$ | 0,85 | Option 1-6 UC | 2.2.4.2 |
| | | | | | $d_{cut,max}$ | | 0,70 0,60 | Option 1-6 CS | |

| N° | Purpose of test | Concrete | Crack width | Size | $d_{cut}$ | $n_{min}$ | rqd. $\alpha$ | 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 | | All [7] | 2.2.8 |
| V3 | Group of fasteners | C20/25 | 0 | All | $d_{cut,m}$ | 5 | - | CS [8] | 2.2.7.2 |
| **Characteristic Resistance for seismic performance category C1** | | | | | | | | | |
| C1.1 | Functioning under pulsating tension load [3] | C20/25 | 0,5 [9] | All | $d_{cut,m}$ | 5 [10] | - | All | C.3.3.2<br>C.4.1.1 |
| C1.2 | Functioning under alternating shear load [4] | C20/25 | 0,5 [9] | All | $d_{cut,m}$ | 5 [10] | - | All | C.3.3.3<br>C.4.1.2 |
| **Characteristic Resistance for seismic performance category C2** | | | | | | | | | |
| C2.1a | Reference tension tests in low strength concrete | C20/25 | 0,8 [9] | All | $d_{cut,m}$ | 5 [11] | - | All | C.3.4.1<br>C.4.2.1<br>C.4.2.2 |
| C2.1b | Tension tests in high strength concrete | C50/60 | 0,8 [9] | All | $d_{cut,m}$ | 5 [11] | - | All | C.3.4.1<br>C.4.2.1<br>C.4.2.2 |
| C2.2[3] | Reference shear tests | C20/25 | 0,8 [9] | All | $d_{cut,m}$ | 5 [11] | - | All | C.3.4.1<br>C.4.2.1<br>C.4.2.3 |
| C2.3 | Functioning under pulsating tension load | C20/25 | 0,5 / 0,8 | All | $d_{cut,m}$ | 5 [11] | - | All | C.3.4.2<br>C.4.2.1<br>C.4.2.4 |
| C2.4 | Functioning under alternating shear load | C20/25 | 0,8 [9] | All | $d_{cut,m}$ | 5 [11] | - | All | C.3.4.3<br>C.4.2.1<br>C.4.2.5 |
| C2.5 | Functioning with tension load under varying crack width [13] | C20/25 | $\Delta_{w1}$=0,0<br>$\Delta_{w2}$=0,8 | All | $d_{cut,m}$ | 5 [11] | - | All | C.3.4.4<br>C.4.2.1<br>C.4.2.6 |

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 a < 150 mm.

3) If fewer than three sizes of the fastener are tested together and/or the different sizes are not similar in respect of geometry, friction between cone and sleeve (internal friction) and friction between sleeve and concrete (external friction), then the number of tests shall be increased to 10 for all sizes of the fastener.

4) Test conditions are detailed in section 2.2.4.1.

5) For fasteners that are not similar in respect of geometry and/or friction aspects all sizes have to be tested.

6) Test conditions are detailed in section 2.2.2.9.

7) Tests may be omitted, see section 2.2.8.

8) Tests may be omitted, see section 2.2.7.2.

9) Crack width added to the hairline crack width after fastener installation but before loading of fastener.

10) Test all fastener diameters to be assessed for use in seismic applications. For different fastener types to be tested see C.3.2.

11) Test all fastener diameters for which the fastener is to be assessed for use in seismic applications. For fasteners with different steel types, steel grades, production methods, head configurations (mechanical fasteners), types of inserts, multiple embedment depths and drilling methods see C.3.2.

12) 0,5 ($\leq 0,5 \cdot N/N_{max}$); 0,8 ($> 0,5 \cdot N/N_{max}$)The tests may also be conducted in $\Delta w$ = 0,8 mm at all load levels ($N/N_{max}$).

13) $\Delta w_1$ = 0,0 mm is defined in C.3.4.5.

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 Annex B 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 Annex B. 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 [10].

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** | $N_{u,c} = N_{u,t} \cdot \left(\frac{f_c}{f_{c,t}}\right)^{0,5}$ with $\frac{f_c}{f_{c,t}} \le 1,0$ | (A.1) |
| **Pull-out failure** | $N_{u,p} = N_{u,t} \cdot \left(\frac{f_c}{f_{c,t}}\right)^{m}$ with $\frac{f_c}{f_{c,t}} \le 1,0$ | (A.2) |
| | $m_{ucr} = \frac{\log\left(\frac{N_{u,m,A2}}{N_{u,m,A1}}\right)}{\log\left(\frac{f_{c,t,A2}}{f_{c,t,A1}}\right)} \le 0,50$ | (A.3) |
| | $m_{cr} = \frac{\log\left(\frac{N_{u,m,A4}}{N_{u,m,A3}}\right)}{\log\left(\frac{f_{c,t,A4}}{f_{c,t,A3}}\right)} \le 0,50$ | (A.4) |
| | $\psi_{c,xx} = \left(\frac{f_{ck,xx}}{f_{ck,20}}\right)^{m}$ 1) | (A.5) |
| **Steel failure** | $N_{u,s} = N_{u,t} \frac{f_{uk}}{f_{u,t}}$ (for tension tests)<br>$V_{u,s} = V_{u,t} \frac{f_{uk}}{f_{u,t}}$ (for shear tests) | (A.6) |

1) If no distinction is made for cracked and uncracked conditions, the factor m shall be determined as the minimum of Equations (A3) and (A4).

### 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:

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

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:

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

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, $\beta_{cv}$ = 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.

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

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

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

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

*Note 10: The confidence level of 90% is defined for characteristic resistance of fasteners in EN 1992-4 and is therefore used for the assessment in this EAD.*

### A2.4 Determination of reduction factors $\alpha$

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:

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

If the number of tests in both series is n ≥ 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 $\alpha$ 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 $\alpha$ is used to determine the factor $\gamma_{inst}$.

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 $\alpha_1$ 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

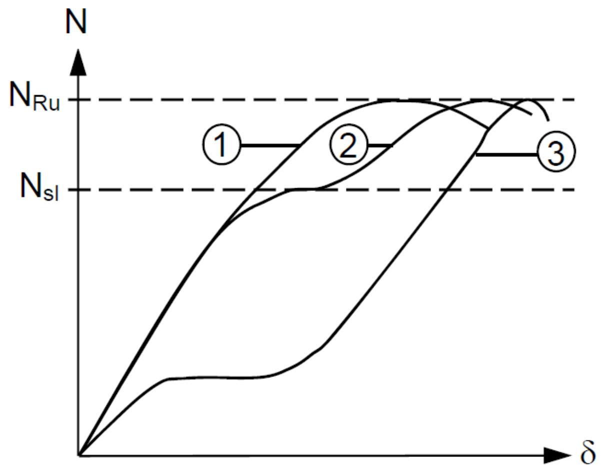
$N_{Ru,t}$ = ultimate load in the test

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 $\alpha_1$ / rqd. $\alpha_1$, 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) and (2.9).




1 acceptable function
2 acceptable function
3 non-acceptable function

**Figure A.1 Examples for load/displacement curves**

Uncontrolled slip is defined for the different types of fasteners as follows:

<u>Torque-controlled fasteners (TC)</u>

Uncontrolled slip of the fastener occurs if the expansion sleeve is moving in the drilled hole. This can be recognized by a reduction in load and/or a horizontal or nearly horizontal part in the load/displacement curve (compare Figure A.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.

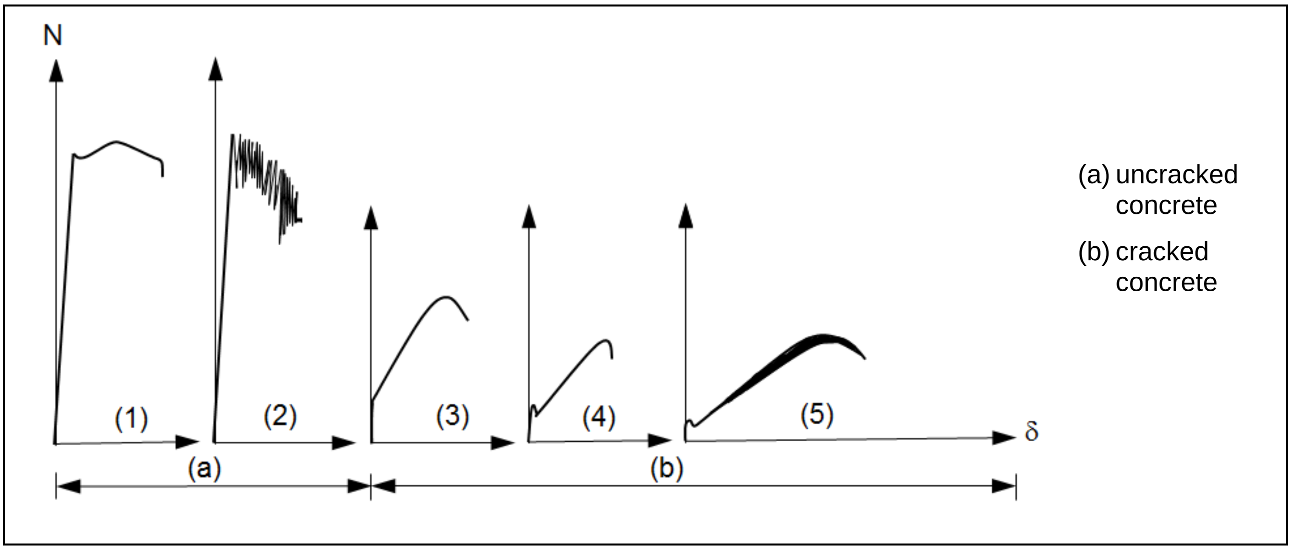



**Figure A.2 Typical load/displacement behaviour**

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.

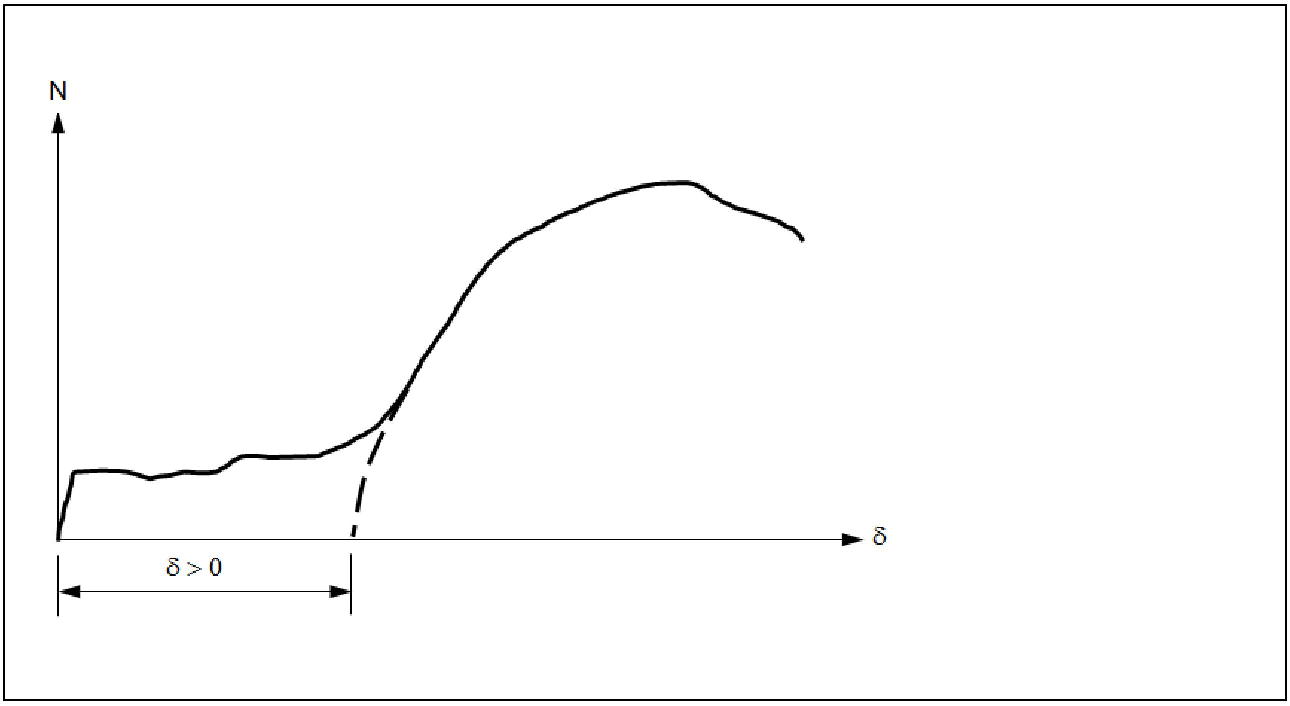



**Figure A.3 Load/displacement behaviour with uncontrolled slip**

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).

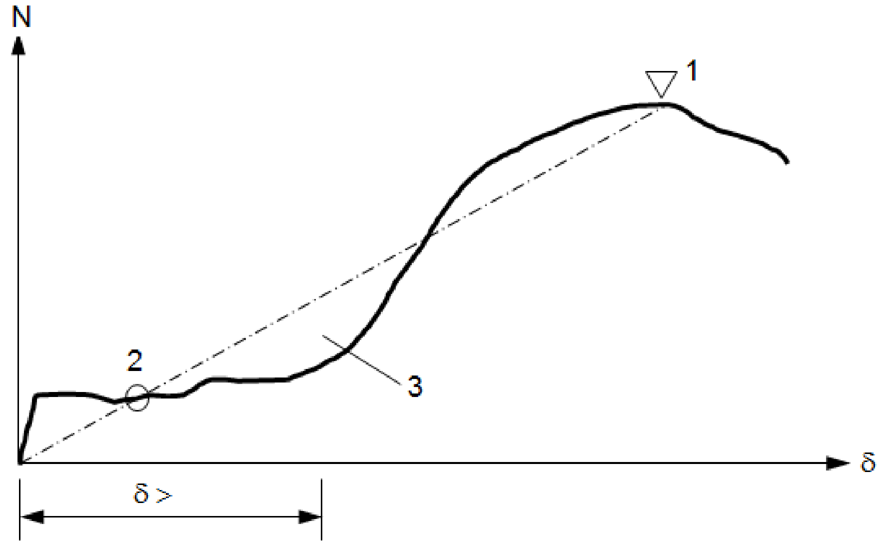



**Figure A.4 Load/displacement behaviour with uncontrolled slip**

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 displacements 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.

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

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

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 the mean value of displacements at a load of 0,5 $N_{u,m}$ are smaller than or equal to 0,4 mm.

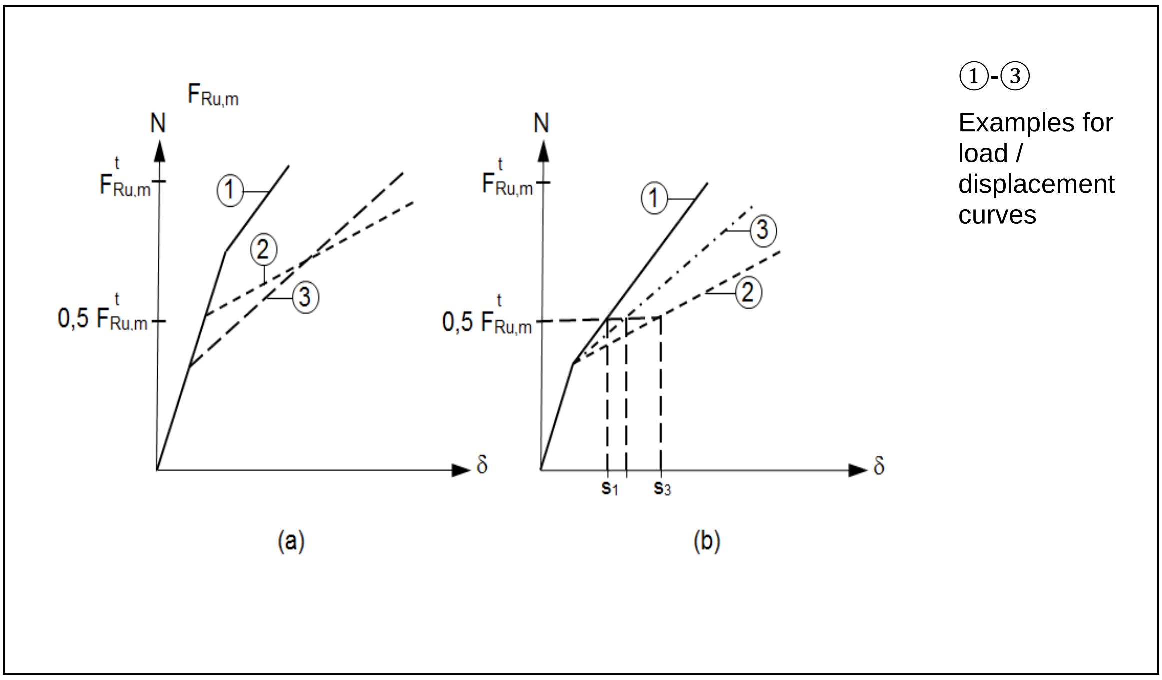



**Figure A.5 Influence of pre-stressing on load/displacement curves**

(a) original curves

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

# ANNEX B - DETAILS OF TESTS FOR MECHANICAL FASTENERS IN CONCRETE

## B.1 Scope

This Annex provides details for the tests with post-installed fasteners in concrete.

## B.2 Notation

| | | |
|---|---|---|
| $a$ | = | Length of square base plate according to Table B.2 |
| $a'$ | = | Length of attachment according to Figure B.15 |
| $c$ | = | Edge distance according to Figure B.8 |
| $f_{c,cube100}$ | = | concrete compressive strength measured on cubes with a side length of 100 mm |
| $f_{c,cube200}$ | = | concrete compressive strength measured on cubes with a side length of 200 mm |
| $N_p$ | = | Tensile load applied during the test |
| $N_{Rk,s,fi}$ | = | Characteristic resistance to steel failure under fire exposure |
| $N_s$ | = | Force applied to the test member to control the crack width according to B.3.3.3 |
| $R_{p02}$ | = | 0,2% yield limit according to EN ISO 898-1 |
| $t$ | = | Profile thickness according to Table B.2 |
| $t_u$ | = | Thickness of the cover according to Figure B.15 |
| $z$ | = | Distance between flanges according to Table B.2 |
| $\Delta w_1$ | = | Upper limit of crack width according to Figure B.10 |
| $\Delta w_2$ | = | Lower limit of crack width according to Figure B.10 |
| $\mu$ | = | Ratio of reinforcement |
| $\phi$ | = | Nominal diameter of a deformed reinforcing bar |

## B.3 Details of Tests

### B.3.1 Test samples, test members, test setup, installation and test equipment

#### B.3.1.1 Test samples

Fasteners with inner threads may be supplied without the fixing elements such as screws or nuts, but the manufacturer of the fastener shall specify the screws or nuts to be used. If according to the chosen design method the characteristic resistance for concrete failure is needed, it may be necessary to use screws or bolts of higher strength than those specified, in order to achieve a concrete failure in tests. If higher strength screws or bolts are used, the functioning of the fasteners must not be influenced in any way. The use of such test specimens shall be clearly stated in the test report.

#### B.3.1.2 Test members

##### B.3.1.2.1 General

This Annex is valid for fasteners tested in concrete members using compacted normal weight concrete without fibres with strength classes in the range of C20/25 - C50/60 in accordance with EN 206:2013 + A1:2016. The fastener performance is only valid for the range of tested concrete.

The test members shall comply with the following:

##### B.3.1.2.2 Aggregates

Aggregates shall be of natural occurrence (i.e. non-artificial) and with a grading curve falling within the boundaries given in Figure B.1. The maximum aggregate size shall be 16 mm or 20 mm. The aggregate density shall be between 2.0 and 3.0 t/m$^3$ (see EN 206 ).

The boundaries reported in Figure B.1 are valid for aggregate with a maximum size of 16 mm. For different values of maximum aggregate sizes, different boundaries may be adopted, if previously agreed with the responsible TAB.

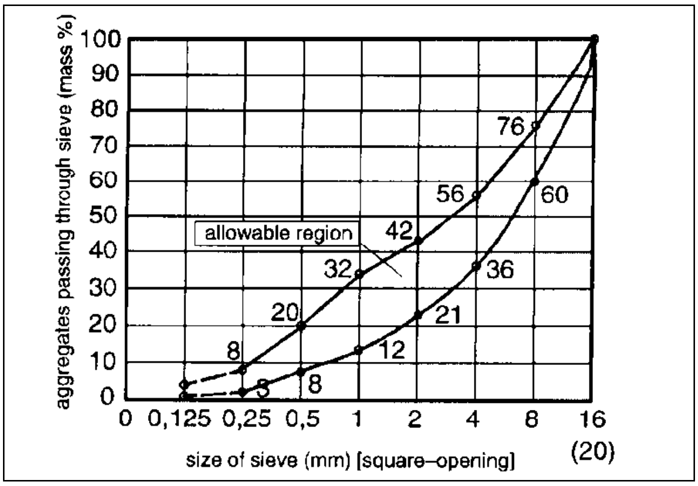



**Figure B.1 Admissible region for the grading curve**

**B.3.1.2.3 Cement**

The concrete shall be produced using Portland cement Type CEM I or Portland-Composite cement Type CEM II/A-LL, CEM II/B-LL (see EN 197-1:2014)

**B.3.1.2.4 Water/cement ratio and cement content**

The water/cement ratio shall not exceed 0,75 and the cement content shall be at least 240 kg/m$^3$.

No additives likely to change the concrete properties (e.g., fly ash, or silica fume or other powders) shall be included in the mixture.

**B.3.1.2.5 Concrete strength**

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

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

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

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

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

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

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

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

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

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

*Note B.1 Additional literature for conversion is given by R. Lewandowski, Beurteilung von Bauwerksfestigkeiten an Hand von Betongütewürfeln und –bohrproben, Schriftenreihe der Institute für Konstruktiven Ingenieurbau der Technischen Universität Braunschweig, Heft 3, Werner Verlag, Düsseldorf, 1971*

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

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

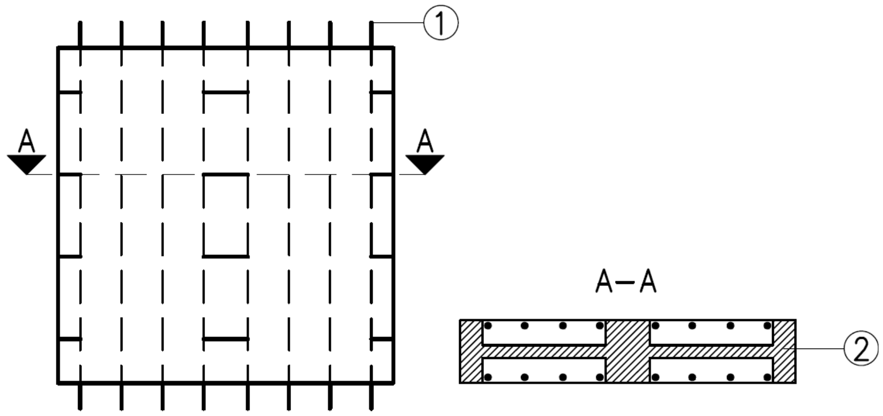
The concrete strength at a certain age shall be measured on at least 3 specimens. The mean value of the measurements governs.

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

**B.3.1.2.6 Test members for tests in cracked concrete**

The tests are carried out on test members with unidirectional cracks. The crack width shall be approximately constant throughout the member thickness. The thickness of the test member shall be $h \geq 2\ h_{ef}$ but at least 100 mm. To control cracking, so-called 'crack-formers' may be built into the member, provided they are not situated near the anchorage zone. An example for a test member is given in Figure B.2.

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




1 reinforcement

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

**B.3.1.2.7 Test members for tests in uncracked concrete**

Generally, the tests are carried out on unreinforced test members. In cases where the test member contains reinforcement to allow handling or for the distribution of loads transmitted by the test equipment, the reinforcement shall be positioned such as to ensure that the loading capacity of the tested fasteners is not affected. This requirement will be met if the reinforcement is located outside the zone of concrete cones having a vertex angle of 120°.

### B.3.1.2.8 Casting and curing of test members

The test members shall be cast horizontally. They may also be cast vertically if the maximum height is 1,5 m and complete compaction is ensured.

Test members and concrete specimens (cylinders, cubes) shall be cured and stored indoors for seven days. Thereafter they may be stored outside provided they are protected such that frost, rain and direct sun does not cause a deterioration of the concrete compression and tension strength. When testing the fasteners, the concrete shall be at least 21 days old.

Test members and concrete specimen shall be stored in the same way.

### B.3.1.3 Unconfined test setup

Unconfined tests allow an unrestricted formation of the rupture concrete cone. An example for an unconfined test setup is shown in Figure B.3.

