EUROPEAN ASSESSMENT DOCUMENT

EAD 330250-00-0601

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POST-INSTALLED FASTENERS IN CONCRETE UNDER FATIGUE CYCLIC LOADING

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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 No (EU) 305/2011 as a basis for the preparation and issuing of European Technical Assessments (ETA).

Contents

1 SCOPE

1.1 Description of the construction product

This EAD covers post-installed fasteners in concrete with characteristic resistance for options 1-6 according to EAD 330232-01-0601[1] [1] or EAD 330499-01-0601 [2] and with characteristic resistance under fatigue cyclic loading (in the following referred to as fasteners).

This EAD covers fasteners that are secured against turning of the nut under fatigue cyclic loading by suitable means. Loosening of the nut or screw is avoided (e.g., by the use of lock nuts, counter nuts or other suitable means).

This EAD covers fasteners under fatigue cyclic shear loads only without an annular gap between the hole in the fixture and the fastener. Under fatigue cyclic tension loading a gap is possible.

Note: The annular gap can be filled with injection mortar.

A stand-off installation of fasteners under fatigue cyclic loading is not covered, i.e. the conditions of EN 1992-4 [5], 6.2.2.3 (1) b) are fulfilled.

The effective embedment depth is h_{ef} ≥ 40 mm.

This EAD covers fasteners made of either carbon steel or stainless steel. The surface of the steel may be coated or uncoated. This EAD is valid for fasteners with a nominal steel tensile strength f_{uk} ≤ 1000 N/mm^2.

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

The intended use of the product is not fully covered by the following harmonised technical specifications. EAD 330232-01-0601 [1] or EAD 330499-01-0601 [2]

EAD 330232-01-0601 [1] and EAD 330499-01-0601 [2] cover essential characteristics of fasteners under static, quasi-static or seismic actions and related assessment methods but EAD 330250-00-0601 covers assessment and essential characteristics of fasteners under fatigue cyclic loading.

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

The fasteners are intended to be 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 [4]. The hardened concrete is at least 21 days old.

The fastener is intended to be used in cracked and uncracked concrete.

The covered temperature range of the anchorage base concrete during the working life is within the range -40 °C to +80 °C (maximum long-term temperature +50°C, maximum short-term temperature +80°C).

The thickness of the concrete member in which the fastener is installed corresponds to the thickness of concrete members in EAD 330232-01-0601 [1] or EAD 330499-01-0601 [2].

The fastener is intended to be used

- in cracked and uncracked concrete (EAD 330232-01-0601 [1], Table 1.2, option 1 – 6)
- under static or quasi-static actions,
- under seismic actions,
- with requirements related to resistance to fire

loaded in tension, shear or combined tension and shear.

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

In addition fasteners are intended to be used under fatigue cyclic loads in combination with or without static or quasi-static loads. The fastener is used to transmit tension loads ($+N$), shear loads ($\pm V$) without lever arm or any combination of these loads into the concrete.

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

The intended use of the fastener regarding environmental conditions results from EAD 330232-01-0601 [1], 1.2.1 or EAD 330499-01-0601 [2], 1.2.1.

In this EAD the assessment is made to determine characteristic values of the fasteners for calculation according to EN 1992-4 [5] and for calculation according to TR 061 [3] (only for fatigue cyclic loading).

Tables 2.3 to 2.5 show how the performance of the post-installed fastener in concrete under fatigue cyclic loading is assessed in relation to the essential characteristics.

The relevant assessment method depends on the intended use in design of the fastenings, given by the manufacturer in its technical file.

If the exact fatigue resistance function (Wöhler curve) is intended to be used, assessment method A (Table 2.3) is used.

If only the fatigue limit resistance is intended to be used in design, assessment method B (Table 2.4) is used.

If a linearized function of the fatigue resistance (simplifying the real behaviour) is intended to be used in design for post-installed bonded fasteners with threaded rods (effective embedment depth is h_{ef} ≥ 60 mm or h_{ef} ≥ 4 d) or torque-controlled expansion fasteners (bolt type with external thread) made of carbon steel or stainless steel, assessment method C (Table 2.5) is used.

If no information is given by the manufacturer, the most simple method, method B, is recommended.

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

Indices

E	action effects
N	normal force
R	resistance
V	shear force
n	number of load cycles or oscillations
k	characteristic value

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

d	design value
u	ultimate value
s	steel
c	concrete cone/edge
cp	concrete pry-out
p	concrete pull-out
sp	concrete splitting
cb	concrete blow-out
up	upper
lo	lower
fat	fatigue
RT	run-out test
r	reference
ef	effective
lim	limit
cr	cracked
ucr	uncracked
F	load
∞	infinite number
β	angle
0	origin load ($F_{lo} = 0$)

Abbreviations:

BEF = bonded expansion fastener (torque-controlled bonded fastener)
BF = bonded fastener
C1 = seismic performance category C1 (use in design according to EN 1992-4 [5]
C2 = seismic performance category C2 (use in design according to EN 1992-4 [5]

Essential resistances in axial and transverse direction regarding the relevant failure modes under fatigue cyclic loading

$\Delta N_{Rk,s,0,n}$	Characteristic steel fatigue resistance with origin load (F_{lo} = 0) in axial direction and n load cycles	[N]
$\Delta V_{Rk,s,0,n}$	Characteristic steel fatigue resistance with origin load (F_{lo} = 0) in transverse direction and n load cycles	[N]
$\Delta N_{Rk,s,0,\infty}$	Characteristic steel fatigue limit resistance with origin load (F_{lo} = 0) in axial direction	[N]
$\Delta V_{Rk,s,0,\infty}$	Characteristic steel fatigue limit resistance with origin load (F_{lo} = 0) in transverse direction	[N]
$\Delta N_{Rk,c(p,sp,cb),0,n}$	Characteristic concrete fatigue resistance with origin load (F_{lo} = 0) in axial direction and n load cycles	[N]
$\Delta V_{Rk,c(cp),0,n}$	Characteristic concrete fatigue resistance with origin load (F_{lo} = 0) in transverse direction and n load cycles	[N]
$\Delta N_{Rk,c(p,sp,cb),0,\infty}$	Characteristic concrete fatigue limit resistance with origin load (F_{lo} = 0) in axial direction	[N]
$\Delta V_{Rk,c(cp),0,\infty}$	Characteristic concrete fatigue limit resistance with origin load (F_{lo} = 0) in transverse direction	[N]
$\Delta F^{\beta}_{Rk,s,0,n}$	Characteristic steel fatigue resistance with origin load (F_{lo} = 0) for combined tension and shear with the angle β and n load cycles	[N]

α_{sn}	Exponent for combined tension and shear verification regarding steel failure according to TR 061 [3]	[-]
α_c	Exponent for combined tension and shear verification regarding failure modes other than steel failure	[-]
α_s	Exponent for combined tension and shear verification regarding steel failure under static and cyclic loading according to EN 1992-4 [5], 8.3.3	[-]
ψ_{FN}	Load-transfer factor in axial direction	[-]
ψ_{FV}	Load-transfer factor transverse direction	[-]

Further abbreviations for the assessment

A_s	stressed cross-section of the fastener used for determining the tensile capacity	[mm^2]
a_m	positive dimensionless number for the average function	[-]
a_5	positive dimensionless number for the 5%-quantile function	[-]
a_s	axis intercept of displacement regression line for one area	[mm]
a_{ucr}	coefficient of regression line for test results in uncracked concrete	[mm]
a_{cr}	coefficient of regression line for test results in cracked concrete	[mm]
a_{ucr_1}	coefficient of power function for test results in uncracked concrete	[mm]
a_{cr_1}	coefficient of power function for test results in cracked concrete	[mm]
b_m	positive dimensionless number for the average function	[-]
b	width of concrete member	[mm]
b_5	positive dimensionless number for the 5%-quantile function	[-]
b_t	average exponent of power function for test results in uncracked and cracked concrete	[mm]
b_s	slope of displacement regression line for one area	[mm]
b_{ucr}	exponent of power function for test results in uncracked concrete	[mm]
b_{cr}	exponent of power function for test results in cracked concrete	[mm]
c_{min}	minimum allowable edge distance	[mm]
d	fastener bolt / thread diameter	[mm]
d_0	drill hole diameter	[mm]
$d_{cut,m}$	medium cutting diameter of drill bit (see Figure D.14)	[mm]
$d_{cut,min}$	cutting diameter at the lower tolerance limit (see Figure D.14, minimum diameter bit)	[mm]
$d_{cut,max}$	utting diameter at the upper tolerance limit (see Figure D.14, maximum diameter bit)	[mm]
F_{upi}	upper level of the sinusoidal course	[N]
F_{lo}	lower level of the sinusoidal course	[N]
$F_{up,ucr,i}$	upper load level for a chosen displacement for test results in uncracked concrete for every step i	[N]
$F_{up,cr,j}$	upper load level for a chosen displacement for test results in cracked concrete for every step j	[N]
$\bar{F}_{up,ucr}$	mean value of power function for test results in uncracked concrete including average exponent b	[N]

$\bar{F}_{up,cr}$	mean value of power function for test results in cracked concrete including average exponent b	[N]
$\bar{F}_{up,ucr\_1}$	mean value of power function for test results in uncracked concrete	[N]
$\bar{F}_{up,cr\_1}$	mean value of power function for test results in cracked concrete	[N]
$\bar{F}_{up,ucr,i}$	mean value of the section for every step i for test results in uncracked concrete	[N]
$\bar{F}_{up,cr,j}$	mean value of the section for every step j for test results in cracked concrete	[N]
f_c	concrete compressive strength measured on cylinders	[N/mm²]
$f_{c,cube}$	concrete compressive strength measured on cubes with a side length of 150 mm	[N/mm²]
$f_{c,cube100}$	concrete compressive strength measured on cubes with a side length of 100 mm	[N/mm²]
$f_{c,cube200}$	concrete compressive strength measured on cubes with a side length of 200 mm	[N/mm²]
k	inclination factor	[-]
$k_{h-u,p,1-\alpha}$	OWEN factor; h: total number of available fatigue cyclic test results; u: known condition of static resistance and positive dimensionless numbers (u = 3); p: 5%-quantile (p = 0,05); 1 - α: level of confidence of 90% (1 - α = 0,9)	[-]
$k_{n-u,p,1-\alpha}$	OWEN factor; n: number of static test results; u: known condition of mean value (u = 1); p: 5%-quantile (p = 0,05); 1 - α: level of confidence of 90% (1 - α = 0,9)	[-]
h	total number of fatigue cyclic test results	[-]
h_m	thickness of concrete member	[mm]
h_{ef}	effective embedment depth	[mm]
m	number of measured values	[-]
n	number of cycles	[-]
n_i	number of cycles in the cross section for every step i	[-]
$\dot{n}$	number of cycles in centroid of test result scatter for one area, regarding the upper limit S_{upi} of a sinusoidal load process	[-]
$\mathrm{n}_{\mathrm{cal}}$	calculated number of cycles	[-]
$\dot{n}_A$	number of cycles in centroid of test result scatter for area A	[-]
$\dot{n}_B$	number of cycles in centroid of test result scatter for area B	[-]
$\dot{n}_C$	number of cycles in centroid of test result scatter for area C	[-]
$\dot{n}_j$	number of cycles in centroid of test result scatter for each three results	[-]
n_{lim}	limit number of cycles	[-]
$n_{lim,lo}$	lower limit of the limit number of cycles n_{lim} interval	[-]
$\bar{n}_r$	average number of cycles from reference tests	[-]
n_{ri}	number of cycles from reference tests in the horizontal section ΔS_{RT} for every step i	[-]
$n_{RT,min}$	minimum number of cycles for run-out test	[-]
r_{cr}	total number of available fatigue cyclic test results performed in cracked concrete	[-]

r_{ucr}	total number of available fatigue cyclic test results performed in uncracked concrete	[-]
$\hat{s}$	standard deviation of static test results	[N]
$\hat{s}_A$	average standard deviation of area A	[N]
$\hat{s}_B$	average standard deviation of area B	[N]
$\hat{s}_C$	average standard deviation of area C	[N]
$\hat{s}_j$	average standard deviation for each three results	[N]
$\hat{s}_j^2$	average variance for each three results	[-]
$\dot{s}_{up}$	displacement in centroid of test result scatter for one area, regarding the upper limit S_{upi} of a sinusoidal load process	[mm]
s_{min}	minimum allowable spacing	[mm]
$s_{0,ucr,i}$	displacement of a test result in uncracked concrete at the beginning of test, regarding the lower limit F_{lo} of a sinusoidal load process, for every step i	[mm]
$s_{0,cr,j}$	displacement of a test result in cracked concrete at the beginning of test, regarding the lower limit F_{lo} of a sinusoidal load process, for every step j	[mm]
$s_{n,ucr,i}$	displacement of a test result in uncracked concrete at n_{cal}, regarding the upper limit F_{upi} of a sinusoidal load process, for every step i	[mm]
$s_{n,cr,j}$	displacement of a test result in cracked concrete at n_{cal}, regarding the upper limit F_{upj} of a sinusoidal load process, for every step j	[mm]
s_{up}	displacement regression line for one area	[mm]
$s_{up,i}$	displacement in the cross section, regarding the upper limit S_{upi} of a sinusoidal load process, for every step i	[mm]
$\overline{S}$	mean value of static test results	[N]
S_k	characteristic static resistance	[N]
S_{upi}	upper level of the sinusoidal course	[N]
$\hat{s}_r$	average standard deviation from reference tests	[N]
S_{lo}	lower level of the sinusoidal course	[N]
$t_{fix,min}$	Minimum thickness of fixture	[mm]
T_{inst}	required setting torque specified by the manufacturer for expansion or pre-stressing of fastener	[Nm]
x_{ucr}	x-value of regression line for test results in uncracked concrete	[mm]
x_{cr}	x-value of regression line for test results in cracked concrete	[mm]
β	angle for combined tension and shear testing	[°]
$\bar{\psi}_F$	mean value of the load transfer factors	[-]
$\hat{\psi}_F$	standard deviation of the load transfer factors	[-]
$\hat{\psi}_F^2$	variance of the load transfer factors	[-]
$\psi_{F,ij}$	load transfer factors	[-]
$\Delta\bar{F}$	mean load range for the chosen displacement with consideration of the load transfer	[N]

$\Delta\hat{F}$	standard deviation of the load for the chosen displacement with consideration of the load transfer	[N]
$\Delta\hat{F}^2$	variance of the load for the chosen displacement with consideration of the load transfer	[N]
$\Delta F_{95\%}$	characteristic acting load for the chosen displacement with consideration of the load transfer	[N]
$\Delta\bar{F}_{cal}$	mean load range for the chosen displacement without consideration of the load transfer	[N]
$\Delta\hat{F}_{cal}$	standard deviation of the load for the chosen displacement without consideration of the load transfer	[N]
$\Delta\hat{F}_{cal}^2$	variance of the load for the chosen displacement without consideration of the load transfer	[-]
$\Delta F_{cal,95\%}$	characteristic acting load for the chosen displacement without consideration of the load transfer	[N]
ΔF_i	load level in the cross section for every step i	[-]
ΔN_{Ek}	characteristic cyclic action in axial direction	[N]
ΔV_{Ek}	characteristic cyclic action in transverse direction	[N]
ΔS	load range for fatigue resistance	[N]
$\Delta\overline{S}$	load range of average regression line	[N]
ΔS_a	load level of test a for quality control	[N]
$\Delta\bar{\dot{S}}_A$	mean load range of area A	[N]
$\Delta\dot{S}_{A,5\%}$	5%-quantile of area A	[N]
ΔS_b	load level of test b for quality control	[N]
$\Delta\bar{\dot{S}}_B$	mean load range of area B	[N]
$\Delta\dot{S}_{B,5\%}$	5%-quantile of area B	[N]
ΔS_c	load level of test c for quality control	[N]
$\Delta\bar{\dot{S}}_C$	mean load range of area C	[N]
$\Delta\dot{S}_{C,5\%}$	5%-quantile of area C	[N]
$\Delta\overline{S}_D$	mean load range of fatigue limit resistance	[N]
$\Delta\overline{\dot{S}}_j$	mean load range in the cross section for every step j	[N]
$\Delta\dot{S}_{j,5\%}$	5%-quantile in cross section n_j	[N]
Δs_D	chosen displacement	[mm]
$\Delta S_{D,k}$	characteristic fatigue limit resistance	[N]
$\Delta S_D^{\approx}$	estimated value of the fatigue limit resistance	[N]
ΔS_i	load level in the cross section for every step i	[N]
$\Delta\overline{S}_i$	mean load range in the cross section for every step i	[N]
ΔS_k	characteristic load range value of fatigue resistance	[N]
ΔS_{RT}	load level for run-out test	[N]
Δs_{ucr}	displacement of power function for test results in uncracked concrete	[mm]
Δs_{cr}	displacement of power function for test results in cracked concrete	[mm]

$\Delta s_{ucr,i}$	differential displacement of a test result in uncracked concrete for every step i	[mm]
$\Delta s_{cr,j}$	differential displacement of a test result in uncracked concrete for every step j	[mm]
Δw	crack width	[mm]
$\Delta\Delta F_{up,ucr,i}$	residual load in the cross section for every step i for test results in uncracked concrete	[N]
$\Delta\Delta F_{up,cr,j}$	residual load in the cross section for every step j for test results in cracked concrete	[N]
$\Delta\Delta S_i$	residual load in the cross section for every step i	[N]
η_A	reduction factor for mean load range of fatigue limit resistance	[-]
$\eta_{k,c,N,fat}$	reduction factor for concrete cone failure	[-]
$\eta_{k,p,N,fat}$	reduction factor for pull-out failure	[-]
$\eta_{k,sp,N,fat}$	reduction factor for splitting failure	[-]
$\eta_{k,cb,N,fat}$	reduction factor for blow-out failure	[-]
$\eta_{k,c,V,fat}$	reduction factor for concrete edge failure	[-]
$\eta_{k,cp,V,fat}$	reduction factor for pry-out failure	[-]
μ	Ratio of reinforcement	[-]

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 in concrete under static, quasi-static loading and seismic loading and under fire exposure is assessed in relation to the essential characteristics, as basis for the assessment of the performance under fatigue cyclic loading.

Table 2.2 shows how the performance of bonded fasteners in concrete under static, quasi-static loading and seismic loading is assessed in relation to the essential characteristics, as basis for the assessment of the performance under fatigue cyclic loading.

Tables 2.3 to 2.5 show how the performance of the post-installed fastener in concrete is assessed in relation to those essential characteristics which are additionally relevant under the specific intended use under fatigue cyclic loading.

The relevant assessment method depends on the intended use in design of the fastenings, given by the manufacturer in its technical file (see 1.2.1).

The assessment method A (interactive method) is made to determine characteristic values of the fastener for design method I and design method II according to TR 061 [3] and design according to EN 1992-4, clause 8.

The assessment method B (simple method) is made to determine characteristic values of the fastener for design method II according to TR 061 [3] and design according to EN 1992-4, clause 8.

The assessment method C (linearized method) is made to determine the characteristic values of the fastener for design method I and design method II according to TR 061 [3] and design according to EN 1992-4, clause 8.

Note: Design method I according to TR 061 [3] based on the S-n-curve according to Figure 2.1 and design method II according to TR 061 [3] based on fatigue limit resistance.

The assessment method used shall be reported in the ETA.