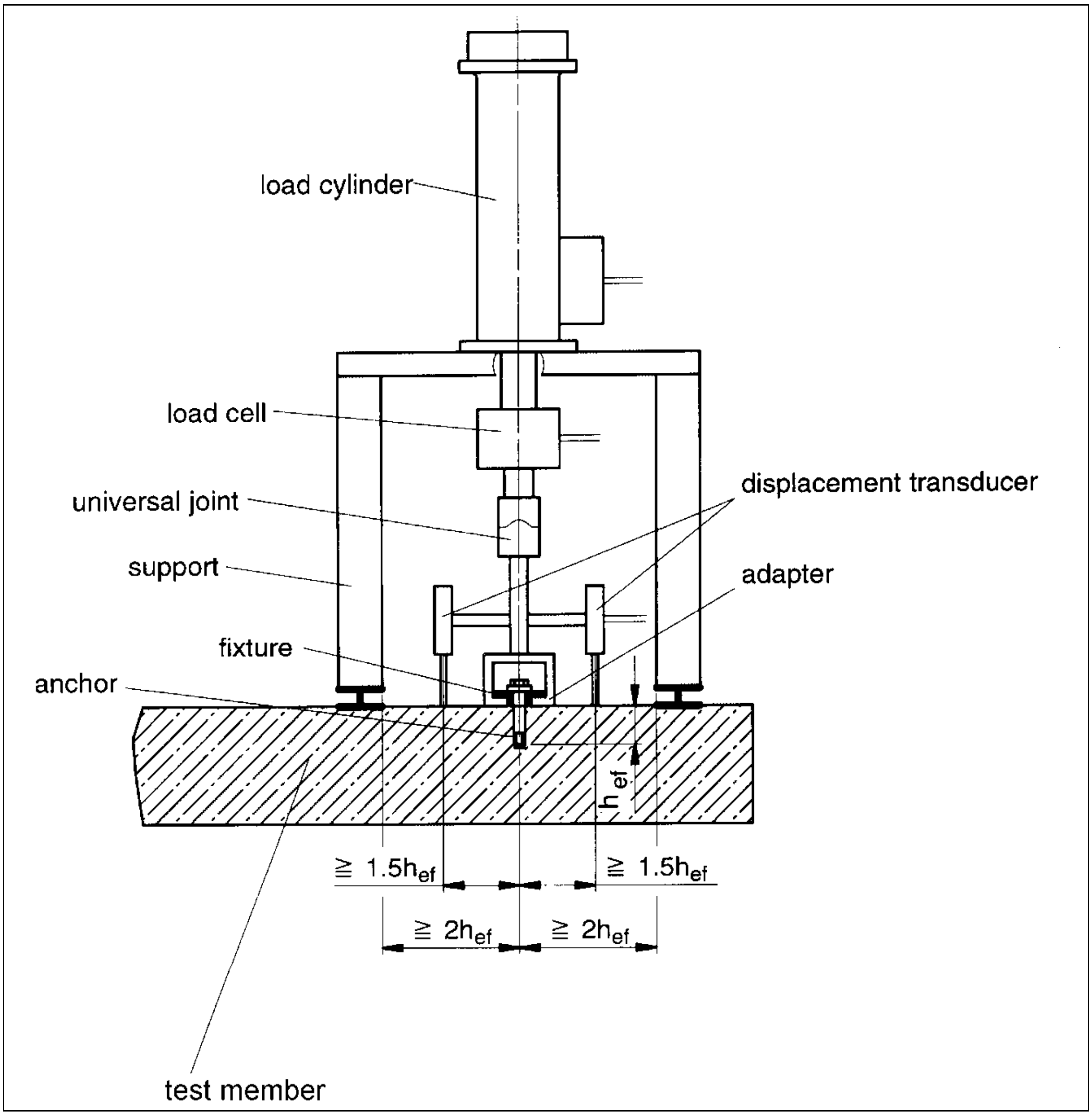



**Figure B.3 Example of a tension test rig for unconfined tests**

### B.3.1.4 Installation of fasteners

The tested fasteners shall be installed in a concrete surface that has been cast against a form of the test member.

The fasteners shall be installed in accordance with the manufacturer's product installation instructions (MPII), except where special conditions are specified in the EAD for the test series.

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

For torque-controlled fasteners, about 10 minutes after torqueing the fasteners with the torque $T_{inst}$ required by the manufacturer, the torque shall be reduced to 0,5 $T_{inst}$ to account for relaxation of the pre-stressing force with time.

Fasteners not needing the application of a defined torque (e.g., deformation-controlled expansion fasteners, many types of undercut fasteners) shall be finger-torqued before testing.

With fasteners which need to be torqued, the test results can be influenced by the roughness of the fixture. Therefore, the washer shall not turn relative to the fixture. To ensure defined test conditions, e.g., double-sided abrasive material may be inserted between washer and fixture (see Figure B.7).

When testing in cracked concrete, fasteners are placed in the middle of hairline cracks. It shall be verified that the fastener is placed over the entire anchoring zone in the crack by suitable methods (e.g., borescope).

The holes for fasteners shall be perpendicular (± 5° deviation) to the surface of the concrete member.

In the tests the drilling tools specified by the manufacturer for the fasteners shall be used. If hard metal hammer-drill bits are required, these bits shall meet the requirements laid down in ISO 5468:2006 with regard to dimensional accuracy, symmetry, symmetry of insert tip, height of tip and tolerance on concentricity.

The diameter of the cutting edges as a function of the nominal drill bit diameter is given in Figure B.4. The EADs specify the required cutting diameter of drill bits ($d_{cut,min}$, $d_{cut,max}$, $d_{cut,m}$) for the test series.

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

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

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

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

For concrete screws the reduction of the torque is not required.

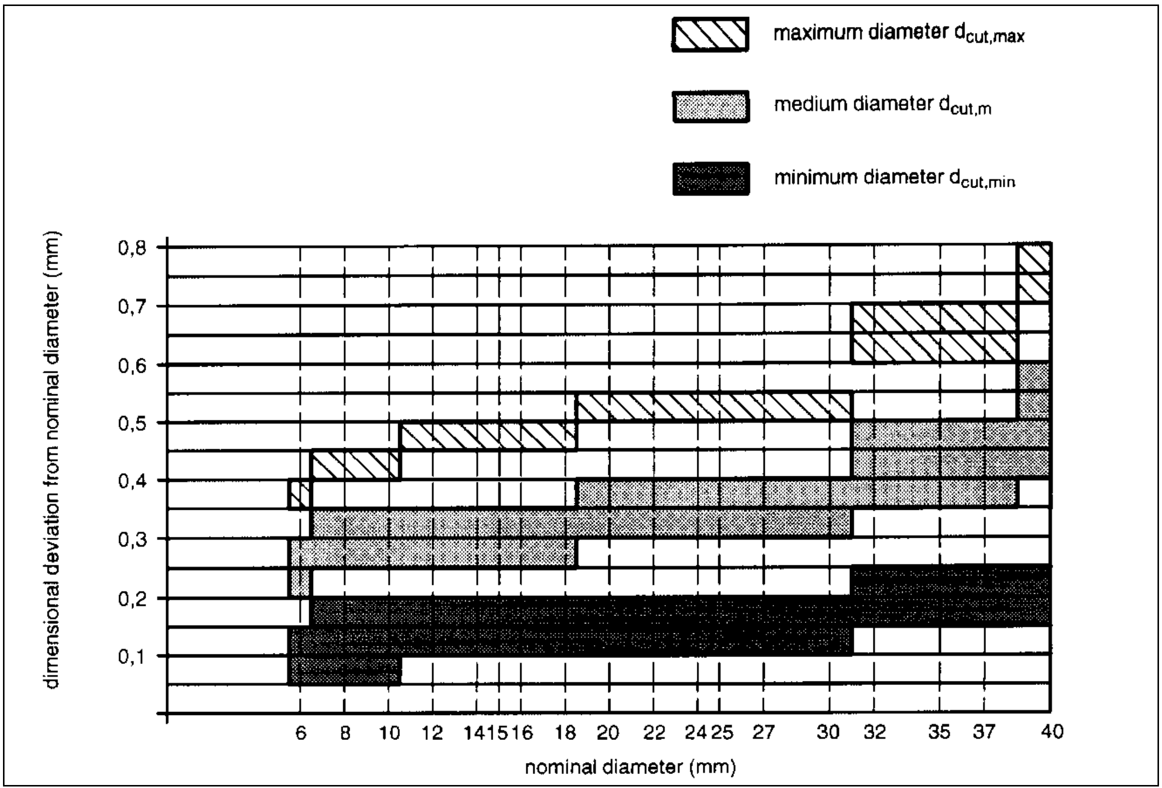



**Figure B.4 Cutting diameter of hard metal hammer-drill bits**

### B.3.1.5 Test equipment

Tests shall be carried out using measuring equipment having a documented calibration according to international standards. The load application equipment shall be designed to avoid sudden increase in load especially at the beginning of the test. The measurement bias of the measuring chain of the load shall not exceed 2% of the measured quantity value.

Displacements shall be recorded continuously (e.g., by means of electrical displacement transducers) with a measuring bias not greater than 0,020 mm or 2,0 % for displacements > 1 mm.

For unconfined tests the test raigs shall allow the formation of an unrestricted rupture cone. For this reason, the distance between the support reaction and a fastener (single fastener) or an outer fastener (fastener group) respectively shall be at least 2 $h_{ef}$ (tension test) as shown in Figure B.3 or 2 $c_1$ (shear test at the edge with load applied towards the edge, with $c_1$ = edge distance in load direction) as shown in Figure B.6. Only in shear tests without edge influence where steel failure is expected this distance may be less than 2 $c_1$.

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

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

During tension tests the load shall be applied concentrically to the fastener. To achieve this, hinges shall be incorporated between the loading device and the fastener. Requirements for the diameter of the clearance hole of the fixture may be given in the EADs. An example of a tension test rig is illustrated in Figure B.3.

In shear tests (see B.3.6), the load shall be applied parallel to the concrete surface. A plate with interchangeable sleeves may be used for testing the different sizes of fasteners (see Figure B.5). The sleeves shall be made of quenched steel and have radiused edges (0,4 mm) where in contact with the fastener. The height of the sleeves shall be approximately equal to the outside diameter of the fastener. To reduce friction, smooth sheets (e.g., PTFE) with a maximum thickness of 2 mm shall be placed between the plate with sleeve and the test member.

An example of a shear test rig is illustrated in Figure B.6. As there is a lever arm between the applied load and the support reaction, the test member is stressed by torsion. This shall be taken up by additional reaction forces placed sufficiently far away from the fastener.

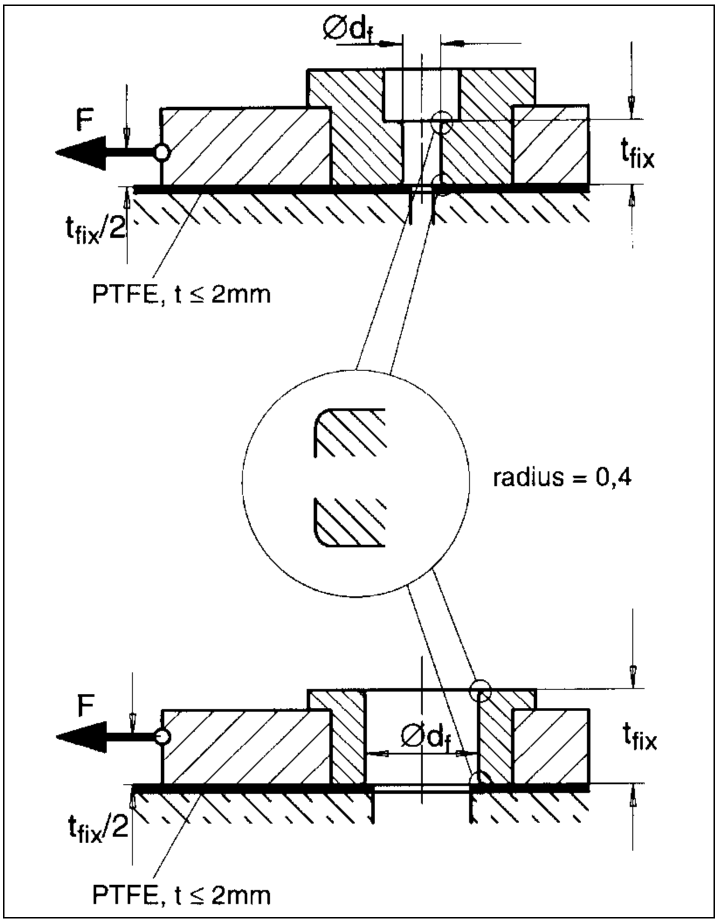
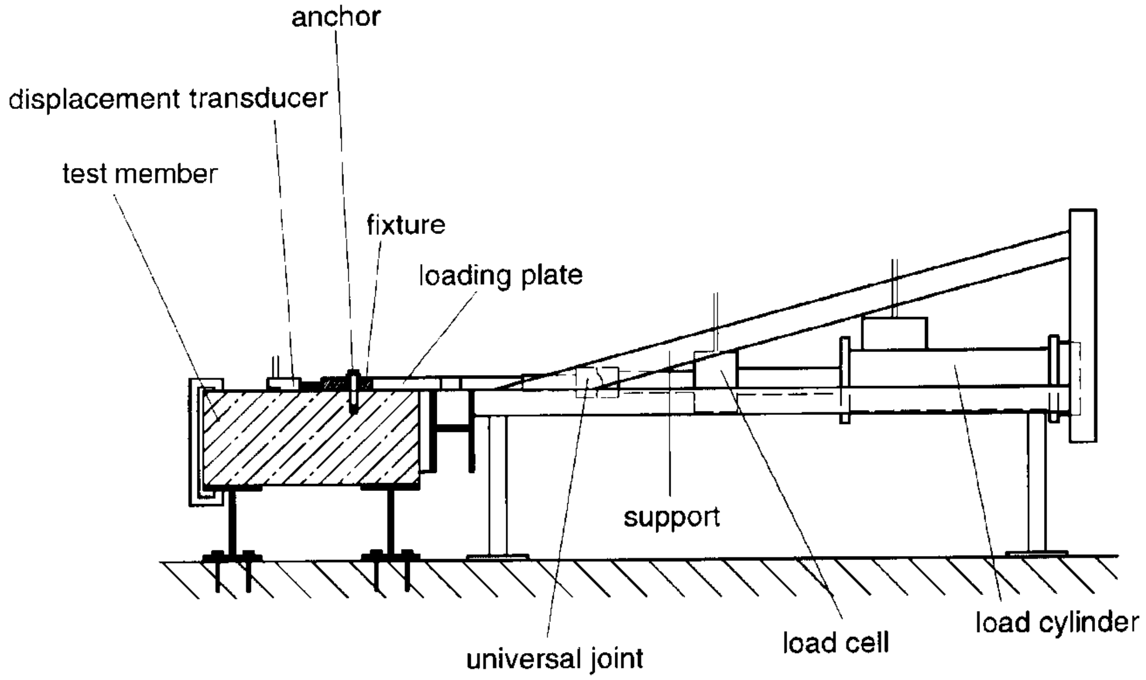



**Figure B.5 Examples of shear test sleeves**

**Side view:**




**Top view:**

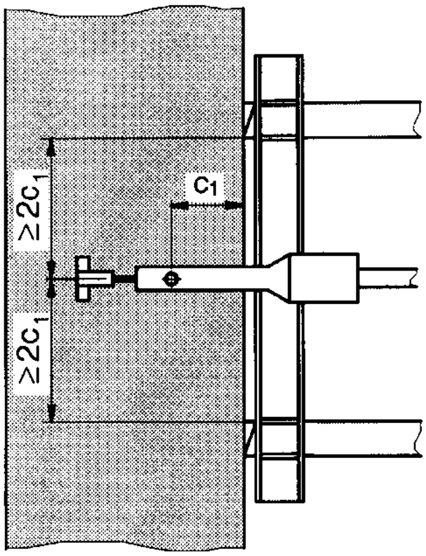



**Figure B.6 Example of a shear test rig**

In torque tests (see B.3.5) the relation between the applied torque and the tension force in the bolt is measured. For this, a calibrated load cell with a measuring error ≤ 3,0 % throughout the whole measuring range is used as a fixture (see Figure B.7).

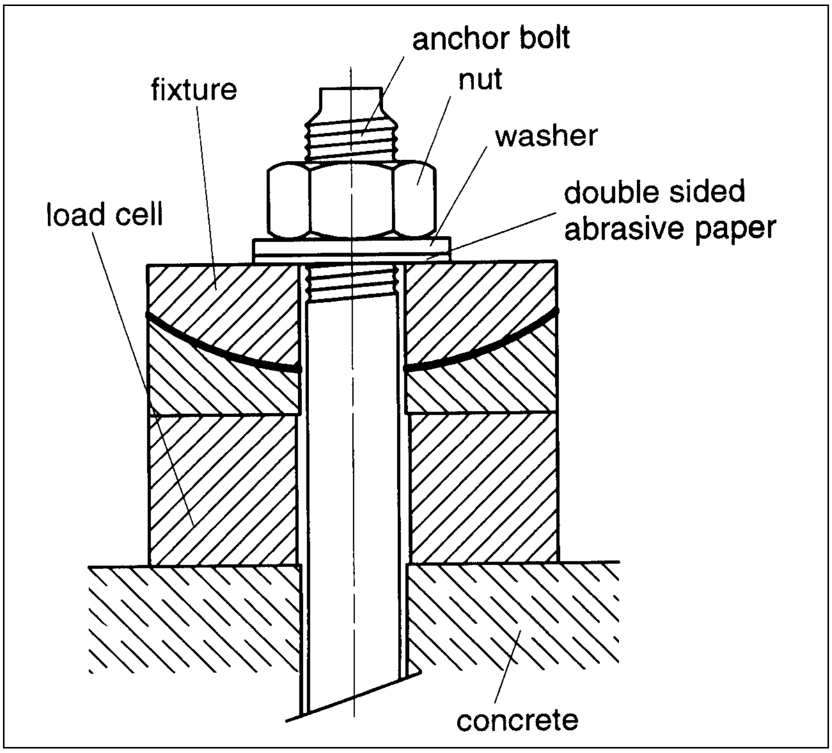



**Figure B.7 Example for torque test (schematic)**

Any rotation of the spherical part of the fixture shall be prevented.

### B.3.2 Test procedure – general aspects

The fasteners shall be installed in accordance with the MPII, except where special conditions are specified in the EAD for the test series.

The tests in cracked concrete are undertaken in unidirectional cracks. The required crack width $\Delta w$ is given in the relevant EAD. $\Delta w$ is the difference between the crack width when loading the fastener and the crack width at fastener installation. After installation of the fastener the crack is widened to the required crack width while the fastener is unloaded. The initial crack width shall be set to within +10 % of the specified value. However, the mean value of a series shall reflect the specified value.

Use one-sided tolerance for crack width.

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

- at a constant width, for example, by means of a servo system, or
- limited to a width close to the initial value by means of the reinforcement and depth of the test member.

In both cases the crack width at the face opposite to that through which the fastener is installed be maintained at a value larger than or equal to the specified value.

The load shall be increased in such a way that the peak load occurs after 1 to 3 minutes from commencement. Load and displacement shall be recorded continuously. The tests may be carried out with load, displacement or hydraulic control. In case of displacement-control the test shall be continued beyond the peak of the load/displacement curve to at least 75 % of the maximum load to be measured (to allow the drop of the load/displacement curve). In case of a displacement-controlled test setup the speed shall be kept constant.

The data shall be collected with a frequency of 3 Hz – 5 Hz.

### B.3.3 Tension tests

#### B.3.3.1 Single fastener under tension load

After installation, the fastener is connected to the test rig and loaded to failure. The displacements of the fastener relative to the concrete surface shall be measured by use of either one displacement transducer on the head of the fastener or by use of at least two displacement transducers on either side at a distance of ≥ 1,5 $h_{ef}$ from the fastener; the mean value of the transducer readings shall be recorded in the latter case.

When testing fasteners at the corner of an uncracked test member, the test rig shall be placed such that an unrestricted concrete failure towards the corner is possible (see Figure B.8). It may be necessary to support the test rig outside the test member.

When testing in cracked concrete, the crack width shall be regularly measure during the test on both sides of the fastener at a distance of approximately 1,0 $h_{ef}$ and at least on the face of the test member in which the fasteners are installed.

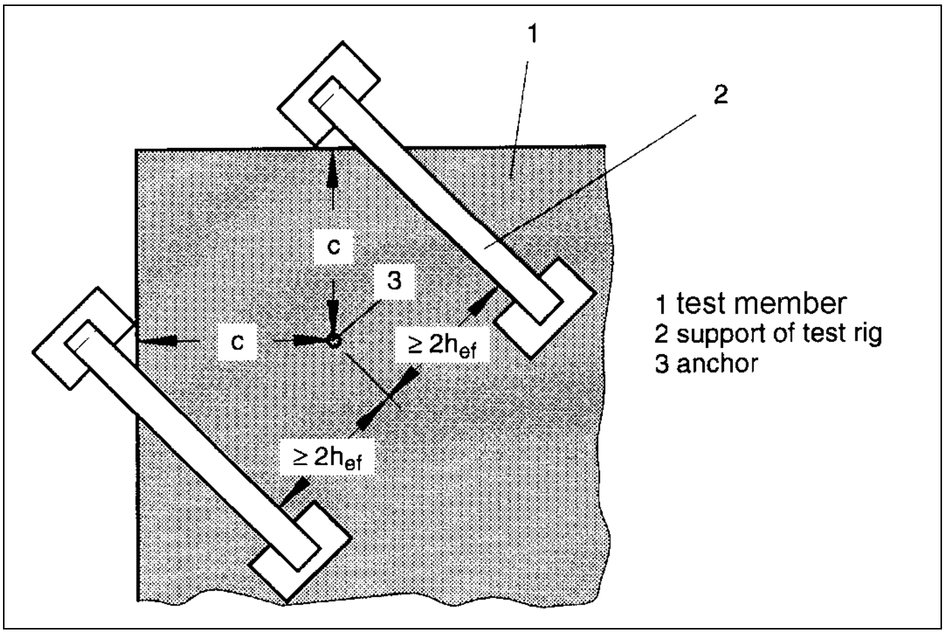



**Figure B.8 Example of the test rig for tension tests on fasteners at a corner**

#### B.3.3.2 Robustness to contact with reinforcement

For tests with robustness to contact with reinforcement the specimen shall be reinforced with smooth bars (bar diameter $\phi$ = 25 mm, spacing a > 150 mm). The concrete cover shall correspond to the value $h_{ef} - \phi / 2$ (so that the effective embedment depth is at the same depth as the axis of the bar).

When drilling the cylindrical hole, the drilling tool shall be mounted in a drilling stand and positioned such that the reinforcing bar is clearly cut. On the average the depth of the notch cut shall be 1 mm. Apart from the contact with reinforcement the fastener shall be installed according to the MPII. Then a tension test shall be performed.

A fastener after installation in contact with reinforcement is shown in Figure B.9.

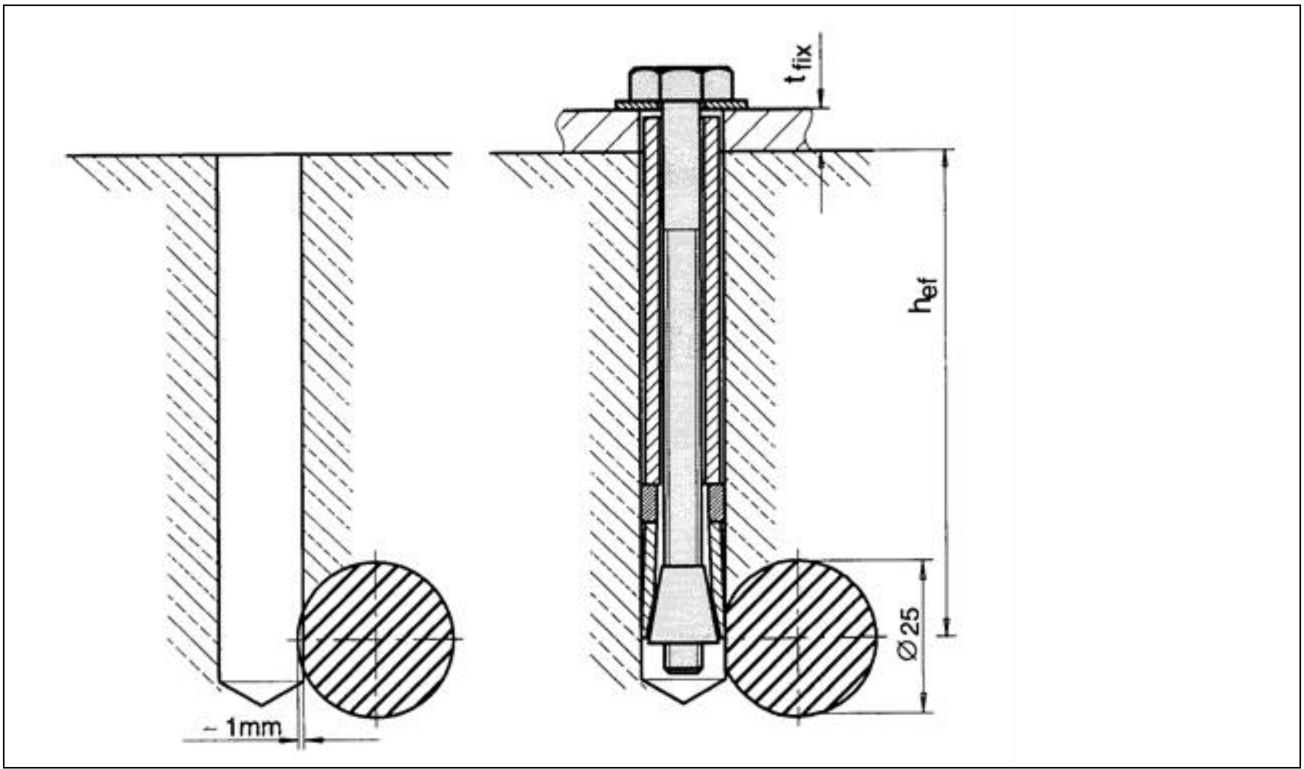



**Figure B.9 Position of fastener when tested in contact with reinforcement**

### B.3.3.3 Crack cycling under load

After installation of the fastener the maximum (max $N_s$) and minimum (min $N_s$) loads applied to the test member shall be determined such that the crack width under max $N_s$ is $\Delta w_1$ = 0,3 mm and under min $N_s$ is $\Delta w_2$ = 0,1 mm. To stabilize crack formation, up to 10 load changes varying between max $N_s$ and min $N_s$ may be applied. Then a tensile load $N_p$ as specified in the relevant EAD is applied to the fastener after opening the crack to $\Delta w_1$ = 0,3 mm.

$N_p$ shall remain constant during the test (variation ± 5%). Then the crack is opened and closed 1000 times (frequency approximately 0,2 Hz). During opening of the cracks, the crack width $\Delta w_1$ is kept approximately constant (see Figure B.10); for this purpose, the load max $N_s$ applied to the test member may have to be reduced. The load min $N_s$ is kept constant. Therefore, the crack width $\Delta w_2$ may increase during the test (see Figure B.10). The crack width difference $\Delta w_1$ - $\Delta w_2$, however, shall be ≥ 0,1 mm during the 1000 movements of the crack. If this condition cannot be fulfilled with $\Delta w_1$ = 0,3 mm, then either min $N_s$ shall be reduced or $\Delta w_1$ shall be increased accordingly.

The load/displacement behaviour shall be measured up to the load $N_p$. Afterwards under $N_p$, the displacements of the anchor and the crack widths $\Delta w_1$ and $\Delta w_2$ shall be measured either continuously or at least after 1, 2, 5, 10, 20, 50, 100, 200, 500, 750 and 1000 crack movements.

After completion of the crack movements the anchor shall be unloaded, the displacement measured and a tension test to failure performed with $\Delta w$ = 0,3 mm.

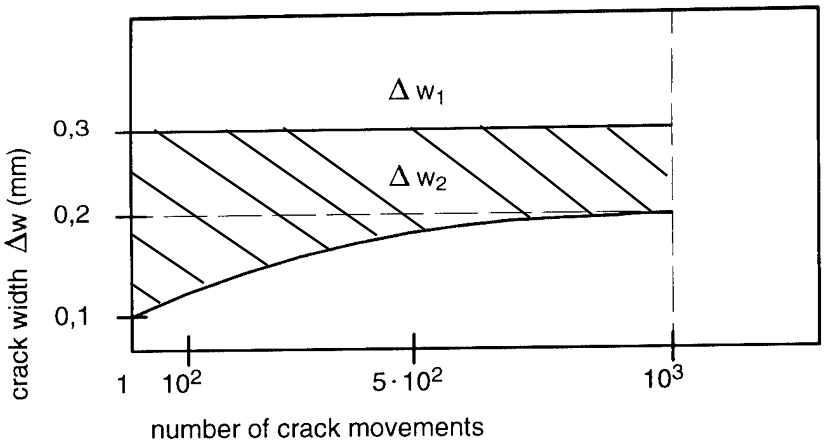



**Figure B.10 Allowable crack opening variations during the crack movement test**

### B.3.3.4 Repeated loads

The test is performed in uncracked concrete. The fastener is subjected to $10^5$ load cycles with a maximum frequency of approximately 6 Hz. During each cycle the load shall change as a sine curve between maximum and minimum value, i.e. max N and min N, respectively, given in the relevant EAD. The displacements shall be measured during the first loading up to max N and then either continuously or at least after 1, 10, $10^2$, $10^3$, $10^4$ and $10^5$ load cycles.

After completion of the load cycles the fastener shall be unloaded, the displacement measured and a tension test to failure performed.

<u>Concrete screws:</u>

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

The concrete screw shall be set on bevelled washers (inclination angle ≥ 4°) and shall be installed according to the MPII. The corner of the hexagon nut shall rest on the bevelled washer. The position is shown in Figure B.11. When the installation torque $T = T_{inst}$ is applied, the fastener head might just reach the bevelled washer (see Figure B.11 b) or might be fully pressed against the washer (see Figure B.11 c). Any position of the fastener head between the extreme positions shown in Figure B.11 is acceptable.

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

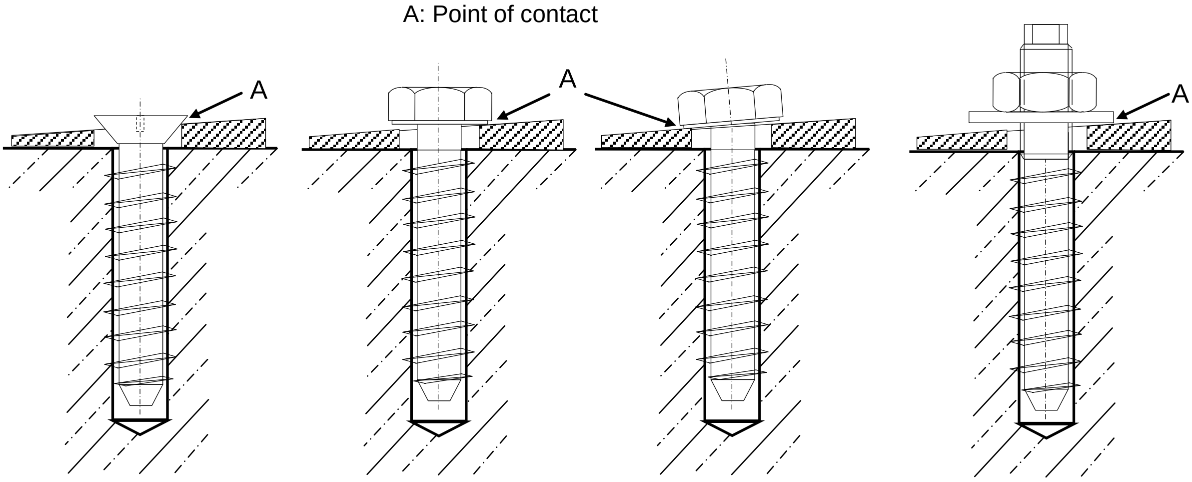



**Figure B.11 Position of the fastener head on bevelled washers in tests with repeated loads**

### B.3.4 Test for minimum edge distance and spacing

If no other specification is given in the relevant EAD, the tests shall be performed in uncracked concrete of strength class C20/25 (minimum concrete strength class).

The tests are carried out with double fasteners with a spacing $s = s_{min}$ and an edge distance $c = c_{min}$. The double fasteners are placed with a distance $a > 3\ h_{ef}$ between neighbouring groups. The dimensions of the fixture shall be width = 3 $d_f$, length = $s_{min}$ + 3 $d_f$ and thickness $\cong d_f$

The fasteners shall be torqued alternately in steps of 0,2 $T_{inst}$. After each load step the concrete surface shall be inspected for cracks. The test is stopped when the torque cannot be increased further.

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

### B.3.5 Maximum torque

The torque is applied with a calibrated torque wrench until it cannot be increased further or at least to 1,3 $T_{inst}$.

The tension force in the bolt or screw shall be measured as a function of the applied torque.

### B.3.6 Tests under shear load

#### B.3.6.1 Single fastener

After installation, the fastener is connected to the test rig without gap between the fastener and the interchangeable sleeve in the loading plate and is then loaded to failure. The displacements of the fastener relative to the concrete shall be measured in the direction of the load application, e.g., by use of a displacement transducer fixed behind the fastener (seen from the direction of load application) on the concrete (see Figure B.6).

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

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

### B.3.6.2 Quadruple fastener group

After installation, the 4 fasteners shall be connected by a rigid fixture with the dimension given in Figure B.12.

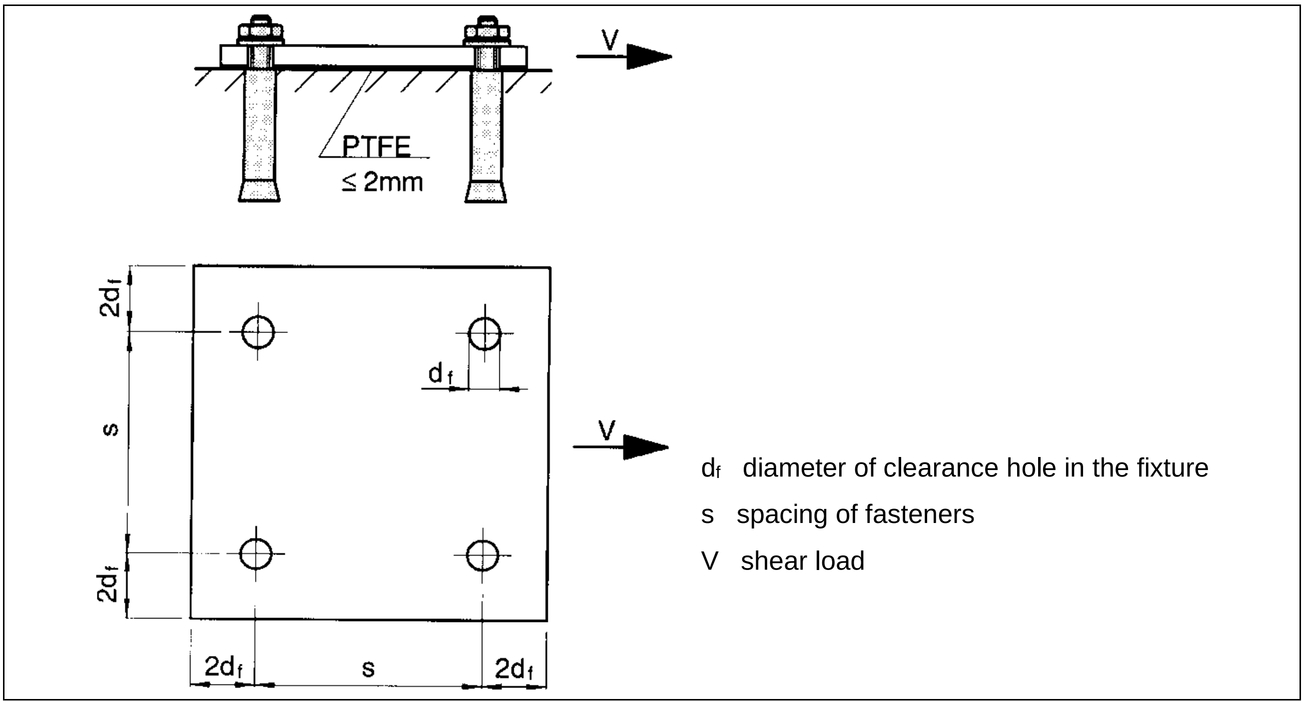



**Figure B.12 Dimensions of fixture**

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

The load on the fastener group and the shear mean displacement of the fixture relative to the concrete outside the rupture cone shall be measured.

### B.3.7 Degree of expansion for deformation-controlled expansion fasteners

In order to achieve reproducible results for deformation-controlled expansion fasteners, defined conditions for the expansion shall be defined.

The fastener behaviour can be sensitive to the effectiveness of expansion. The effectiveness of fastener expansion depends on:

- energy of blows either by hand or machine, including setting tool
- material, geometry, tolerances, etc. of the fastener and the setting tool
- diameter of the drilled hole
- concrete strength class

The influence of these parameters on the fastener behaviour is covered by tests with reference expansion.

**Test conditions**

The tests shall be performed with single fasteners, without edge and spacing effects.

The tests are performed with at least 5 fasteners of every size in concrete with a strength class of C50/60, using a drill bit with a diameter of the cutting edge $d_{cut,m}$ in the cast side of an uncracked concrete member. Prior to expansion the fasteners are installed according to the manufacturer's written installation specification MPII.

The expansion of the fasteners is achieved by an impact device. The principle test setup is shown in Figure B.13. The impact device is kept perpendicular to the fastener and the setting tool. The drop mass of the impact device generates the expansion by impacting on the setting tool. Impact device, setting tool and fastener shall be in line to prevent energy losses due to additional friction, e.g., by shortening of the setting device outside the concrete and/or by use of a special device to keep the setting tool in line with the fastener axis.

Before the first blow and at least after the number of blows according to Table B.1, lines 5 and 6, the fastener expansion shall be measured.

This shall be undertaken by measuring the distance between the outer end of the sleeve and the surface of the cone / nail for cone down type fasteners (drop-in fastener), shank-down type fastener (stud fastener) and sleeve-down type fasteners. For the stud version of sleeve-down type fasteners this can be done by measuring the displacement of the stud in relation to the concrete surface or by measuring the distance of the marking on the fastener to the concrete surface.

Three different expansion conditions a), b) and c) are distinguished:

a) Full expansion:

Expansion achieved when setting the fastener according to the manufacturer's written installation instructions.

b) Reference expansion:

Expansion achieved by applying specified expansion energy (see Table B.1, line 5). The reference expansion is defined as the mean expansion achieved in tests with the number of applied blows in accordance with Table B.1, line 5.

c) Installation expansion:

Expansion achieved by applying a specified expansion energy which is reduced in relation to reference expansion. The installation expansion is defined as the mean expansion achieved with the number of applied blows in accordance with Table B.1, line 6.

If the reference expansion and/or installation expansion is less than full expansion, these values have to be used in the relevant test series.

Machine setting:

If a manufacturer recommends in the written installation instructions setting by machine, then it is to be shown that the installation and reference expansion achieved in the machine setting test shall be at least equal to the corresponding expansion in the setting test by impact device according to Figure B.13.

The machine setting tests shall be performed with at least 5 fasteners of every size in concrete of strength class C50/60, using a drill bit with a diameter of the cutting edge $d_{cut,m}$ in the cast side of a uncracked concrete member. The setting shall be undertaken vertically upwards by the setting machine with the smallest energy output of the range of machines defined in the manufacturer's installation specifications. Care shall be taken to hold the machine in line with the fastener axis. Before the first blow and after a maximum of 10 and 15 seconds of setting time the expansion shall be measured.

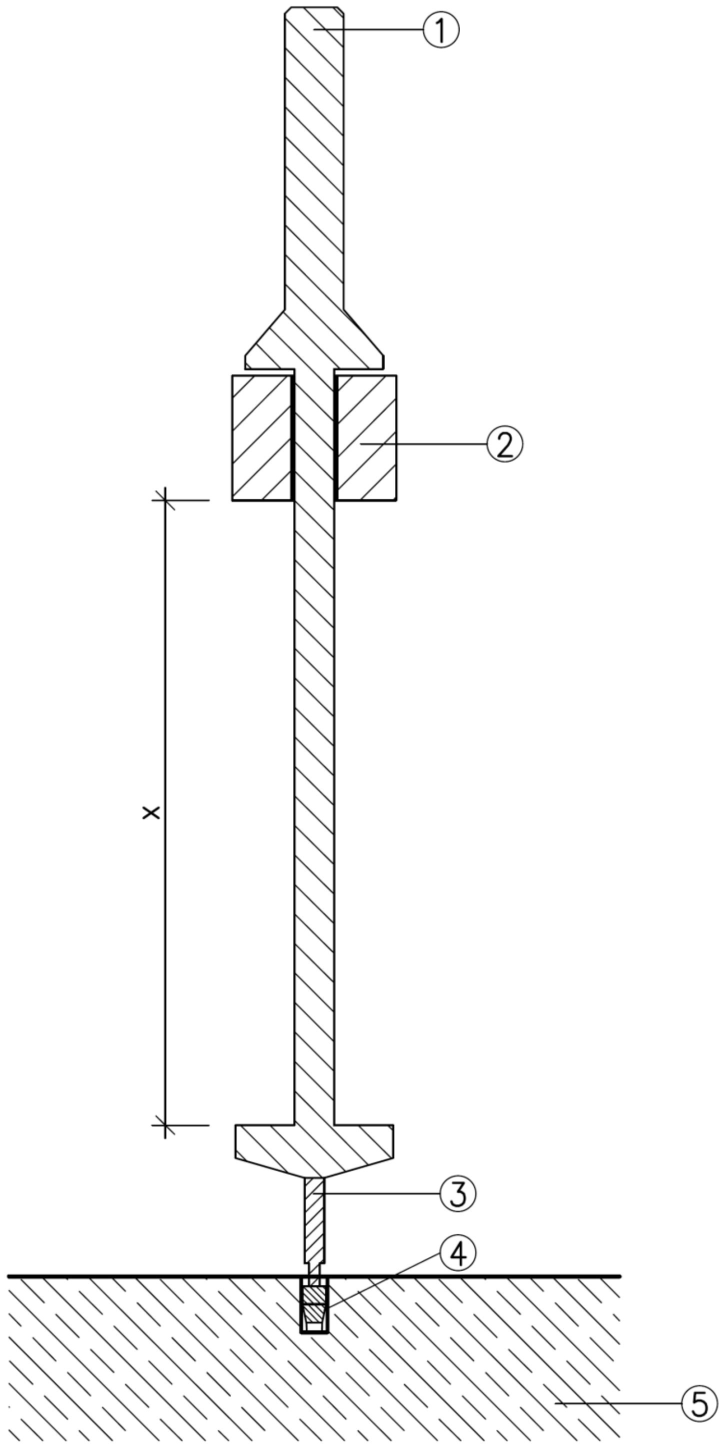
The installation expansion is achieved in the setting test by the impact device. In setting tests, using a machine, this expansion shall be achieved on average after a setting time of at maximum 10 seconds.

The reference expansion is achieved in the setting test by the impact device. In setting tests, using a machine, this expansion shall be achieved on average after a setting time of at maximum 15 seconds.

**Table B.1 Test conditions**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | fastener size | | M6 | M8 | M10 | M12 | M16 | M20 |
| 2 | impact device, type | | B | B | B | B | C | C |
| 3 | Mass | [kg] | 4,5 | 4,5 | 4,5 | 4,5 | 15 | 15 |
| 4 | height of fall | [mm] | 450 | 450 | 450 | 450 | 600 | 600 |
| 5 | number of blows [1)] for evaluation of reference expansion. | - | 3 | 5 | 6 | 7 | 4 | 5 |
| 6 | number of blows [1)] for evaluation of installation expansion. | - | 2 | 3 | 4 | 5 | 3 | 4 |

1) The tests are carried out with a standardized device applying a constant energy per blow. In practice, the energy applied during setting of the fastener by a hand hammer depends on the fastener size. Therefore, the number of blows is different for the different fastener sizes.




1 Bubble level

2 Drop weight

x Height of fall

3 Setting tool

**Figure B.13 Arrangement for tests to determine the degree of expansion (schematic) – example of setting a drop-in fastener**

### B.3.8 Fire exposure

#### B.3.8.1 Tests for steel failure under tension load

**Test set-up:**

The tests for the determination of the carrying capacity under steel failure have to be carried out in uncracked concrete using an unloaded slab. The principle test set-up can be seen in Figure B.14.

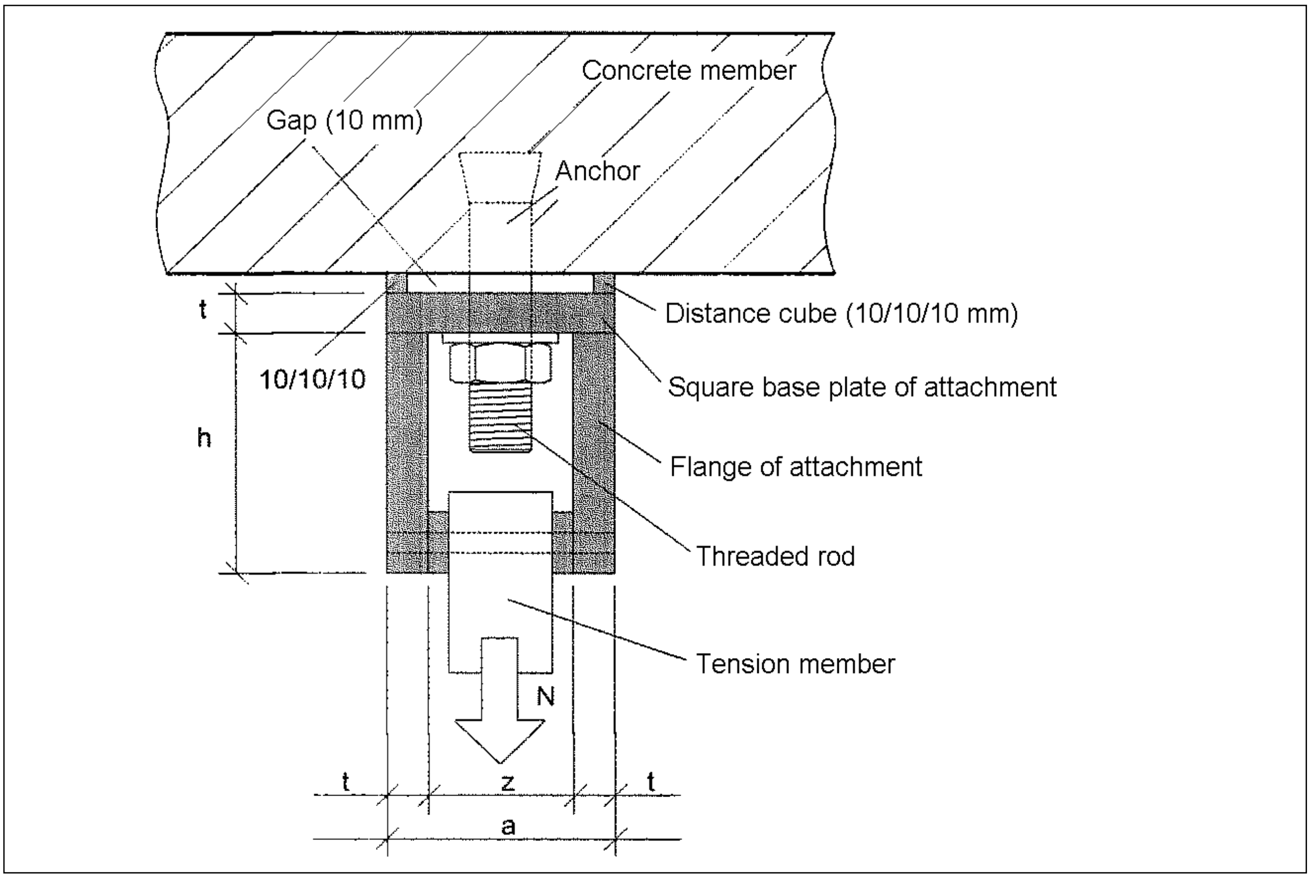



**Figure B.14 Test setup for the determination of the steel failure under fire exposure**

The dimensions of fixture have to be chosen depending on the load categories according to Table B.2. The fixture has to provide a steel stress of 2 – 4 N/mm$^2$ in the relevant parts. Ordinary punched hole tapes can be used for the tests up to a load of 1,0 kN.

For fasteners with sleeve:

Fastening screws of the minimum strength according to the specifications given in the ETA should be used. It is proven by experience that failure of nuts on threaded rods is decisive and should be used for the tests. If commercial standard screws or rods are allowed in the ETA, they should not be delivered by the manufacturer.

**Table B.2 Dimensions of the fixture during the test under fire exposure**

| Type of adapter | Load categories | Length of the square base plate | flange height/ width | profile thickness | distance between the flanges |
|---|---|---|---|---|---|
| | $N_{Rk,s,fi}$ [kN] | a [mm] | h / b [mm] | t [mm] | z [mm] |
| **I** | > 1 - ≤ 3 | 90 | 100 / 90 | 15 | 60 |
| | > 3 - ≤ 5 | 90 | 100 / 90 | 15 | 60 |
| **II** | > 5 - ≤ 7 | 110 | 120 / 110 | 20 | 70 |
| | > 7 - ≤ 9 | 110 | 120 / 110 | 20 | 70 |
| **III** | > 9 - ≤ 11 | 120 | 120 / 120 | 25 | 70 |
| | > 11 - ≤ 13 | 120 | 120 / 120 | 25 | 70 |

**Test procedure:**

The fastener has to be loaded in tension during the test under fire exposure via the fixture which is defined in Table B.2. The fire tests have to be carried out according to EN 1363-1:1999 – tests in electric ovens are permitted.