Table 2.1 Essential characteristics of mechanical fasteners and methods and criteria for assessing the performance of mechanical fasteners 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		EAD 330232-01-0601 [1], 2.2.1	Level $N_{Rk,s}$ [kN]
2	Resistance to pull-out failure		EAD 330232-01-0601 [1], 2.2.2	Level $N_{Rk,p}$ [kN], ψ_c [-]
3	Resistance to concrete cone failure		EAD 330232-01-0601 [1], 2.2.3	Level $k_{cr,N}$, $k_{ucr,N}$ [-], h_{ef}, $c_{cr,N}$ [mm]
4	Robustness		EAD 330232-01-0601 [1], 2.2.4	Level γ_{inst} [-]
5	Minimum edge distance and spacing		EAD 330232-01-0601 [1], 2.2.5	Level c_{min}, s_{min}, h_{min} [mm]
6	Edge distance to prevent splitting		EAD 330232-01-0601 [1], 2.2.6	Level $N^0_{Rk,sp}$ [kN], $c_{cr,sp}$ [mm]
Characteristic resistance to shear load (static and quasi-static loading)				
7	Resistance to steel failure under shear load		EAD 330232-01-0601 [1], 2.2.7	Level $V^0_{Rk,s}$ [kN], $M^0_{Rk,s}$ [Nm], k_7 [-]
8	Resistance to pryout failure		EAD 330232-01-0601 [1], 2.2.8	Level k_8 [-]
Displacements (static and quasi-static loading)				
9	Displacements under static and quasi-static loading		EAD 330232-01-0601 [1], 2.2.10	Level δ_{N0}, $\delta_{N\infty}$, δ_{V0}, $\delta_{V\infty}$ [mm]
Characteristic resistance and displacements for seismic performance categories C1 and C2				
10	Resistance to tension load, displacements	C1	EAD 330232-01-0601 [1], 2.2.11	Level $N_{Rk,s,C1}$, $N_{Rk,p,C1}$ [kN]
		C2	EAD 330232-01-0601 [1], 2.2.12	Level $N_{Rk,s,C2}$, $N_{Rk,p,C2}$ [kN], $\delta_{N,C2}$, [mm]
11	Resistance to shear load, displacements	C1	EAD 330232-01-0601 [1], 2.2.13	Level $V_{Rk,s,C1}$ [kN]
		C2	EAD 330232-01-0601 [1], 2.2.14	Level $V_{Rk,s,C2}$, [kN], $\delta_{V,C2}$ [mm]
12	Factor for annular gap		EAD 330232-01-0601 [1], 2.2.15	Level α_{gap} [-]
Basic Works Requirement 2: Safety in case of fire				
13	Reaction to fire		EAD 330232-01-0601 [1], 2.2.16	Class A1
Resistance to fire				
14	Fire resistance to steel failure (tension load)		EAD 330232-01-0601 [1], 2.2.17	Level $N_{Rk,s,fi}$ [kN]
15	Fire resistance to pull-out failure (tension load)		EAD 330232-01-0601 [1], 2.2.18	Level $N_{Rk,p,fi}$ [kN]
16	Fire resistance to steel failure (shear load)		EAD 330232-01-0601 [1], 2.2.19	Level $V_{Rk,s,fi}$ [kN], $M^0_{Rk,s,fi}$ [Nm]
Aspects of durability				
17	Durability		EAD 330232-01-0601 [1], 2.2.20	Description

Table 2.2 Essential characteristics of bonded fasteners and methods and criteria for assessing the performance of bonded fasteners in relation to those essential characteristics

No	Essential characteristic		Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability				
Characteristic resistance to tension load (static and quasi-static loading)				
1	Resistance to steel failure		EAD 330499-01-0601 [2], 2.2.1	Level $N_{Rk,s}$ [kN]
2	Resistance to combined pull-out and concrete failure		EAD 330499-01-0601 [2], 2.2.2	Level τ_{Rk} and/or $\tau_{Rk,100}$ [N/mm²], ψ^0_{sus} [-] (BF)
			EAD 330499-01-0601 [2], C.5	Level $N_{Rk,p}$ and/or $N_{Rk,p,100}$ [kN] (BEF)
3	Resistance to concrete cone failure		EAD 330499-01-0601 [2], 2.2.3	Level $c_{cr,N}$ [mm], $k_{cr,N}$, $k_{ucr,N}$ [-]
4	Edge distance to prevent splitting under load		EAD 330499-01-0601 [2], 2.2.4	Level $c_{cr,sp}$ [mm]
5	Robustness		EAD 330499-01-0601 [2], 2.2.5	Level γ_{inst} [-]
6	Maximum installation torque		EAD 330499-01-0601 [2], 2.2.1.2	Level max T_{inst} [Nm] (BF)
	Installation torque		EAD 330499-01-0601 [2], 2.2.1.2	Level T_{inst} [Nm] (BEF)
7	Minimum edge distance and spacing		EAD 330499-01-0601 [2], 2.2.5	Level c_{min}, s_{min}, h_{min} [mm]
Characteristic resistance to shear load (static and quasi-static loading)				
8	Resistance to steel failure		EAD 330499-01-0601 [2], 2.2.7	Level $V^0_{Rk,s}$ [kN], $M^0_{Rk,S}$ [Nm], k_7 [-]
9	Resistance to pry-out failure		EAD 330499-01-0601 [2], 2.2.8	Level k_8 [-]
10	Resistance to concrete edge failure		EAD 330499-01-0601 [2], 2.2.9	Level d_{nom}, ℓ_f [mm]
Displacements under short-term and long-term (static and quasi-static loading)				
11	Displacements under short-term and long-term loading		EAD 330499-01-0601 [2], 2.2.10	Level δ_0, δ_∞ [mm or mm/(N/mm²)]
Characteristic resistance and displacements for seismic performance categories C1 and C2				
12	Resistance to tension load, displacements	C1	EAD 330499-01-0601 [2], 2.2.11	$N_{Rk,s,C1}$ [kN] (all) $\tau_{Rk,C1}$ [N/mm²] (BF) $N_{Rk,p,C1}$ [kN] (BEF)
		C2	EAD 330499-01-0601 [2], 2.2.12	$N_{Rk,s,C2}$ [kN] (all) $\tau_{Rk,C2}$ [N/mm²] (BF) $N_{Rk,p,C2}$ [kN] (BEF) $\delta_{N,C2}$ [mm] (all)
13	Resistance to shear load, displacements	C1	EAD 330499-01-0601 [2], 2.2.13	$V_{Rk,s,C1}$ [kN] (all)
		C2	EAD 330499-01-0601 [2], 2.2.14	$V_{Rk,s,C2}$ [kN] (all) $\delta_{V,C2}$ [mm] (all)
14	Factor for annular gap		EAD 330499-01-0601 [2], 2.2.15	α_{gap} [-]
Basic Works Requirement 3: Hygiene, health and the environment				
15	Content, emission and/or release of dangerous substances		EAD 330499-01-0601 [2], 2.2.16	Description

Table 2.3 Essential characteristics of the product and assessment methods and criteria for the performance of the product in relation to those essential characteristics - Assessment method A: Continuous function of fatigue resistance

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability			
1	Characteristic steel fatigue resistance under tension loading	2.2.1	Level $\Delta N_{Rk,s,0,n}$ (n = 1 to n = ∞)
2	Characteristic concrete cone, pull-out, splitting and blow out fatigue resistance under tension loading	2.2.2	Level $\Delta N_{Rk,c,0,n}$ $\Delta N_{Rk,sp,0,n}$ (all fasteners) $\Delta N_{Rk,cb,0,n}$ $\Delta N_{Rk,p,0,n}$ (mechanical fasteners) (n = 1 to n = ∞)
3	Characteristic combined pull-out /concrete cone fatigue resistance under tension loading	2.2.3	Level $\Delta N_{Rk,p,0,n}$ (bonded fasteners) (n = 1 to n = ∞)
4	Characteristic steel fatigue resistance under shear loading	2.2.4	Level $\Delta V_{Rk,s,0,n}$ (n = 1 to n = ∞)
5	Characteristic concrete edge fatigue resistance under shear loading	2.2.5	Level $V_{Rk,c,0,n}$ (n = 1 to n = ∞)
6	Characteristic concrete pry-out fatigue resistance under shear loading	2.2.6	Level $\Delta V_{Rk,cp,0,n}$ (n = 1 to n = ∞)
7	Characteristic steel fatigue resistance under tension and shear	2.2.7	Level a_{sn} (n = 1 to n = ∞)
8	Load transfer factor for tension and shear loading	2.2.8	Level ψ_{FN}, ψ_{FV}

Table 2.4 Essential characteristics of the product and assessment methods and criteria for the performance of the product in relation to those essential characteristics - Assessment method B: Fatigue limit resistance

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability			
1	Characteristic steel fatigue limit resistance under tension loading	2.2.9	Level $\Delta N_{Rk,s,0,\infty}$
2	Characteristic concrete cone, pull-out, combined pull-out /concrete cone splitting and blow out fatigue limit resistance under tension loading	2.2.10	Level $\Delta N_{Rk,c,0,\infty}$ $\Delta N_{Rk,sp,0,\infty}$ (for all fasteners) $\Delta N_{Rk,cb,0,\infty}$ (for mechanical fasteners) $\Delta N_{Rk,p,0,\infty}$ (for all fasteners)
3	Characteristic steel fatigue limit resistance under shear loading	2.2.11	Level $\Delta V_{Rk,s,0,\infty}$
4	Characteristic concrete edge and pry-out fatigue limit resistance	2.2.12	Level $\Delta V_{Rk,c,0,\infty}$ $\Delta V_{Rk,cp,0,\infty}$
5	Characteristic steel fatigue limit resistance under tension and shear	2.2.13	Level a_s (n = ∞)
6	Load transfer factor for tension and shear loading	2.2.14	Level ψ_{FN}, ψ_{FV}

Table 2.5 Essential characteristics of the product and assessment methods and criteria for the performance of the product in relation to those essential characteristics - Assessment method C: Linearized function

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability			
1	Characteristic steel fatigue resistance under tension loading	2.2.15	Level $\Delta N_{Rk,s,0,n}$ (n = 1 to n = ∞)
2	Characteristic concrete cone, pull-out, splitting and blow out fatigue resistance under tension loading	2.2.16	Level $\Delta N_{Rk,c,0,n}$ $\Delta N_{Rk,sp,0,n}$ (for bonded and torque-controlled expansion fasteners) $\Delta N_{Rk,cb,0,n}$ (for torque-controlled expansion fasteners) (n = 1 to n = ∞)
3	Characteristic pull-out or combined pull-out /concrete cone fatigue resistance under tension loading	2.2.17	Level $\Delta \tau_{Rk,p,0,n}$ (for bonded fasteners) or $\Delta N_{Rk,p,0,n}$ (for torque-controlled expansion fasteners – bolt type with external thread) (n = 1 to n = ∞)
4	Characteristic steel fatigue resistance under shear loading	2.2.18	Level $\Delta V_{Rk,s,0,n}$ (n = 1 to n = ∞)
5	Characteristic concrete edge fatigue resistance under shear loading	2.2.19	Level $\Delta V_{Rk,c,0,n}$ (n = 1 to n = ∞)
6	Characteristic concrete pry-out fatigue resistance under shear loading	2.2.20	Level $\Delta V_{Rk,cp,0,n}$ (n = 1 to n = ∞)
7	Characteristic steel fatigue resistance under tension and shear	2.2.21	Level a_s
8	Load transfer factor for tension and shear loading	2.2.22	Level ψ_{FN}, ψ_{FV}

For the determination of the characteristic fatigue resistances of fasteners there are three assessment methods:

- If a continuous function of the fatigue resistance depending on the number of load cycles (see Fig. 2.1a) shall be provided, test method A is to be used. This test method corresponds to the Interactive Method according to [9], [10], [11] and is described in Annex A.
- If only the value of the characteristic fatigue limit resistance for infinite number of cycles shall be provided, test method B is to be used. This test method is a simple method and is described in Annex B.
- Post-installed bonded fasteners in concrete with threaded rods and torque-controlled expansion fasteners (bolt type with external thread) made of carbon steel and stainless steel may be assessed by test method C. This test method comes up with a linearized function of the fatigue resistance depending on the number of load cycles (see Figure 2.1b) and simplifies the real behavior given in Figure 2.1a. The effective embedment depth is h_{ef} ≥ 60 mm or h_{ef} ≥ 4 d.

The test methods must not be mixed.

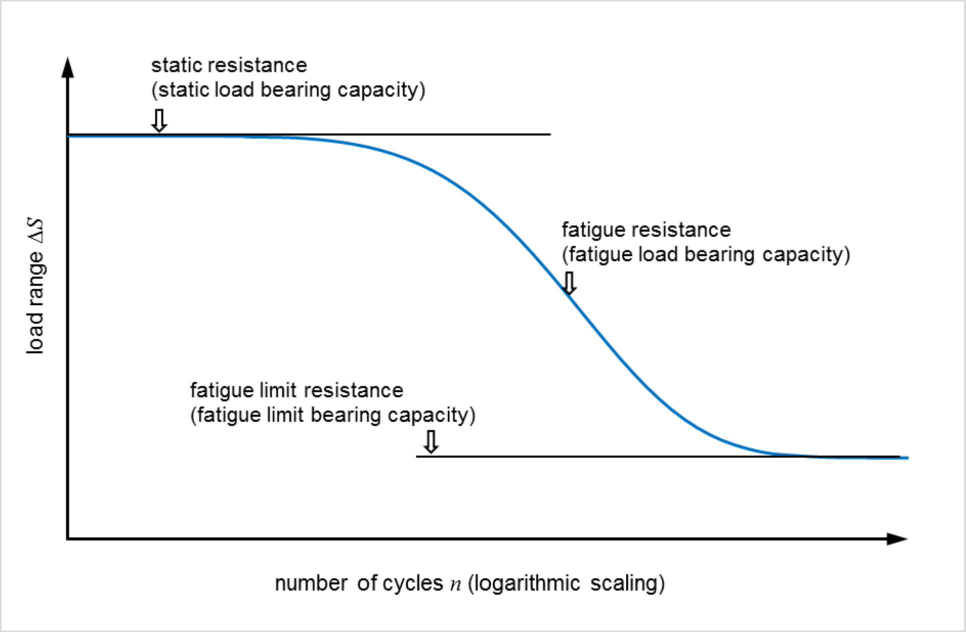


Figure 2.1a: Example of a fatigue resistance function determined with assessment method A

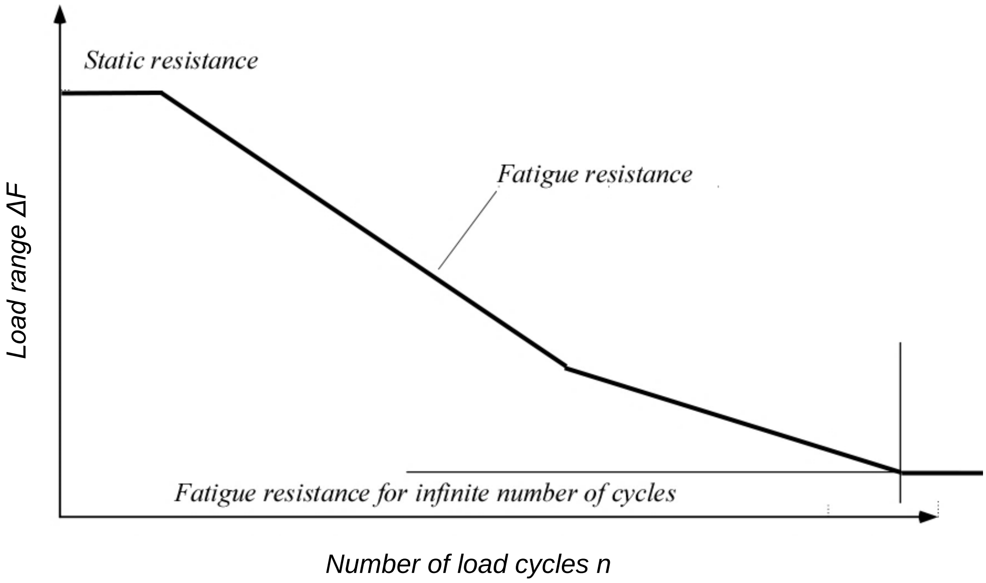


Figure 2.1b: Example of a fatigue resistance function determined with assessment method C

2.2 Methods and criteria for assessment of performance of the product in relation to essential characteristics of the product under fatigue cyclic loading

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.

2.2.1 Characteristic steel fatigue resistance under tension loading (Method A)

Purpose of assessment:

Determination of the characteristic steel fatigue resistance under cyclic tension loading as a function of the number of load cycles n.

Assessment method

Required tests: For the determination of the characteristic fatigue resistance function, $\Delta N_{Rk,s,0,n}$, testing in accordance with Table A.1 (test series FA.1) shall be performed. All fastener sizes with all steel qualities/properties and coatings specified by the manufacturer shall be tested.

Test conditions: The tests shall be performed according to Annex D, Figure D.1 and Figure D.8 with a single fastener. The fastener shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex A.

The number of cycles to failure n for each range of force ΔN shall be determined through testing. The test results shall be used for the determination of the fatigue resistance function.

Tests which are stopped without failure (first load level) and re-loaded with a higher stress range (second load level) may be included in the final evaluation. (Only results on the first load level can be used for evaluation. The results on the second load level are used only to detect damage on the tests previously stopped. Reference Annex A for additional information).

The characteristic fatigue resistance function is determined by statistical evaluation according to Annex A based on the 5%-quantile with a confidence level of 90% (Example see Figure 2.2):

$$\Delta N_{Rk,s,0,n} = \Delta S_k$$

where:

ΔS_k according to Equation (A.16), characteristic value of fatigue resistance after n load cycles

The characteristic resistance $N_{Rk,s}$ as determined in static tension tests in accordance with [1], [2] shall be taken as the characteristic fatigue resistance for n = 1 cycles.

The following information regarding the fatigue resistance function shall be determined:

- Equations of the average and characteristic fatigue resistance functions
- Four calculated values for the control of the characteristic fatigue resistance function
- Diagram according to Figure A.6 (Annex A) showing cyclic test results, average and characteristic fatigue resistance functions and four calculated control values
- Tables listing cyclic and lower cyclic load, number of cycles to failure, type of failure, etc.

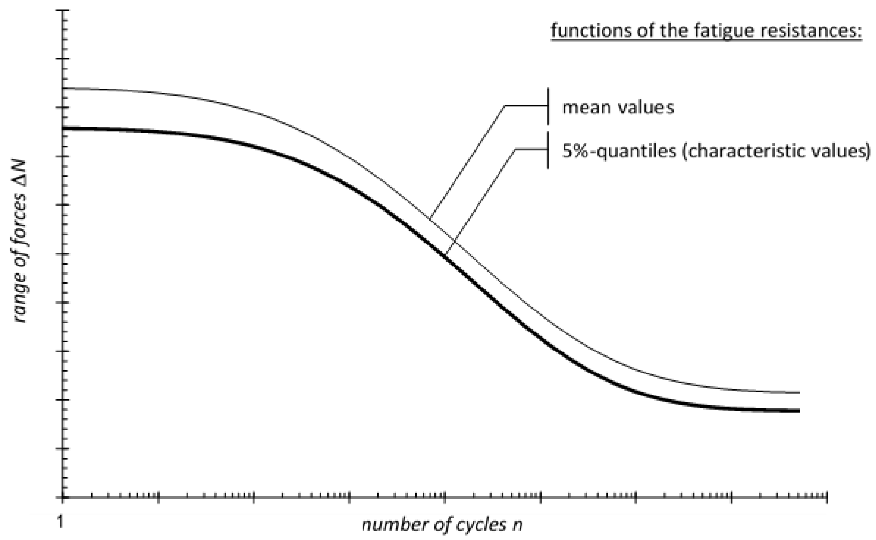


Figure 2.2: Example of the characteristic fatigue resistance function (test method A)

Expression of results: $\Delta N_{Rk,s,0,n}$ with (n = 1 to n = ∞)

2.2.2 Characteristic concrete cone, pull-out, splitting and blow out fatigue resistance under tension loading (Method A)

Purpose of assessment

Determination of the characteristic fatigue resistance function for concrete cone, pull-out, splitting and blow out failure under cyclc tension loading as a function of the number of load cycles n.

Assessment method

The characteristic fatigue resistances to concrete cone failure, pull-out failure, splitting and blow out failure are calculated as follows:

$$\Delta N_{Rk,c,0,n} = \eta_{k,c,N,fat,n} \cdot N_{Rk,c} \quad (2.1)$$

$$\Delta N_{Rk,p,0,n} = \eta_{k,p,N,fat,n} \cdot N_{Rk,p} \quad (2.2)$$

$$\Delta N_{Rk,sp,0,n} = \eta_{k,sp,N,fat,n} \cdot N_{Rk,sp} \quad (2.3)$$

$$\Delta N_{Rk,cb,0,n} = \eta_{k,cb,N,fat,n} \cdot N_{Rk,cb} \quad (2.4)$$

where:

$N_{Rk,c}$	characteristic value of static resistance to concrete cone failure according to EN 1992-4 [5], Equation (7.1)
$N_{Rk,p}$	characteristic value of static resistance to pull-out failure of mechanical fasteners specified in the European Technical Assessment (ETA) on the basis of [1]
$N_{Rk,sp}$	characteristic value of static resistance to splitting failure according to EN 1992-4 [5], Equation (7.23)
$N_{Rk,cb}$	characteristic value of static resistance to blow out failure of mechanical fasteners according to EN 1992-4 [5], Equation (7.25)
$\eta_{k,c,N,fat,n}$	reduction factor for concrete cone failure determined without tests according to Equation (2.5) or determined by tests according to Equation (2.7)

$\eta_{k,p,N,fat,n} = \eta_{k,sp,N,fat,n} = \eta_{k,cb,N,fat,n} = \eta_{k,c,N,fat,n}$

If no tests are performed the reduction factor $\eta_{k,c,N,fat,n}$ for fatigue resistances is calculated as a function of the number of cycles n on the safe side as follows:

$$1{,}0 \geq \eta_{k,c,N,fat,n} = 1{,}1 \cdot n^{-0{,}055} \geq 0{,}5 \qquad (2.5)$$

When a manufacturer wishes to get more favourable values it shall be determined by tests of series FA.2 and series FA.3 according to Table A.1. The tests may be performed with the smallest decisive fastener size, which fulfils Equation (2.6):

$$\Delta N_{Rk,s,0,\infty} > \Delta N_{Rk,c,0,\infty} \qquad (2.6)$$

where:

$\Delta N_{Rk,s,0,\infty}$ characteristic value of fatigue limit resistance as determined from tests series FA.1

$\Delta N_{Rk,c,0,\infty}$ characteristic value of fatigue limit resistance calculated by using Equations (2.1) and Equation (2.5) for uncracked concrete

Test conditions:

The tests shall be performed according to Annex D, Figure D.5 and D.8 with a quadruple fastener group. The fastener group shall be loaded until failure.

In test series FA.3 the fastener group shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex A.

Assessment:

Test series FA.2: The characteristic static (or, equivalently, fatigue) resistance for n = 1 cycles, $N_{Rk,c,test}$, shall be determined by statistical evaluation based on the 5%-quantile with a confidence level of 90%.

Test series FA.3: The number of cycles to failure n for each range of force ΔN shall be determined through testing.

Tests, which are stopped without failure shall be re-loaded as pure static tests. A possible damage of the specimen, despite of reaching the limit number of cycles, may be located by applying this so-called run-out test. The specimen is considered as a „real“ run-out specimen on the first load level, if the static result reaches or exceeds the characteristic static resistance $N_{Rk,c,test}$.

Test results on their first load level may be used for the final assessment (Reference Annex A for additional information).

The reduction factor $\eta_{k,c,N,fat,n}$ shall be calculated as follows:

$$\eta_{k,c,N,fat,n} = \frac{\Delta N_{Rk,c,0,\infty}}{\Delta N_{Rk,c,test}} + \left(1 - \frac{\Delta N_{Rk,c,0,\infty}}{\Delta N_{Rk,c,test}}\right) \cdot \frac{\left(\Delta N_{Rk,c,0,n^*} - \Delta N_{Rk,c,0,\infty}\right)}{\left(\Delta N_{Rk,c,test} - \Delta N_{Rk,c,0,\infty}\right)} \qquad (2.7)$$

where:

$\Delta N_{Rk,c,test}$ characteristic value of static resistance as determined from tests series FA.2

$\Delta N_{Rk,c,0,n^*}$ = ΔS_k according to Equation (A.16), characteristic value of fatigue resistance after n load cycles as determined from tests series FA.3

$\Delta N_{Rk,c,0,\infty}$ = ΔS_k according to Equation (A.16), characteristic value of fatigue limit resistance as determined from tests series FA.3

Expression of results

$\Delta N_{Rk,c,0,n}$ *and* $\Delta N_{Rk,sp,0,n}$ with (n = 1 to n = ∞) for all fasteners

$\Delta N_{Rk,cb,0,n}$ *and* $\Delta N_{Rk,p,0,n}$ with (n = 1 to n = ∞) for mechanical fasteners

2.2.3 Characteristic combined pull-out/concrete cone fatigue resistance under tension loading (Method A)

Purpose of assessment: Determination of the characteristic fatigue resistance function for pull-out/combined failure of bonded fasteners under cyclic tension loading as a function of the number of load cycles n.

Assessment method

For bonded fasteners the characteristic fatigue resistance to combined pull-out and concrete cone failure is calculated as follows:

$$\Delta N_{Rk,p,0,n} = \eta_{k,p,N,fat,n} \cdot N_{Rk,p} \quad (2.8)$$

where:

$N_{Rk,p}$	characteristic value of static resistance to pull-out failure according to EN 1992-4 [5], Equation (7.13)
$\eta_{k,p,N,fat,n}$	reduction factor for pull-out failure according to Equation (2.9)

The reduction factor for fatigue resistances is calculated as a function of the number of cycles n as follows:

$$1{,}0 \geq \eta_{k,p,N,fat,n} = 1{,}2 \cdot n^{-0{,}08} \geq 0{,}4 \quad (2.9)$$

Expression of results: $\Delta N_{Rk,p,0,n}$ with (n = 1 to n = ∞) for bonded fasteners

2.2.4 Characteristic steel fatigue resistance under shear loading (Method A)

Purpose of assessment

Determination of the characteristic steel fatigue resistance under cyclic shear loading as a function of the number of load cycles n.

Assessment method

Required tests: For the determination of the characteristic fatigue resistance function, $\Delta V_{Rk,s,0,n}$, testing in accordance with Table A.1 (test series FA.4) shall be performed. All fastener sizes with all steel qualities/properties and coatings specified by the manufacturer shall be tested.

Test conditions: The tests shall be performed according to Annex D, Figure D.2 and Figure D.8 with a single fastener. The fastener shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex A.

The number of cycles to failure n for each range of force ΔV shall be determined through testing. The test results shall be used for the determination of the fatigue resistance function.

Tests, which are stopped without failure and re-loaded with a higher stress range, may be included in the final evaluation, but only test results performed on their first load level (Reference Annex A for additional information).

The characteristic fatigue resistance function is determined by statistical evaluation according to Annex A based on the 5%-quantile with a confidence level of 90% (Example see Figure 2.2):

$$\Delta V_{Rk,s,0,n} = \Delta S_k$$

where:

ΔS_k	according to Equation (A.16), characteristic value of fatigue resistance after n load cycles

The characteristic resistance $V_{Rk,s}$ as determined in static shear tests in accordance with [1], [2] shall be taken as the characteristic fatigue resistance for n = 1 cycles.

The following information regarding the fatigue resistance function shall be determined:

- Equations of the average and characteristic fatigue resistance functions
- Four calculated values for the control of the characteristic fatigue resistance function
- Diagram according to Figure A.6 (Annex A) showing cyclic test results, average and characteristic fatigue resistance functions and four calculated control values
- Tables listing cyclic and lower cyclic load, number of cycles to failure, type of failure, etc.

Expression of results: $\Delta V_{Rk,s,0,n}$ with (n = 1 to n = ∞)

2.2.5 Characteristic concrete edge fatigue resistance under shear loading (Method A)

Purpose of assessment: Determination of the characteristic fatigue resistance function for concrete edge failure under cyclic shear loading as a function of the number of load cycles n.

Assessment method

The characteristic fatigue resistance to concrete edge failure is calculated as follows:

$$\Delta V_{Rk,c,0,n} = \eta_{k,c,V,fat,n} \cdot V_{Rk,c} \tag{2.10}$$

where:

$V_{Rk,c}$	characteristic value of static resistance to concrete edge failure according to EN 1992-4 [5], Equation (7.40)
$\eta_{k,c,V,fat,n}$	reduction factor for concrete edge failure, determined without tests according to Equation (2.11) or determined by tests according to Equation (2.13)

If no tests are performed the reduction factor $\eta_{k,c,V,fat,n}$ for fatigue resistances is calculated as a function of the number of cycles n on the safe side as follows:

$$1{,}0 \geq \eta_{k,c,V,fat,n} = 1{,}2 \cdot n^{-0{,}08} \geq 0{,}5 \tag{2.11}$$

When a manufacturer wishes to get more favourable values it shall be determined by tests of series FA.5 and series FA.6 according to Table A.1. The tests may be performed with the smallest decisive fastener size, which fulfils Equation (2.12):

$$\Delta V_{Rk,s,0,\infty} > \Delta V_{Rk,c,0,\infty} \tag{2.12}$$

where:

$\Delta V_{Rk,s,0,\infty}$	characteristic value of fatigue limit resistance as determined from tests series FA.5
$\Delta V_{Rk,c,0,\infty}$	characteristic value of fatigue limit resistance calculated by using Equations (2.10) and (2.11)

Test conditions:

The tests shall be performed according to Annex D, Figure D.6 and D.8 with a group of two fasteners. The fastener group shall be loaded until failure.

In test series FA.6 the fastener group shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex A.

Assessment:

Test series FA.5: The characteristic static (or, equivalently, fatigue) resistance for n =1 cycles, $V_{Rk,c,test}$, shall be determined by statistical evaluation based on the 5%-quantile with a confidence level of 90%.

Test series FA.6: The number of cycles to failure n for each range of force ΔV shall be determined through testing.

Tests, which are stopped without failure shall be re-loaded as pure static tests. A possible damage of the specimen, despite of reaching the limit number of cycles, may be located by applying this so-called run-out test. The specimen is considered as a „real" run-out specimen on the first load level, if the static result reaches or exceeds the characteristic static resistance $V_{Rk,c,test}$.

Test results on their first load level may be included in the final evaluation (Reference Annex A for additional information).

$$\eta_{k,c,V,fat,n} = \frac{\Delta V_{Rk,c,0,\infty}}{\Delta V_{Rk,c,test}} + \left(1 - \frac{\Delta V_{Rk,c,0,\infty}}{\Delta V_{Rk,c,test}}\right) \cdot \frac{\left(\Delta V_{Rk,c,0,n}{}^{*} - \Delta V_{Rk,c,0,\infty}\right)}{\left(\Delta V_{Rk,c,test} - \Delta V_{Rk,c,0,\infty}\right)} \tag{2.13}$$

where:

$\Delta V_{Rk,c,test}$	characteristic value of static resistance as determined from tests series FA.5
$\Delta V_{Rk,c,0,n}{}^{*}$	= ΔS_k according to Equation (A.16), characteristic value of fatigue resistance after n load cycles as determined from tests series FA.6
$\Delta V_{Rk,c,0,\infty}$	= ΔS_k according to Equation (A.16), characteristic value of fatigue limit resistance as determined from tests series FA.6

Expression of results: $\Delta V_{Rk,c,0,n}$ with (n = 1 to n = ∞)

2.2.6 Characteristic concrete pry-out fatigue resistance under shear loading (Method A)

Purpose of assessment:

Determination of the characteristic fatigue resistance function for concrete pry-out failure under cyclic shear loading as a function of the number of load cycles n.

Assessment method

The characteristic fatigue resistance to pry-out failure is calculated as follows:

$$\Delta V_{Rk,cp,0,n} = \eta_{k,cp,V,fat,n} \cdot V_{Rk,cp} \tag{2.14}$$

where:

$\eta_{k,cp,V,fat,n}$ = $\eta_{k,c,V,fat,n}$

$\eta_{k,c,V,fat,n}$ reduction factor for concrete cone failure according to Section 2.2.5, determined without tests according to Equation (2.11) or determined by tests according to Equation (2.13)

$V_{Rk,cp}$ characteristic value of static resistance according to EN 1992-4 [5], Equations (7.39c) and (7.39d)

Expression of results: $\Delta V_{Rk,cp,0,n}$ with (n = 1 to n = ∞)

2.2.7 Characteristic steel fatigue resistance under combined tension and shear loading (Method A)

Purpose of assessment: Determination of the characteristic steel fatigue resistance under cyclic combined tension and shear loading as a function of the number of load cycles n and determination of the a_{sn}-values for combined tension and shear verification.

Assessment method

Required tests: For the determination of the characteristic fatigue resistance function, $\Delta F^{\beta}_{Rk,s,0,n}$, testing in accordance with Table A.1 (test series FA.7) shall be performed. All fastener sizes with all steel qualities/properties and coatings specified by the manufacturer shall be tested.

Test conditions: The tests shall be performed according to Annex D, Figure D.3 and Figure D.8 with a single fastener. The fastener shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex A.

For all tests of series FA.7 one angle β between the axis of the fastener and load direction shall be chosen according to the relation between fatigue tension resistance $\Delta N_{Rk,s,0,\infty}$ and fatigue shear resistance $\Delta V_{Rk,s,0,\infty}$:

$$\beta = 30°: \quad \Delta N_{Rk,s,0,\infty} / \Delta V_{Rk,s,0,\infty} > 1{,}33 \tag{2.15}$$

$$\beta = 45°: \quad 0.75 \leq \Delta N_{Rk,s,0,\infty} / \Delta V_{Rk,s,0,\infty} \leq 1{,}33 \tag{2.16}$$

$$\beta = 60°: \quad \Delta N_{Rk,s,0,\infty} / \Delta V_{Rk,s,0,\infty} < 0{,}75 \tag{2.17}$$

where:

$\Delta N_{Rk,s,0,\infty}$ characteristic value of fatigue limit resistance as determined from tests series FA.1

$\Delta V_{Rk,s,0,\infty}$ characteristic value of fatigue limit resistance as determined from tests series FA.4

Tests, which are stopped without failure and re-loaded with a higher stress range, may be included in the final evaluation, but only test results performed on their first load level (Reference Annex A for additional information).

The number of cycles to failure n for each range of force ΔF^{β} shall be determined through testing. The test results shall be used for the determination of the fatigue resistance function.

The characteristic fatigue resistance function is determined by statistical evaluation according to Annex A based on the 5%-quantile with a confidence level of 90% (Example see Figure 2.2):

$$\Delta F^{\beta}_{Rk,s,0,n} = \Delta S_k$$

where:

ΔS_k according to Equation (A.16) characteristic value of fatigue resistance after n load cycles

The characteristic resistance $\Delta F^{\beta}_{Rk,s}$ shall be determined in accordance with EN 1992-4 [5], 8.3.3 using the exponent α_s = 2,0 for steel failure and an angle β as determined according to Equations (2.15), (2.16), (2.17). The characteristic resistance $\Delta F^{\beta}_{Rk,s}$ shall be taken as the characteristic fatigue resistance for n = 1 cycles.

The assessment includes following steps:

- Equations of the average and characteristic fatigue resistance functions
- Four calculated values for the control of the characteristic fatigue resistance function
- Diagram according to Figure A.6 (Annex A) showing cyclic test results, average and characteristic fatigue resistance functions and four calculated control values

The calculated characteristic fatigue resistance function $\Delta F^{\beta}_{Rk,s,0,n}$ for combined tension and shear loads shall be used for the determination of a_{sn}-values (see Figure 2.3).

The α_{sn}-values shall be determined using the following Equation for combined tension and shear verification. The following equation must be solved:

$$\left(\frac{\Delta F^{\beta}_{Rk,s,0,n}\cdot\sin\beta}{\Delta N_{Rk,s,0,n}}\right)^{\alpha_{sn}}+\left(\frac{\Delta F^{\beta}_{Rk,s,0,n}\cdot\cos\beta}{\Delta V_{Rk,s,0,n}}\right)^{\alpha_{sn}}=1{,}0 \tag{2.17}$$

where:

$\Delta N_{Rk,s,0,n}$	characteristic value of fatigue resistance as determined from tests series FA.1
$\Delta V_{Rk,s,0,n}$	characteristic value of fatigue resistance as determined from tests series FA.4
$\Delta F^{\beta}_{Rk,s,0,n}$	characteristic value of fatigue resistance as determined from tests series FA.7
n	number of cycles: ≤ 10^1, ≤ $3\cdot10^1$, ≤ 10^2, ≤ $3\cdot10^2$, ≤ 10^3, ≤ $3\cdot10^3$, ≤ 10^4, ≤ $3\cdot10^4$, ≤ 10^5, ≤ $3\cdot10^5$, ≤ 10^6, ≤ $5\cdot10^6$ and > $5\cdot10^6$ for the fatigue limit resistance

The α_{sn}-values shall be determined by interactive steps with calculation the equation in such a way that the graph connects the resistances $\Delta N_{Rk,s}$, $\Delta F^{\beta}_{Rk,s}$ and $\Delta V_{Rk,s}$ (see Figure 2.3) for each given number of cycles n.

Note: The exponent α_{sn} for combined tension and shear verification can be lower than 1.

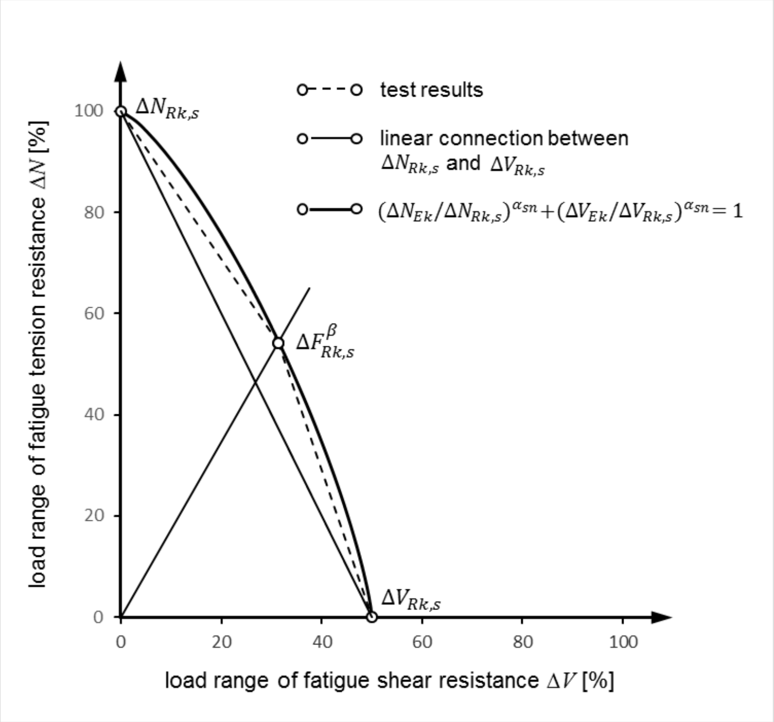


Figure 2.3: Example for an interaction diagram for combined tension and shear loads

<u>Expression of results:</u> a_{sn} with (n = 1 to n = ∞)

2.2.8 Load transfer factor for tension and shear loading (Method A)

Purpose of assessment:

Determination of the load transfer factor under cyclic tension and shear loading.

A load transfer within the fastener group is a result of the different values of the cyclic creep and the cyclic stiffness at the position of the anchorage and additionally cracks in the base material affect the increasing load transfer.

Assessment method

No tests are required if, on the safe side, the load transfer factors ψ_{FN} = ψ_{FV} = 0,5 have to be applied.

When a manufacturer wishes to get more favourable values it shall be determined by tests in accordance with Table C.1, test series FC.1 (cracked concrete) and test series FC.2 (uncracked concrete) for tension and test series FC.3 (cracked concrete) and series FC.4 (uncracked concrete) for shear.

The tests may be performed only with the smallest fastener size if the resulting load transfer factors are applied to all other fastener sizes specified by the manufacturer.

Test conditions: The tests shall be performed according to Annex D, Figure D.1, Figure D.2 and Figure D.8 with a single fastener. The fastener shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex A.

The number of cycles to failure n for each range of force ΔN and ΔV shall be determined through testing.

The test results shall be used for the determination of the load transfer factor (see Annex C for additional details):

ψ_{FN} = ψ_F according to Equation (C.26) for tension

ψ_{FV} = ψ_F according to Equation (C.26) for shear

The assessment includes following steps:

- Determination of the two average functions (see Annex C, C.3.2)
- Diagram according to Figure C.3 (Annex C) showing cyclic test results and average functions
- Tables listing cyclic and lower cyclic load, number of cycles to failure, type of failure, etc.

Expression of results: ψ_{FN}, ψ_{FV}

2.2.9 Characteristic steel fatigue limit resistance under tension loading (Method B)

Purpose of assessment: Determination of the characteristic steel fatigue limit resistance under cyclic tension loading and determination of the minimum number of load cycles for run-out tests for steel failure to detect possible damage of the specimen, despite reaching the limit number of cycles.

Assessment method

Required tests: For the determination of the characteristic fatigue limit resistance, $\Delta N_{Rk,s,0,\infty}$, testing in accordance with Table B.1 test series FB.1 and test series FB.2 shall be performed. All fastener sizes with all steel qualities/properties and coatings specified by the manufacturer shall be tested.

Test conditions: The tests shall be performed according to Annex D, Figure D.1 and Figure D.8 with a single fastener. The fastener shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex B.

During the fatigue cyclic tests with constant load amplitude, the increase of deformation into the direction of the acting force shall be measured and monitored.

Assessment of characteristic fatigue limit resistance (test series FB.1):

Testing shall be considered successful when all the following conditions are fulfilled:

- no steel failure occurs for all tests
- a stabilization of the displacement vs. number of cycles function occurs. Additional information on the assessment of the displacement vs. number of cycles function is included in Annex B.

- run-out verification test is passed

In the case that one or multiple failures are observed, the test program shall be repeated using a lower fatigue cyclic load. It shall not be permitted to combine results from tests performed at different load levels.

The characteristic fatigue limit resistance is calculated by applying Annex B:

$\Delta N_{Rk,s,0,\infty} = \Delta S_{D,k}$

where: $S_{D,k}$ according to Equation (B.10)

Assessment of the minimum number of load cycles for run-out tests (test series FB.2):

All tests according to Table B.1, series FB.2, shall be evaluated according to test method B. The tests to determine the minimum number of load cycles for run-out tests shall be tested to failure.

The minimum number of load cycles for run-out tests shall be determined in accordance with Annex B, B.3.3.

Expression of results: $\Delta N_{Rk,s,0,\infty}$

2.2.10 Characteristic concrete cone, pull-out, combined pull-out/concrete cone, splitting and blow-out fatigue limit resistance under tension loading (Method B)

Purpose of assessment: Determination of the characteristic fatigue limit resistance function for concrete cone, pull-out, combined pull-out/concrete cone, splitting and blow out failure under cyclic tension loading.

Assessment method

The characteristic limit resistances $\Delta N_{Rk,c,0,\infty}$, $\Delta N_{Rk,p,0,\infty}$, $\Delta N_{Rk,sp,0,\infty}$ and $\Delta N_{Rk,cb,0,\infty}$ for fatigue loads shall be calculated as follows:

Concrete cone, pull-out: $\Delta N_{Rk,c,0,\infty} = 0{,}5 \cdot N_{Rk,c} = \Delta N_{Rk,p,0,\infty}$ (2.18)

Combined pull-out/concrete cone: $\Delta N_{Rk,p,0,\infty} = 0{,}4 \cdot N_{Rk,p}$ (2.19)

Splitting: $\Delta N_{Rk,sp,0,\infty} = 0{,}5 \cdot N_{Rk,sp}$ (2.20)

Blow-out: $\Delta N_{Rk,cb,0,\infty} = 0{,}5 \cdot N_{Rk,cb}$ (2.21)

Expression of results:

$\Delta N_{Rk,c,0,\infty}$ $\Delta N_{Rk,p,0,\infty}$ and $\Delta N_{Rk,sp,0,\infty}$ for all fasteners

$\Delta N_{Rk,cb,0,\infty}$ for mechanical fasteners

2.2.11 Characteristic steel fatigue limit resistance under shear loading (Method B)

Purpose of assessment:

Determination of the characteristic steel fatigue limit resistance under cyclic shear loading determination of the minimum number of load cycles for run-out tests for steel failure to detect possible damage of the specimen, despite reaching the limit number of cycles.

Assessment method

Required tests: For the determination of the characteristic fatigue limit resistance, $\Delta V_{Rk,s,0,\infty}$, testing in accordance with Table B.1 test series FB.3 and test series FB.4 shall be performed. All fastener sizes with all steel qualities/properties and coatings specified by the manufacturer shall be tested.

Test conditions: The tests shall be performed according to Annex D, Figure D.2 and Figure D.8 with a single fastener. The fastener shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex B.

During the fatigue cyclic tests with constant load amplitude, the increase of deformation into the direction of the acting force shall be measured and monitored.

Assessment of characteristic fatigue limit resistance (test series FB.3):

Testing shall be considered successful when all the following conditions are fulfilled:

- no steel failure occurs for all tests

- a stabilization of the displacement vs. number of cycles function occurs. Additional information on the assessment of the displacement vs. number of cycles function is included in Annex B.
- run-out verification test is passed

In the case that one or multiple failures are observed, the test program shall be repeated using a lower fatigue cyclic load. It shall not be permitted to combine results from tests performed at different load levels.

The characteristic fatigue limit resistance is calculated by applying Annex B:

$\Delta V_{Rk,s,0,\infty} = \Delta S_{D,k}$

where: $\Delta S_{D,k}$ according to Equation (B.10)

Assessment of the minimum number of load cycles for run-out tests (test series FB.4):

All tests according to Table B.1, series FB.4, shall be evaluated according to test method B. The tests to determine the minimum number of load cycles for run-out tests shall be tested to failure.

The minimum number of load cycles for run-out tests shall be determined in accordance with Annex B, B.3.3.

Expression of results: $\Delta V_{Rk,s,0,\infty}$

2.2.12 Characteristic concrete edge and pry-out fatigue limit resistance under shear loading (Method B)

Purpose of assessment:

Determination of the characteristic fatigue limit resistance for concrete edge and pry-out failure under cyclic shear loading.

Assessment method

The characteristic limit resistances $\Delta V_{Rk,c,0,\infty}$ and $\Delta V_{Rk,cp,0,\infty}$ for fatigue loads shall be calculated as follows:

$$\Delta V_{Rk,c,0,\infty} = 0{,}5 \cdot V_{Rk,c} \qquad (2.22)$$

$$\Delta V_{Rk,cp,0,\infty} = 0{,}5 \cdot V_{Rk,cp} \qquad (2.23)$$

Expression of results: $\Delta V_{Rk,c,0,\infty}$ $\Delta V_{Rk,cp,0,\infty}$

2.2.13 Characteristic steel fatigue limit resistance under combined tension and shear loading (Method B)

Purpose of assessment:

Determination of the characteristic steel fatigue limit resistance under combined cyclic tension and shear loading.