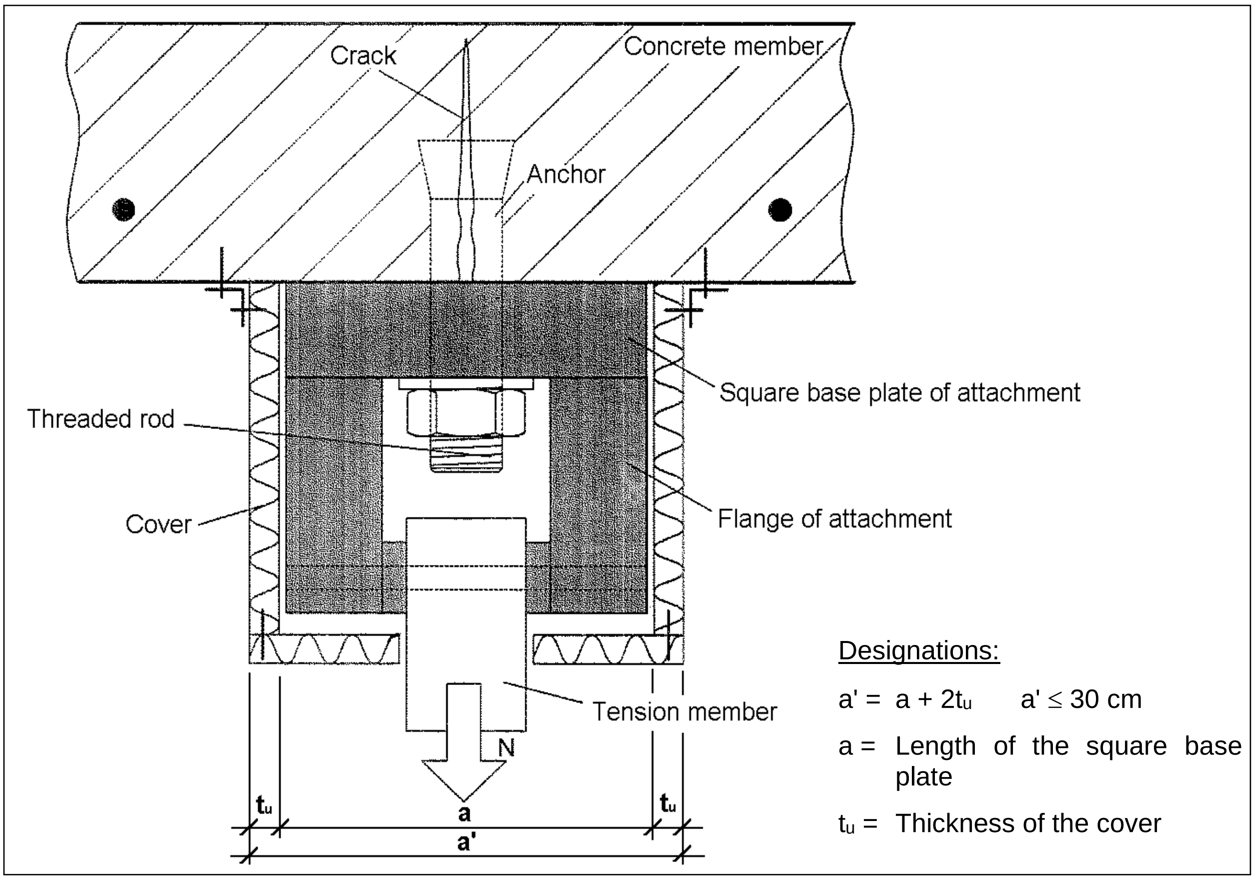
At least 5 tests each using the smallest size $d_1$ and the medium size $d_2$ (≤ M12) of the fastener have to be carried out. The duration of fire resistance must be more than 60 min in at least 4 tests per fastener size.

For each test record the test load and the corresponding duration to failure.

### B.3.8.2 Tests for pull-out failure under tension load

**Test setup:**

The tests have to be carried out in reinforced concrete slabs (C20/25) with a reinforcement of $\phi$ = 12 mm / a = 150 mm and a degree of reinforcement of $A_S$ / (b · d) of approximately 0,4 %. Steel failure shall not occur. Hence the fixation including the fastener must be lagged or protected. The fixation may be more compact than in the tests according to section B.3.8.1. The reinforced concrete slab has to be at least designed for the desired duration of fire resistance. The thickness of the slab shall be ≥ 2 $h_{ef}$ and at least be 250 mm. The test set-up can be seen in principle in Figure B.15.



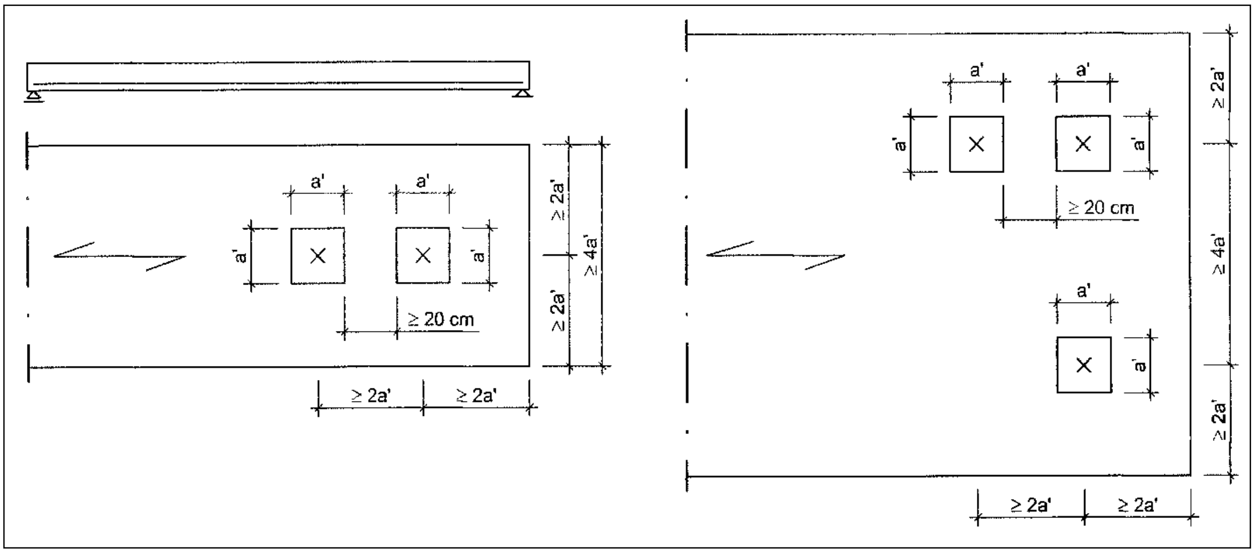




**Figure B.15 Test setup for the determination of the characteristic resistance under fire exposure to pull-out failure**

**Test procedure:**

The reinforced concrete slab must be loaded until cracks appear. The fastener has to be set directly into the crack after the load release. Afterwards the slab has to be loaded again; up to a calculated reinforcement stress of approximately 270 N/mm² ± 20 N/mm² in the area of the fastener. This will lead to crack widths of approximately 0,10 to 0,25 mm. Next the fastener has to be loaded with the designated load for the fire test according to EN 1363-1:1999. The steel stress of the reinforcement has to be held constant during the test.

At least 5 tests using fastener with the smallest size, which have an effective embedment depth $h_{ef}$ of approximately 60 mm to 70 mm, have to be carried out for the determination of the limit value curve. The duration of the fire resistance shall be more than 60 min in at least 4 tests.

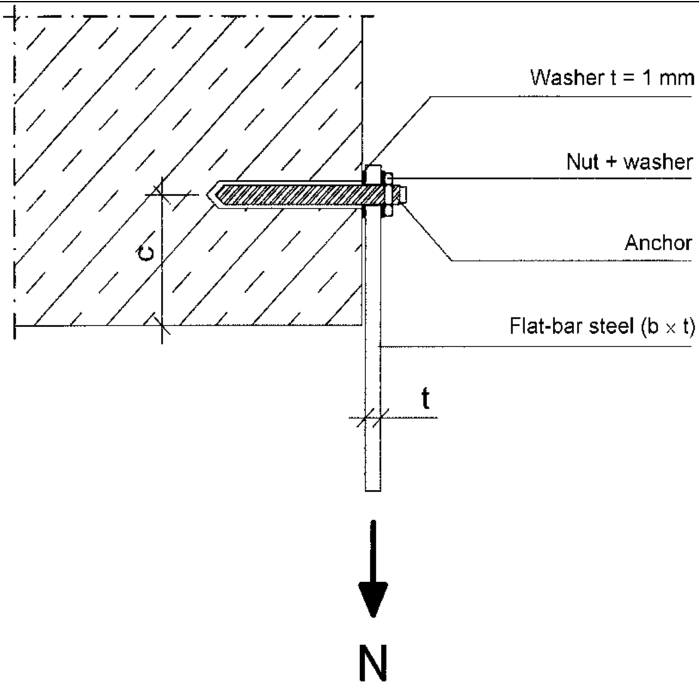
For each test record the test load and the corresponding duration to failure.

### B.3.8.3 Tests for steel failure under shear load

The test procedure shall be done according to section B.3.8.1. The shear load shall be applied via flat-bar steel, which is adequate for a steel stress of 2 to 4 N/mm$^2$.

The test set-up can be seen in principle in Figure B.16.

For each test record the test load and the corresponding duration to failure.




Designations:

c = edge distance

t = thickness of the flat-bar steel

10 mm $\leq t \leq$ 20 mm

b = width of the flat-bar steel

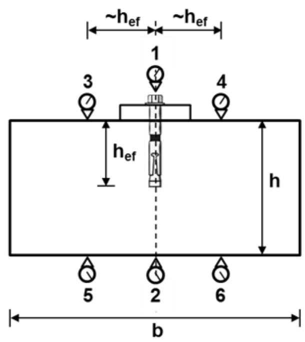
$b = N / (t \times \sigma_{Rk,s,fi})$ with
2 N/mm² $\leq \sigma_{Rk,s,fi} \leq$ 4 N/mm²

**Figure B.16 Test setup for the determination of the characteristic resistance under fire exposure to steel failure due to shear loads**

## B.4 Test Report

Since only relevant parameter shall be followed for each test series this table is meant as a check list. The test report shall include at least the relevant information for the particular test series.

| | | |
|---|---|---|
| **1. Description test specimen** | | |
| Fastener type | | Manufacturer, trade name, dimensions, material |
| status of specimen | | serial product / prototype |
| production lot / batch | | |
| Steel parts | Mechanical properties (tensile strength, yield limit, fracture elongation), type of coating, | e.g., ($f_u$ = 970 N/mm², $R_{p02}$ = 890 N/mm², $A_5$ = 18%, galvanized 5 µm, functional coating) |
| Mortar | Designation, size of package, type of cartridge | xy injection mortar – fast curing version, side by side cartridge xxx ml |
| | Mass of components, density, viscosity, reactivity, infrared analysis | |
| | Type of dispenser and other tools, if any | e.g., Manual dispenser xy, piston plug size xx |
| **2. Test member** | | |
| element type / drawing no. | | sketch according to "examples cross section" and "example for test member with bond breaking pipes" |
| Dimensions | | (l / w / h) |
| concrete mix | | e.g., cement, aggregate type and content, w/c-ratio |
| curing conditions | | |
| age of concrete member at time of testing | | |
| type and grade of reinforcement | | |
| longitudinal reinforcement quantity. | | |
| longitudinal reinforcement size | | |
| pre-debonding length | | |
| type of bond breaker sheets | | e.g., wood/ plastic/ metal/ none |
| reinforcement spacing | | e.g., 254 mm horizontal, 50 mm from edges |
| distribution of reinforcement over depth of member | | e.g., two rows, 100 mm from top and bottom |
| reinforcement is distributed double symmetrically | | |
| **3. Setting/ Installation information** | | |
| ratio member thickness / $h_{nom}$ | | e.g., 2,2 |
| place of fastener installation | | formwork side |
| type/ diameter of support | | unconfined d = 450 mm |
| spacing between rebar and fastener | | 200 mm |
| drilling in hairline crack | | yes / no |
| drill hole prepared separately before each test | | yes / no |
| Drilling method | | |
| Type of drilling machine | | |
| Type and cutting diameter of drill bit | | |
| For stop drills: length of drill bit | | |

| | |
|---|---|
| Tools for cleaning of drill holes (if relevant) | |
| borehole depth $h_1$ [mm] | |
| borehole cleaning procedure (if any) | |
| nominal / effective embedment depth $h_{nom}/h_{ef}$ | |
| thickness of fixture ($t_{fix}$) [mm] | |
| clearance hole $d_f$ [mm] | |
| installation torque $T_{Inst}$ [Nm] | |
| position of the fastener over load transfer zone in the crack | sketch |
| verification method of fastener position in crack | e.g., borescope (sketch of crack formation over load transfer zone) |
| **4. Test parameter** | |
| crack opening mechanism | Describe how the crack width in the area of the load transfer zone is ensured |
| loading/ unloading rates [sec.] | e.g., 2,5 / 2,5 |
| nominal sustained load | e.g., 10 kN |
| min. sustained load | 10,1 kN |
| max. sustained load | 10,9 kN |
| mean sustained load | 10,3 kN |
| no. of replicates tested simultaneously | e.g., one |
| measuring of fastener displacement | e.g., continuously / at the fastener |
| no. of replicates tested in one specimen/ crack | e.g., 6 per specimen / 2 per crack |
| amount / type of crack width measurement | e.g., 4 / capacitive sensor |
| position of the crack width sensors | sketch with distances e.g.:   |
| determination of crack width at fastener | e.g., (linear interpolation) |
| Diagram containing:<br>- crack width at the fastener position for the top and bottom of the load transfer zone<br>- plot the cycles in normal logarithmic scale<br>- plot the upper and the lower crack width | |
| measuring uncertainty for crack width transducers | e.g., ±0,005 mm. |
| minimal frequency during the test | |
| maximal frequency during the test | |
| **5. Test results** | |
| Load at failure | |

| | |
|---|---|
| Load at loss of adhesion | |
| Displacement at failure | |
| Displacement at 50% of failure load | |
| Diagram with load displacement curve | |
| Failure mode (If initial failure is not clear, a combination of failure modes may be reported.) | - (cc) concrete cone failure – give diameter and depth of concrete cone<br>- (sp) splitting– test condition for tests in uncracked concrete in case when a first crack of the concrete is observed<br>- (po) pull-out – pull-out failure may be combined with a shallow concrete breakout<br>- (pt) pull-through– cone being pulled through the expansion sleeve<br>- (s) steel failure– define position of the steel rupture over length of the fastener<br>- (pr) pry-out – concrete breakout opposite to the load direction (may occur for shallow embedment) |
| Torque at failure (torque tests only) | |
| Diagram with displacement over time of testing (long-term tests only) | |

# ANNEX C - MECHANICAL FASTENERS IN CONCRETE UNDER SEISMIC ACTION

## C.1 SCOPE

### C.1.1 General

The tests in this Annex are intended to evaluate the performance of fasteners under simulated seismic tension and shear loading, including the effects of cracks, and under simulated seismic crack cycling conditions. The behaviour of fasteners in regions of reinforced concrete structures, where plastic steel strains are expected (e.g., in plastic hinge zones) is not covered in the requirements of this annex; fasteners shall be placed outside of these regions.

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

The compressive strength of concrete $f_{c,test}$ used in the various equations in this document shall consistently represent the value measured with standard cylinders or standard cubes, unless specifically required otherwise. If necessary, the concrete compressive strength may be converted accordingly.

### C.1.2 Categories

For the evaluation of the performance of fasteners subjected to seismic loading two seismic performance categories, i.e. C1 and C2, with C2 being more stringent than C1, are distinguished. The recommended use of the performance categories C1 and C2 as they relate to the design of fastenings in concrete is given in EN1992-4:2018.

Performance category C1 provides fastener capacities in terms of strength (forces), while performance category C2 provides fastener capacities in terms of both strength (forces) and displacements. In both cases, the effect of concrete cracking is taken into account. The maximum crack width considered in C1 is $\Delta w$ = 0,5 mm and in C2 it is $\Delta w$ = 0,8 mm, where $\Delta w$ is additive to the hairline crack width in the concrete member after fastener installation but before fastener loading.

The assessment of fasteners for category C1 comprises tests under pulsating tension load and tests under alternating shear load. The assessment of fasteners for category C2 includes reference tests up to failure, tests under pulsating tension load, tests under alternating shear load as well as tests under crack cycling. In these tests forces and displacements are measured either continuously or at certain intervals. The assessment of fasteners for category C2 places higher demands on the performance of fasteners under seismic action as compared to category C1.

Based on the respective load histories and crack widths, which are different for the two categories C1 and C2, the design information for C1 contains values of tension and shear resistance of the fastener, while for C2 it contains values of tension and shear resistance as well as fastener displacement.

Detailed information regarding the various testing protocols and assessment criteria for both seismic performance categories is given in Chapters 3 and 4.

## C.2 ABBREVIATION AND NOTATION

### C.2.1 Abbreviation

| | | |
|---|---|---|
| C1, C2 | = | seismic performance categories |
| DLS | = | Damage Limitation State (see EN 1998-1:2004, 2.2.1) |
| ULS | = | Ultimate Limit State (see EN 1998-1:2004, 2.2.1) |

### C.2.2 Notation

| | | |
|---|---|---|
| $A$ | = | percentage elongation after fracture |
| $A_g$ | = | cross section area of test member |
| $b$ | = | width of test member (see Figure C.1 and Figure C.2) |
| $c$ | = | edge distance (see Figure C.1) |
| $C_{ini}$ | = | initial centric compression force on concrete test member in test series C2.5 |
| $C_{test}$ | = | centric compression force on concrete test member during crack cycling in test series C2.5 |
| $d_s$ | = | diameter of the reinforcing bar (see Figure C.1) |

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

$f_u$ = mean ultimate steel strength

$h_{iz}$ = interaction zone between fastener and concrete

$h_{ltz}$ = effective load transfer zone of fasteners

$\ell_b$ = bond length (see Figure C.2))

$\ell_{db}$ = de-bonding length (see Figure C.2)

$n_{cyc}$ = number of cycles

$N_{eq}$ = maximum tension load to be applied in the seismic tension test series C1.1

$N_i$ = intermediate tension load to be applied in the seismic tension test series C1.1

$N_m$ = minimum tension load to be applied in the seismic tension test series C1.1

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

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

$N_{Rk,p,Cx}$ = characteristic tension pull-out resistance under seismic action reported in the ETA for seismic performance category C1, C2

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

$N_{w1}$ = tension load to be applied in the serviceability range ($\Delta w \leq$ 0,5 mm) of the varying crack width test series C2.5

$N_{w2}$ = tension load to be applied in the suitability range (0,5 mm < $\Delta w \leq$ 0,8 mm) of the varying crack width test series C2.5

$t$ = time

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

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

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

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

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

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

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

$\Delta w$ = crack width, which is additive to the width of the hairline crack after fastener installation but before fastener loading

$\Delta w_{hef}$ = crack width at embedment depth $h_{ef}$

$\Delta w_{top}$ = crack width at the top side of the test member in which the fastener is installed

$\Delta w_{bot}$ = crack width at the bottom side of the test member in which the fastener is installed

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

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

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

$\beta_{cv,C2.x}$ = reduction factor resulting from large coefficients of variation in test series C2.x

$\beta_{cv,N}$ = reduction factor for tension resistance resulting from large coefficients of variation

$\beta_{cv,V}$ = reduction factor for shear resistance resulting from large coefficients of variation

$\delta_{N,lim}$ = displacement limit corresponding to excessive displacement of the fastener in the assessment of the results of test series C2.3 and C2.5

$\delta_{N,C2}$ = displacement of the fastener associated with the seismic test series C2.3 and C2.5

$\delta_{V,lim}$ = displacement limit corresponding to excessive displacement of the fastener in the assessment of the results of test series C2.4

$\delta_{V,C2}$ = displacement of the fastener associated with the seismic test series C2.4

$\gamma_{M,C1}$, $\gamma_{M,C2}$ = partial factor for material under seismic loading

$\gamma_{Mp,C1}$, $\gamma_{Mp,C2}$ = partial factor for pull-out failure mode under seismic loading

$\gamma_{Ms,C1}$, $\gamma_{Ms,C2}$ = partial factor for steel under seismic loading

## C.3 TEST METHODS

### C.3.1 General testing requirements

As far as applicable the Annex B shall be followed for test members, test setup and details of tests. Modifications are addressed in Section C.3 of this document, which overrule conflicting provisions in the Annex B.

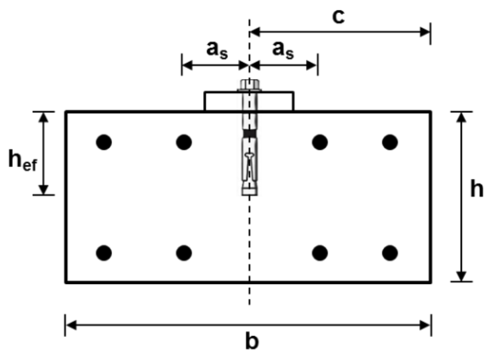
#### C.3.1.1 Test members

The thickness of the test member shall be at least the maximum of 1,5 $h_{ef}$ and the minimum member thickness requested by the manufacturer which is given in the ETA. The width of the test member shall be large enough to avoid any influence of the edges on the fastener behaviour. The test member shall be designed such that the crack width is approximately constant throughout the thickness of the test member during the test (including crack cycling (for crack widths ≥ 0,3 mm), load cycling and peak load). This requirement is considered to be fulfilled if

a) the crack width $\Delta w_{hef}$ at the level of the embedment depth $h_{ef}$ is equal to or greater than the required value, and
b) the crack width $\Delta w_{top}$ at the top side of the test member (i.e. the side in which the fastener is installed) is equal to or larger than $\Delta w_{hef}$ for $\Delta w_{hef}$ ≥ 0,3 mm.

The reinforcement shall be of equal size and placed symmetrically (see Figure C.1). The spacing of the reinforcement in the test member shall be ≤ 400 mm. The capacity of the fastener shall not be affected by the reinforcement. The reinforcement shall remain well in the elastic range during each test. Buckling of the reinforcement shall be avoided. The bond length $\ell_b$ between possible crack planes and at both ends of the specimen (see Figure C.2) shall be large enough to introduce the tension force into the concrete.

To facilitate the opening of the crack by $\Delta w$ = 0,8 mm a bond breaker may be applied at both sides of the crack (see Figure C.2). A plastic pipe with an inner diameter of ≈ 1,2 $d_s$ may be used for this purpose, where $d_s$ denotes the diameter of the reinforcing bar. When using bond breakers, the de-bonding length $\ell_{db}$ is recommended to be ≤ 5 $d_s$.




$a_s$ … distance between fastener and reinforcement bar

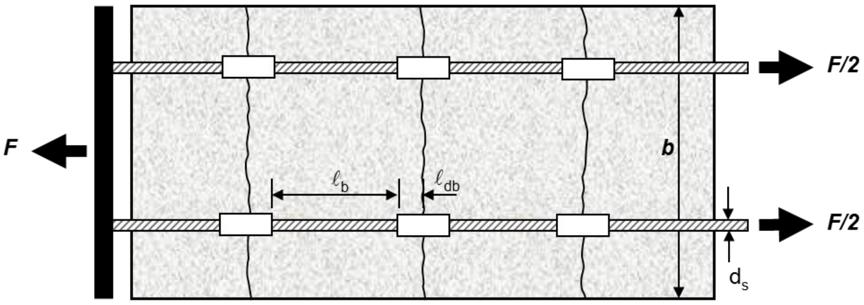
$b$ … width of test member

$c$ … edge distance

$h$ … height of test member

$h_{ef}$ … embedment depth of fastener

**Figure C.1 Example cross section of test member**




▭ … bond breaker

$\ell_b$ … bond length

$\ell_{db}$ … de-bonding length

$d_s$ … diameter of rebar

$b$ … width of test member

$F$ … force on test member

**Figure C.2 Example for test member with bond breaking pipes on rebar (plan view)**

The requirement that the fastener behaviour is not influenced by the edges of the test member is considered to be fulfilled if for unconfined testing the concrete breakout body (see EN 1992-4 Figure 7.1 b) does not intersect with an edge or the edge distance of the fastener in all directions is $c \geq 2{,}0\ h_{ef}$.

The requirement that the capacity of the fastener is not affected by the reinforcement is considered to be fulfilled for unconfined tests if the distance $a_s$ between the fastener and the nearest reinforcement bar (see Figure C.1) is at least 75 mm and ≥ 0,60 $h_{ef}$. If for large embedment depths this distance requirement and the spacing requirement of the reinforcement ≤ 400 mm cannot be fulfilled at the same time an expertise is required showing that the nearest reinforcement bar does not affect the capacity of the fastener.