Assessment method

For steel failure under combined tension and shear verification the following exponents shall be given:

$\alpha_s = \alpha_{sn} = 0{,}5$ for thread size M10 and M12

$\alpha_s = \alpha_{sn} = 0{,}7$ for thread size M16 and larger

where:

α_s	exponent for verification of steel failure according to EN 1992-4 [5] Equation (8.1)
α_{sn}	exponent for verification of steel failure according to TR 061 [3] Table 2.5

Expression of results: a_s $(n = \infty)$

2.2.14 Load transfer factor for tension and shear loading (Method B)

Purpose of assessment:

Determination of the load transfer factor under cyclic tension and shear loading.

A load transfer within the fastener group is a result of the different values of the cyclic creep and the cyclic stiffness at the position of the anchorage and additionally cracks in the base material affect the increasing load transfer.

Assessment method

For tension and shear verification the following load transfer factor shall be given:

$\psi_{FN} = \psi_{FV} = 0{,}5$

where:

ψ_{FN}, ψ_{FV}	reduction factor for verification of the most loaded fastener in a group according to EN 1992-4 [5] Table 8.1 and Table 8.2 or according to TR 061 [3] Table 2.2, Table 2.3 and Table 2.5

Expression of results: ψ_{FN}, ψ_{FV}

2.2.15 Characteristic steel fatigue resistance under tension loading (Method C)

Purpose of assessment

Determination of the characteristic steel fatigue resistance function under cyclic tension loading for steel failure as a linearized function of the number of load cycles n.

Assessment method

Required tests: For the determination of the linearized characteristic fatigue resistance function, $\Delta N_{Rk,s,0,n}$, test series FE.1 to FE.4 in accordance with Table E.1 (for bonded fasteners) or Table E.2 (for torque-controlled expansion fasteners (bolt type with external thread)) shall be performed.

Test conditions: The tests shall be performed according to Annex D, Figure D.1 and Figure D.8 with a single fastener. In test series FE.2 and FE.4 the fastener shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex E.

The number of cycles to failure n for each range of force ΔN shall be determined through testing. The test results shall be used for the determination of the fatigue resistance.

The following information regarding the fatigue resistance function shall be determined:

- Linearized functions of the average and characteristic fatigue resistance
- Diagram according to Figure E.2 (Annex E) showing cyclic test results, average and characteristic fatigue resistance functions
- Tables listing cyclic and lower cyclic load, number of cycles to failure, type of failure, etc.

The characteristic fatigue resistance is determined by statistical evaluation according to Annex E based on the 5%-quantile with a confidence level of 90% (Example see Figure E.2). The static characteristic resistance as the reference value is used to normalize the characteristic fatigue resistance.

$$\Delta N_{Rk,s,0,n} = k \cdot \frac{\Delta F_{k,n} \cdot N_{Rk,s}}{F_{k,Ref}} \tag{2.24}$$

where:

$\Delta F_{k,n}$	according to E.3.2, characteristic value of fatigue resistance after n load cycles determined from fatigue test series FE.2 (for uncracked concrete) and FE.4 (for cracked concrete)
$F_{k,Ref}$	according to E.3.1, characteristic value of static resistance determined from reference test series FE.1 (for uncracked concrete) and FE.3 (for cracked concrete), may be calculated according to EAD 330499-01-0601 [2], Equation (2.1) by using the steel strength of threaded rods which are used in tests FE.2 if the static characteristic steel resistance (according to ETA based on [2]) is not larger than this calculated value
$N_{Rk,s}$	characteristic value of static resistance as determined in static tension tests in accordance with [2]
k	inclination factor = 1,0 for tests performed with inclination of 3° = 0,75 for tests performed without inclination of 3°

If the fatigue tests of different sizes are assessed using a joint evaluation with at least 20 tests in total (based on the stress at the cross section), the characteristic fatigue resistance may be calculated as follows:

The assessment according to E.3.2 is done for the stress ($\Delta\sigma_k$) at the cross section instead of ΔF_k. The characteristic fatigue resistance for each size is calculated according to following Equation:

$$\Delta N_{Rk,s,0,n} = k \cdot \frac{\Delta\sigma_{k,n} \cdot A_s \cdot \sigma_{Rk,s}}{\sigma_{k,Ref}} \tag{2.25}$$

where:

$\Delta\sigma_{k,n}$	according to E.3.2, characteristic value of fatigue resistance after n load cycles determined from fatigue test series FE.2 (for uncracked concrete) and FE.4 (for cracked concrete), result of the joint evaluation
A_s	stressed cross section of the relevant fastener size
$\sigma_{Rk,s}$	$N_{Rk,s}$ / A_s (stress in the cross section)
$\sigma_{k,Ref}$	$F_{k,ref}$ / A_s (stress in the cross section), $\sigma_{k,Ref} \geq \sigma_{Rk,s}$
$N_{Rk,s}$, $F_{k,ref}$, k	see Equation (2.24)

<u>Expression of results</u>: $\Delta N_{Rk,s,0,n}$ with (n = 1 to n = ∞)

2.2.16 Characteristic concrete cone, splitting and blow out fatigue resistance under tension loading (Method C)

<u>Purpose of assessment:</u>

Determination of the characteristic fatigue resistance function for concrete cone, splitting and blow out failure under cyclic tension loading as a linearized function of the number of load cycles n

<u>Assessment method</u>

The characteristic fatigue resistances to concrete cone failure, pull-out failure, splitting and blow out failure are calculated as follows:

$$\Delta N_{Rk,c,0,n} = \eta_{k,c,N,fat,n} \cdot N_{Rk,c} \tag{2.26}$$

$$\Delta N_{Rk,sp,0,n} = \eta_{k,sp,N,fat,n} \cdot N_{Rk,sp} \tag{2.27}$$

$$\Delta N_{Rk,cb,0,n} = \eta_{k,cb,N,fat,n} \cdot N_{Rk,cb} \tag{2.28}$$

where:

$N_{Rk,c}$	characteristic value of static resistance to concrete cone failure according to EN 1992-4 [5], Equation (7.1)
$N_{Rk,sp}$	characteristic value of static resistance to splitting failure according to EN 1992-4 [5], Equation (7.23)
$N_{Rk,cb}$	characteristic value of static resistance to blow out failure of mechanical fasteners according to EN 1992-4 [5], Equation (7.25)
$\eta_{k,c,N,fat,n}$	reduction factor for concrete cone failure determined without tests according to Equation (2.5) or determined by tests according to Equation (2.29)

$\eta_{k,sp,N,fat,n} = \eta_{k,cb,N,fat,n} = \eta_{k,c,N,fat,n}$

If no tests are performed the reduction factor $\eta_{k,c,N,fat,n}$ for fatigue resistances is calculated on the safe side according to Equation (2.5).

When a manufacturer wishes to get more favourable values it shall be determined by tests of series FE.5 to series FE.8 according to Table E.1 (for bonded fasteners) or Table E.2 (for torque-controlled expansion fasteners (bolt type with external thread)).

Test conditions: The tests shall be performed according to Annex D, Figure D.5 and D.8 with a quadruple fastener group. The fastener group shall be loaded until failure. In test series FE.6 and FE.8 the fastener group shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex E.

The number of cycles to failure n for each range of force ΔN shall be determined through testing. The test results shall be used for the determination of the fatigue resistance.

The following information regarding the fatigue resistance function shall be determined:

- Linearized functions of the average and characteristic fatigue resistance
- Diagram according to Figure E.2 (Annex E) showing cyclic test results, average and characteristic fatigue resistance functions
- Tables listing cyclic and lower cyclic load, number of cycles to failure, type of failure, etc.

The characteristic fatigue resistance is determined by statistical evaluation according to Annex E based on the 5%-quantile with a confidence level of 90% (Example see Figure E.2).

The reduction factor $\eta_{k,c,N,fat,n}$ shall be calculated as follows:

$$\eta_{k,c,N,fat,n} = \frac{\Delta F_{k,n}}{F_{k,Ref}} \tag{2.29}$$

where:

$\Delta F_{k,n}$	according to E.3.2, characteristic value of fatigue resistance after n load cycles determined from fatigue test series FE.6 (for uncracked concrete) and FE.8 for cracked concrete)
$F_{k,Ref}$	according to E.3.1, characteristic value of reference static resistance as determined from tests series FE.5 (for uncracked concrete) or FE.7 (for cracked concrete)

Expression of results

$\Delta N_{Rk,c,0,n}$ *and* $\Delta N_{Rk,sp,0,n}$ with (n = 1 to n = ∞)	for bonded and torque-controlled expansion fasteners - bolt type with external thread
$\Delta N_{Rk,cb,0,n}$ with (n = 1 to n = ∞)	for torque-controlled expansion fasteners - bolt type with external thread

2.2.17 Characteristic pull-out or combined pull-out /concrete cone fatigue resistance under tension loading (Method C)

Purpose of assessment:

Determination of the characteristic fatigue resistance function for pull-out failure of torque-controlled expansion fasteners (bolt type with external thread) or combined pull-out /concrete cone failure of bonded fasteners under cyclic tension loading as a linearized function of the number of load cycles n.

Assessment method for combined pull-out /concrete cone of bonded fasteners

The characteristic fatigue resistances to combined pull-out /concrete cone failure is calculated as follows:

$$\Delta\tau_{Rk,0,n} = \eta_{k,p,N,fat,n} \cdot \tau_{Rk} \tag{2.30}$$

where:

τ_{Rk}	characteristic value of static resistance to combined pull-out /concrete cone failure of bonded fasteners specified in the European Technical Assessment (ETA) on the basis of [2]
$\eta_{k,p,N,fat,n}$	reduction factor for combined pull-out /concrete cone failure according to Equation (2.31)

Required tests: For the determination of the linearized characteristic fatigue resistance function $\Delta\tau_{Rk,0,n}$ test series FE.9 to FE.12 in accordance with Table E.1 (for bonded fasteners) or Table E.2 (for torque-controlled expansion fasteners (bolt type with external thread)) shall be performed.

Test conditions: The tests shall be performed according to Annex D, Figure D.1 and Figure D.8 with a single fastener. In test series FE.10 and FE.12 the fastener shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex E.

The number of cycles to failure n for each range of force ΔN shall be determined through testing. The test results shall be used for the determination of the fatigue resistance.

The following information regarding the fatigue resistance function shall be determined:

- Linearized functions of the average and characteristic fatigue resistance
- Diagram according to Figure E.2 (Annex E) showing cyclic test results, average and characteristic fatigue resistance functions
- Tables listing cyclic and lower cyclic load, number of cycles to failure, type of failure, etc.

The characteristic fatigue resistance is determined by statistical evaluation according to Annex E based on the 5%-quantile with a confidence level of 90% (Example see Figure E.2).

The reduction factor $\eta_{k,p,N,fat,n}$ for bond strength at the effective embedment depth is calculated as follows:

$$\eta_{k,p,N,fat,n} = \frac{\Delta\tau_{k,n}}{\tau_{k,Ref}} \tag{2.31}$$

where:

$\Delta\tau_{k,n}$	$= \Delta F_{k,n} \,/\, (h_{ef} \cdot \pi \cdot d)$
$\tau_{k,Ref}$	$= F_{k,ref} \,/\, (h_{ef} \cdot \pi \cdot d)$ $\tau_{k,Ref} \geq \tau_{Rk}$
$\Delta F_{k,n}$	according to E.3.2, characteristic value of fatigue resistance after n load cycles determined from fatigue test series FE.10 (for uncracked concrete) and FE.12 for cracked concrete), result of the joint evaluation
$F_{k,Ref}$	according to E.3.1, characteristic value of static resistance determined from reference test series FE.9 (for uncracked concrete) and FE.11 (for cracked concrete)
h_{ef}	effective embedment depth
d	diameter of the fastener

<u>Assessment method for pull-out failure of torque-controlled expansion fasteners (bolt type with external thread)</u>

The characteristic fatigue resistances to pull-out failure is calculated as follows:

$$\Delta N_{Rk,p,0,n} = \eta_{k,p,N,fat,n} \cdot N_{Rk,p} \tag{2.32}$$

where:

$N_{Rk,p}$	characteristic value of static resistance to pull-out failure of mechanical fasteners specified in the European Technical Assessment (ETA) on the basis of [1]
$\eta_{k,p,N,fat,n}$	determined without tests according to Equation (2.5) or determined by tests according to Equation (2.33)

If no tests are performed the reduction factor $\eta_{k,p,N,fat,n}$ for fatigue resistances is calculated on the safe side according to Equation (2.5).

When a manufacturer wishes to get more favourable values it shall be determined by tests of series FE.9 to series FE.12 according to Table E.2.

Test conditions: The tests shall be performed according to Annex D, Figure D.1 and Figure D.8 with a single fastener. In test series FE.10 and FE.12 the fastener shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex E.

The number of cycles to failure n for each range of force ΔN shall be determined through testing. The test results shall be used for the determination of the fatigue resistance.

The following information regarding the fatigue resistance function shall be determined:

- Linearized functions of the average and characteristic fatigue resistance
- Diagram according to Figure E.2 (Annex E) showing cyclic test results, average and characteristic fatigue resistance functions

- Tables listing cyclic and lower cyclic load, number of cycles to failure, type of failure, etc.

The characteristic fatigue resistance is determined by statistical evaluation according to Annex E based on the 5%-quantile with a confidence level of 90% (Example see Figure E.2).

The reduction factor $\eta_{k,p,N,fat,n}$ shall be calculated as follows:

$$\eta_{k,p,N,fat,n} = \frac{\Delta F_{k,n}}{F_{k,Ref}} \tag{2.33}$$

where:

$\Delta F_{k,n}$ according to E.3.2, characteristic value of fatigue resistance after n load cycles determined from fatigue test series FE.10 (for uncracked concrete) and FE.12 for cracked concrete)

$F_{k,Ref}$ according to E.3.1, characteristic value of reference static resistance as determined from tests series FE.9 (for uncracked concrete) or FE.11 (for cracked concrete)

Expression of results

$\Delta\tau_{Rk,p,0,n}$ with (n = 1 to n = ∞) for bonded fasteners

$\Delta N_{Rk,p,0,n}$ with (n = 1 to n = ∞) for torque-controlled expansion fasteners - bolt type with external thread

2.2.18 Characteristic steel fatigue resistance under shear loading (Method C)

Purpose of assessment:

Determination of the characteristic fatigue resistance function for steel failure as a linearized function of the number of load cycles n.

Assessment method

Required tests: For the determination of the linearized characteristic fatigue resistance function, $\Delta V_{Rk,s,0,n}$, test series FE.13 to FE.16 in accordance with Table E.1 (for bonded fasteners) or Table E.2 (for torque-controlled expansion fasteners (bolt type with external thread)) shall be performed.

Test conditions: The tests shall be performed according to Annex D, Figure D.2 and Figure D.8 with a single fastener. In test series FE.14 and FE.16 the fastener shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex E.

The number of cycles to failure n for each range of force ΔV shall be determined through testing. The test results shall be used for the determination of the fatigue resistance function.

The following information regarding the fatigue resistance function shall be determined:

- Linearized functions of the average and characteristic fatigue resistance
- Diagram according to Figure E.2 (Annex E) showing cyclic test results, average and characteristic fatigue resistance functions
- Tables listing cyclic and lower cyclic load, number of cycles to failure, type of failure, etc.

The characteristic fatigue resistance is determined by statistical evaluation according to Annex E based on the 5%-quantile with a confidence level of 90% (Example see Figure E.2). The static characteristic resistance as the reference value is used to normalize the characteristic fatigue resistance.

$$\Delta V_{Rk,s,0,n} = \frac{\Delta F_{k,n} \cdot V_{Rk,s}}{F_{k,Ref}} \tag{2.34}$$

where:

$\Delta F_{k,n}$ according to E.3.2, characteristic value of fatigue resistance after n load cycles determined from fatigue test series FE.14 (for uncracked concrete) and FE.16 for cracked concrete)

$F_{k,Ref}$ according to E.3.1, characteristic value of static resistance determined from reference test series FE.13 (for uncracked concrete) and FE.15 (for cracked concrete)

$V_{Rk,s}$ characteristic value of static resistance as determined in static tension tests in accordance with [2]

If the fatigue tests of different sizes are assessed using a joint evaluation with at least 20 tests in total (based on the stress at the cross section), the characteristic fatigue resistance may be calculated as follows:

The assessment according to E.3.2 is done for the stress ($\Delta\sigma_k$) at the cross section instead of ΔF_k. The characteristic fatigue resistance for each size is calculated according to following Equation:

$$\Delta V_{Rk,s,0,n} = \frac{\Delta\sigma_{k,n} \cdot A_s \cdot \sigma_{Rk,s}}{\sigma_{k,Ref}} \tag{2.35}$$

where:

$\Delta\sigma_{k,n}$	according to E.3.2, characteristic value of fatigue resistance after n load cycles determined from fatigue test series FE.14 (for uncracked concrete) and FE.16 (for cracked concrete), result of the joint evaluation
A_s	stressed cross section of the relevant fastener size
$\sigma_{Rk,s}$	$V_{Rk,s}$ / A_s (stress in the cross section)
$\sigma_{k,Ref}$	$F_{k,ref}$ / A_s (stress in the cross section), $\sigma_{k,Ref} \geq \sigma_{Rk,s}$
$V_{Rk,s}$, $F_{k,ref}$	see Equation (2.34)

Expression of results: $\Delta V_{Rk,s,0,n}$ (n = 1 to n = ∞)

2.2.19 Characteristic concrete edge fatigue resistance under shear loading (Method C)

Purpose of assessment:

Determination of the characteristic fatigue resistance function for concrete edge failure as a linearized function of the number of load cycles n.

Assessment method

The characteristic fatigue resistance to concrete edge failure is calculated as follows:

$$\Delta V_{Rk,c,0,n} = \eta_{k,c,V,fat,n} \cdot V_{Rk,c} \tag{2.36}$$

where:

$V_{Rk,c}$	characteristic value of static resistance to concrete edge failure according to EN 1992-4 [5], Equation (7.40)
$\eta_{k,c,V,fat,n}$	reduction factor for concrete edge failure determined without tests according to Equations (2.11) or determined by tests according to Equation (2.37)

If no tests are performed the reduction factor $\eta_{k,c,V,fat,n}$ for fatigue resistances is calculated on the safe side according to Equation (2.11).

When a manufacturer wishes to get more favourable values it shall be determined by tests of series FE.17 to series FE.18 according to Table E.1 (for bonded fasteners) or Table E.2 (for torque-controlled expansion fasteners (bolt type with external thread)).

Test conditions: The tests shall be performed according to Annex D, Figure D.6 and D.8 with a group of two fasteners. The fastener group shall be loaded until failure. In test series FE.18 the fastener group shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex E.

The number of cycles to failure n for each range of force ΔV shall be determined through testing. The test results shall be used for the determination of the fatigue resistance.

The following information regarding the fatigue resistance function shall be determined:

- Linearized functions of the average and characteristic fatigue resistance
- Diagram according to Figure E.2 (Annex E) showing cyclic test results, average and characteristic fatigue resistance functions
- Tables listing cyclic and lower cyclic load, number of cycles to failure, type of failure, etc.

The characteristic fatigue resistance is determined by statistical evaluation according to Annex E based on the 5%-quantile with a confidence level of 90% (Example see Figure E.2).

The reduction factor $\eta_{k,c,V,fat,n}$ shall be calculated as follows:

$$\eta_{k,c,V,fat,n} = \frac{\Delta F_{k,n}}{F_{k,Ref}} \tag{2.37}$$

where:

$\Delta F_{k,n}$	according to E.3.2, characteristic value of fatigue resistance after n load cycles determined from fatigue test series FE.18 (for uncracked concrete)
$F_{k,Ref}$	according to E.3.1, characteristic value of reference static resistance as determined from tests series FE.17 (for uncracked concrete)

Expression of results: $\Delta V_{Rk,c,0,n}$ (n = 1 to n = ∞)

2.2.20 Characteristic concrete pry-out fatigue resistance under shear loading (Method C)

Purpose of assessment:

Determination of the characteristic fatigue resistance function for concrete pry-out failure under cyclic shear loading as a linearized function of the number of load cycles n.

Assessment method

The characteristic fatigue resistance to concrete pry-out failure is calculated as follows:

$$\Delta V_{Rk,cp,0,n} = \eta_{k,cp,V,fat,n} \cdot V_{Rk,cp} \tag{2.38}$$

where:

$V_{Rk,cp}$	characteristic value of static resistance to concrete edge failure according to EN 1992-4 [5], Equation (7.39c) or (7.39d)
$\eta_{k,cp,V,fat,n}$	reduction factor for concrete edge failure determined without tests according to Equations (2.11): $\eta_{k,cp,V,fat,n} = \eta_{k,c,V,fat,n}$, or determined by tests according to Equation (2.39)

If no tests are performed the reduction factor $\eta_{k,cp,V,fat,n}$ for fatigue resistances is calculated on the safe side according to Equation (2.11).

When a manufacturer wishes to get more favourable values it shall be determined by tests of series FE.19 to series FE.20 according to Table E.1 (for bonded fasteners) or Table E.2 (for torque-controlled expansion fasteners (bolt type with external thread)).

Test conditions: The tests shall be performed according to Annex D, Figure D.6 and D.8 with a group of two fasteners. The fastener group shall be loaded until failure. In test series FE.20 the fastener group shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex E.

The number of cycles to failure n for each range of force ΔV shall be determined through testing. The test results shall be used for the determination of the fatigue resistance.

The following information regarding the fatigue resistance function shall be determined:

- Linearized functions of the average and characteristic fatigue resistance
- Diagram according to Figure E.2 (Annex E) showing cyclic test results, average and characteristic fatigue resistance functions
- Tables listing cyclic and lower cyclic load, number of cycles to failure, type of failure, etc.

The characteristic fatigue resistance is determined by statistical evaluation according to Annex E based on the 5%-quantile with a confidence level of 90% (Example see Figure E.2). The reduction factor $\eta_{k,cp,V,fat,n}$ shall be calculated as follows:

$$\eta_{k,cp,V,fat,n} = \frac{\Delta F_{k,n}}{F_{k,Ref}} \tag{2.39}$$

where:

$\Delta F_{k,n}$ according to E.3.2, characteristic value of fatigue resistance after n load cycles determined from fatigue test series FE.20 (for uncracked concrete)

$F_{k,Ref}$ according to E.3.1, characteristic value of reference static resistance as determined from tests series FE.19 (for uncracked concrete)

Expression of results

$\Delta V_{Rk,cp,0,n}$ (n = 1 to n = ∞)

2.2.21 Characteristic steel fatigue resistance under combined tension and shear loading (Method C)

Purpose of assessment

Determination of the characteristic fatigue resistance function for steel failure as a linearized function of the number of load cycles n and determination of the a_{sn}-values for combined tension and shear verification.

Assessment method

Characteristic steel fatigue resistance under combined tension and shear is only given if after tests of test series FE.2 and FE.4 no failure on the concrete surface is observed. If this condition is not fulfilled, in the ETA is stated, that steel fatigue resistance under combined tension and shear loading = 0.

Under combined tension and shear verification the following exponents shall be given on the safe side for bonded fasteners and torque-controlled expansion fasteners (bolt type with external thread) made of carbon steel and stainless steel:

$\alpha_s = \alpha_{sn}$ = 0,5 for thread size smaller than M16

$\alpha_s = \alpha_{sn}$ = 0,7 for thread size M16 and larger

where:

α_s exponent for verification of steel failure according to EN 1992-4 [5] Equation (8.1)

α_{sn} exponent for verification of steel failure according to TR 061 [3] Table 2.5

When a manufacturer wishes to get more favourable values it shall be determined by tests of series FE.21 and FE.22 according to Table E.1 (for bonded fasteners) or Table E.2 (for torque-controlled expansion fasteners (bolt type with external thread)).

Test conditions: The tests shall be performed according to Annex D, Figure D.3 and Figure D.8 with a single fastener. The fastener shall be loaded with a sinusoidal load process according to Figure D.9. Additional information on the testing and loading requirements is included in Annex E.

For all tests of series FE.21 and FE.22 one angle β between the axis of the fastener and load direction shall be chosen according to the relation between fatigue tension resistance $\Delta N_{Rk,s,0,\infty}$ and fatigue shear resistance $\Delta V_{Rk,s,0,\infty}$:

$$\beta = 30°: \quad \Delta N_{Rk,s,0,\infty} / \Delta V_{Rk,s,0,\infty} > 1{,}33 \tag{2.40}$$

$$\beta = 45°: \quad 0{,}75 \leq \Delta N_{Rk,s,0,\infty} / \Delta V_{Rk,s,0,\infty} \leq 1{,}33 \tag{2.41}$$

$$\beta = 60°: \quad \Delta N_{Rk,s,0,\infty} / \Delta V_{Rk,s,0,\infty} < 0{,}75 \tag{2.42}$$

where:

$\Delta N_{Rk,s,0,\infty}$ characteristic value of fatigue limit resistance as determined from tests series FE.2 (for uncracked concrete) or FE.4 (for cracked concrete)

$\Delta V_{Rk,s,0,\infty}$ characteristic value of fatigue limit resistance as determined from tests series FE.14 (for uncracked concrete) or FE.16 (for cracked concrete)

The characteristic fatigue resistance is determined by statistical evaluation according to Annex E based on the 5%-quantile with a confidence level of 90% (Example see Figure E.2). The following equation must be solved to a_{sn} to determine a_{sn} as a function of the number of cycles.

$$\left(\frac{\cos(\beta)\cdot\Delta F^{\beta}_{Rk,s,n}}{\Delta N_{Rk,s,n}}\right)^{a_{sn}}+\left(\frac{\sin(\beta)\cdot\Delta F^{\beta}_{Rk,s,n}}{\Delta V_{Rk,s,n}}\right)^{a_{sn}}=1{,}0 \tag{2.43}$$

where:

$\Delta F^{\beta}_{Rk,s,n}$ according to E.3.2, characteristic value of fatigue resistance after n load cycles determined from fatigue test series FE.21 (for uncracked concrete) and FE.22 (for cracked concrete)

$\Delta N_{Rk,s,n}$ according to E.3.2, characteristic value of fatigue resistance after n load cycles determined from fatigue test series FE.2 (for uncracked concrete) and FE.4 (for cracked concrete)

$\Delta V_{Rk,s,n}$ according to E.3.2, characteristic value of fatigue resistance after n load cycles determined from fatigue test series FE.14 (for uncracked concrete) and FE.16 (for cracked concrete)

The α_{sn}-values shall be determined by interactive steps with calculation the equation in such a way that the graph connects the resistances $\Delta N_{Rk,s,n}$, $\Delta F^{\beta}_{Rk,s,n}$ and $\Delta V_{Rk,s,n}$ (see also 2.2.7 and Figure 2.3) for each given number of cycles n.

The lowest value α_{sn} shall be given in the ETA as value α_s.

The number of cycles to failure n for each range of force ΔF^{β} shall be determined through testing. The test results shall be used for the determination of the linearized fatigue resistance function.

The assessment includes following steps:

- Equations of the average and characteristic fatigue resistance functions
- Four calculated values for the control of the characteristic fatigue resistance function
- Diagram according to Figure E.2 (Annex E) showing cyclic test results, average and characteristic fatigue resistance functions and four calculated control values

Expression of results: a_s

2.2.22 Load transfer factor for tension and shear loading (Method C)

Purpose of assessment

The purpose of the assessment is to determine the influence of non-equally loaded fasteners within a group on the fatigue resistance under shear (ψ_{FV}) and tension (ψ_{FN}) loading.

Assessment method

No tests are required if the load transfer factors ψ_{FN} = ψ_{FV} = 0,5 are applied on the safe side.

When a manufacturer wishes to get more favourable values it shall be determined by tests in accordance with Table E.1 (for bonded fasteners) or Table E.2 (for torque-controlled expansion fasteners (bolt type with external thread)), test series FE.2 and FE.4 for tension and test series FE.14 and FE.16 for shear and assessment according to Annex C, C.3.2 and C.3.3.

The determination may be done only with the smallest and largest fastener size if the resulting load transfer factors are applied to all other fastener sizes specified by the manufacturer. The smallest load transfer factors ψ_{FN} and ψ_{VN} must be applied.

For assessment of the parameters a_{cr}, a_{ucr}, b_{cr} and b_{ucr} according to C.3.2 and C.3.3 the single values F_{up} and Δs of each test are used to determine the power function in cracked and non-cracked concrete as given in figure C.3.

$F_{up,ucr}$ = upper load level tested in uncracked concrete
(for tension from test series FE.2 and for shear from test series FE.14)

Δs_{ucr} = displacements of a test results in uncracked concrete
(for tension from test series FE.2 and for shear from test series FE.14)

$F_{up,cr}$ = upper load level tested in cracked concrete
(for tension from test series FE.4 and for shear from test series FE.16)

Δs_{cr} = displacements of a test results in cracked concrete
(for tension from test series FE.4 and for shear from test series FE.16)

The test results shall be used for the determination of the load transfer factor (see Annex C for additional details):

$\psi_{FN} = \psi_F$ according to Equation (C.26) for tension

$\psi_{FV} = \psi_F$ according to Equation (C.26) for shear

<u>Expression of results</u>

ψ_{FN}, ψ_{FV}

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 Commission Decision 96/582/EC.

The system is 1.

3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of the post-installed fastener in concrete under fatigue cyclic loading in the procedure of assessment and verification of constancy of performance are laid down in Table 3.1.

These actions are be undertaken by the manufacturer in addition to the actions given in EAD 330232-01-0601 [1] or EAD 330499-01-0601 [2].

Table 3.1 Control plan for the manufacturer; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC) [**including testing of samples taken at the factory in accordance with a prescribed test plan**]*					
1	Characteristic steel fatigue resistance for assessment method A	tests 1) 5) under different fatigue cyclic load levels 2)	3)	3 tension tests 3 shear tests 9) (1 per load level)	1/material batch 8)
2	Characteristic steel fatigue limit resistance for assessment method B	tests 5) on load level ΔS_D / 0.92	4)	3 tension tests 3 shear tests 9)	1/material batch 8)
3	Characteristic steel fatigue resistance for assessment method C	Tension/ shear tests under different fatigue cyclic load levels 6)	7)	3 tension tests 3 shear tests 9) (1 per load level) One test with n > 10^6	1/material batch 8)
4	Characteristic bond fatigue resistance for assessment method C	Tests under different fatigue cyclic load levels 6)	7)	3 tension tests (1 per load level) One test with n > 10^6	1 mortar per year, all mortars within 5 years,
5	Geometry and roughness	Measuring	Min. value within the tolerances given by the manufac-turer	3	1/production batch
6	Rupture elongation A_5	Tests according to [2], Table 3.1		3	1/material batch
7	Yield strength f_{yk}	Tests according to [2], Table 3.1		3	1/material batch

1) The same test conditions as for steel failure under fatigue cyclic tension tests (see Section 2.2.1) shall be applied. In general, the tests shall be performed in cracked concrete. If the position of steel failure of the fastener, as determined in tests for verification of constancy of performance, is above the concrete surface then tests may be performed in non-cracked concrete.

2) The load levels are determined as follows:

Load level a: $$\Delta S_a = \left(S_k - \frac{1}{3}\left(S_k - \Delta S_{D,k}\right)\right) / \, 0{,}92 \qquad (3.1)$$

Load level b: $\Delta S_b = \left(S_k - \frac{2}{3}\left(S_k - \Delta S_{D,k}\right)\right) / 0{,}92$ (3.2)

Load level c: $\Delta S_c = \Delta S_{D,k} / 0{,}92$ (3.3)

3) The constancy of performance is verified if the number of cycles of the first two specimens exceeds the characteristic resistance. The number of cycles of the third specimen shall reach the limit number of cycles n_{lim} and pass the run-out test on the load level a.

4) The constancy of performance is verified if the number of cycles of tested specimens reaches the limit number of cycles n_{lim} and pass the run-out test on the load level ΔS_{RT}.

5) The conditions for the tests shall be performed according to Annex D

6) The load levels are determined as follows:

Load level a: characteristic steel fatigue resistance given in the ETA for n = 10 000 load cycles

Load level b: characteristic steel fatigue resistance given in the ETA for n = 200 000 load cycles

Load level c: characteristic steel fatigue resistance given in the ETA for $n > 10^6$ load cycles

7) The constancy of performance is verified if the failure load exceeds the characteristic resistance.

8) If the material and production have not changed and 3 material batches passed the criteria, the control plan has to be done only on one material batch once a year. This condition applies separately for each size.

9) Tension tests are necessary, if performance under tension loading or performance under tension and shear loading is assessed.

Shear tests are necessary, if only performance under shear loading is assessed.

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 post-installed fasteners in concrete under fatigue cyclic loading 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	Notified Body will ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the fastener.	Verification of the complete FPC as described in the control plan agreed between the TAB and the manufacturer	According to Control plan	According to Control plan	When starting the production or a new line
Continuous surveillance, assessment and evaluation of factory production control					
2	The Notified Body will ascertain that the system of factory production control and the specified manufacturing process are maintained taking account of the control plan.	Verification of the controls carried out by the manufacturer as described in the control plan agreed between the TAB and the manufacturer with reference to the raw materials, to the process and to the product as indicated in Table 3.1	According to Control plan	According to Control plan	1/year

4 REFERENCE DOCUMENTS

[1] EAD 330232-01-0601:2019	Mechanical fasteners for use in concrete
[2] EAD 330499-01-0601:2018	Bonded fasteners for use in concrete
[3] EOTA TR 061:2020	Design Method for fasteners in concrete under fatigue cyclic loading
[4] EN 206:2013	Concrete - Specification, performance, production and conformity, 2013
[5] EN 1992-4:2018	Design of concrete structures; Part 4: Design of fastenings for use in concrete
[6] EN 197-1:2014	Cement – Part 1:Composition, specifications and conformity criteria for common cements
[7] EN 13791:2007	Assessment of in-situ compressive strength in structures and precast concrete componentes

Further information and background for assessment methods is given in the following documents:

[9] Materialprüfung 40 (1998) 3	"Die Ermüdungsfestigkeit zuverlässig und kostengünstig ermitteln - Das Interaktive Verfahren." Author: Block, K.; Dreier, F
[10] Deutscher Ausschuss für Stahlbeton, Heft 541. Beuth Verlag, Berlin 2003	"Das Ermüdungsverhalten von Dübelbefestigungen". Author: Block, K.; Dreier, F
[11] Bauingenieur, Band 85, Januar 2010, S. 17-28	"Ermüdungstragfähigkeit von Betonstahl – Bestimmung mit dem Interaktiven Verfahren" Author: Maurer, R.; Block, K.; Dreier, F
[12] Owen, D:1962	Handbook of Statistical Tables, Addison/Wesley Publishing Company Inc.

ANNEX A TEST METHOD A TO DETERMINE THE CHARACTERISTIC FATIGUE RESISTANCE

A.1 Test program

The characteristic fatigue resistance function (test method A) shall be determined by testing performed in accordance with Table A.1. All tests are performed in concrete of strength class C20/25.

Table A.1: Test method A: Required tests under static and fatigue cyclic loading

N°	**Tests according to Sections**	**Crack width Δw [mm]**	**Load direction**	**Minimum number of tests**	**Fastener Size**	**Fastener steel qualities/properties**	**Fastener Coating**	**Remarks**
Tension								
FA.1	2.2.1 Fatigue tests for steel failure	0.3	0°	20	all	all	all	single fastener
FA.2	2.2.2 Reference static tests for concrete cone failure 1)	0	0°	5	3)	4)	4)	group of 4 fasteners
FA.3	2.2.2 Fatigue tests for concrete cone failure 1)	0	0°	20	3)	4)	4)	group of 4 fasteners
Shear								
FA.4	2.2.4 Fatigue tests for steel failure	0,3	90°	20	all	all	all	single fastener
FA.5	2.2.5 Reference static tests for concrete edge failure 2)	0	90°	5	3)	4)	4)	group of 2 fasteners
FA.6	2.2.5 Fatigue tests for concrete edge failure 2)	0	90°	20	3)	4)	4)	group of 2 fasteners
Combined tension and shear								
FA.7	2.2.7 Steel failure	0,3	β	20	all	all	all	single fastener

1) No tests are required, if the reduction factor for characteristic fatigue resistance for concrete cone failure is calculated according to Equation (2.5).

2) No tests are required, if the reduction factor for characteristic fatigue resistance for concrete edge failure is calculated according to Equation (2.11).

3) The tests may be performed with the smallest decisive fastener size, which fulfil Equation (2.6) for tension or Equation (2.12) for shear.

4) The fastener steel qualities/properties or coatings are not decisive for concrete related tests.

Note: The total number of tests of fasteners having a uniform cross section with variable embedment depths can be reduced, if the resulting fatigue resistance of the smallest embedment depth is applied to all other fastener embedment depths specified by the manufacturer.

Note: If the fastener is intended to be used with different drilling methods (e.g. hammer drilling (including hollow drilling) or diamond drilling) as specified by the manufacturer, the tests summarised in Table A.1 shall be performed separately for each drilling method. In lieu of the complete test program, equivalence of the performances between two different drilling methods shall be established with a minimum of eight test (series FA.1, steel failure) and one "real" run-out test (series FA.1, steel failure).

A.2 Basics

The force-controlled periodic loading with sinusoidal course is used as the most disadvantageous case (practical application) of the test specimen.

The repeated loads consist of a constant lower stress level and an upper stress level with same algebraic sign (no alternating actions) and are applied on the specimen until fatigue failure or a limit number of cycles are reached.

Test specimens reaching the limit number of cycles without failure, are to be tested again at a higher stress level (verification of non-damaged specimen). This run-out test is applied to identify a potential damage of the test specimen despite reaching the limit number of cycles.

The test method A provides an average function and a 5%-quantile function of the fatigue resistance from one $(n = 1)$ to infinite number of cycles $(n \Rightarrow \infty)$.

The used capital letter S in this Annex shall be replaced by the letter N for tension loads, V for shear loads and F^{β} for combined tension and shear loads, respectively.

A.3 Procedure steps

A.3.1 Determination of the characteristic static resistance

For the determination of the characteristic static resistance S_k five tests $(n \geq 5)$ are required.

For the determination of the static and fatigue resistances testing shall be done on the identical product regarding batch, geometry, material etc.

The characteristic value S_k is equivalent to the 5%-quantile $(\mathrm{p} = 0{,}05)$, determined on a level of confidence of 90% $(1 - \alpha = 0{,}9)$ and unknown standard deviation by using the normal distribution.

The value is determined as follows:

$$S_k = \overline{S} - k_{n-u,p,1-\alpha} \cdot \hat{s} \tag{A.1}$$

where

$k_{n-u,p,1-\alpha}$ statistic factor according to Table A.2,
for values $(n - u)$ not given in Table A.2, see also [12]

n degrees of freedom, equal to the number of static test results

u known condition of the mean value $(u = 1)$

Table A.2: Statistic factor $k_{n-u,0{,}05,0{,}9}$ with 5%-quantile and confidence level of 90%

$n-u$	2	3	4	5	6	7	8
$k_{n-u,0{,}05,0{,}9}$	5,311	3,957	3,400	3,092	2,894	2,754	2,650
$n-u$	10	12	14	16	20	24	28
$k_{n-u,0{,}05,0{,}9}$	2,503	2,402	2,329	2,272	2,190	2,132	2,089

$$\hat{s} = \sqrt{\frac{\sum_{i=1}^{n}(\overline{S} - S_i)^2}{n-1}}, \text{ standard deviation} \tag{A.2}$$

A.3.2 Planning of the fatigue cyclic load levels

The stress range ΔS_i is the difference between upper and lower level for every load level i:

$$\Delta S_i = S_{upi} - S_{lo} \tag{A.3}$$

The lower level of the sinusoidal course, S_{lo}, is equal for all fatigue cyclic load levels and shall be kept to a minimum.

Results from testing with only one cycle, i.e. under quasi-static loading, already exist (see Section A.3.1). These results will be included later in the evaluation. The first test under fatigue cyclic loading with constant load range is carried out on a level close to the elastic limit (yield strength f_{yk}) of the specimen/system made of steel.

After the first test, the expected fatigue limit resistance ΔS_D shall be estimated by existing experiences. The estimated value, $\Delta S_D^{\approx}$, may be the expected mean value of the fatigue limit resistance.

Note: As an orientation guide for the estimated value the following range for fasteners may be used subject to the static mean resistance $\overline{S}$.

$$\Delta S_{D}^{\approx} \approx (0{,}20; \dots ; 0{,}50) \cdot \overline{S}$$

Thus, test two and three may be planned by setting the load ranges between the first load level and the estimated fatigue limit resistance.

The fourth test is carried out on the estimated fatigue limit resistance level, which may be amended on the basis of the first three test results. The first evaluation to determine the average function and the 5%-quantile is conducted after the fourth test, without distinction between failed and run-out specimens (see Section A.3.4 and A.3.5).

Afterward a second test sequence starts with a test whose level is lying between the first and second test. The load levels of test six and seven are arranged between the second and third respectively third and fourth test. Test eight has a load level above the average value of fatigue limit resistance determined after seven test results. The ninth test falls below the average value of fatigue limit resistance but already on the basis of eight evaluated test results.

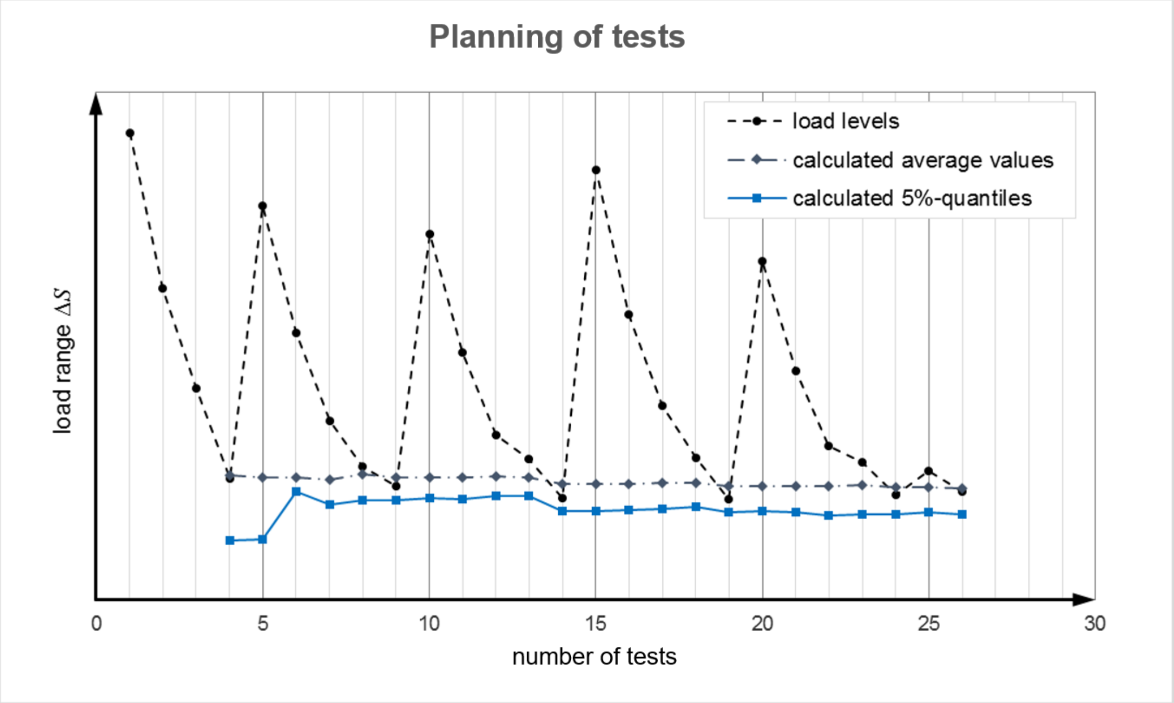


Figure A.1: Planning of tests – average values and 5%-quantiles of the fatigue limit resistance (example)

The further course of experimental design is detailed shown in Figure A.1. The analysis is carried out after each test and shall include all fatigue cyclic tests inclusive run-out tests on their first (lower) load level. Run-out test results on their second (higher) load level are not included in the evaluation. A new test sequence always starts with the fifth, tenth, 15th and 20th test on high stress level. As a rule, testing may be stopped after at least 20 test because calculated results have stabilized. The stabilization of fatigue limit resistance is shown in Figure A.1.

During the testing at least three „real“ run-out specimens shall be identified. Failure of specimens between run-outs is permitted.