*Note C.1 The above requirement for $a_s$ is based on the consideration that the reinforcement does not intersect the portion of the concrete breakout cone that has developed at peak load and the following two assumptions:*

1. *The crack length at ultimate load is approximately 0,4 times the side length of the final cone. The slope of the cone as measured from the horizontal is on the average about 35°.*
2. *The spacing of the reinforcement used to create and control the crack width is typically not less than 150 mm.*

The fulfilment of the requirements regarding the constant crack width shall be demonstrated for each test member design for the fastener with the highest ultimate load to be tested in this test member for the crack width required for the specific test (see Table A.1) and for crack width $\Delta w$ = 0,3 mm to 0,8 mm for test series C2.5. At least 3 test members shall be tested for each test member design and in each test the conditions given above shall be fulfilled. The results of this assessment shall be reported in the test report. There are two options for the assessment shown in Figure C.3a) and Figure C.3b).

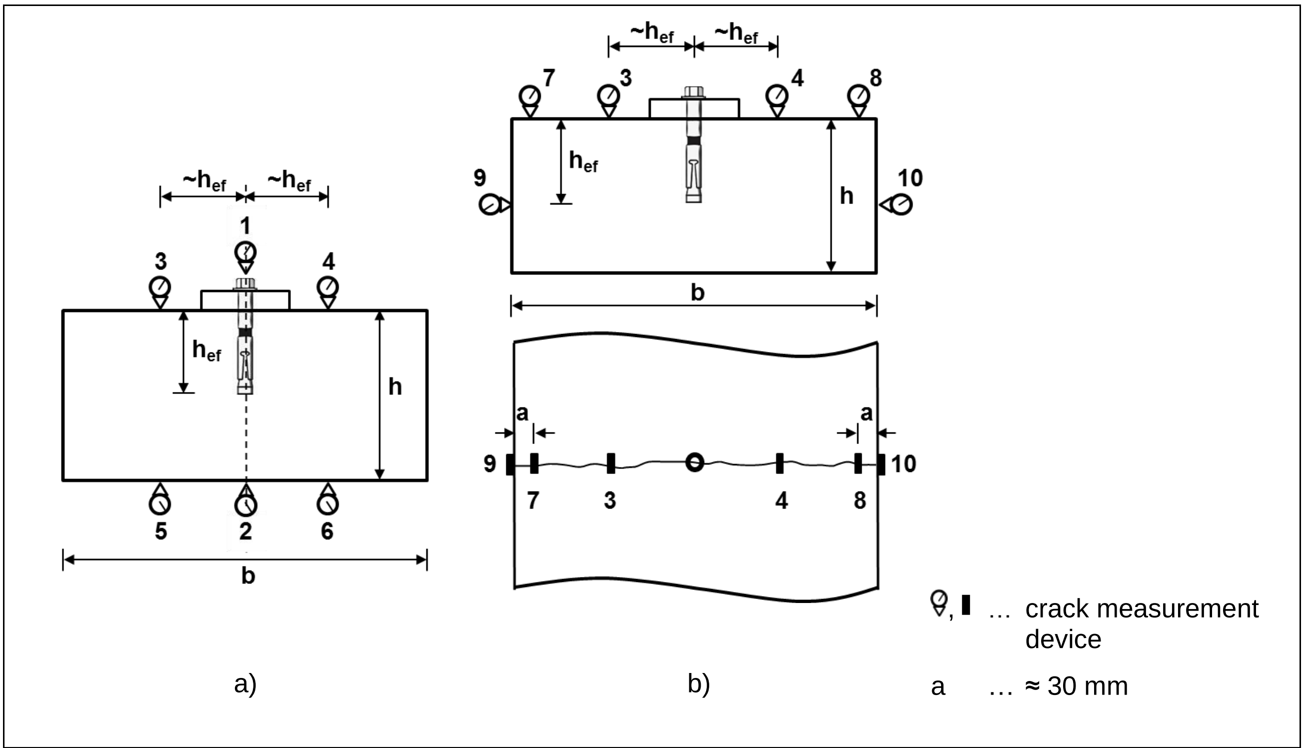



**Figure C.3 Measurements to show fulfilment of the constant crack width requirement**

<u>Crack measurement and tolerance on crack width</u>

The crack width shall be measured continuously during the test with a measuring error not greater than 0,02 mm.

In tension tests the crack width $\Delta w_{hef}$ shall be determined by either one of the following two approaches:

a) Linear interpolation of crack measurements at the top $\Delta w_{top}$ and bottom $\Delta w_{bot}$ of the test member (see Figure C.3a). In this case the crack width shall be measured either at the location of the fastener (i.e. locations 1 ($\Delta w_{top}$) and 2 ($\Delta w_{bot}$) in Figure C.3a) or on both sides of the fastener (i.e. locations 3 & 4 (for $\Delta w_{top}$) and 5 & 6 (for $\Delta w_{bot}$) in Figure C.3a) with the two mean values of the measurements at the top and bottom representing $\Delta w_{top}$ and $\Delta w_{bot}$, respectively.

b) Measuring the crack width at the side of the test member at the embedment depth level $h_{ef}$ (i.e. locations 9 & 10 in Figure C.3b). In this case the mean value of the measurements at the side of the test member shall be determined to represent $\Delta w_{hef}$.

For both approaches in unconfined tension tests the measurement devices shall be placed as shown in Figure C.3.

In shear tests the crack width shall be measured within a distance of approximately 1,0 $h_{ef}$ in front of and behind the fastener (and the mean value is determined) or directly at the fastener location where possible.

The mean of the measured crack widths $\Delta w_{hef}$ for each test series determined for each fastener shall be equal to or greater than the specified crack width for the test series. Individual crack widths shall be within the following tolerance:

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

#### C.3.1.2 Installation of fasteners

Install the fastener in a hairline crack, and the manufacturer's printed installation instructions (MPII). For tests described in C.3.4.4, a compression load is applied to the test member before installation of the fastener. Use drill bits with a diameter $d_{cut,m}$ (medium).

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

If no torque is specified by the manufacturer's printed installation instructions, finger-tighten the fastener prior to testing. Test internally threaded fasteners with the bolt specified by the manufacturer and report the bolt type in the test report.

#### C.3.1.3 Test setup

The fastener shall be located in the crack over the entire effective load transfer zone, $h_{ltz}$, of the fastener (meaning, e.g., over the entire embedment depth for a concrete screw, over 1,5 times the length of the interaction zone $h_{iz}$ of a torque-controlled expansion fastener or undercut fastener see Figure C.4).

*Note C.2 One way to achieve this, at least for larger fastener diameters, is to drill the fastener hole at the desired position prior to initiating the cracking.*

It shall be verified that the fastener is located in the crack over the length defined above, e.g., by use of a borescope.

All tension tests shall be performed as unconfined tests according to Annex B unless specified otherwise in the specific test section below.

In shear tests uplift of the fixture (steel plate) shall be restrained such that no significant friction forces are induced. Such friction forces are avoided if for example a setup as shown in Figure C.5 is used, which prevents the uplift, limits friction by roller bearing and does not actively apply a compression force. Furthermore, the maximum allowed annular gap of the clearance hole (see Annex B) shall be selected in the shear tests. For fasteners with a specified smaller gap or without an annular gap, both of which have to be stated in the ETA, the specific fastener system may be tested.

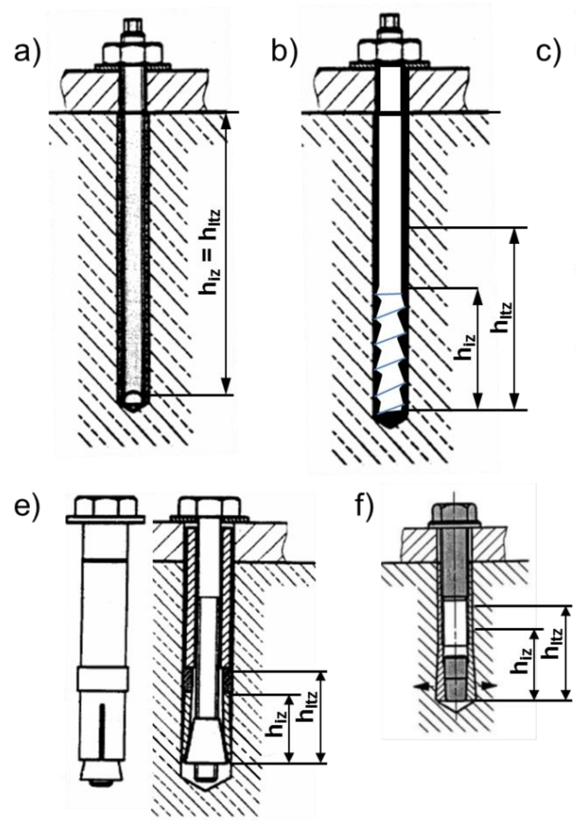
*Note C.3 The effect of high loading rates on the fastener behaviour is conservatively neglected.*

According to Figure C.3a) the crack widths are measured at the top and bottom of the test member either at the fastener location (locations 1 and 2 in Figure C.3a) or at a distance of approximately $h_{ef}$ on both sides of the fastener (locations 3 & 4 and 5 & 6 in Figure C.3a). The mean value of the crack width measurements at locations 3 and 4 represents $\Delta w_{top}$ and the mean value of the crack width measurements at locations 5 and 6 represents $\Delta w_{bot}$. The crack width $\Delta w_{hef}$ is obtained by linear interpolation of the top and bottom crack widths, i.e. $\Delta w_{top}$ and $\Delta w_{bot}$, respectively.

Equally, the approach shown in Figure C.3b) may be pursued if it is shown that the width of the crack remains approximately constant across the width of the test member. This condition is considered to be fulfilled if the ratio of the mean value of the crack width measurements at locations 7 and 8 to the mean value of the measurements at locations 3 and 4 is ≤ 1,05. The mean value of the crack width measurements at locations

3 and 4 represents $\Delta w_{top}$ and the mean value of the crack width measurements at locations 9 and 10 represents $\Delta w_{hef}$.

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




key

a) bonded fastener (see EAD 330499)

b) bonded expansion fastener (see EAD 330499)

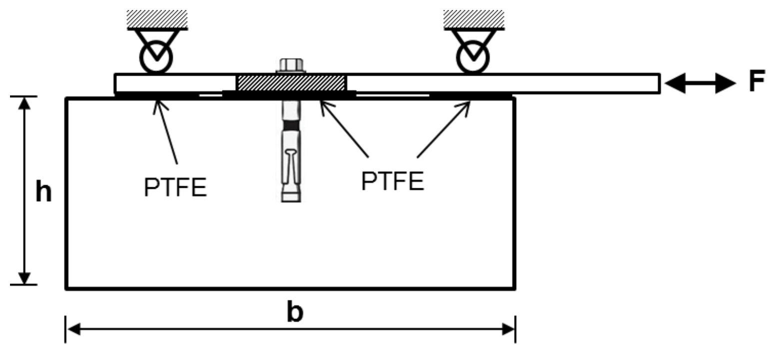
c) undercut fastener

d) concrete screw

e) torque-controlled expansion fastener

f) deformation-controlled expansion fastener

**Figure C.4 Effective load transfer zone**




… roller bearing

PTFE … Teflon layer

F … shear force

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

<u>Control of crack width</u>

In the tests to failure (monotonic tests and residual capacity tests) the fastener is subjected to load while the crack width is controlled, either

a) at a constant width taking into account the requirements given in section C.3.1.1, for example, by means of a servo system, or
b) limited to a width close to the specified value by means of the reinforcement and test member dimensions (see C.3.1.1).

### C.3.2 Fastener types to be tested

In general, the tests described in C.3.2.4 and C.3.4 shall be performed with all fastener diameters, embedment depths, steel types (galvanized steel, stainless steel, high corrosion resistant steel) and grades (strength classes and lowest rupture elongation), production methods, head configurations (mechanical fasteners), types of inserts (threaded rod, threaded sleeve) as well as drilling methods to be assessed for use in seismic applications. The number of variants to be tested may be reduced as described below. It shall be allowed to perform additional tests beyond the minimum number of tests described below to verify fastener characteristics for additional parameters (e.g., tests at different embedment depths).

If certain reference tension tests, which are required in the context of this assessment, have not been performed in the non-seismic part of the assessment, these tests shall be performed. Equally, it shall be permitted that the corresponding resistance under ultimate load is calculated from the data obtained in the non-seismic assessment for cracked concrete.

#### C.3.2.1 Torque-controlled expansion fasteners

#### C.3.2.1.1 Steel type, steel grade and production methods

#### C.3.2.1.1.1 Tension tests

If all of the following conditions are fulfilled, and the eventual reduction factor is accepted for all fasteners, only fasteners of one steel type, the highest steel grade and one production method need to be tested. Otherwise fasteners of all steel types, steel grades and production methods shall be tested. Meaning, if all conditions are fulfilled for all steel types and steel grades but not for different production methods, the fasteners of different production methods shall be tested.

a) The geometry of the fastener is identical.
b) The pre-stressing forces at torque $T$ = 0,5 $T_{inst}$ as well as at $T$ = 1,0 $T_{inst}$ are statistically equivalent for the different steel types, steel grades and production methods. The installation torque $T_{inst}$ may be different for different steel types and steel grades.
c) The friction between cone and sleeve (internal friction) and the friction between sleeve and concrete (external friction) are identical for the different steel types, steel grades and production methods. This condition shall be considered to be fulfilled if the fasteners are made out of the same material, and any coatings are the same, and the surface roughness and hardness of the cone and the sleeve are statistically equivalent. For fasteners made out of different materials (e.g., galvanized and corrosion resistant steel) this condition shall be considered to be fulfilled if the coating is identical, and the internal friction between cone and sleeve depends mainly on the coating, and the surface roughness and hardness of the cone and the sleeve are statistically equivalent.

If the geometry is not identical but almost identical (similar) and the above conditions b) and c) are fulfilled, the seismic tests for the other steel type, steel grade or production method may be omitted if all of the following requirements are met. In this context “fast 1“ is the fastener for which the tests have been performed and “fast 2” is the fastener for which the tests are omitted.

- The geometrical data of the two fasteners, i.e. “fast 1” and “fast 2”, are compared with each other and the comparison including the identified differences are documented and submitted for the assessment.
- The fastener “fast 2” has an ETA for cracked concrete for static loading conditions.
- The performance of “fast 2” is better or equal to the performance of “fast 1”, which has to be shown in terms of
  - $N_{Rk,p,fast\ 2} \geq N_{Rk,p,fast\ 1}$ (where $N_{Rk,p}$ is the characteristic value given in the ETA);
  - reference tension tests in cracked concrete C20/25 and C50/60 according to Table A.1, series A3 and A4: performance of fastener “fast 2” ≥ performance of fastener “fast 1”;
  - tests for “maximum crack width and large hole diameter” and “maximum crack width and small hole diameter” according to Table A.1, series F1 and F2: performance of fastener “fast 2” ≥ performance of fastener “fast 1”;
  - tests for “crack cycling under load” according to Table A.1, series F3: sustained load for which fastener “fast 2” passes the criteria is larger than or equal to the corresponding load for fastener “fast 1”;
  - in the load/displacement curves fasteners “fast 1” and “fast 2” show the same stiffness
  - the ductility in terms of the $A_5$-value of fastener “fast 2” ≥ ductility for fastener “fast 1”.
- The seismic resistance for “fast 2” is determined as min ($N_{Rk,p,fast\ 1} \cdot \alpha_{N,Cx,fast\ 1}$; $N_{Rk,p,fas\ 2} \cdot \alpha_{N,Cx,fast\ 1}$).

*Note C.4* *In case the highest steel grade is tested pull-out failure might be decisive and steel failure does not occur. For lower steel grades steel failure may become decisive and the corresponding seismic performance may be relevant.*

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

**C.3.2.1.1.2 Shear tests**

Only fasteners made of galvanized steel of the highest grade and lowest rupture elongation (percentage of elongation after fracture, A, see ISO 898-1 [11] need to be tested if the reduction of the characteristic steel shear resistance due to simulated seismic shear testing as compared to the characteristic steel shear resistance under static loading is accepted for all steel types and steel grades. Otherwise all steel types and steel grades shall be tested. The measured displacements shall be applied to the fasteners made from other steel types, steel grades or by other production methods.

**C.3.2.1.2 Head configuration**

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

**C.3.2.1.3 Embedment depth**

**C.3.2.1.3.1 Tension tests**

a) Fasteners under category C1 (test series C1.1):
If multiple embedment depths are specified, in general, minimum and maximum embedment depths shall be tested. However, only the maximum embedment depth needs to be tested if the reduction factor for seismic loading $\alpha_{N,C1}$ according to Equation (C.20) is accepted for all embedment depths.
b) Fasteners under category C2 (test series C2.1, C2.3 and C2.5):
If multiple embedment depths are specified, it is allowed to only perform tests at the maximum embedment depth. If only the maximum embedment depth is tested, the reduction factors $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ according to Equation (C.66) and Equation (C.67), respectively, for the maximum embedment depth shall be applied to fasteners with shallower embedment depths and the displacements measured for fasteners with the maximum embedment shall be applied to fasteners with shallower embedment depths.

**C.3.2.1.3.2 Shear tests**

a) Fasteners under category C1 (test series C1.2):
If there is more than one embedment depth specified for a fastener diameter, tests need to be performed for the minimum and maximum embedment depth only. If in the tests with minimum embedment depth steel failure occurs tests at the maximum embedment depth may be omitted if the reduction factor $\alpha_{V,C1}$ according to Equation (C.21) is applied to all embedment depths.
b) Fasteners under category C2 (test series C2.2, C2.4):
Only the minimum embedment depth needs to be tested if the reduction factor for seismic loading $\alpha_{V,C2}$ according to Equation (C.68) is accepted for all embedment depths. If at the minimum embedment depth pry-out failure is encountered, select a larger embedment depth avoiding pry-out failure. The displacements measured in the tests with the minimum embedment depth shall be applied to fasteners with a larger embedment depth.

If for a specified embedment depth deeper setting is allowed, the embedment depth for the tests shall be selected such that the most unfavourable position with regard to the shear plane is accounted for. For example, fasteners may consist of a smooth shaft and a threaded part. Depending on the thickness of the fixture the shear plane may pass through the smooth portion or the threaded part (see Figure C.6).

*Note C.5* *For mechanical fasteners a single embedment depth $h_{ef}$ is frequently specified for each diameter (e.g., M12, $h_{ef}$ = 70 mm). Different lengths of the fastener for the same diameter may account for different thicknesses of the fixture $t_{fix}$. It may therefore be allowed to set the fastener deeper than the specified value (as long as all other requirements such as for example $h_{min}$ are met) for ease of use to avoid extensive projection of the fastener above the fixture. This may result in an unfavourable position with regards to shear loading.*

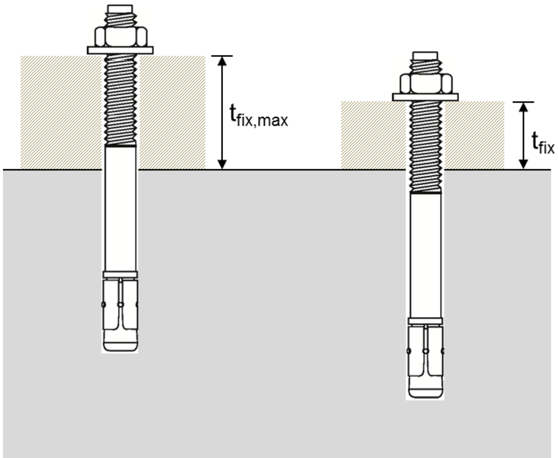



**Figure C.6 Shear test with unfavourable position with regard to shear plane**

#### C.3.2.1.4 Drilling method

A reduction of number of drilling methods to be tested is only allowed for shear tests. In this case the hole shall be drilled with the most adverse drilling method, which in many cases will be diamond coring.

### C.3.2.2 Undercut fasteners (not including concrete screws)

#### C.3.2.2.1 Steel type, steel grade and production method

##### C.3.2.2.1.1 Tension tests

If the undercut of the concrete is identical in all models for full expansion according to B.3.7 a) and partial expansion during the tests for “robustness to variation in use conditions” according to Table A.1 series F9, only fasteners of one steel type, the highest steel grade and one production method need to be tested. The measured displacements shall be applied to all steel types, steel grades and production methods. If this condition is not fulfilled, test all fasteners; however, only fasteners with the minimum undercut for full expansion according to B.3.7 a) need to be tested if the reduction factor due to simulated seismic tension testing $\alpha_{N,C1}$ according to Equation (C.20) and $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ according to Equation (C.66) and Equation (C.67), respectively, are accepted for all fasteners.

In addition, an undercut fastener that shows a follow-up expansion during loading shall comply with the requirements for torque-controlled expansion fasteners in C.3.2.1.1.1.

##### C.3.2.2.1.2 Shear tests

See C.3.2.1.1.2.

#### C.3.2.2.2 Head configuration

See C.3.2.1.2.

#### C.3.2.2.3 Embedment depth

See C.3.2.1.3.

#### C.3.2.2.4 Drilling method

See C.3.2.1.4.

### C.3.2.3 Concrete screws

#### C.3.2.3.1 Tension tests

The seismic tests for the other steel type, steel grade or production method may be omitted if all of the following requirements are met. In this context “fast 1“ is the fastener for which the tests have been performed and “fast 2” is the fastener for which the tests are omitted.

- The fastener “fast 2” has an ETA for cracked concrete for static loading conditions.
- The performance of fastener “fast 2” is better or equal to the performance of fastener “fast 1”, which has to be shown in terms of

- $N_{Rk,p,fast\,2} \geq N_{Rk,p,fast\,1}$ (where $N_{Rk,p}$ is the characteristic value given in the ETA);
- tests for “crack cycling under load” according to Table A.1 series F3: sustained load for which fastener “fast 2” passes the criteria is larger than or equal to the corresponding load for fastener “fast 1”;
- the ductility in terms of the $A_5$-value of fastener “fast 2” ≥ ductility for fastener “fast 1”;
- the seismic resistance for fastener “fast 2” is determined as $\min(N_{Rk,p,fast\,1} \cdot \alpha_{N,Cx,fast\,1}; N_{Rk,p,fast\,2} \cdot \alpha_{N,Cx,fast\,1})$.

#### C.3.2.3.2 Shear tests

A reduction of number of variants to be tested is only allowed for shear tests with respect to the embedment depth as given in C.3.2.1.3.2 and the drilling method as given in C.3.2.1.4.

### C.3.2.4 Deformation-controlled expansion fasteners

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

## C.3.3 Tests for category C1

### C.3.3.1 Tests under pulsating tension load (test series C1.1)

The test shall be performed with an unconfined test setup according to Annex B.

In addition, tests with the maximum embedment depth are required.

For all types of fasteners, the pulsating tension load tests shall be executed as described in the following:

Open the crack by $\Delta w$ = 0,5 mm. Subject the fasteners to sinusoidal tension loads with the levels and cycle counts specified in Table C.1 and Figure C.7, where $N_{C1}$ is given in Equation (C.1) in case of concrete or bond failure and in Equation (C.2) in case of steel failure, $N_i$ is given in Equation (C.3), and $N_m$ is given in Equation (C.4). The cycling frequency shall be between 0,1 and 2 Hz. The bottom of the tension load pulses may be taken to be slightly greater than zero to avoid servo control problems but shall not exceed $N_{min}$, with $N_{min}$ being the maximum of 3% of $N_{C1}$ and 200 N.

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

where

$N_{u,m}$ = [N] - all fasteners:
mean tension capacity from “basic tension tests” in cracked concrete C20/25 according to Table A.1, for the considered embedment depth;

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

$f_{c,3}$ = [N/mm²] - mean compressive strength of concrete used for the “Basic tension tests” according to Table A.1 at the time of testing;

m = normalization exponent according to A2.1.

$$N_{C1} = 0{,}5 \cdot N_{u,m} \cdot \left( \frac{f_{u,C1.1}}{f_{u,3}} \right) \quad \text{[N]} \quad \text{(steel failure)} \qquad \text{(C.2)}$$

where

$N_{u,m}$ = [N] - mean tension steel capacity from “Basic tension tests” in cracked concrete C20/25 according to Table A.1;

$f_{u,C1.1}$ = [N/mm²] - ultimate mean steel strength of fasteners used for test series C1.1;

$f_{u,3}$ = [N/mm²] - ultimate mean steel strength of fasteners used for “Basic tension tests” according to Table A.1;

Adjustment for different steel strengths in Equation (C.2) is not required if the fasteners used in test series C1.1 and “Basic tension tests” according to Table A.1are taken from the same production lot.