A.3.3 Determination of the limit number of cycles and load level for run-out test

The limit number of cycles n_{lim} is allocated to the interval $5 \cdot 10^6 \leq n_{lim} \leq 8 \cdot 10^6$ for carbon steel and $7 \cdot 10^6 \leq n_{lim} \leq 10^7$ for stainless steel. In case of concrete the limit number of cycles n_{lim} is respectively in the interval $10^7 \leq n_{lim} \leq 2 \cdot 10^7$.

If a stabilization of deformations is detected at $5 \cdot 10^6$ respectively $7 \cdot 10^6$ cycles, then the limit number of cycles n_{lim} is assigned to the lower limit $n_{lim,lo}$ of the respective interval. If no stabilization is detected, then the limit number of cycles has to be increased.

For the verification of the stabilization, regarding the upper limit S_{upi} of a sinusoidal load process, a linear regression analysis for two numbers of cycles areas is carried out and the slopes of the lines are compared with each other. One area includes $2 \cdot 10^6$ number of cycles and at least 80 measured values. If there is a decrease of the slope of the line from one area to the other, then a stabilization has occurred and the upper limit of cycles for the areas used for comparison shall be chosen as n_{lim}.

The first comparison is carried out for the areas A and B (see Fig. A.2). If no stabilization occurs the next higher areas (B and C) are compared with each other. This is continued until the upper limit of each respective interval ($8 \cdot 10^6$ respectively 10^7) is reached. If the upper limit is reached and no stabilization occurs, then the only criterion for a „real“ run-out (specimen) is a passed run-out test.

The following parameters are used in the verification for displacement stabilization.

Centroid of test result scatter for one area:

$$\dot{s}_{up} = \frac{1}{m}\sum_{i=1}^{m} s_{up,i} \tag{A.4}$$

$$\dot{n} = \frac{1}{m}\sum_{i=1}^{m} n_i \tag{A.5}$$

where		
	$s_{up,i}$	Displacement in the cross section, regarding the upper limit S_{upi} of a sinusoidal load process, for every step i
	n_i	number of cycles in the cross section for every step i
	m	number of measured values ($m \geq 80$)

Regression line:

$$s_{up} = a_s + b_s n \tag{A.6}$$

where

$$a_s = \dot{s}_{up} - b_s \dot{n} \tag{A.7}$$

$$b_s = \frac{\sum_{i=1}^{m}(n_i - \dot{n})\left(s_{up,i} - \dot{s}_{up}\right)}{\sum_{i=1}^{m}(n_i - \dot{n})^2} \tag{A.8}$$

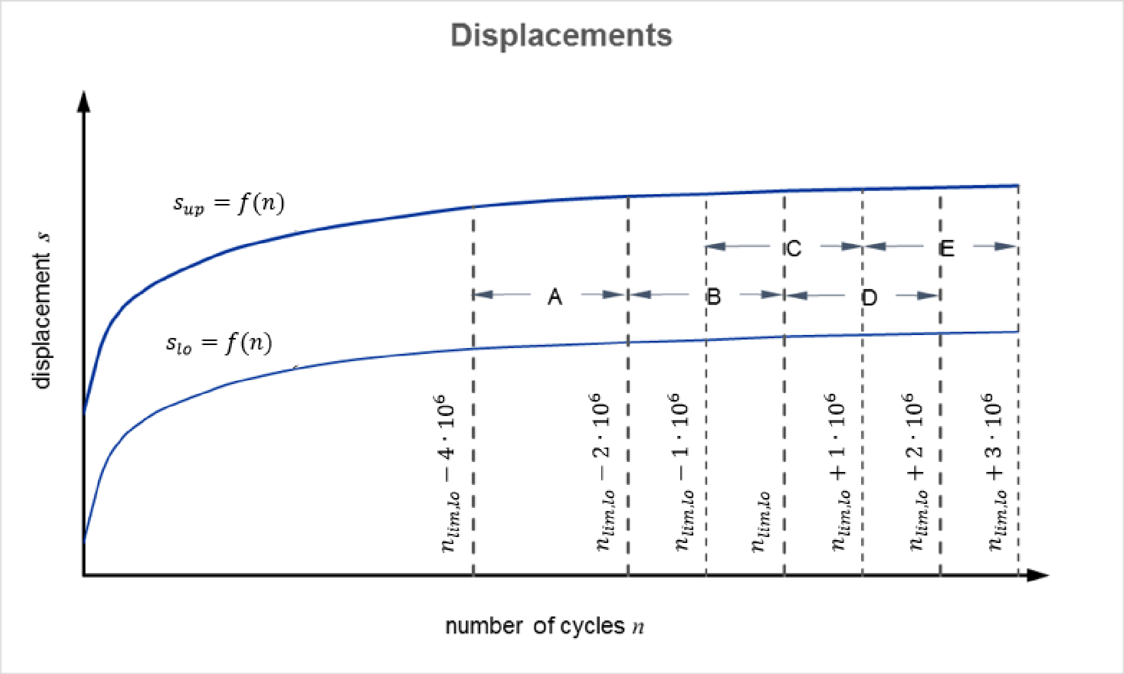


Figure A.2: Stabilization of deformations of a run-out

Specimens reaching $n \geq n_{lim}$ without failure, are to be tested again with the stress range ΔS_{RT} until failure occurs. A possible damage of the specimen, despite reaching the limit number of cycles, may be located by applying this so-called run-out test. The specimen is considered as a „real“ run-out specimen on the first load level, if the number of cycles on the second load level exceed the 5%-quantile function. If the run-out test is not passed, then the specimen was damaged during the first load level and is not considered as a „real“ run-out specimen.

Only results of run-out tests performed on their first load level shall be included in the determination of the average (Section A.3.4) and characteristic resistance functions (Section A.3.5). Results of run out tests performed on their second load level are required only to verify that damage to the specimens was not occurring during the tests at a lower load level.
This second test is to be set on the lower limit of the upper third of the finite fatigue life area (see Figure A.3) and is calculated as follows:

$$\Delta S_{RT} \approx \bar{S} - \left(\bar{S} - \Delta\bar{S}_D\right) / 3 \qquad \text{(A.9)}$$

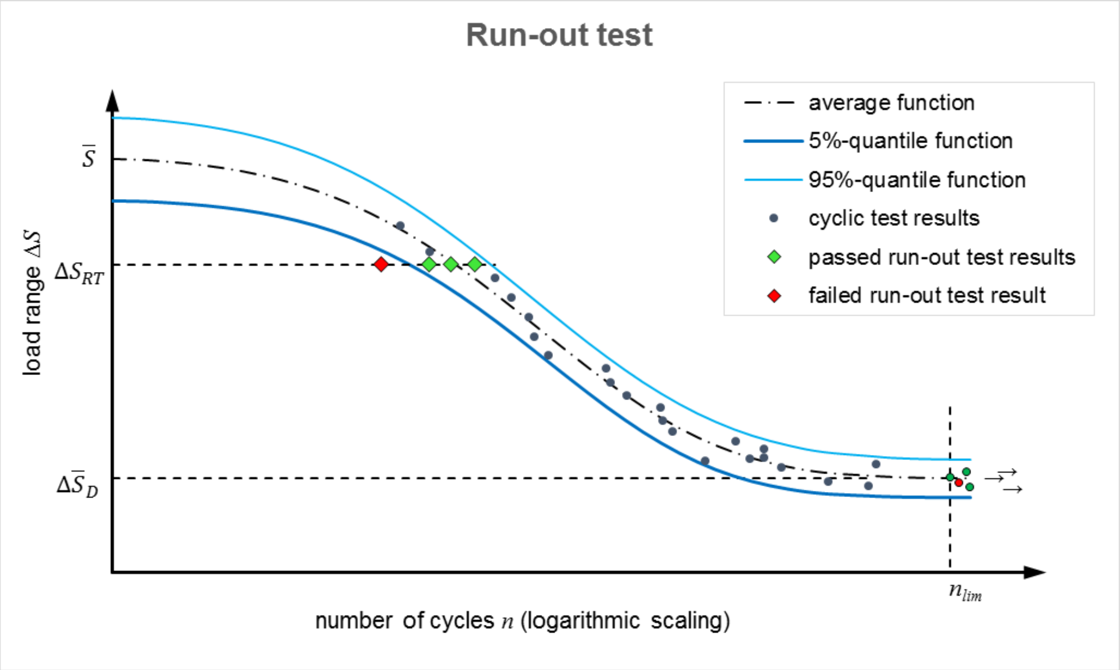


Figure A.3: Load level for run-out test

A.3.4 Determination of the average function

If test results with different load ranges and number of cycles are available, then the results are described by the Equation (A.10) according to the principles of the least squares method. The free parameters a_m, b_m and $\Delta\bar{S}_D$ are adjusted by using a regression analysis to find the minimum of least squares from the difference between load ranges. This function corresponds to the average of the fatigue resistance (see Figure A.4).

$$\Delta\bar{S} = \Delta\bar{S}_D + (\bar{S} - S_{lo} - \Delta\bar{S}_D) \cdot {a_m}^{(\lg n)^{bm}} \qquad \text{(A.10)}$$

where

a_m, b_m	positive dimensionless numbers for the average function, where $a_m < 1{,}0$
n	number of cycles
$\Delta\bar{S}$	mean load range of fatigue resistance
$\Delta\bar{S}_D$	mean load range of fatigue limit resistance
$\bar{S}$	mean static resistance determined in preliminary static tests
S_{lo}	lower limit of fatigue cyclic loads

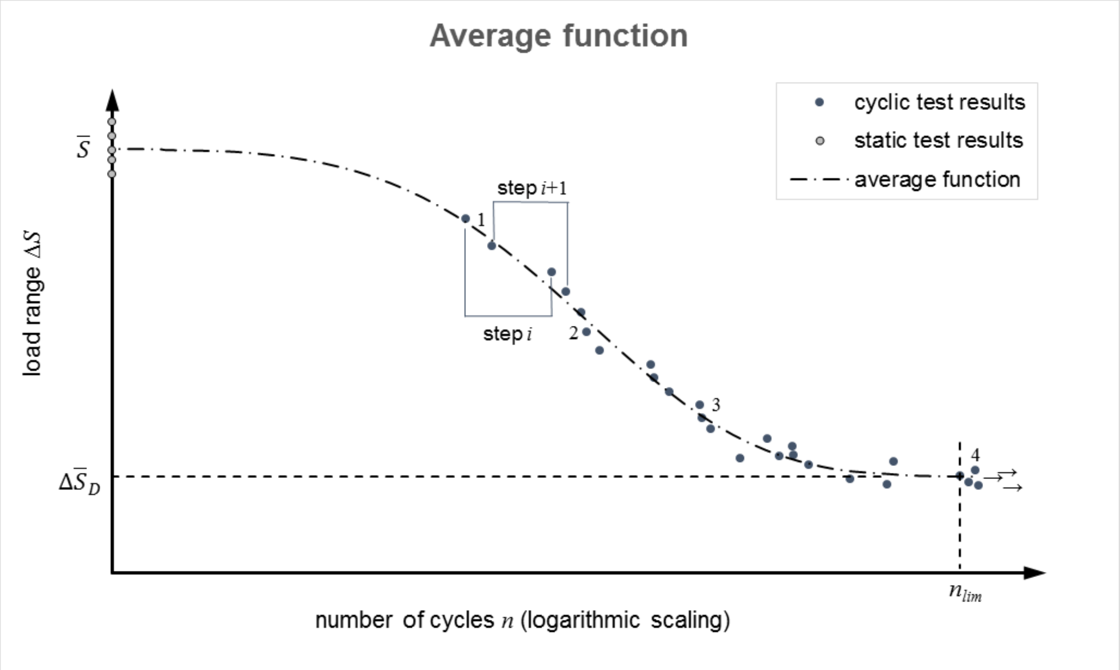


Figure A.4: Tests results and average function of fatigue resistance

A.3.5 Determination of the characteristic fatigue resistance

For the statistical evaluation three juxtaposed results are considered, independently of the COV. Due to the average function a calculated mean value for each number of cycles is available, thus, the deviation between test result load range and average function may be determined. This gives the standard deviation, which is valid for these three values (step i see Figure A.4).

In the next step $i + 1$ the following pair of values with next higher number of cycles is taken into account and the values with smallest number of cycles of step i is disregarded. This gives also the standard deviation, which is valid for these three values (step $i + 1$ see Figure A.4).

Consequently, the variance is obtained along the S/N-curve and thus, also the 5%-quantile.

The 5%-quantiles are determined according to the following sequence:

1. For n_i cross sections corresponding mean load ranges and residuals are calculated:

   $\Delta\bar{S}_i$ mean load range in the cross section for every step i according to Equation (A.10)

   where

   n_i number of cycles in the cross section for every step i

   $$\Delta\Delta S_i = \Delta S_i - \Delta\bar{S}_i\,, i = 1, \ldots, h \tag{A.11}$$

   where

   $\Delta\Delta S_i$ residual load in the section for every step i

   h total number of available fatigue cyclic test results

2. Estimation of the average variance and average standard deviation for each three results:

   $$\hat{s}_j^2 = \frac{((\Delta\Delta S_i)^2 + (\Delta\Delta S_{i+1})^2 + (\Delta\Delta S_{i+2})^2) \cdot h}{3 \cdot (h-3)}, j = 1, \ldots, h-3 \tag{A.12}$$

   $$\hat{s}_j = \sqrt{\hat{s}_j^2} \tag{A.13}$$

3. The mean load ranges in cross sections $\dot{n}_j$ are calculated as follows:

$\Delta\bar{\dot{S}}_j$	mean load range in the cross section for every step j according to Equation (A.10)

where

$$\dot{n}_j = 10^{((\lg n_i + \lg n_{i+1} + \lg n_{i+2})/3)} \tag{A.14}$$

4. The 5%-quantile in cross section $\dot{n}_j$ is calculated on a level of confidence of 90% by using the normal distribution:

$$\Delta\dot{S}_{j,5\%} = \Delta\bar{\dot{S}}_j - k_{h-u,p,1-\alpha}\cdot\hat{\dot{s}}_j, j = 1, \dots, h-3 \tag{A.15}$$

$k_{h-u,p,1-\alpha}$	statistic factor according to Table A.2 or [12]
u	known condition of static resistance and positive dimensionless numbers a, b $(u = 3)$

The course of the 5%-quantiles is calculated using Equation (A.16) according to the principles of the least squares method (ref. Eq. (A.10)). An example of the 5%-quantile function is shown in Figure A.5.

$$\Delta S_k = \Delta S_{D,k} + (S_k - S_{lo} - \Delta S_{D,k})\cdot {a_5}^{(\lg n)^{b_5}} \tag{A.16}$$

where

a_5, b_5	positive dimensionless numbers for the 5%-quantile function are readjusted
n	number of cycles
ΔS_k	characteristic load range value of fatigue resistance
$\Delta S_{D,k}$	characteristic load range value of fatigue limit resistance
S_k	characteristic static resistance determined in preliminary static tests
S_{lo}	lower limit of fatigue cyclic loads

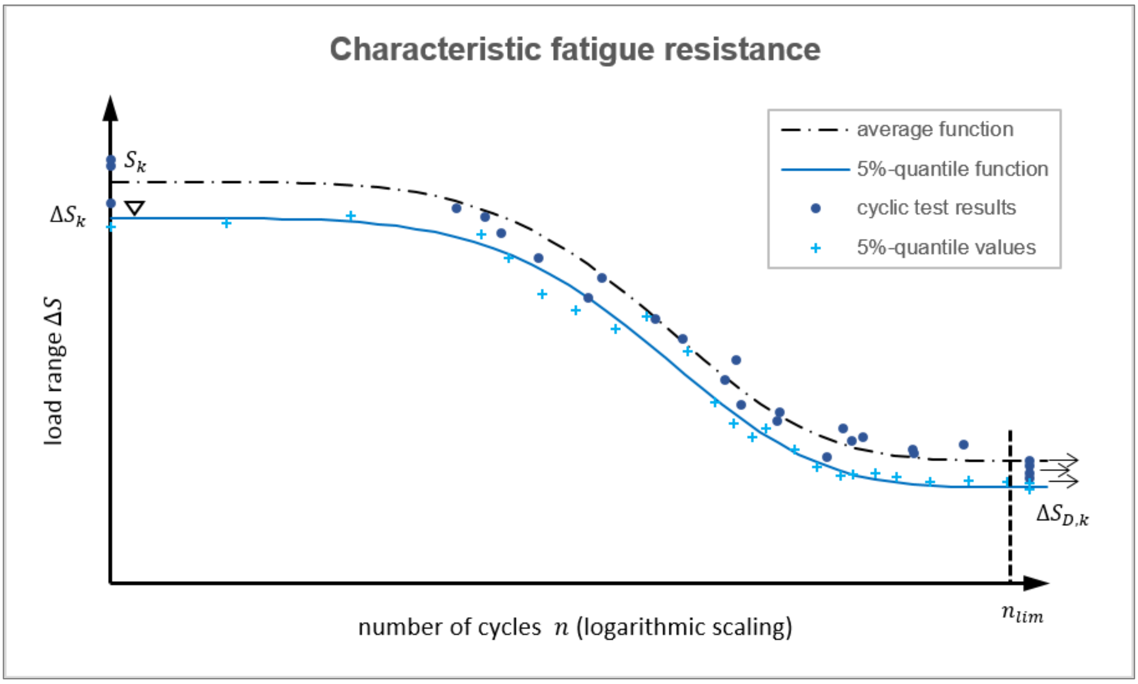


Figure A.5: Tests results, average function and 5%-quantile after regression analysis

A.3.6 Control of the characteristic fatigue resistance

On one hand, to check the characteristic fatigue resistance 5%-quantiles are determined at three cross sections along the number of cycles-axis (see Figure A.6):

Area A – all fatigue cyclic test results (h):

$$\Delta\dot{S}_{A,5\%} = \Delta\bar{\dot{S}}_A - k_{h-u,p,1-\alpha} \cdot \hat{s}_A \tag{A.17}$$

where

$\Delta\bar{\dot{S}}_A$ mean load range of area A according to Equation (A.10)

where $\dot{n}_A = 10^{\left(\left(\sum_{i=1}^{h} \lg n_i\right)/h\right)}$ (A.18)

$$\hat{s}_A = \sqrt{\frac{\sum_{i=1}^{h}(\Delta\Delta S_i)^2}{h-3}} \tag{A.19}$$

Area B – first half quantity of the fatigue cyclic test results ($0{,}5h$):

$$\Delta\dot{S}_{B,5\%} = \Delta\bar{\dot{S}}_B - k_{h-u,p,1-\alpha} \cdot \hat{s}_B \tag{A.20}$$

where

$\Delta\bar{\dot{S}}_B$ mean load range of area B according to Equation (A.10)

where $\dot{n}_B = 10^{\left(\left(\sum_{i=1}^{0.5h} \lg n_i\right)/0{,}5h\right)}$ (A.21)

$$\hat{s}_B = \sqrt{\frac{\left(\sum_{i=1}^{0{,}5h}(\Delta\Delta S_i)^2\right) \cdot h}{0{,}5h \cdot (h-3)}} \tag{A.22}$$

Note: if h is an odd number, then round down $0{,}5h$ to a whole number

Area C – second half quantity of the fatigue cyclic test results ($0{,}5h$):

$$\Delta\dot{S}_{C,5\%} = \Delta\bar{\dot{S}}_C - k_{h-u,p,1-\alpha} \cdot \hat{s}_C \tag{A.23}$$

where

$\Delta\bar{\dot{S}}_C$ mean load range of area C according to Equation (A.10)

where $\dot{n}_C = 10^{\left(\left(\sum_{i=1}^{0{,}5h} \lg n_i\right)/0{,}5h\right)}$ (A.24)

$$\hat{s}_C = \sqrt{\frac{\left(\sum_{i=1}^{0{,}5h}(\Delta\Delta S_i)^2\right) \cdot h}{0{,}5h \cdot (h-3)}} \tag{A.25}$$

Note: if h is an odd number, then round up $0{,}5h$ to a whole number

Furthermore, the control of the fatigue limit resistance is carried out using the reduction factor η_A, which results from the ratio of 5%-quantile to the mean load range in the centroid $\dot{n}_A$:

$$\eta_A = \Delta\dot{S}_{A,5\%} / \Delta\bar{\dot{S}}_A \tag{A.26}$$

Using this factor the mean load range of the fatigue limit resistance is reduced as follows:

$$\eta_A \cdot \Delta\bar{S}_D \tag{A.27}$$

The coefficient of variation is determined for the different areas by:

$$v_A = \frac{\Delta\bar{\dot{S}}_A - \Delta\dot{S}_{A,5\%}}{k_{h-u,p,1-\alpha}} \cdot \frac{1}{\Delta\bar{\dot{S}}_A} \tag{A.28}$$

$$v_B = \frac{\Delta\bar{\dot{S}}_B - \Delta\dot{S}_{B,5\%}}{k_{h-u,p,1-\alpha}} \cdot \frac{1}{\Delta\bar{\dot{S}}_B} \tag{A.29}$$

$$v_C = \frac{\Delta\bar{\dot{S}}_C - \Delta\dot{S}_{C,5\%}}{k_{h-u,p,1-\alpha}} \cdot \frac{1}{\Delta\bar{\dot{S}}_C} \tag{A.30}$$

$$v_D = \frac{\Delta S_{D,k} - \Delta S_{D,k,5\%}}{k_{h-u,p,1-\alpha}} \cdot \frac{1}{\Delta S_{D,k}} \tag{A.31}$$

$$v_{max} = \max\,(v_A, v_B, v_C) \tag{A.32}$$

If the four calculated values $\Delta\dot{S}_{A,5\%}$, $\Delta\dot{S}_{B,5\%}$, $\Delta\dot{S}_{c,5\%}$ and $\eta_A \cdot \Delta\bar{S}_D$ lie above the characteristic fatigue resistance or at the same level (see Figure A.6) and the coefficient of variation v_D is higher or equal to v_{max}, the control is passed. Otherwise the characteristic fatigue resistance shall be reduced to a level such that all the four calculated values lie above or coincide with the calculated function and v_D is higher than v_{max}. All the information required to control and verify the characteristic fatigue resistance shall be reported in the test and evaluation reports accompanying the assessment of the test results.

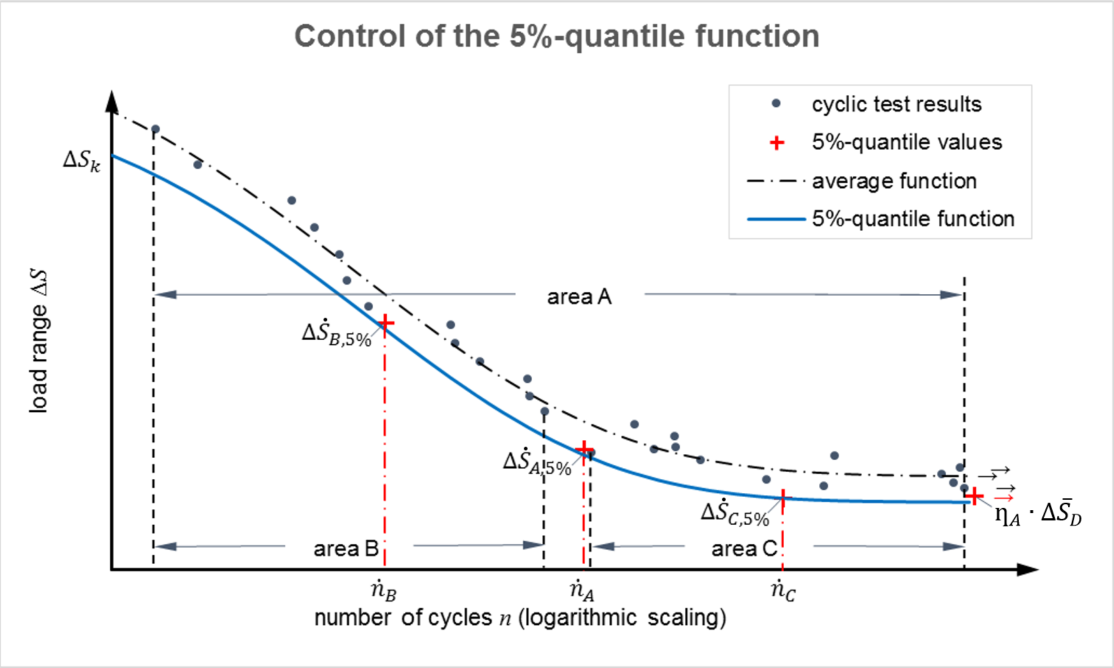


Figure A.6: Control of the characteristic fatigue resistance

ANNEX B TEST METHOD B TO DETERMINE THE CHARACTERISTIC FATIGUE LIMIT RESISTANCE

B.1 Test program

The value of the characteristic fatigue limit resistance (test method B) shall be determined by testing in accordance with Table B.1. All tests are performed in concrete of strength class C20/25.

Table B.1: Test method B: Required tests under fatigue cyclic loading

N°	Tests according to the sections	Crack width ∆w [mm]	Load direction	Minimum number of tests	Fastener Size	Fastener steel qualities/properties	Fastener Coating	Remarks
Tension								
FB.1	2.2.9 Fatigue tests for steel failure	0,3	0°	3	all	all	all	single fastener
FB.2	2.2.9 Reference fatigue tests for steel failure	0,3	0°	3	all	all	all	single fastener
Shear								
FB.3	2.2.11 Fatigue tests for steel failure	0,3	90°	3	all	all	all	single fastener
FB.4	2.2.11 Reference fatigue tests for steel failure	0,3	90°	3	all	all	all	single fastener

Note: The total number of tests of fasteners having a uniform cross section with variable embedment depths can be reduced, if the resulting fatigue resistance of the smallest embedment depth is applied to all other fastener embedment depths specified by the manufacturer.

Note: If the fastener is intended to be used with different drilling methods (e.g. hammer drilling (including hollow drilling) or diamond drilling) as specified by the manufacturer, the tests summarised in Table B.1 shall be performed separately for each drilling method.

Note: The reference fatigue tests for steel failure in Table B.1 are tests for determination of the minimum number of cycles for run-out test (see section B.3.3).

B.2 Basics

The force-controlled periodic loading with sinusoidal course shall be used as the most disadvantageous case (practical application) of the test specimen.

The repeated loads consist of a constant lower stress level and an upper stress level with same algebraic sign (no alternating actions) and shall be applied on the specimen until fatigue failure or a limit number of cycles is reached.

Test specimen reaching the limit number of cycles without failure, are to be tested again at a higher stress level (verification of non-damaged specimen). This run-out test is applied to identify a potential damage of the test specimen despite reaching the limit number of cycles.

This method provides the characteristic fatigue limit resistance for infinite number of cycles ($n \Rightarrow \infty$).

The used capital letter S in this Annex shall be replaced by the letter N for tension loads and V for shear loads, respectively.

B.3 Procedure steps

B.3.1 Planning of the fatigue cyclic load levels

The expected fatigue limit resistance ΔS_D is to be estimated by existing experiences. The estimated value $\Delta S_D^{\approx}$ may be the expected mean value of the fatigue limit resistance.

Note: As an orientation guide for the estimated value the following range for fasteners may be used subject to the static mean resistance $\overline{S}$. However, this estimated value does not necessarily correspond to the actual fatigue limit resistance if, for example, the estimated value is set too low.

$$\Delta S_D^{\approx} \approx (0{,}20; \dots; 0{,}50) \cdot \overline{S}$$

The load level for reference tests corresponds to the load level ΔS_{RT} (see Section B.3.2).

B.3.2 Determination of the limit number of cycles and load level for run-out test

The limit number of cycles n_{lim} is allocated to the interval $5 \cdot 10^6 \leq n_{lim} \leq 8 \cdot 10^6$ for carbon steel and $7 \cdot 10^6 \leq n_{lim} \leq 10^7$ for stainless steel, respectively.

If a stabilization of deformations is detected at $5 \cdot 10^6$ or $7 \cdot 10^6$ cycles, respectively, then the limit number of cycles n_{lim} is assigned to the lower limit $n_{lim,lo}$ of the respective interval. If no stabilization is detected, then the limit number of cycles has to be increased.

For the verification of the stabilization, regarding the upper limit S_{upi} of a sinusoidal load process, a linear regression analysis for two number of cycles areas is carried out and the slopes of the lines are compared with each other. One area includes $2 \cdot 10^6$ number of cycles and at least 80 measured values. If there is a decrease of the slope of the line from one area to the other, then a stabilization has occurred and the upper limit of cycles for the areas used for comparison shall be chosen as n_{lim}.

The first comparison is carried out for the areas A and B (see Figure B.1). If no stabilization occurs the next higher areas (B and C) are compared with each other. This is continued until the upper limit of each respective interval ($8 \cdot 10^6$ or 10^7, respectively) is reached. If the upper limit is reached and no stabilization occurs, then the only criterion for a „real“ run-out (specimen) is a passed run-out test.

The following parameters are used in the verification for displacement stabilization.

Centroid of test result scatter for one area:

$$\dot{s}_{up} = \frac{1}{m} \sum_{i=1}^{m} s_{up,i} \tag{B.1}$$

$$\dot{n} = \frac{1}{m} \sum_{i=1}^{m} n_i \tag{B.2}$$

where	$s_{up,i}$	Displacement in the cross section, regarding the upper limit S_{upi} of a sinusoidal load process, for every step i
	n_i	number of cycles in the cross section for every step i
	m	number of measured values ($m \geq 80$)

Regression line:

$$s_{up} = a_s + b_s n \tag{B.3}$$

where

$$a_s = \dot{s}_{up} - b_s \dot{n} \tag{B.4}$$

$$b_s = \frac{\sum_{i=1}^{m} (n_i - \dot{n})(s_{up,i} - \dot{s}_{up})}{\sum_{i=1}^{m} (n_i - \dot{n})^2} \tag{B.5}$$

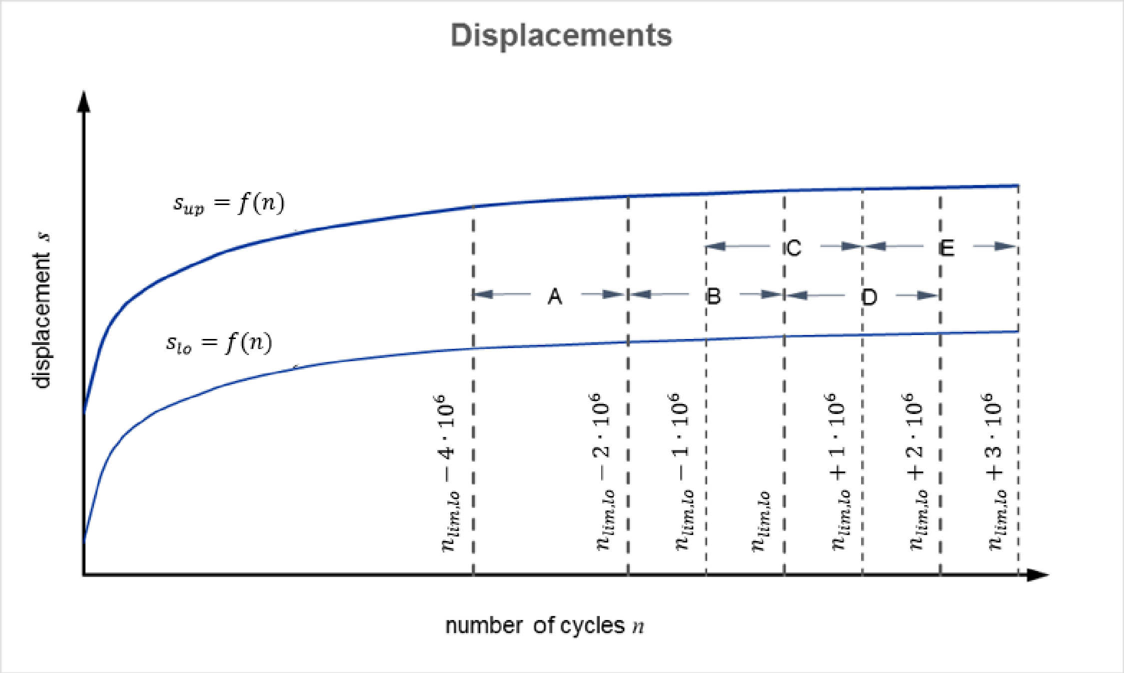


Figure B.1: Stabilization of deformations of a run-out

Specimens reaching $n \geq n_{lim}$ without failure, are to be tested again with the stress range ΔS_{RT} until failure occurs. A possible damage of the specimen, despite reaching the limit number of cycles, may be located by applying this so-called run-out test. The specimen is considered as a „real“ run-out specimen on the first load level, if the number of cycles on the second load level exceed the minimum number of cycles $n_{RT,min}$ (see Section B.3.3). If the run-out test is not passed, then the specimen was damaged during the first load level and is not considered as a „real“ run-out specimen. Results of run out tests performed on their second load level are required only to verify that damage to the specimens was not occurring during the tests at a lower load level. This second test is to be set on the lower limit of the upper third of the finite fatigue life area (see Figure B.2) and is calculated as follows:

$$\Delta S_{RT} = \bar{S} - (\bar{S} - \Delta S_D) / 3 \tag{B.6}$$

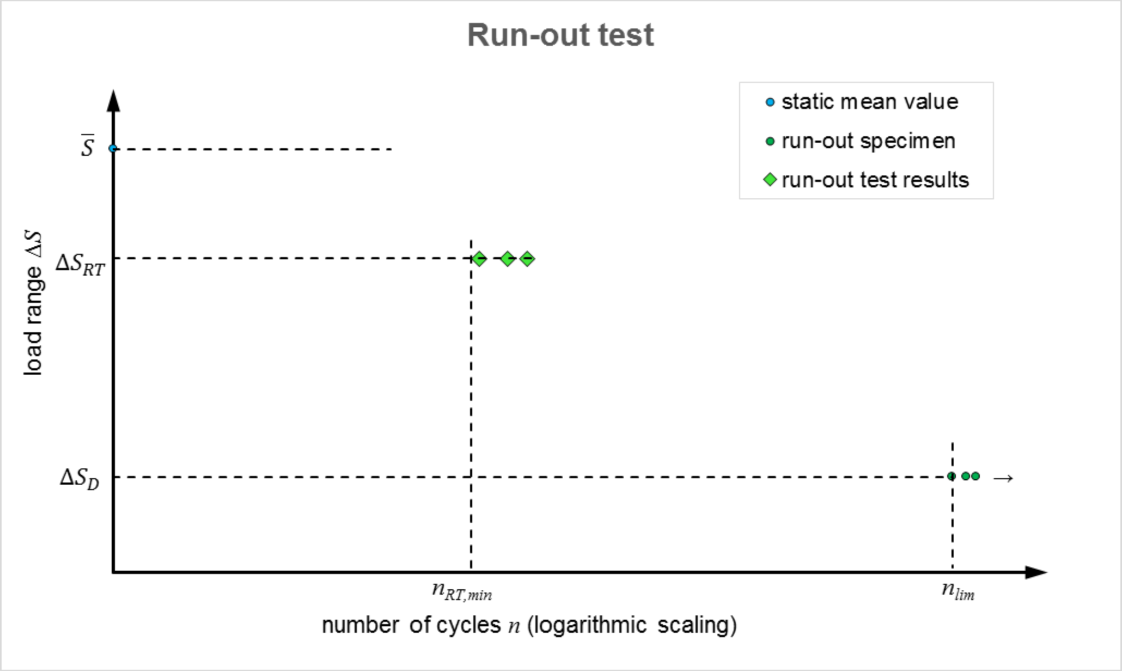


Figure B.2: Load level for run-out test

B.3.3 Reference tests for determination of the minimum number of cycles for the confirmation of run-out test

The determination of the minimum number of cycles $n_{RT,min}$ for the confirmation of run-out test is carried out based on the number of cycles from reference tests and is calculated as follows:

$$n_{RT,min} = 10^{(\bar{x}_r - 2 \cdot \hat{x}_r)} \quad \text{(B.7)}$$

where

$$\bar{x}_r = (x_{r1} + x_{r2} + x_{r3})/3 \quad \text{(use at least 5 decimal places)} \quad \text{(B.8)}$$

$$\hat{x}_r = \sqrt{\frac{\sum_{i=1}^{3}(\bar{x}_r - x_{ri})^2}{2}} \quad \text{(use at least 5 decimal places)} \quad \text{(B.9)}$$

where x_{ri} $= \lg n_{ri}$, logarithm of the number of cycles, with at least 5 decimal places in the horizontal section ΔS_{RT} for every step i

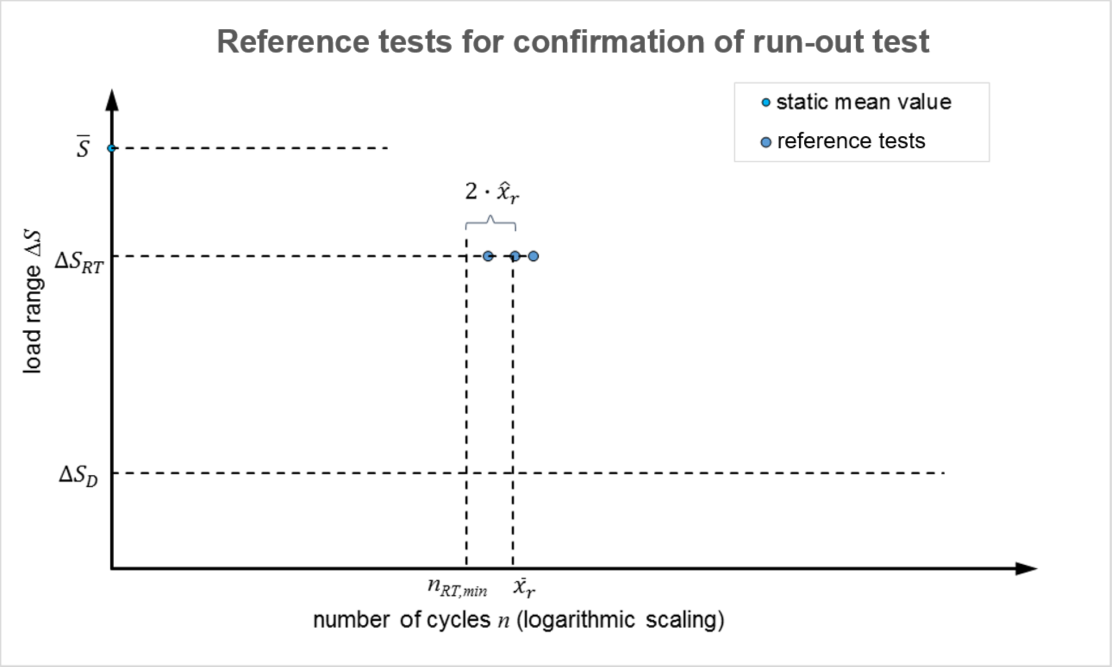


Figure B.3: Minimum number of cycles for run-out test

B.3.4 Determination of the characteristic fatigue limit resistance

If three specimen are considered as „real“ run-out specimen on the first load level ΔS_D, the characteristic fatigue limit resistance may be calculated as follows:

$$\Delta S_{D,k} = 0{,}5 \cdot \Delta S_D \quad \text{(B.10)}$$

ANNEX C METHOD TO DETERMINE THE LOAD TRANSFER FACTOR

C.1 Test program

The load-transfer factor (test method A) shall be determined by testing performed in accordance with Table C.1. All tests are performed in concrete of strength class C20/25.

Table C.1: Test method A: Required tests

N°	Tests according to Sections	Crack width Δw [mm]	Load direction	Minimum number of tests	Fastener Size	Remarks
Tension						
FC.1	2.2.8 Fatigue tests for load transfer for steel failure [1]	0,3	0°	8 [2]	all [3]	single fastener
FC.2	2.2.8 Fatigue tests for load transfer for steel failure [1]	0	0°	8	all [3]	single fastener
Shear						
FC.3	2.2.8 Fatigue tests for load transfer for steel failure [1]	0,3	90°	8 [2]	all [3]	single fastener
FC.4	2.2.8 Fatigue tests for load transfer for steel failure [1]	0	90°	8	all [3]	single fastener

[1] If no tests are performed, the load transfer factors ψ_{FN} = ψ_{FV} = 0,5 have to be applied.

[2] The number of tests can be reduced, if results from series FA.1 (tension) and series FA.4 (shear) respectively are used for these test series. However only results which fit into the range given in Section C.3.1 can be used.

[3] The total number of tests can be reduced, if the resulting fatigue resistance of the smallest fastener size is applied to all other fastener sizes specified by the manufacturer.

Note: The total number of tests of fasteners having a uniform cross section with variable embedment depths can be reduced, if the resulting fatigue resistance of the smallest embedment depth is applied to all other fastener embedment depths specified by the manufacturer.

Note: If the fastener is intended to be used with different drilling methods (e.g. hammer drilling (including hollow drilling) or diamond drilling) as specified by the manufacturer, the tests summarised in Table C.1 shall be performed separately for each drilling method.

C.2 Basics

The force-controlled periodic loading with sinusoidal course shall be used as the most disadvantageous case (practical application) of the test specimen.

The repeated loads consist of a constant lower load level and an upper load level with same algebraic sign (no alternating actions) and shall be applied on the specimen until fatigue failure or a stabilization of deformations has occurred.

In most cases fastener group fixings with a statically indeterminate or seemingly statically determinate system may lead in reality to significant difference between calculated and effective fastener loads. These differences are caused by load transfer within the fastener group as a result of the different values of a cyclic creep and a cyclic stiffness at the position of the anchorage. If cracks occur additionally in the base material and not all fasteners are positioned in crack, these cracks and their widths principally affect the increasing load transfer caused by the more flexible fasteners, positioned in the crack. This is valid for tension and shear loads and is principally different. Therefore a testing program for the determination of these load transfers is necessary.

In an extreme case some fasteners are positioned in uncracked concrete and other fasteners of the group in a crack with maximum admissible crack width (compare double fastener fixing with torsion proof support as given in Figure C.1).

This mechanical system leads to the following Equations for the load transfer factor:

Axial direction (tension):

$$\psi_{FN} = (0{,}5 \cdot N) \,/\, N_{ucr} \qquad \text{(C.1)}$$

where

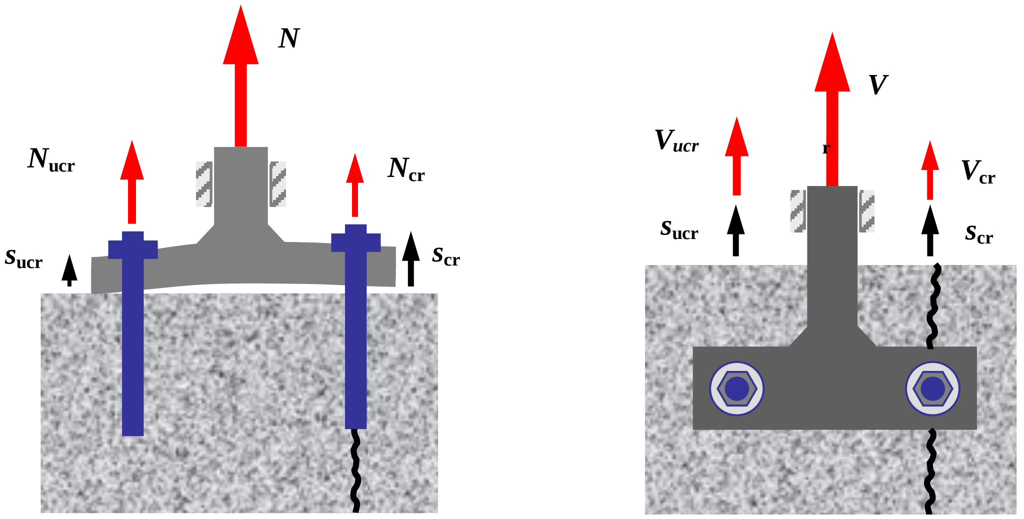
$$N = N_{ucr} + N_{cr}$$

Transverse direction (shear):

$$\psi_{FV} = (0{,}5 \cdot V) \,/\, V_{ucr} \qquad \text{(C.2)}$$

where

$$V = V_{ucr} + V_{cr}$$



axial direction (tension)

$s_{ucr} \leq s_{cr}, \qquad N_{ucr} > N_{cr}$

transverse direction (shear)

$s_{ucr} \leq s_{cr}, \qquad V_{ucr} > V_{cr}$

Figure C.1 Principles of load transfer in fastener groups under tension and shear load

The basic idea of this investigation concept is that it is possible to measure the fastener-load-relation in case of known load-displacement behavior of the fastener under cyclic loading and considering the total displacement of a fastener group. Therefore load-displacement-investigations under cyclic loading at single fasteners in uncracked and cracked (w = 0,3 mm) concrete are sufficient to derive the load transfer factors for fastener groups.