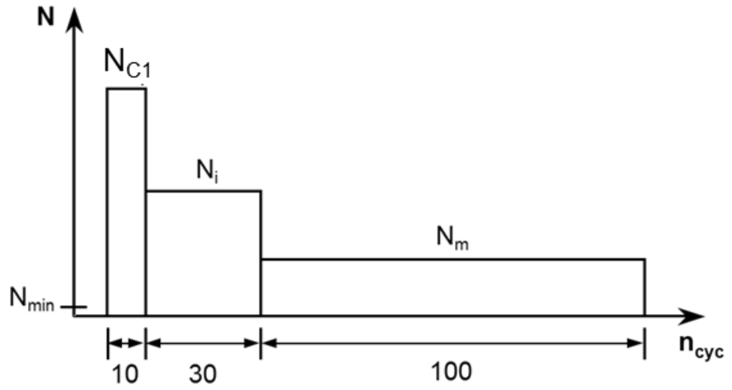
If mixed failure modes occur in the "Basic tension tests" according to Table A.1, the load $N_{C1}$ shall be determined assuming that the failure mode, which was observed in the majority of tests in the test series, occurred in all tests.

$$N_i = 0{,}75 \cdot N_{C1} \quad [N] \tag{C.3}$$

$$N_m = 0{,}5 \cdot N_{C1} \quad [N] \tag{C.4}$$

**Table C.1 Required loading history for test series C1.1**

| Load level | $N_{C1}$ | $N_i$ | $N_m$ |
|---|---|---|---|
| Number of cycles ($n_{cyc}$) | 10 | 30 | 100 |




N … load

$n_{cyc}$ … number of cycles

**Figure C.7 Required loading history for test series C1.1**

Record the crack width, fastener displacement and applied tension load. Following completion of the simulated seismic tension cycles, open the crack by $\Delta w$ = 0,5 mm, but not less than the crack opening width as measured at the end of the cyclic test and load the fastener in tension to failure. Record the maximum tension load (residual tension capacity), the corresponding displacement, the crack width, and plot the load-displacement response.

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

### C.3.3.2 Tests under alternating shear load cycling (test series C1.2)

Purpose:

These tests are intended to evaluate the performance of fasteners under simulated seismic shear loading, including the effects of concrete cracking.

General test conditions:

The test shall be performed according to B.3.6.1 with the following modifications.

Open the crack by $\Delta w$ = 0,5 mm. Subject the fasteners to sinusoidal shear loads in the direction of the crack with the levels and cycle counts specified in Table C.2 and Figure C.7, where $V_{C1}$ is given in Equation (C.5), Equation (C.6), or Equation (C.7) as applicable, $V_i$ is given in Equation (C.8) and $V_m$ is given in Equation (C.9). The cycling frequency shall be between 0,1 and 2 Hz.

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

where

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

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

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

For fasteners with a sleeve in the shear plane $V_{C1}$ shall be calculated according to Equation (C.6).

$$V_{C1} = 0{,}5 \cdot V_{u,m} \cdot \left( \frac{f_{u,bol,C1.2}}{f_{u,bol,5}} \cdot \frac{A_{s,bol}}{A_{s,fas}} + \frac{f_{u,sle,C1.2}}{f_{u,sle,5}} \cdot \frac{A_{s,sle}}{A_{s,fas}} \right) [N] \quad (C.6)$$

where

$V_{u,m}$ = [N] - as defined in Equation(C.5);

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

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

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

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

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

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

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

Adjustment for different steel strengths in Equations (C.5) and (C.6) is not required if the fasteners tested in C1.2 and in in tests for “characteristic resistance to steel failure under shear load” in uncracked concrete C20/25 according to Table A.1 series V1, are taken from the same production lot.

If tests for “characteristic resistance to steel failure under shear load” have not been performed according to ´Table A.1 series V1, (which is allowed only for fasteners with no significantly reduced section along the length of the bolt and no sleeve in the shear plane, that is taken into account in the shear resistance), $V_{C1}$, shall be permitted to be calculated in accordance with Equation (C.7).

$$V_{C1} = 0{,}35 \cdot A_s \cdot f_{uk} \text{ [N]} \quad (C.7)$$

where

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

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

$$V_i = 0{,}75 \cdot V_{C1} \quad \text{[N]} \quad (C.8)$$

$$V_m = 0{,}5 \cdot V_{C1} \quad \text{[N]} \quad (C.9)$$

**Table C.2 Required loading history for test series C1.2**

| Load level | $\pm V_{C1}$ | $\pm V_i$ | $\pm V_m$ |
|---|---|---|---|
| Number of cycles ($n_{cyc}$) | 10 | 30 | 100 |

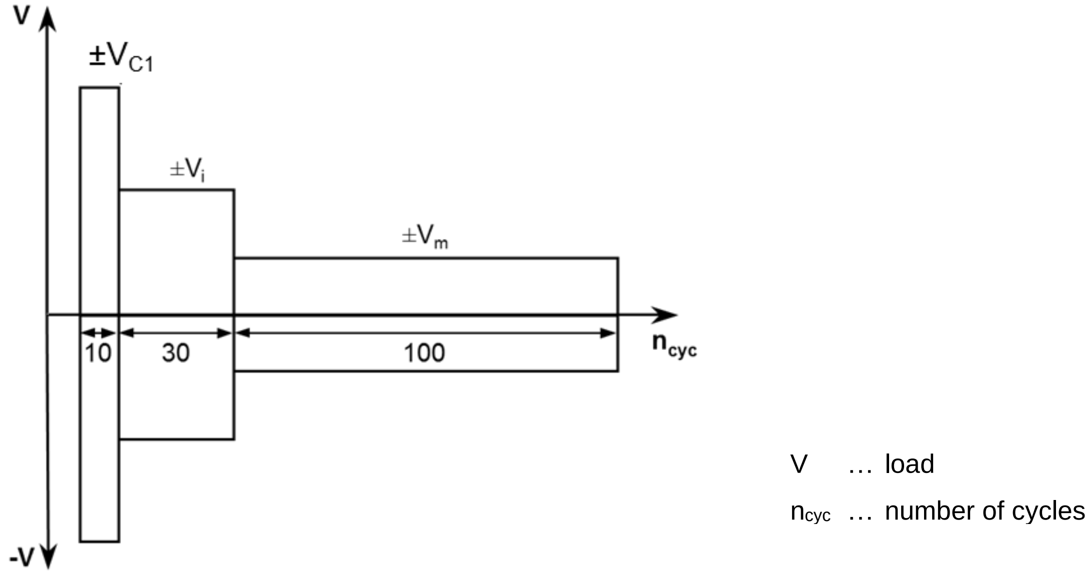



**Figure C.8 Required load history for test series C1.2**

To reduce the potential for uncontrolled slip during load reversal, the alternating shear loading (Figure C.9b) is permitted to be approximated by two half-sinusoidal load cycles at the required frequency connected by a reduced speed, ramped load as shown in Figure C.9b, or by simply triangular loading cycles as shown in Figure C.9c.

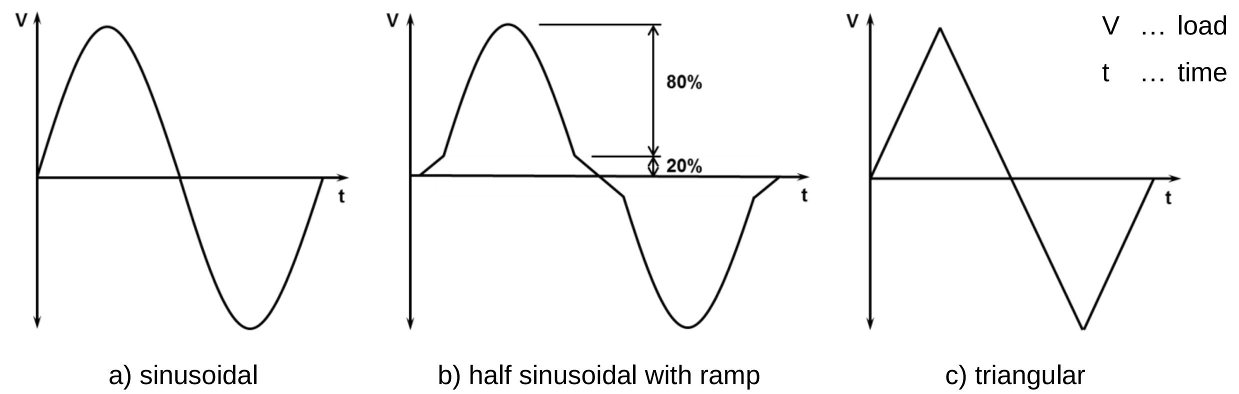



**Figure C.9 Permitted seismic shear cycle C1.2**

Record the crack width, fastener displacement and applied shear load. Plot the load-displacement history in the form of hysteresis loops.

Following completion of the simulated seismic shear cycles, open the crack by $\Delta w$ = 0,5 mm, but not less than the crack opening width as measured at the end of the cyclic shear test and load the fastener in shear to failure. Record the maximum shear load (residual shear capacity), the corresponding displacement, the crack width, and plot the load-displacement response.

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

### C.3.4 Tests for category C2

#### C.3.4.1 Reference tension and shear tests (test series C2.1 and C2.2)

The tension test series C2.1 and shear test series C2.2 shall be performed in accordance with Annex B, with a crack width as specified in Table A.1.

The test series C2.2 may be omitted if the results of the service condition tests "characteristic under shear load (V1)" in uncracked concrete C20/25, ($\Delta w$ = 0,0 mm) are accepted as $V_{u,m,C2.2}$. In this case the steel properties of the samples in the tests for "characteristic resistance to steel failure under shear load" in uncracked concrete C20/25, have to be used for the normalization in the context of the C2.4 test series.

If in the test series C2.2 failure is caused by pull-out or pull-through of the fastener the test may be repeated with a larger embedment depth avoiding these failure modes (compare C.4.2.3).

#### C.3.4.2 Tests under pulsating tension load (test series C2.3)

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

Open the crack by $\Delta w$ = 0,5 mm (see exception in Footnote 4 of Table A.1). Subject the fastener to the sinusoidal tension loads specified in Table C.3 and Figure C.10 with a cycling frequency no greater than 0,5 Hz, where $N_{max}$ is given by Equation (C.10) to Equation (C.11). Triangular loading cycles may be used in place of sinusoidal cycles. The bottom of the tension load pulses may be taken to be slightly greater than zero to avoid servo control problems but shall not exceed $N_{min}$, with $N_{min}$ being the maximum of 2% of $N_{max}$ and 200 N. Crack width shall be controlled during load cycling. The crack shall be opened to $\Delta w$ = 0,8 mm after the load cycles at 0,5 $N/N_{max}$ have been completed.

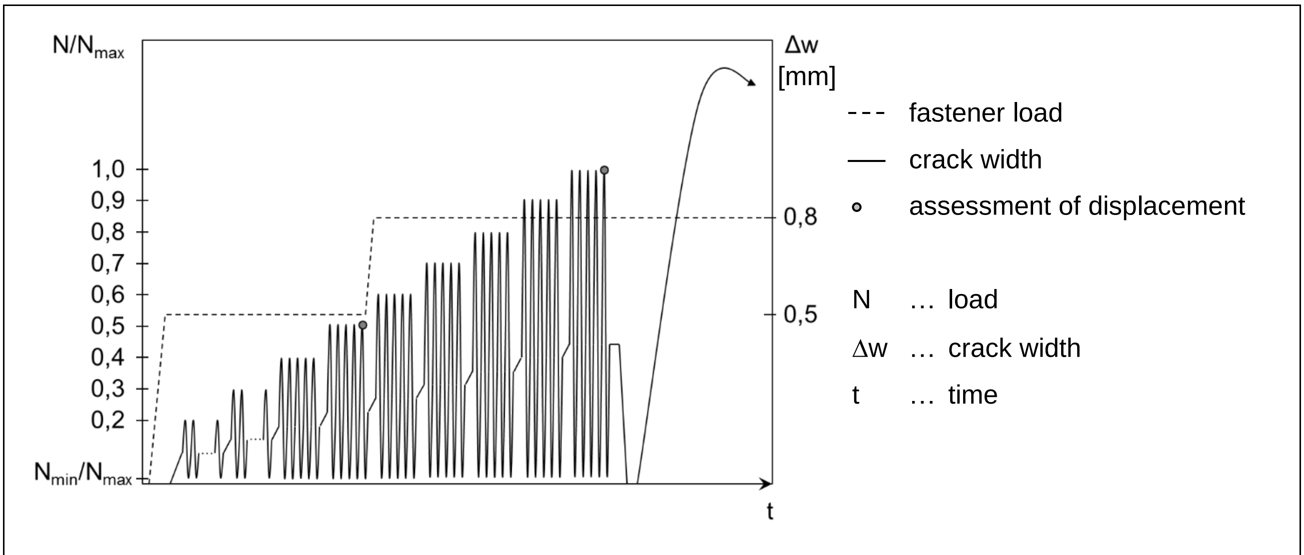



**Figure C.10 Schematic test procedure C2.3**

**Table C.3 Required load amplitudes for test series C2.3**

| ***N/N**$_{max}$* | **Number of cycles** | **Crack width $\Delta w$ [mm]** |
|---|---|---|
| 0,2 | 25 | 0,5 |
| 0,3 | 15 | 0,5 |
| 0,4 | 5 | 0,5 |
| 0,5 | 5 | 0,5 |
| 0,6 | 5 | 0,8 |
| 0,7 | 5 | 0,8 |
| 0,8 | 5 | 0,8 |
| 0,9 | 5 | 0,8 |
| 1 | 5 | 0,8 |
| SUM | 75 | |

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

Steel failure

$$N_{\max} = 0{,}75 \cdot N_{u,m,C2.1a} \cdot \left( \frac{f_{u,C2.3}}{f_{u,C2.1a}} \right) \quad [\text{N}] \qquad (C.10)$$

All other failure modes

$$N_{\max} = 0{,}75 \cdot N_{u,m,C2.1a} \cdot \left( \frac{f_{c,C2.3}}{f_{c,C2.1a}} \right)^{0,5} \quad [\text{N}] \qquad (C.11)$$

where

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

$f_{u,C2.3}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.3;

$f_{u,C2.1a}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.1a

$f_{c,C2.3}$ = [N/mm²] - mean compressive strength of concrete at the time of testing of the test series C2.3;

$f_{c,C2.1a}$ = [N/mm²] - mean compressive strength of concrete at the time of testing of the test series C2.1a;

If mixed failure modes occur in test series C2.1a, the largest value of Equations (C.10) and (C.11) shall be applied.

Adjustment for different steel strengths in Equation (C.10) is not required if the fasteners tested in C2.1a and C2.3 are taken from the same production lot.

Record the crack width, fastener displacement and applied tension load continuously during the simulated seismic tension cycles. Report the displacements at minimum and maximum load and the crack width as a function of the number of load cycles.

Following completion of the simulated seismic tension cycles unload the fastener. During the unloading of the fastener the crack width may get smaller. For the residual capacity test open the crack to $\Delta w$ = 0,8 mm, but not less than the crack opening width as measured at the end of the cyclic test, and load the fastener in tension to failure. Record the maximum tension load (residual tension capacity), the corresponding displacement, the crack width, and plot the load-displacement response.

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

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

#### C.3.4.3 Tests under alternating shear load (test series C2.4)

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

Open the crack by $\Delta w$ = 0,8 mm. Subject the fastener to the sinusoidal shear loads specified in Table C.4 and Figure C.11 with a cycling frequency no greater than 0,5 Hz, where $V_{max}$ is given by Equation (C.12) or Equation (C.13) as applicable.

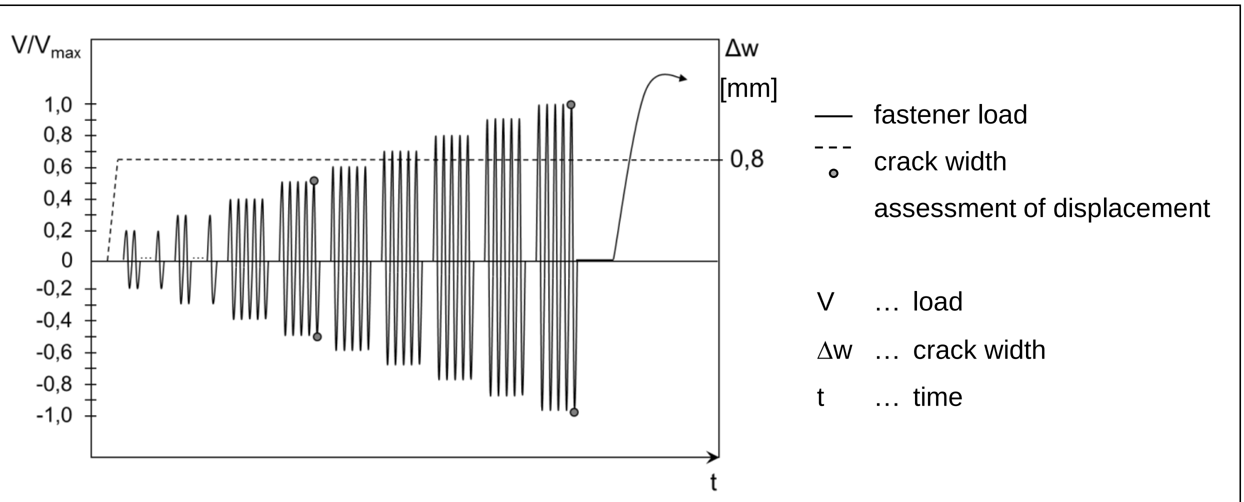



**Figure C.11 Schematic test procedure C2.4**

**Table C.4 Required load amplitudes for test series C2.4**

| **±$V/V_{max}$** | **Number of cycles** | **Crack width $\Delta w$ [mm]** |
|---|---|---|
| 0,2 | 25 | 0,8 |
| 0,3 | 15 | 0,8 |
| 0,4 | 5 | 0,8 |
| 0,5 | 5 | 0,8 |
| 0,6 | 5 | 0,8 |
| 0,7 | 5 | 0,8 |
| 0,8 | 5 | 0,8 |
| 0,9 | 5 | 0,8 |
| 1 | 5 | 0,8 |
| SUM | 75 | |

$$V_{\max} = 0{,}85 \cdot V_{u,m,C2.2} \left( \frac{f_{u,C2.4}}{f_{u,C2.2}} \right) \text{ [N]} \qquad \text{(fasteners without sleeve in shear plane)} \qquad \text{(C.12)}$$

where

$V_{u,m,C2.2}$ = [N] - mean shear capacity from the reference test series C2.2;

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

$f_{u,C2.2}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.2.

For fasteners with a sleeve in the shear plane $V_{max}$ shall be calculated according to Equation (C.13).

$$V_{max} = 0{,}85 \cdot V_{u,m,C2.2} \cdot \left( \frac{f_{u,bol,C2.4}}{f_{u,bol,C2.2}} \cdot \frac{A_{s,bol}}{A_{s,fas}} + \frac{f_{u,sle,C2.4}}{f_{u,sle,C2.2}} \cdot \frac{A_{s,sle}}{A_{s,fas}} \right) \text{[N]} \qquad \text{(C.13)}$$

where

$V_{u,m,C2.2}$ = [N] - as defined in Equation (C.12);

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

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

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

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

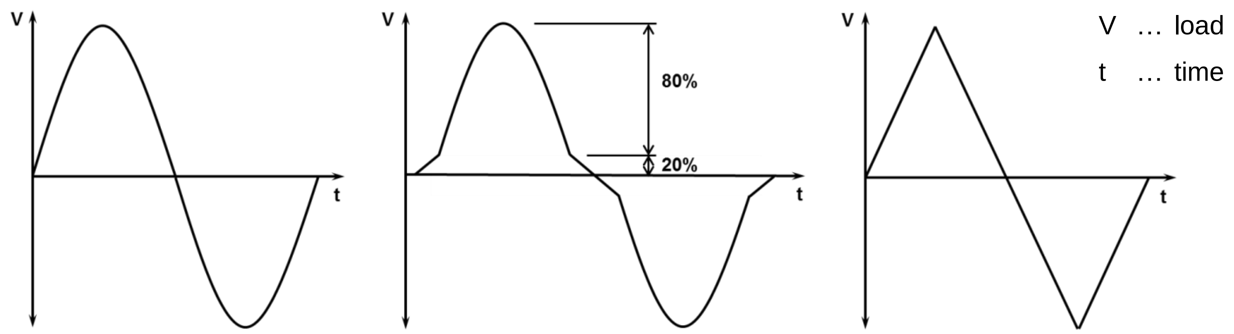
$A_{s,bol}$ = [mm²] - effective cross section of bolt;

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

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

Adjustment for different steel strengths in Equations (C.12) and (C.13) is not required if the fasteners tested in C2.2 and C2.4 are taken from the same production lot.

The load shall be applied parallel to the direction of the crack. To reduce the potential for uncontrolled slip during load reversal, an approximation by two half-sinusoidal load cycles at the required frequency connected by a reduced speed, ramped load (see Figure C.12b) or simply triangular loading cycles (see Figure C.12c) may be used in place of sinusoidal cycles (see Figure C.12a). The crack width shall be controlled during load cycling.




a) sinusoidal b) half sinusoidal with ramp c) triangular

**Figure C.12 Permitted seismic shear cycle C2.4**

Record the crack width, fastener displacement and applied shear load continuously during the simulated seismic shear cycles. Report the displacements at minimum and maximum load and the crack width as a function of the number of load cycles.

Following completion of the simulated seismic shear cycles unload the fastener. During the unloading of the fastener the crack width may get smaller. For the residual capacity test open the crack to $\Delta w$ = 0,8 mm, but not less than the crack opening width as measured at the end of the cyclic test, and load the fastener in shear to failure. Record the maximum shear load (residual shear capacity), the corresponding displacement, the crack width, and plot the load-displacement response.

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

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

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

*Note C.7* *During the shear load cycling test failure may occur in the embedded portion of the fastener. If such a failure occurs close to the embedded end of the fastener the residual capacity may not be significantly affected. Hence, in this case failure of the fastener during cycling may easily be overlooked. Attention should be paid to this aspect.*

### C.3.4.4 Tests with tension load and varying crack width (test series C2.5)

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

Tests shall be carried out on one fastener at a time with no other fasteners installed in the same crack.

Prior to installing fasteners in the test member, loading cycles as required to initiate cracking and to stabilise the relationship between crack width and applied load may be applied to the test member. This loading shall not exceed the elastic limit of the test member.

In order to create similar starting conditions when using a test member with one crack plane and a test member with multiple crack planes the initiated hairline crack may be closed by applying a centric compression force. Before installation of the fastener it shall be ensured that the compression force is not larger than $C_{ini}$ according to Equation (C.14).

$$C_{ini} = 0{,}01 \cdot f_{c,C2.5} \cdot A_g \quad [N] \tag{C.14}$$

where

$A_g$ = [mm²] - cross section area of the test member;

= $b \cdot h$, with $b$ and $h$ being the width and thickness of the test member, respectively;

$f_{c,C2.5}$ = [N/mm²] - mean compressive strength of concrete measured on cubes at the time of testing of the test series C2.5.

Install the fastener in the hairline crack according to C.3.1.2.

Place crack measurement displacement transducers according to C.3.1.3 and zero the devices. Following application of load to the fastener sufficient to remove any slack in the loading mechanism, begin recording the fastener displacement and increase the tension load on the fastener to $N_{w1}$ as given by Equation (C.16) to Equation (C.17). With the fastener load $N_{w1}$ held constant, begin the crack cycling program specified in Table C.5 and Figure C.13 with a cycling frequency no greater than 0,5 Hz. The first crack movement is in the direction of crack closure by applying a compression load on the test member.

*Note C.1:* *The initial crack width $w_{ini}$ after applying $N_{w1}$ may exceed $\Delta w$ = 0,1 mm. In this case the first crack movement in the direction of crack closure will close the crack and the crack cycling program is performed starting with $\Delta w$ = 0,1 mm (see Figure C.13).*

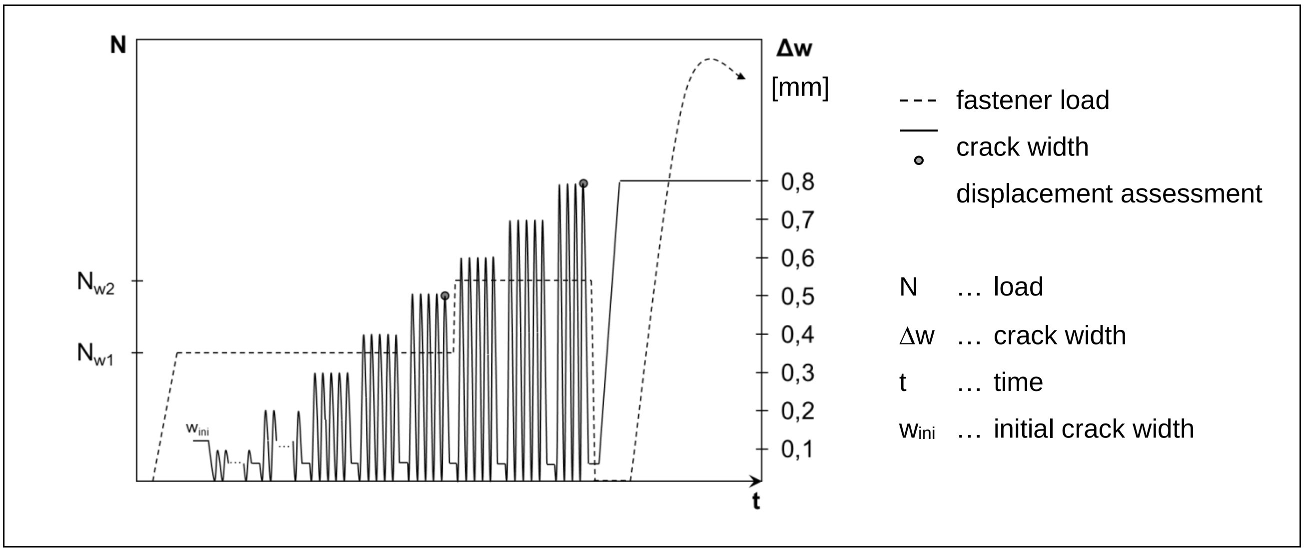



**Figure C.13 Schematic test procedure C2.5**

**Table C.5 Required crack widths for test series C2.5**

| Fastener load | Number of cycles | Crack width $\Delta w$ [mm] |
|---|---|---|
| $N_{w1}$ | 20 | 0,1 |
| $N_{w1}$ | 10 | 0,2 |
| $N_{w1}$ | 5 | 0,3 |
| $N_{w1}$ | 5 | 0,4 |
| $N_{w1}$ | 5 | 0,5 |
| $N_{w2}$ | 5 | 0,6 |
| $N_{w2}$ | 5 | 0,7 |
| $N_{w2}$ | 4 | 0,8 |
| | 59 | SUM |

In each cycle the crack shall be closed by applying a centric compression force $C_{test}$ according to Equation (C.15).

$$C_{test} = 0{,}1 \cdot f_{c,C2.5} \cdot A_g \quad [N] \tag{C.15}$$

where

$A_g$ = [mm²] - cross section area of the test member;

= $b \cdot h$, with $b$ and $h$ being the width and thickness of the test member, respectively;

$f_{c,C2.5}$ = [N/mm²] - mean compressive strength of concrete measured on cubes at the time of testing of the test series C2.5

If the crack is not closed to $\Delta w \le 0{,}1$ mm when applying $C_{test}$ according to Equation (C.15), the compression force shall be increased until either $\Delta w \le 0{,}1$ mm is achieved or the compression force reaches the maximum value of $C_{test,max} = 0{,}15 \cdot f_{c,C2.5} \cdot A_g$. This procedure fulfils the requirement of $\Delta w_1 = 0$ mm (see Table A.1).

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

Steel Failure

$$N_{w1} = 0{,}4 \cdot N_{u,m,C2.1a} \cdot \left( \frac{f_{u,C2.5}}{f_{u,C2.1a}} \right) \text{ [N]} \tag{C.16}$$

All other failure modes

$$N_{w1} = 0{,}4 \cdot N_{u,m,C2.1a} \cdot \left( \frac{f_{c,C2.5}}{f_{c,C2.1a}} \right)^{0,5} \text{ [N]} \tag{C.17}$$

where

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

$f_{u,C2.5}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.5;

$f_{u,C2.1a}$ = [N/mm²] - ultimate mean steel strength of fasteners used in the test series C2.1a;

$f_{c,C2.5}$ = [N/mm²] - mean compressive strength of concrete used at the time of testing in the test series C2.5;

$f_{c,C2.1a}$ = [N/mm²] - mean compressive strength of concrete used at the time of testing in the test series C2.1a;

If mixed failure modes occur in the test series C2.1a, the largest value of Equations (C.16) and (C.17) shall be applied.

After completion of the crack cycles at crack width $\Delta w$ = 0,5 mm, increase the tension load on the fastener to $N_{w2}$ as given by Equation (C.18) to Equation (C.19) and then continue the crack cycling sequence to completion.

Depending on the failure mode observed in the test series C2.1a, $N_{w2}$ is determined as follows:

Steel Failure

$$N_{w2} = 0{,}5 \cdot N_{u,m,C2.1a} \cdot \left( \frac{f_{u,C2.5}}{f_{u,C2.1a}} \right) \text{ [N]} \tag{C.18}$$

All other failure modes

$$N_{w2} = 0{,}5 \cdot N_{u,m,C2.1a} \cdot \left( \frac{f_{c,C2.5}}{f_{c,C2.1a}} \right)^{0,5} \text{ [N]} \tag{C.19}$$

with $N_{u,m,C2.1a}$, $f_{u,C2.5}$, $f_{u,C2.1a}$, $f_{c,C2.5}$ and $f_{c,C2.1a}$, as defined in Equation (C.16) and Equation(C.17).

If mixed failure modes occur in the test series C2.1a, the largest value of Equations (C.18) and (C.19) shall be applied.

Adjustment for different steel strengths in Equation (C.16) and Equation (C.18) is not required if the fasteners tested in C2.1 and C2.5 are taken from the same production lot.

Record the crack width, fastener displacement and applied tension load continuously during the simulated seismic crack cycles. Report the displacements at minimum and maximum crack width and the applied tension load as a function of the number of crack cycles.

Following completion of the simulated seismic crack cycles unload the fastener. During the unloading of the fastener the crack width may get smaller. For the residual capacity test open the crack to $\Delta w$ = 0,8 mm, but not less than the crack opening width as measured at the end of the cyclic test, and load the fastener in tension to failure. Record the maximum tension load (residual tension capacity), the corresponding displacement, the crack width, and plot the load-displacement response.

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

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

## C.4 ASSESSMENT OF TEST RESULTS

### C.4.1 Assessment for category C1

#### C.4.1.1 Assessment of tests under pulsating tension load (test series C1.1)

All fasteners in a test series shall complete the simulated seismic tension load history specified in Table C.1 and Figure C.7. Failure of a fastener to develop the required resistance in any cycle prior to completing the load history specified in Table C.1 and Figure C.7 shall be recorded as an unsuccessful test. The mean residual capacity of the fasteners in the test series shall be equal to or greater than 160% of $N_{C1}$ as given by Equation (C.1) or Equation (C.2), as applicable.

Successful completion of the cyclic loading history and fulfilment of the residual tension capacity requirement of this section shall be reported. In this case the seismic reduction factor for tension loading according to Equation (C.20) is $\alpha_{N,C1}$ = 1,0.

If the fastener fails to fulfil one of the above requirements at $N_{C1}$, it shall be permitted to conduct the test with reduced cyclic loads $N_{C1,red}$ until the requirements are met. The loading history specified in Table C.1 and Figure C.7 shall be applied, where $N_{C1,red}$, $N_{i,red}$ and $N_{m,red}$ are substituted for $N_{C1}$, $N_i$ and $N_m$, respectively. All fasteners in a test series shall complete the simulated seismic tension load history. Failure of a fastener to develop the required tension resistance in any cycle prior to completing the loading history given in Table C.1 and Figure C.7 shall be recorded as an unsuccessful test. The mean residual capacity of the fasteners in the test series shall be at least 160 % of the reduced load $N_{C1,red}$. Successful completion of the cyclic loading history with reduced load values and fulfilment of the residual tension capacity requirement of this section shall be recorded together with the type of failure mode causing the reduced load values and the reduction factor $\alpha_{N,C1}$, which is calculated as given in Equation (C.20).

$$\alpha_{N,C1} = \frac{N_{C1,red}}{N_{C1}} \qquad \text{(C.20)}$$

If the fastener successfully completes the cyclic loading history but does not fulfil the residual capacity requirement, a linear reduction (in the extent of actual residual capacity divided by required residual capacity) may be applied in terms of $\alpha_{N,C1}$ without repeating the test series.

The reduction factor $\alpha_{N,C1}$ is then valid for fasteners with the tested embedment depth and all smaller embedment depths.

If fasteners with more than one embedment depth have been tested and different failures are observed in these tests, different reduction factors for steel and pull-out (bond) failure may be obtained.

The reduction factor $\alpha_{N,C1}$ shall be used to determine the characteristic resistances under seismic loading according to C.4.3.1.

#### C.4.1.2 Assessment of tests under alternating shear load (test series C1.2)

All fasteners in a test series shall complete the simulated seismic shear load history specified in Table C.2 and Figure C.8. Failure of a fastener to develop the required resistance in any cycle prior to completing the loading history specified in Table C.2 and Figure C.8 shall be recorded as an unsuccessful test. The mean residual capacity of the fasteners in the test series shall be at least 160% of $V_{C1}$ given by Equation (C.5), Equation (C.6) or Equation (C.7), as applicable.

Successful completion of the cyclic loading history and fulfilment of the residual shear capacity requirement of this section shall be reported. In this case the seismic reduction factor for shear loading according to Equation (C.21) is $\alpha_{V,C1}$ = 1,0.

If the fastener fails to fulfil one of the above requirements at $V_{C1}$, it shall be permitted to conduct the test with reduced cyclic loads $V_{C1,red}$ until the requirements are met. The loading history specified in Table C.2 and Figure C.8 shall be applied, where $V_{C1,red}$, $V_{i,red}$ and $V_{m,red}$ are substituted for $V_{C1}$, $V_i$ and $V_m$, respectively. All fasteners in a test series shall complete the simulated seismic shear load history. Failure of a fastener to develop the required shear resistance in any cycle prior to completing the loading history given in Table C.2 and Figure C.8 shall be recorded as an unsuccessful test. The mean residual capacity of the fasteners in the test series shall be at least 160% of the reduced load $V_{C1,red}$. Successful completion of the cyclic history with reduced load values and fulfilment of the residual capacity requirement of this section shall be recorded together with a corresponding reduction factor $\alpha_{V,C1}$, which is calculated as given in Equation (C.21).

$$\alpha_{V,C1} = \frac{V_{C1,red}}{V_{C1}} \quad \text{(C.21)}$$

If the fastener successfully completes the cyclic loading history but does not fulfil the residual capacity requirement, a linear reduction (in the extent of actual residual capacity divided by required residual capacity) may be applied in terms of $\alpha_{V,C1}$ without repeating the test series.

The reduction factor $\alpha_{V,C1}$ shall be used to determine the characteristic resistance for seismic loading according to C.4.3.1.

The reduction factor $\alpha_{V,C1}$ according to Equation (C.21) is valid for all embedment depths greater than the tested embedment depth. If more than one embedment depth has been tested the reduction factor $\alpha_{V,C1}$ for an intermediate embedment depth may be determined by linear interpolation.

### C.4.2 Assessment for category C2

#### C.4.2.1 General requirements

##### C.4.2.1.1 Normalization of test results

The test results shall be normalised as follows:

Steel Failure

$$N_{u,m}(f_u) = N_{u,m,test} \cdot \left(\frac{f_u}{f_{u,test}}\right) \quad [N] \quad \text{(C.22)}$$

$$V_{u,m}(f_u) = V_{u,m,test} \cdot \left(\frac{f_u}{f_{u,test}}\right) \quad [N] \quad \text{(C.23)}$$

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

$$V_{u,m}(f_u) = V_{u,m,test} \cdot \left(\frac{f_u}{f_{u,test}} \cdot \frac{A_{s,bol}}{A_{s,fas}} + \frac{f_{u,sle}}{f_{u,sle,test}} \cdot \frac{A_{s,sle}}{A_{s,fas}}\right) [N] \quad \text{(C.24)}$$

All other failure modes

$$N_{u,m}(f_c) = N_{u,m,test} \cdot \left(\frac{f_c}{f_{c,test}}\right)^{0.5} \quad [N] \quad \text{(C.25)}$$

where

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

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

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

$N_{u,m}$ = [N] - normalized mean tension capacity;

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

$V_{u,m}$ = [N] - normalized mean shear capacity;

$V_{u,m,test}$ = [N] - mean shear capacity from the test series;

$f_c$ = [N/mm²] - mean compressive strength of concrete to which the capacity is to be normalized;

$f_{c,test}$ = [N/mm²] - mean compressive strength of concrete used at the time of testing;

$f_u$ = [N/mm²] - mean ultimate steel strength of bolt, threaded rod or insert to which the capacity is to be normalized;

$f_{u,sle}$ = [N/mm²] - mean ultimate steel strength of the sleeve to which the capacity is to be normalized;

$f_{u,sle,test}$ = [N/mm²] - ultimate steel strength of the sleeve of fasteners used in the tests;

$f_{u,test}$ = [N/mm²] - ultimate mean steel strength of bolt, threaded rod or insert of fasteners used in the tests;

m = normalization exponent according to A2.1.

Adjustment for different steel strengths in Equation (C.22) to Equation (C.24) is not required if the fasteners in all tests are taken from the same production lot.

If mixed failure modes occur in the test series C2.1, C2.3 and C2.5 the normalization shall be performed assuming that the failure mode, which was observed in the majority of tests in the test series, occurred in all tests.

#### C.4.2.1.2 Load/displacement behaviour

In the load/displacement curve for each fastener tested, a load plateau with a corresponding slip greater than 10% of the displacement at ultimate load, and/or a temporary drop in load of more than 5% of the ultimate load is not acceptable up to a load of 70 % of the ultimate load in the single test.

This requirement shall be fulfilled in the test series C2.1a and C2.1b, and in the initial loading as well as in the residual capacity tests of test series C2.3 and C2.5. If this requirement is not fulfilled, the fastener is not suitable for use in category C2.

### C.4.2.2 Assessment of reference tension tests (test series C2.1)

The following conditions apply:

1. Scatter of displacements:

$$cv\left(\delta\left(0{,}5 \cdot N_{u,m,C2.1}\right)\right) \leq 40\% \tag{C.26}$$

with

$cv$ = [%] - coefficient of variation;

$\delta(0{,}5 \cdot N_{u,m,C2.1})$ = [mm] - displacement of the fastener at 50% of mean ultimate load of test series C2.1a and b, i.e. $N_{u,m,C2.1a}$ and $N_{u,m,C2.1b}$, respectively .

If this condition is not fulfilled for one of the test series, the fastener is not suitable for use in category C2. It is allowed to increase the number of tests to fulfil this requirement. Note that if in a test series displacements of all fasteners at the load 0,5 $N_{u,m}$ are smaller than or equal to 0,4 mm the above condition on the scatter of the displacement does not apply.

2. Ultimate load:

   a. Test series C2.1a in low strength concrete C20/25:

$$N_{u,m,C2.1a} \geq 0{,}8 \cdot N_{u,m,3} \tag{C.27}$$

with

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

$N_{u,m,3}$ = [N] - mean tension capacity from the tests for “maximum crack width and large hole diameter” in cracked concrete C20/25 according to Table A.1 series F1;

If this condition is fulfilled, $\alpha_{C2.1a}$ = 1,0. If the condition is not fulfilled, the reduction factor $\alpha_{C2.1a}$ is determined for the test series C2.1a according to Equation (C.28).

$$\alpha_{C2.1a} = \frac{N_{u,m,C2.1a}}{0{,}8 \cdot N_{u,m,3}} \tag{C.28}$$

In Equations (C.27) and (C.28) the resistances from the tests for “maximum crack width and large hole diameter” in cracked concrete C20/25 according Table A.1 series F1, shall be normalized according to Equation (C.22) or Equation (C.24), as applicable, to the strength in test series C2.1a.

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

$$N_{u,m,C2.1b} \geq 0{,}8 \cdot N_{u,m,4} \tag{C.29}$$

with

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

$N_{u,m,4}$ = [N] - mean tension capacity from the tests for “maximum crack width and small hole diameter” in cracked concrete C50/60 according to Table A.1 series F2.

If this condition is fulfilled, $\alpha_{C2.1b}$ = 1,0. If the condition is not fulfilled, the reduction factor $\alpha_{C2.1b}$ is determined for the test series C2.1b according to Equation (C.30).

$$\alpha_{C2.1b} = \frac{N_{u,m,C2.1b}}{0{,}8 \cdot N_{u,m,4}} \tag{C.30}$$

In Equations (C.29) and (C.30) the resistances from the tests for “maximum crack width and small hole diameter” in cracked concrete C50/60 according to Table A.1 series F2 shall be normalized according to Equation (C.22) or Equation (C.24), as applicable, to the strength in test series C2.1b.

The reduction factor $\alpha_{C2.1}$ is determined according to Equation (C.31).

$$\alpha_{C2.1} = \min\left(\alpha_{C2.1a}; \alpha_{C2.1b}\right) \tag{C.31}$$

3. Scatter of ultimate loads:

$$cv(N_u) \leq 20\% \tag{C.32}$$

If this condition is fulfilled for both test series C2.1a and C2.1b, $\beta_{cv,C2.1a} = \beta_{cv,C2.1b}$ = 1,0. If this condition is not fulfilled in a test series, the factors $\beta_{cv,C2.1a}$ and/or $\beta_{cv,C2.1b}$ shall be calculated according to Equation (C.33) and Equation (C.34), respectively.

$$\beta_{cv,C2.1a} = \frac{1}{1 + \left(cv\left(N_{u,C2.1a}\right) - 20\right) \cdot 0{,}03} \tag{C.33}$$

$$\beta_{cv,C2.1b} = \frac{1}{1 + \left(cv\left(N_{u,C2.1b}\right) - 20\right) \cdot 0{,}03} \tag{C.34}$$

where $cv(N_{u,C2.1a})$ and $cv(N_{u,C2.1b})$ are the coefficients of variation of the ultimate loads in test series C2.1a and C2.1b, respectively.

The factor $\beta_{cv,C2.1}$ is determined as given in Equation (C.35):

$$\beta_{cv,C2.1} = \min\left(\beta_{cv,C2.1a}; \beta_{cv,C2.1b}\right) \tag{C.35}$$

If $cv(N_u)$ is larger than 30% in one test series, the fastener is not suitable for use in category C2. It shall be allowed to increase the number of tests in a test series to possibly fulfil this requirement.

### C.4.2.3 Assessment of reference shear tests (test series C2.2)

If calculated values or results of tests for “characteristic resistance to steel failure under shear load” according to Table A.1 series V1, are taken as reference tests, this section does not apply. If test series C2.2 are performed for reference shear values the following conditions apply:

1. Failure mode:

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

2. Ultimate load:

$$V_{u,m,C2.2} \geq 0{,}8 \cdot V_{u,m,5} \tag{C.36}$$

with

$V_{u,m,C2.2}$ = [N] - mean ultimate shear load from test series C2.2;

$V_{u,m,5}$ = [N] - mean shear capacity from the tests for “characteristic resistance to steel failure under shear load" according to Table A.1 series V1.

If this condition is fulfilled, $\alpha_{C2.2}$ = 1,0. If this condition is not fulfilled, the factor $\alpha_{C2.2}$ shall be determined according to Equation (C.37).

$$\alpha_{C2.2} = \frac{V_{u,m,C2.2}}{0{,}8 \cdot V_{u,m,5}} \tag{C.37}$$

In Equations (C.36) and (C.37) the resistances from the tests for “characteristic resistance to steel failure under shear load” according to Table A.1 series V1, shall be normalized according to Equation (C.23) or Equation (C.24), as applicable, to the strength in test series C2.2.

3. Scatter of ultimate loads:

$$cv(V_u) \leq 15\% \tag{C.38}$$

If this condition is fulfilled, $\beta_{cv,C2.2}$ = 1,0. If this condition is not fulfilled, the factor $\beta_{cv,C2.2}$ shall be determined according to Equation (C.39).

$$\beta_{cv,C2.2} = \frac{1}{1 + (cv(V_u) - 15) \cdot 0{,}03} \tag{C.39}$$

where $cv(V_u)$ is the coefficient of variation of the ultimate loads in test series C2.2.

If $cv(V_u)$ is larger than 30%, the fastener is not suitable for use in category C2.

### C.4.2.4 Assessment of tests under pulsating tension load (test series C2.3)

The following conditions apply:

1. All fasteners in a test series shall complete the pulsating tension load history specified in Figure C.10 and Table C.3. Failure of a fastener to develop the required resistance in any cycle prior to completing the loading history specified in Table C.3 shall be recorded as an unsuccessful test. In case of an unsuccessful test, the test series shall be repeated with a reduced value $N_{max,red,1}$ until the requirement is fulfilled. In this case the reduction factor $\alpha_{C2.3a}$ shall be calculated according to Equation (C.40).

$$\alpha_{C2.3a} = \frac{N_{max,red,1}}{N_{max}} \tag{C.40}$$

with

$N_{max}$ = [N] - maximum tension load according to Equation (C.10) to Equation (C.11).

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

2. Displacements are assessed during the last cycle at $0{,}5 \cdot N/N_{max}$ and at $1{,}0 \cdot N/N_{max}$ or at $0{,}5 \cdot N/N_{max,red,1}$ and at $1{,}0 \cdot N/N_{max,red,1}$, respectively, (refer to Figure C.10). Displacements shall be reported in terms of the mean value.

   To avoid excessive displacement of the fastener a displacement limit at the end of load cycling at $0{,}5 \cdot N/N_{max}$ or $0{,}5 \cdot N/N_{max,red,1}$ (i.e. after 50 load cycles (see Figure C.10 and Table C.3) is introduced for the assessment of fasteners. The following condition shall be fulfilled:

$$\delta_m(0{,}5 \cdot N/N_{\max}) \leq \delta_{N,\lim} \tag{C.41}$$

with

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

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

If this condition is not fulfilled repeat the tests with a reduced value $N_{max,red,2}$ until the requirement is fulfilled and calculate the reduction factor $\alpha_{C2.3b}$ according to Equation (C.42).

$$\alpha_{C2.3b} = \frac{N_{max,red,2}}{N_{max}} \tag{C.42}$$

with

$N_{max}$ = [N] - maximum tension load according to Equation (C.10) to Equation (C.11);

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

If the condition according to Equation (C.41) is fulfilled but a smaller displacement is intended it shall be permitted to repeat the tests with a reduced value $N_{max,red}$.

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

   a. Scatter of displacement:

$$cv\left(\delta\left(0{,}5 \cdot N_{u,m,C2.3}\right)\right) \leq 40\% \tag{C.43}$$

with

$\delta\,(0{,}5 \cdot N_{u,m,C2.3})$ = [mm] - displacement of the fastener at 50% of the mean ultimate tension load from the residual capacity tests of test series C2.3. Only the displacement in the residual capacity test is taken, i.e., the displacement that occurred during the cyclic loading is neglected.

$N_{u,m,C2.3}$ = [N] - mean ultimate tension load from residual capacity tests of test series C2.3.

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

   b. Ultimate load:

$$N_{u,m,C2.3} \geq 0{,}9 \cdot N_{u,m,C2.1a} \tag{C.44}$$

with

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

$N_{u,m,C2.3}$ = [N] - mean ultimate tension load from residual capacity tests of test series C2.3.

If this condition is fulfilled, $\alpha_{C2.3c}$ = 1,0. If this condition is not fulfilled, the factor $\alpha_{C2.3c}$ shall be determined according to Equation (C.45).

$$\alpha_{C2.3c} = \frac{N_{u,m,C2.3}}{0{,}9 \cdot N_{u,m,C2.1a}} \tag{C.45}$$

In Equations (C.44) and (C.45) the resistances from test series C2.1a shall be normalized according to Equation (C.22) or Equation (C.24), as applicable, to the strength in test series C2.3.

Equally, the test series C2.3 may be repeated with a reduced value of $N_{max}$ until the requirement given in Equation (C.44) is fulfilled.

   c. Scatter of ultimate loads:

$$cv\left(N_u\right) \leq 20\% \tag{C.46}$$

If this condition is fulfilled, $\beta_{cv,C2.3}$ = 1,0. If this condition is not fulfilled, $\beta_{cv,C2.3}$ shall be determined according to Equation (C.47).

$$\beta_{cv,C2.3} = \frac{1}{1 + \left(cv(N_u) - 20\right) \cdot 0{,}03} \tag{C.47}$$

where $cv(N_u)$ is the coefficient of variation of the ultimate loads in the residual capacity tests in test series C2.3.

If $cv(N_u)$ is larger than 30%, the fastener is not suitable for use in category C2.

The reduction factor $\alpha_{C2.3}$ resulting from the pulsating tension test series C2.3 is determined according to Equation (C.48).

$$\alpha_{C2.3} = \min(\alpha_{C2.3a};\alpha_{C2.3b}) \cdot \alpha_{C2.3c} \tag{C.48}$$

Report the displacements after successful completion at $0{,}5 \cdot N/N_{max}$ and $1{,}0 \cdot N/N_{max}$ or at $0{,}5 \cdot N/N_{max,red}$ and $1{,}0 \cdot N/N_{max,red}$ in case the tests are repeated with a reduced load value, as applicable.

### C.4.2.5 Assessment of tests under alternating shear load (test series C2.4)

The following conditions apply:

1. All fasteners in a test series shall complete the alternating shear load history specified in Figure C.11 and Table C.4. Failure of a fastener to develop the required resistance in any cycle prior to completing the loading history specified in Table C.4 shall be recorded as an unsuccessful test. In case of an unsuccessful test, the test series shall be repeated with a reduced value $V_{max,red,1}$ until the requirement is fulfilled. In this case the reduction factor $\alpha_{C2.4a}$ shall be calculated according to Equation (C.49).

$$\alpha_{C2.4a} = \frac{V_{max,red,1}}{V_{max}} \tag{C.49}$$

with

$V_{max}$ = [N] - maximum shear load according to Equation (C.12) or Equation (C.13);

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

2. Displacements are assessed during the last cycle at $\pm 0{,}5 \cdot V/V_{max}$ and $\pm 1{,}0 \cdot V/V_{max}$ or $\pm 0{,}5 \cdot V/V_{max,red,1}$ and $\pm 1{,}0 \cdot V/V_{max,red,1}$ (refer to Figure C.11). Displacements shall be reported as the maximum of the mean of the absolute values in the positive loading direction and the mean of the absolute values in the negative loading direction.

   To avoid excessive displacement of the fastener a displacement limit at the end of load cycling at $\pm 0{,}5 \cdot V/V_{max}$ (i.e. at load cycle 50 (see Figure C.11 and Table C.4) is introduced for the assessment of fasteners. Due to lack of sufficient test data this limit is assumed as $\delta_{V,lim}$ = 7 mm. The following condition shall be fulfilled:

$$\delta_m(0{,}5 \cdot V/V_{\max}) \le \delta_{V,\lim} \tag{C.50}$$

with

$\delta_m(0{,}5 \cdot V/V_{max})$ = [mm] - max ($|\delta_m(+0{,}5 \cdot V/V_{max})|$; $|\delta_m(-0{,}5 \cdot V/V_{max})|$); maximum of the mean value of displacements of the fastener after load cycling at $+0{,}5 \cdot V/V_{max}$ and the mean value of displacements of the fastener after load cycling at $-0{,}5 \cdot V/V_{max}$ of test series C2.4; if the tests have been performed with $V_{max,red,1}$ replace $V_{max}$ by $V_{max,red,1}$;

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

If the condition is not fulfilled repeat the tests with a reduced value $V_{max,red,2}$ until the requirement is fulfilled. Determine the corresponding reduction factor $\alpha_{C2.4b}$ in accordance with Equation (C.51).

$$\alpha_{C2.4b} = \frac{V_{max,red,2}}{V_{max}} \tag{C.51}$$

with

$V_{max}$ = [N] - maximum shear load according to Equation (C.12) or Equation (C.13);

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

If the condition according to Equation (C.50) is fulfilled but a smaller displacement is intended it shall be permitted to repeat the tests with a reduced value $V_{max,red}$.

3. Residual capacity tests (both conditions apply):
   a. Failure mode:

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

   b. Ultimate load:

$$V_{u,m,C2.4} \geq 0{,}95 \cdot V_{u,m,C2.2} \tag{C.52}$$

with

$V_{u,m,C2.4}$ = [N] - mean ultimate shear load from residual capacity tests of test series C2.4.

$V_{u,m,C2.2}$ = [N] - mean ultimate shear load from residual capacity tests of test series C2.2.

If this condition is fulfilled, $\alpha_{C2.4c}$ = 1,0. If this condition is not fulfilled, the factor $\alpha_{C2.4c}$ shall be determined according to Equation (C.53).

$$\alpha_{C2.4c} = \frac{V_{u,m,C2.4}}{0{,}95 \cdot V_{u,m,C2.2}} \tag{C.53}$$

In Equations (C.55) and (C.56) the resistances from test series C2.2 shall be normalized according to Equation (C.23) or Equation (C.24), as applicable, to the strength in test series C2.4.

Equally, the test series C2.4 may be repeated with a reduced value of $V_{max}$ until the requirement given in Equation (C.52) is fulfilled.

   c. Scatter of ultimate loads:

$$cv(V_u) \leq 15\% \tag{C.54}$$

If this condition is fulfilled, $\beta_{cv,C2.4}$ = 1,0. If this condition is not fulfilled, $\beta_{cv,C2.4}$ shall be determined according to Equation (C.55).

$$\beta_{cv,C2.4} = \frac{1}{1 + (cv(V_u) - 15) \cdot 0{,}03} \tag{C.55}$$

where $cv(V_u)$ is the coefficient of variation of the ultimate loads in the residual capacity tests in test series C2.4.

If $cv(V_u)$ is larger than 30%, the fastener is not suitable for use in category C2.

The reduction factor $\alpha_{C2.4}$ resulting from the alternating shear load test series C2.4 is determined according to Equation (C.56).

$$\alpha_{C2.4} = \min(\alpha_{C2.4a}; \alpha_{C2.4b}) \cdot \alpha_{C2.4c} \tag{C.56}$$

Report the displacements after successful completion at ±0,5·$V/V_{max}$ and ±1,0·$V/V_{max}$ or at ±0,5·$V/V_{max,red}$ and ±1,0·$V/V_{max,red}$ in case the tests are repeated with a reduced shear load, as applicable.

#### C.4.2.6 Assessment of tests under tension load with varying crack width (test series C2.5)

The following conditions apply:

1. All fasteners in the test series shall complete the varying crack width history under tension load specified in Figure C.13 and Table C.5. Failure of a fastener to develop the required resistance in any cycle prior to completing the crack cycling history specified in Table C.5 shall be recorded as an unsuccessful test. In case of an unsuccessful test, the test series shall be repeated with proportionally reduced values of $N_{w1}$ and $N_{w2}$, i.e. $N_{w1,red,1}$ and $N_{w2,red,1}$, respectively, until the requirement is fulfilled. The corresponding reduction factor $\alpha_{C2.5a}$ shall be calculated according to Equation (C.57).

$$\alpha_{C2.5a} = \frac{N_{w2,red,1}}{N_{w2}} \tag{C.57}$$

with

$N_{w2}$ = [N] - tension load according to Equation (C.18) and Equation (C.19) as applicable;

$N_{w2,red,1}$ = [N] - reduced tension load to fulfil the requirement.

2. Displacements are assessed during the last cycle at $\Delta w$ = 0,5 mm and $\Delta w$ = 0,8 mm (see Figure C.13). Displacements shall be reported in terms of the mean value.

   To avoid excessive displacement of the fastener a displacement limit at the end of cycling at $\Delta w$ = 0,5 mm (i.e. at the end of cycle 45, see Figure C.13 and Table C.5) is introduced for the assessment of fasteners. Due to lack of sufficient test data this limit is assumed as $\delta_{N,lim}$ = 7 mm. The following condition shall be fulfilled:

$$\delta_m(\Delta w = 0{,}5) \leq \delta_{N,\mathrm{lim}} \tag{C.58}$$

   with

   $\delta_m$ ($\Delta w$ = 0,5) = [mm] - mean value of displacements of the fastener at the end of cycling at $\Delta w$ = 0,5 mm of test series C2.5;

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

   If this condition is not fulfilled repeat the tests with proportionally reduced values of $N_{w1}$ and $N_{w2}$, i.e. $N_{w1,red,2}$ and $N_{w2,red,2}$, respectively, until the requirement is fulfilled and calculate the reduction factor $\alpha_{C2.5b}$ according to Equation (C.59).

$$\alpha_{C2.5b} = \frac{N_{w2,red,2}}{N_{w2}} \tag{C.59}$$

   with

   $N_{w2}$ = [N] - tension load according to Equation (C.18) and Equation (C.19);

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

   If the condition according to Equation (C.58) is fulfilled but a smaller displacement is intended it shall be permitted to repeat the tests with proportionally reduced values $N_{w1,red,2}$ and $N_{w2,red,2}$.

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

   a. Scatter of displacement:

$$cv\left(\delta\left(0{,}5 \cdot N_{u,m,C2.5}\right)\right) \leq 40\% \tag{C.60}$$

      with

      $\delta$ (0,5 · $N_{u,m,C2.5}$) = [mm] - displacement of the fastener at 50% of the mean ultimate tension load from the residual capacity tests of test series C2.5; displacement in the residual capacity test only, i.e., neglecting the displacement that occurred during the crack cyclic.

      $N_{u,m,C2.5}$ = [N] - mean ultimate tension load from residual capacity tests of test series C2.5.

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

   b. Ultimate load:

$$N_{u,m,C2.5} \geq 0{,}9 \cdot N_{u,m,C2.1a} \tag{C.61}$$

      with

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

      $N_{u,m,C2.5}$ = [N] - mean ultimate tension load from residual capacity tests of test series C2.5.

      If this condition is fulfilled, $\alpha_{C2.5c}$ = 1,0. If this condition is not fulfilled, the factor $\alpha_{C2.5c}$ shall be determined according to Equation (C.62).

$$\alpha_{C2.5c} = \frac{N_{u,m,C2.5}}{0{,}9 \cdot N_{u,m,C2.1a}} \qquad (C.62)$$

In Equations (C.61) and (C.62) the resistances from test series C2.1a shall be normalized according to Equation (C.22) or Equation (C.25), as applicable, to the strength in test series C2.5.

Equally, the test series C2.5 may be repeated with a reduced value of $N_{max}$ until the requirement given in Equation (C.61) is fulfilled.

c. Scatter of ultimate loads:

$$cv(N_u) \leq 20\% \qquad (C.63)$$

If this condition is fulfilled, $\beta_{cv,C2.5}$ = 1,0. If this condition is not fulfilled, $\beta_{cv,C2.5}$ shall be determined according to Equation (C.64).

$$\beta_{cv,C2.5} = \frac{1}{1 + (cv(N_u) - 20) \cdot 0{,}03} \qquad (C.64)$$

If $cv(N_u)$ is larger than 30%, the fastener is not suitable for use in category C2.

The reduction factor $\alpha_{C2.5}$ resulting from the varying crack width test series C2.3 is determined according to Equation (C.65).

$$\alpha_{C2.5} = \min(\alpha_{C2.5a}; \alpha_{C2.5b}) \cdot \alpha_{C2.5c} \qquad (C.65)$$

Report the displacements after successful completion at the end of crack cycling at $\Delta w$ = 0,5 mm and $\Delta w$ = 0,8 mm.

### C.4.2.7 Determination of decisive reduction factors for seismic category C2

#### C.4.2.7.1 Tension

The reduction factors $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ are determined according to Equations (C.66) and (C.67), respectively.

$$\alpha_{N,C2} = \alpha_{C2.1} \cdot \min(\alpha_{C2.3}; \alpha_{C2.5}) \qquad (C.66)$$

where

$\alpha_{C2.1}$ = reduction factor $\alpha$ according to C.4.2.2;

$\alpha_{C2.3}$ = reduction factor $\alpha$ according to C.4.2.4;

$\alpha_{C2.5}$ = reduction factor $\alpha$ according to C.4.2.6.

$$\beta_{cv,N,C2} = \min(\beta_{cv,C2.1}; \beta_{cv,C2.3}; \beta_{cv,C2.5}) \qquad (C.67)$$

where

$\beta_{cv,C2.1}$ = reduction factor $\beta_{cv}$ accounting for large scatter according to C.4.2.2;

$\beta_{cv,C2.3}$ = reduction factor $\beta_{cv}$ accounting for large scatter according to C.4.2.4;

$\beta_{cv,C2.5}$ = reduction factor $\beta_{cv}$ accounting for large scatter according to C.4.2.6.

The reduction factors according to Equation (C.66) and Equation (C.67) are valid for fasteners with the tested embedment depth and all smaller embedment depths.

If fasteners with more than one embedment depth have been tested and different failure modes are observed in these tests, different reduction factors for steel and pull-out (bond) failure may be obtained.

The reduction factors $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ shall be used to determine the characteristic resistances under seismic loading according to C.4.3.2.1.

#### C.4.2.7.2 Shear

The reduction factors $\alpha_{V,C2}$ and $\beta_{cv,V,C2}$ are determined according to Equations (C.68) and (C.69), respectively.

$$\alpha_{V,C2} = \alpha_{C2.2} \cdot \alpha_{C2.4} \quad (C.68)$$

where

$\alpha_{C2.2}$ = reduction factor $\alpha$ according to C.4.2.3;

$\alpha_{C2.4}$ = reduction factor $\alpha$ according to C.4.2.5.

$$\beta_{cv,V,C2} = \min(\beta_{cv,C2.2}; \beta_{cv,C2.4}) \quad (C.69)$$

where

$\beta_{cv,C2.2}$ = reduction factor $\beta_{cv}$ accounting for large scatter according to C.4.2.3;

$\beta_{cv,C2.4}$ = reduction factor $\beta_{cv}$ accounting for large scatter according to C.4.2.5;

The reduction factors according to Equation (C.68) and Equation (C.69) are valid for fasteners with the tested embedment depth and all larger embedment depths. If more than one embedment depth has been tested the reduction factors $\alpha_{V,C2}$ and $\beta_{cv,V,C2}$ for an intermediate embedment depth may be determined by linear interpolation.

The reduction factors $\alpha_{V,C2}$ and $\beta_{cv,V,C2}$ shall be used to determine the characteristic resistances under seismic loading according to C.4.3.2.2.

### C.4.3 Characteristic values for seismic design

In this assessment it is assumed that the characteristic resistances under seismic action for concrete failure modes (concrete cone breakout in tension and concrete edge breakout and pry-out failure in shear) are covered in the design method by applying reduction factors to the corresponding characteristic resistances under non-seismic loading conditions.

### C.4.3.1 Seismic performance category C1

#### C.4.3.1.1 Tension

The characteristic resistances as determined below are valid for fasteners with the tested embedment depth and all smaller embedment depths.

a. Steel failure caused reduction:

The characteristic resistances for steel tension and pull-out under seismic loading, i.e. $N_{Rk,s,C1}$ and $N_{Rk,p,C1}$, respectively, to be reported in the ETA are determined as follows:

$$N_{Rk,s,C1} = \alpha_{N,C1} \cdot N_{Rk,s} \quad [N] \quad (C.70)$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,p} \quad [N] \quad (C.71)$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,c} \quad [N] \quad \text{(if no pull-out failure occurs for static loading)} \quad (C.72)$$

where

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

$N_{Rk,p}$ = [N] - characteristic pull-out resistance in cracked concrete as reported in the ETA for static loading;

$N_{Rk,c}$ = [N] - characteristic concrete cone resistance in cracked concrete for static loading;

$\alpha_{N,C1}$ = reduction factor $\alpha$ according to C.4.1.1.

b. Pull-out failure caused reduction:

The characteristic resistances for steel tension and pull-out under seismic loading, i.e. $N_{Rk,s,C1}$ and $N_{Rk,p,C1}$, respectively, to be reported in the ETA are determined as follows:

$$N_{Rk,s,C1} = N_{Rk,s} \quad [N] \quad (C.73)$$

$$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,p} \quad [N] \quad (C.74)$$

$N_{Rk,p,C1} = \alpha_{N,C1} \cdot N_{Rk,c}$ [N] (if no pull-out failure occurs for static loading) (C.75)

For $N_{Rk,s}$, $N_{Rk,p}$, $N_{Rk,c}$, and $\alpha_{N,C1}$ see a.

**C.4.3.1.2 Shear**

The characteristic shear resistance for steel under seismic loading, $V_{Rk,s,C1}$, to be reported in the ETA is determined as follows:

$V_{Rk,s,C1} = \alpha_{V,C1} \cdot V^0_{Rk,s}$ [N] (C.76)

where

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

$\alpha_{V,C1}$ = reduction factor $\alpha$ according to C.4.1.2.

The value $V_{Rk,s,C1}$ according to Equation (C.76) is valid for all embedment depths greater than the tested embedment depth. If more than one embedment depth has been tested the value $V_{Rk,s,C1}$ for an intermediate embedment depth may be determined by linear interpolation.

**C.4.3.2 Seismic performance category C2**

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

**C.4.3.2.1 Tension loading**

The characteristic resistances as determined below are valid for fasteners with the tested embedment depth and all smaller embedment depths (see C.3.2.1.3.1 b)).

The characteristic resistance for seismic actions as given in the following shall be limited by the values for static and quasi-static loading.

a) Steel failure caused reduction:
The characteristic resistances for steel tension and pull-out under seismic loading, i.e. $N_{Rk,s,C2}$ and $N_{Rk,p,C2}$, respectively, to be reported in the ETA are determined as follows:

$N_{Rk,s,C2} = \alpha_{N,C2} \cdot \beta_{cv,N,C2} \cdot N_{Rk,s}$ [N] (C.77)

$N_{Rk,p,C2} = \alpha_{N,C2} \cdot \beta_{cv,N,C2} \cdot N_{Rk,0}$ [N] (C.78)

where

$N_{Rk,0}$ = [N] - characteristic value of tests for “maximum crack width and large hole diameter (F1)” and “maximum crack width and small hole diameter (F2)” according to Table A.1 series F1, (normalized according to Equation (C.22) to Equation (C.25) to the compressive strength of concrete (measured on cylinders) of $f_c$ = 20 N/mm²);

Note C.2: *The characteristic value $N_{Rk,0}$ may be determined as follows:*
*(1) determine the characteristic value of the test series F1 and F2 separately and take the minimum of the two;*
*(2) determine the characteristic value of the combined test data of the test series F1 and F2;*
*(3) take the maximum of (1) and (2),*
*i.e. $N_{Rk,0}$ = max (min (F1; F2); (F1 U F2)).*

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

$\alpha_{N,C2}$ = reduction factor $\alpha$ as determined in Equation (C.66);

$\beta_{cv,N,C2}$ = reduction factor $\beta_{cv}$ accounting for large scatter as determined in Equation (C.67).

b) Pull-out failure caused reduction:

The characteristic resistances for steel tension and pull-out under seismic loading, i.e. $N_{Rk,s,C2}$ and $N_{Rk,p,C2}$, respectively, to be reported in the ETA are determined as follows:

$N_{Rk,s,C2} = N_{Rk,s}$ [N] (C.79)

$$N_{Rk,p,C2} = \alpha_{N,C2} \cdot \beta_{cv,N,C2} \cdot N_{Rk,0} \text{ [N]} \tag{C.80}$$

with $N_{Rk,0}$, $N_{Rk,s}$, $\alpha_{N,C2}$ and $\beta_{cv,N,C2}$ as given in Equation (C.77) and Equation (C.78).

#### C.4.3.2.2 Shear loading

Under shear loading only steel failure is considered in the evaluation. Pry-out and concrete edge failure are taken into account in the design provisions.

The characteristic steel shear resistance under seismic shear loading, $V_{Rk,s,C2}$, to be reported in the ETA is determined as follows:

$$V_{Rk,s,C2} = \alpha_{V,C2} \cdot \beta_{cv,V,C2} \cdot V^0_{Rk,s} \quad \text{[N]} \tag{C.81}$$

where

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

$\alpha_{V,C2}$ = reduction factor $\alpha$ according to Equation (C.68);

$\beta_{cv,V,C2}$ = reduction factor $\beta_{cv}$ accounting for large scatter according to Equation (C.69).

The characteristic resistance according to Equation (C.81) is valid for fasteners with the tested embedment depth and all larger embedment depths. If more than one embedment depth has been tested the characteristic resistance for an intermediate embedment depth may be determined by linear interpolation.

#### C.4.3.2.3 Displacements

The displacement values reported in the ETA are determined as given in Table C.6.

**Table C.6 Displacement information**

| Displacement [1)] | Obtained from |
|---|---|
| $\delta_{N,C2(DLS)}$ | Maximum of the mean value of displacements reported at 0,5·$N/N_{max}$ and 0,5·$N/N_{max,red}$ (as applicable) of C2.3 tests and the mean value of displacements reported at $\Delta w$ = 0,5 mm of C2.5 tests. |
| $\delta_{N,C2(ULS)}$ | Maximum of the mean value of displacements reported at 1,0·$N/N_{max}$ and 1,0·$N/N_{max,red}$ (as applicable) of C2.3 tests and the mean value of displacements reported at $\Delta w$ = 0,8 mm of C2.5 tests. |
| $\delta_{V,C2(DLS)}$ | Mean value of displacements reported at 0,5·$V/V_{max}$ and 0,5·$V/V_{max,red}$ (as applicable) of C2.4 tests. |
| $\delta_{V,C2(ULS)}$ | Mean value of displacements reported at 1,0·$V/V_{max}$ and 1,0·$V/V_{max,red}$ (as applicable) of C2.4 tests. |

1) DLS – Damage Limitation State (see EN 1998-1 [30], 2.2.1)
ULS – Ultimate Limit State (see EN 1998-1 [30], 2.2.1)

### C.4.3.3 Partial factor $\gamma_{M,C2}$

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

### C.4.3.4 Reduction factor $\alpha_{gap}$

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

In the design approach of EN 1992-4 [4] this effect is considered in the resistance of the fastening by introducing the reduction factor $\alpha_{gap}$.

The factor $\alpha_{gap}$ is taken as equal to 0,5 for fasteners with hole clearance according to EN 1992-4 [4], Table 6.1 or equal to 1,0 if the product specifications and or the MPII require a proper filling of the annular gap and shear tests were carried out accordingly. The TAB shall check if for a group of fasteners, the annular gap can be filled with the respective filling material according to the MPII. Otherwise, $\alpha_{gap}$ is taken as equal to 0,0.

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

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

### C.4.3.5 Content of the European Technical Assessment (ETA)

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

An example of the information for characteristic values for design of fasteners under seismic action is shown in Table C.7 and Table C.8.

**Table C.7 Sample ETA seismic design information for seismic performance category C1**

| **Fastener type** | | **M…** | **…** | **M…** |
|---|---|---|---|---|
| *(static design information)* | | xx | | xx |
| **Seismic design information** | | | | |
| $N_{Rk,s,C1}$ | [kN] | xx | | xx |
| $\gamma_{Ms,C1}$ 1) | [-] | xx | | xx |
| $N_{Rk,p,C1}$ | [kN] | xx | | xx |
| $\gamma_{Mp,C1}$ 1) | [-] | xx | | xx |
| $V_{Rk,s,C1}$ | [kN] | xx | | xx |
| $\gamma_{Ms,C1}$ 1) | [-] | xx | | xx |
| | | | | |

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

**Table C.8 Sample ETA seismic design information for seismic performance category C2**

| **Fastener type** | | **M…** | **…** | **M…** |
|---|---|---|---|---|
| *(static design information)* | | xx | | xx |
| **Seismic design information** | | | | |
| $N_{Rk,s,C2}$ 2) | [kN] | xx | | xx |
| $\gamma_{Ms,C2}$ 3) | [-] | xx | | xx |
| $N_{Rk,p,C2}$ 2) | [kN] | xx | | xx |
| $\gamma_{Mp,C2}$ 3) | [-] | xx | | xx |
| $\delta_{N,C2(DLS)}$ 1) 2) | [mm] | xx | | xx |
| $\delta_{N,C2(ULS)}$ 1) | [mm] | xx | | xx |
| $V_{Rk,s,C2}$ 2) | [kN] | xx | | xx |
| $\gamma_{Ms,C2}$ 3) | [-] | xx | | xx |
| $\delta_{V,C2(DLS)}$ 1) 2) | [mm] | xx | | xx |
| $\delta_{V,C2(ULS)}$ 1) | [mm] | xx | | xx |
| DLS – Damage Limitation State (see EN 1998-1 [30], 2.2.1) | | | | |
| ULS – Ultimate Limit State (see EN 1998-1 [30], 2.2.1) | | | | |

1) The listed displacements represent mean values.

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

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

## C.5 TEST REPORT

In addition to the minimum requirements listed in Annex B, the report shall include at least the following information regarding the seismic tests:

**Test member**

- Reinforcement ratio
- Drawing of test member (including dimensions and position of reinforcement)

**Test setup**

- Loading device
- Type and positioning of crack measurement device(s)
- Particulars concerning restraining uplift in shear tests (where applicable)
- Test method for fastener being located in crack over required length
- Method of crack creation
- Verification of approximately constant crack width throughout thickness of test member (where applicable)

**Measured values**

- Frequency of load cycling (where applicable)
- (hairline) crack width before and after fastener installation
- Minimum and maximum loads in each cycling sequence of load cycling tests
- Annular gap of clearance hole for shear tests
- Crack width for residual capacity tests
- Alternating shear load cycling procedure
- Reduced load levels and reason for reduction (where applicable)
- Location of failure (e.g., in shaft portion, threaded part, neck of fastener)
- Particulars of tests for category C1
  - Crack width $\Delta w$
  - Fastener displacement as a function of number of load cycles
  - Constant load levels $N_{C1}$, $N_i$ and $N_m$ on fastener and method of applying the load in test series C1.1
  - Constant load levels $V_{C1}$, $V_i$ and $V_m$ on fastener and method of applying the load in test series C1.2
- Particulars of tests for category C2
  - Maximum loads $N_{max}$ and $V_{max}$ in test series C2.3 and C2.4, respectively
  - Type of loading cycles (sinusoidal or triangular) in test series C2.3
  - Fastener displacements at minimum and maximum load and crack width as a function of number of load cycles in test series C2.3 and C2.4
  - Fastener displacements at 0,5 $N/N_{max}$ and 1,0 $N/N_{max}$ in test series C2.3
  - Fastener displacements at 0,5 $V/V_{max}$ and 1,0 $V/V_{max}$ in test series C2.4
  - Constant load levels $N_{w1}$ and $N_{w2}$ on fastener and method of applying the load in test series C2.5
  - Frequency of crack cycling in test series C2.5
  - Initial compression force $C_{ini}$ in test series C2.5
  - Compression force $C_{test}$ in test series C2.5
  - Fastener displacements at minimum and maximum crack width and applied tension load as a function of number of crack cycles in test series C2.5
  - Fastener displacements at the end of crack cycling at level $\Delta w$ = 0,5 mm and $\Delta w$ = 0,8 mm in test series C2.5.