C.3 Procedure steps

C.3.1 Planning of the fatigue cyclic load levels

The load range ΔF_i is the difference between upper and lower level for every load level i:

$$\Delta F_i = F_{upi} - F_{lo} \qquad \text{(C.3)}$$

The lower level of the sinusoidal course, F_{lo}, is equal for all fatigue cyclic load levels and shall be kept to a minimum.

Results from fatigue cyclic testing already exist, thus at least the fatigue limit resistance and corresponding displacement is known. Based on the displacement of the fatigue limit resistance the load levels shall be set in a way that displacements arise in the range given below (see Figure C.3). This range shall be uniformly distributed.

$$\Delta s_{ucr,i(cr,j)} \approx (0{,}5; \ldots; 2{,}0) \cdot \Delta s_D$$

where

Δs_D	chosen displacement, which shall not be larger than the value of the displacement corresponding to the average fatigue limit resistance
$\Delta s_{ucr,i(cr,j)}$	for determination see Section C.3.2

C.3.2 Determination of the average functions

The test results (upper load level and concerning displacement) performed in uncracked and cracked concrete are mathematically described by a trend line (see Figure C.3). A power function shall be taken. All results can be projected to a displacement Δs_{ucr} and Δs_{cr} respectively by using the trend line. The values of the displacement Δs_{ucr} and Δs_{cr} are calculated as follows:

$$\Delta s_{ucr,i} = s_{n,ucr,i} - s_{0,ucr,i}\ , i = 1, \dots, r_{ucr} \qquad \text{(C.4)}$$

$$\Delta s_{cr,j} = s_{n,cr,j} - s_{0,cr,j}\ , j = 1, \dots, r_{cr} \qquad \text{(C.5)}$$

where	$s_{n,ucr,i}$	Displacement of a test result in uncracked concrete at n_{cal} (see Figure C.2), regarding the upper limit S_{upi} of a sinusoidal load process, for every step i
	$s_{0,ucr,i}$	Displacement of a test result in uncracked concrete at the beginning of the test, regarding the lower limit S_{lo} of a sinusoidal load process, for every step i
	$s_{n,cr,j}$	Displacement of a test result in cracked concrete at n_{cal} (see Figure C.2), regarding the upper limit S_{upj} of a sinusoidal load process, for every step j
	$s_{0,cr,j}$	Displacement of a test result in cracked concrete at the beginning of the test, regarding the lower limit S_{lo} of a sinusoidal load process, for every step j
	r_{ucr}	total number of available fatigue cyclic test results performed in uncracked concrete
	r_{cr}	total number of available fatigue cyclic test results performed in cracked concrete

s_n of run-out specimen are assigned to the calculated number of cycles n_{cal} (see Figure C.2 b)) which corresponds to the limit number of cycles n_{lim} as determined in Annex A, Section A.3.3 (test method A).

Displacements s_n of failed specimen are assigned to the calculated number of cycles n_{cal} (see Figure C.2a) which corresponds to the inflection point on the function graph on which the graph changes its curvature characteristics. It is recommended to use a polynomial of fourth degree to describe the test results (number of cycles and concerning displacement).

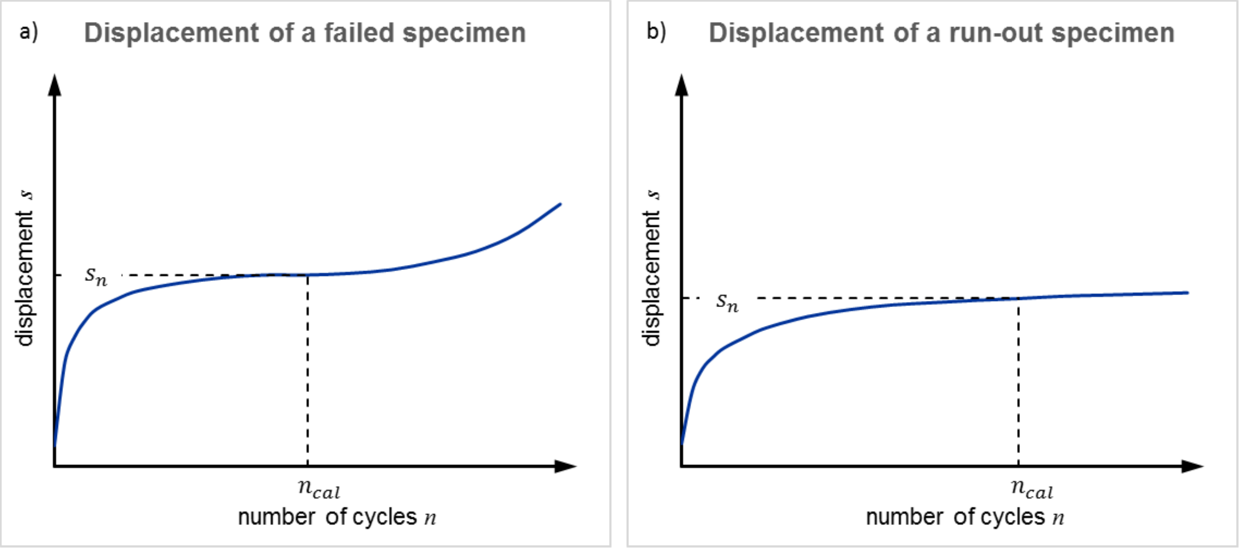


Figure C.2 Displacement of a failed a) and a run-out b) specimen at a calculated number of cycles

If test results with different upper load levels and displacements are available, then the results are described by two power functions (see Figure C.3), (C.11) for the test results performed in uncracked concrete and (C.12) in cracked concrete, according to the principles of the least squares method. These functions correspond to the average functions.

1. The free parameters $a_{cr}, \; a_{ucr}, \; b_{cr}$ and b_{ucr} are adjusted separately for the test results performed in uncracked and cracked concrete by using the regression analysis (least squares method):

   $$\bar{F}_{up,ucr\_1} = a_{ucr\_1} \cdot (\Delta s_{ucr})^{b_{ucr}} \tag{C.6}$$

   $$\bar{F}_{up,cr\_1} = a_{cr\_1} \cdot (\Delta s_{cr})^{b_{cr}} \tag{C.7}$$

2. The averaged exponent b_t will be rearranged subject to the number of tests performed in uncracked and cracked concrete:

   $$b_t = \frac{b_{ucr} \cdot r_{ucr} + b_{cr} \cdot r_{cr}}{r_{ucr} + r_{cr}} \tag{C.8}$$

3. The coefficients a_{ucr} and a_{cr} are adjusted again by using exponent b_t. The results are described by straight lines according to the principles of the least squares method:

   $$\bar{F}_{up,ucr} = a_{ucr} \cdot x_{ucr} \tag{C.9}$$

   where

   $$x_{ucr} = (\Delta s_{ucr})^{b_t}$$

   $$\bar{F}_{up,cr} = a_{cr} \cdot x_{cr} \tag{C.10}$$

   where

   $$x_{cr} = (\Delta s_{cr})^{b_t}$$

4. The average functions are determined using the parameters $a_{cr}, \; a_{ucr}$ and b_t:

   $$\bar{F}_{up,ucr} = a_{ucr} \cdot (\Delta s_{ucr})^{b_t} \tag{C.11}$$

   $$\bar{F}_{up,cr} = a_{cr} \cdot (\Delta s_{cr})^{b_t} \tag{C.12}$$

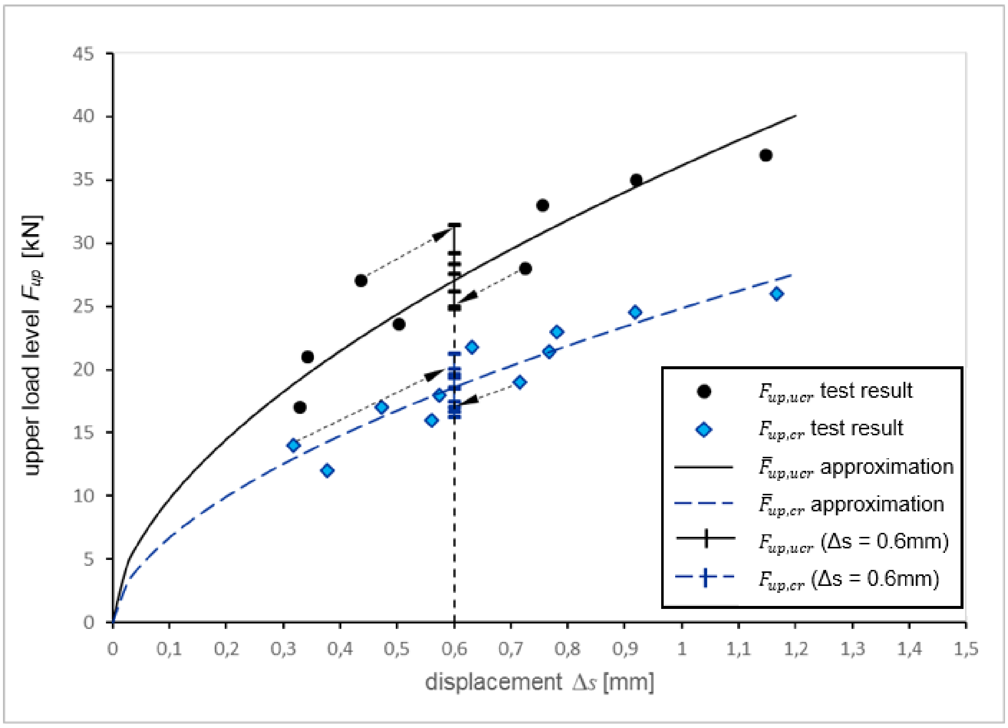


Figure C.3 Example of displacements of the loading fixture and load transfer between the fasteners due to cycling loading

Investigations have shown that the scatter of the test results around this average functions is independent of the displacement, and thus the absolute values of the standard deviations along the approximate curves remain unchanged. That is, a statistical analysis of the forces is carried out for the chosen displacement Δs_D after transferring the experimental test results (upper load levels) to this section with the constant distance from the average function (see Figure C.3). The chosen displacement shall not be larger than the value of the displacement corresponding to the average fatigue limit resistance.

1. For each section corresponding mean values and residual are calculated:

$\bar{F}_{up,ucr,i}$ mean value of the section for every step i according to Equation (C.11) regarding test results performed in uncracked concrete

where

$\Delta s_{ucr,i}$ displacement of the section for every step i

$$\Delta\Delta F_{up,ucr,i} = F_{up,ucr,i} - \bar{F}_{up,ucr,i}\, , i = 1, \dots , r_{ucr} \tag{C.13}$$

$\Delta\Delta F_{up,ucr,i}$ residual load in the section for every step i for test results in uncracked concrete

$\bar{F}_{up,cr,j}$ mean value of the section for every step j according to Equation (C.12) regarding test results performed in cracked concrete

where

$\Delta s_{cr,j}$ displacement of the section for every step j

$$\Delta\Delta F_{up,cr,j} = F_{up,cr,j} - \bar{F}_{up,cr,j}\, , j = 1, \dots , r_{cr} \tag{C.14}$$

$\Delta\Delta F_{up,cr,j}$ residual load in the section for every step j for test results in cracked concrete

2. For the chosen displacement corresponding mean values are calculated:

   $\bar{F}_{up,ucr}$ mean value for a chosen displacement according to Equation (C.11) regarding test results performed in uncracked concrete

   $\bar{F}_{up,cr}$ mean value for a chosen displacement according to Equation (C.12) regarding test results performed in cracked concrete

   where

   Δs_D chosen displacement, which shall not be larger than the value of the displacement corresponding to the average fatigue limit resistance

3. The upper load levels for a chosen displacement are calculated as follows:

$$F_{up,ucr,i} = \bar{F}_{up,ucr} + \Delta\Delta F_{up,ucr,i}, i = 1, \dots , r_{ucr} \tag{C.15}$$

$$F_{up,cr,j} = \bar{F}_{up,cr} + \Delta\Delta F_{up,cr,j}, j = 1, \dots , r_{cr} \tag{C.16}$$

C.3.3 Determination of the load transfer factor

The determination of the load transfer factor is carried out with an origin load ($F_{lo} = 0$), thus the load range of the acting load is assigned to the upper load level ($\Delta F = F_{up}$).

Note: An example for the determination of the load transfer factor is shown in Table C.1.

The characteristic acting load $\Delta F_{cal,95\%}$ (corresponds to the 95%-quantile) without consideration of the load transfer is assigned to the chosen displacement Δs_D. The probability distribution of the acting load without consideration of the load transfer is approximated using a logarithmic normal distribution.

1. The characteristic acting load is calculated as follows:

$$\Delta F_{cal,95\%} = (\bar{F}_{up,ucr} + \bar{F}_{up,cr})/2 \tag{C.17}$$

2. The corresponding mean load range, variance and standard deviation are determined with $\Delta F_{cal,95\%}$ and a coefficient of variation $\Delta\hat{F}_{cal}$ / $\Delta\bar{F}_{cal} = 0{,}07$ (assumption) using a logarithmic normal distribution:

   $\Delta\bar{F}_{cal}$ mean load range for the chosen displacement

$$\Delta\hat{F}_{cal}^2 = (\Delta\bar{F}_{cal} \cdot 0{,}07)^2 \tag{C.18}$$

$$\Delta\hat{F}_{cal} = \sqrt{\Delta\hat{F}_{cal}^2} \tag{C.19}$$

Due to the independence of the test results in uncracked and cracked concrete it is permissible to consider all possible combinations of forces to derive the individual realizations of the load transfer factor. Consequently a sample size of $r_{ucr} \cdot r_{cr}$ elements arise, which represent the random size of the load transfer factor ψ_F. The relative cumulative frequency of the load transfer factor is approximated using a normal distribution.

3. The load transfer factors $\psi_{F,ij}$ $(i = 1, \dots, r_{ucr}; j = 1, \dots, r_{cr})$ are calculated using Equations (C.1) for tension and (C.2) for shear and are summarised in the matrix below:

$$(\psi_{F,ij}) = \begin{pmatrix} \psi_{F,11} & \cdots & \psi_{F,1j} & \cdots & \psi_{F,1r_{cr}} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \psi_{F,i1} & \cdots & \psi_{F,ij} & \cdots & \psi_{F,ir_{cr}} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \psi_{F,r_{ucr}1} & \cdots & \psi_{F,r_{ucr}j} & \cdots & \psi_{F,r_{ucr}r_{cr}} \end{pmatrix}$$

4. The equivalent mean value of the load transfer factors $\psi_{F,ij}$ is calculated as follows:

$$\bar{\psi}_F = \frac{r_{ucr} \cdot r_{cr}}{\left[\sum_{i,j=1}^{r_{ucr} \cdot r_{cr}} \frac{1}{\psi_{F,ij}}\right]} \tag{C.20}$$

5. Estimation of the equivalent variance and standard deviation:

$$\hat{\psi}_F^2 = \frac{\sum_{i,j=1}^{r_{ucr} \cdot r_{cr}} \left(\frac{1}{\psi_{F,ij}} - \frac{1}{\bar{\psi}_F}\right)^2}{(r_{ucr} \cdot r_{cr}) - 1} \tag{C.21}$$

$$\hat{\psi}_F = \sqrt{\hat{\psi}_F^2} \tag{C.22}$$

The statistical values and the characteristic acting load $\Delta F_{95\%}$ are determined with consideration of the load transfer for the distribution of the acting load in uncracked concrete $\Delta\tilde{F}$ for the chosen displacement Δs_D. The probability distribution of the acting load with consideration of the load transfer is approximated using a logarithmic normal distribution.

6. The equivalent mean load range, variance and standard deviation are calculated as follows:

$$\Delta\bar{F} = \left(\frac{1}{\bar{\psi}_F}\right) \cdot \Delta\bar{F}_{cal} \tag{C.23}$$

$$\Delta\hat{F}^2 = \left(\frac{1}{\bar{\psi}_F}\right)^2 \cdot \Delta\hat{F}_{cal}^2 + \hat{\psi}_F^2 \cdot \Delta\bar{F}_{cal}^2 + \hat{\psi}_F^2 \cdot \Delta\hat{F}_{cal}^2 \tag{C.24}$$

$$\Delta\hat{F} = \sqrt{\Delta\hat{F}^2} \tag{C.25}$$

7. The characteristic acting load is calculated as follows:

   $\Delta F_{95\%}$ characteristic value for the chosen displacement calculated using a logarithmic normal distribution

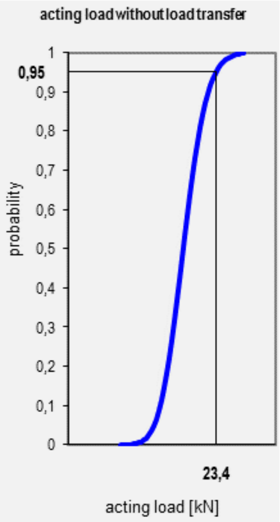
The required load transfer factor is determined on the level of the 95%-quantile of the acting load.

8. The load transfer factor is calculated as follows:

$$\psi_F = \Delta F_{cal,95\%} \,/\, \Delta F_{95\%} \tag{C.26}$$

Table C.2: Example for the determination of the load transfer factor

$\Delta\widetilde{N}_{cal}$



log-normal distribution

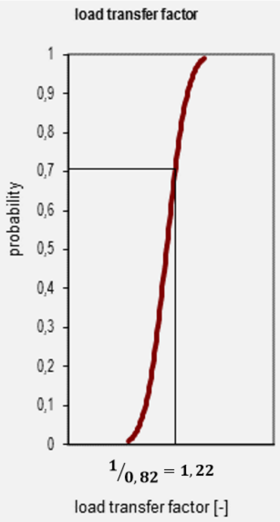
$\Delta\overline{N}_{cal} = 20{,}94\ kN$

$\Delta\widehat{N}^2_{cal} = 2{,}148\ kN^2$

$\Delta N_{cal,95\%} = 23{,}43 \approx 23{,}4\ kN$

×

$\widetilde{\psi}_{FN}$



equivalent normal distribution

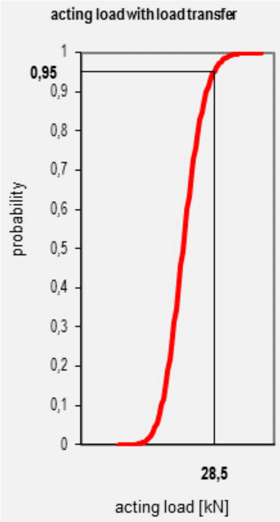
$^1/_{\overline{\psi}_{FN}} = 1{,}1829$

$\widehat{\psi}^2_{FN} = 0{,}004077$

$\psi_{FN} = 0{,}8214 \approx 0{,}82$

=

$\Delta\widetilde{N}$



log-normal distribution

$\Delta\overline{N} = 24{,}77\ kN$

$\Delta\widehat{N}^2 = 4{,}802\ kN^2$

$\Delta N_{95\%} = 28{,}54 \approx 28{,}5\ kN$

<u>evaluation process according to Section C.2.3:</u>

1. The characteristic acting load $\Delta N_{cal,95\%}$ (upper load) without consideration of the load transfer is assigned to the chosen displacement $\Delta s = 0{,}6$ mm (see Figure C.3):

   $\Delta N_{cal,95\%} = (19{,}24\ + 27{,}62)/2 = 23{,}43\ kN$

2. Mean load range, variance and standard deviation are determined with $\Delta N_{cal,95\%} = 23{,}43\ kN$ and a coefficient of variation $\Delta\widehat{F}_{cal}\ /\ \Delta\overline{F}_{cal} = 0.07$ (assumption) using a logarithmic normal distribution:

   $\Delta\overline{N}_{cal} = 1/\mathrm{LOGNORM.INV}(0{,}95; -0{,}00244; 0{,}06991)^{*)} \cdot 23{,}43 = 20{,}94\ kN$

   $m = \ln\left(\mu^2/\sqrt{\sigma^2+\mu^2}\right) = \ln\left(1^2/\sqrt{0{,}07^2+1^2}\right) = -0{,}00244$

   $s = \sqrt{\ln\left([\sigma/\mu]^2+1\right)} = \sqrt{\ln\left([0{,}07/1]^2+1\right)} = 0{,}06991$

   $\Delta\widehat{N}^2_{cal} = (20{,}94 \cdot 0.07)^2 = 2{,}148\ kN^2$

   $\Delta\widehat{N}_{cal} = \sqrt{2{,}148} = 1{,}466\ kN$

3. The load transfer factors $\psi_{F,ij}$ are calculated using Equation (C.1) for tension:

$$
(\psi_{FN,ij}) = \begin{pmatrix}
0{,}828 & 0{,}789 & 0{,}764 & 0{,}848 & 0{,}797 & 0{,}820 & 0{,}780 & 0{,}840 \\
0{,}896 & 0{,}848 & 0{,}819 & 0{,}920 & 0{,}858 & 0{,}886 & 0{,}838 & 0{,}910 \\
0{,}909 & 0{,}860 & 0{,}829 & 0{,}934 & 0{,}870 & 0{,}898 & 0{,}849 & 0{,}923 \\
0{,}927 & 0{,}876 & 0{,}844 & 0{,}952 & 0{,}887 & 0{,}916 & 0{,}864 & 0{,}943 \\
0{,}826 & 0{,}787 & 0{,}762 & 0{,}845 & 0{,}795 & 0{,}817 & 0{,}778 & 0{,}838 \\
0{,}889 & 0{,}842 & 0{,}813 & 0{,}912 & 0{,}852 & 0{,}879 & 0{,}832 & 0{,}903 \\
0{,}822 & 0{,}784 & 0{,}759 & 0{,}842 & 0{,}792 & 0{,}814 & 0{,}775 & 0{,}834 \\
0{,}882 & 0{,}836 & 0{,}807 & 0{,}905 & 0{,}846 & 0{,}872 & 0{,}826 & 0{,}895 \\
0{,}850 & 0{,}808 & 0{,}781 & 0{,}870 & 0{,}816 & 0{,}840 & 0{,}798 & 0{,}862 \\
0{,}858 & 0{,}816 & 0{,}789 & 0{,}809 & 0{,}824 & 0{,}850 & 0{,}806 & 0{,}872 \\
0{,}897 & 0{,}849 & 0{,}819 & 0{,}921 & 0{,}859 & 0{,}887 & 0{,}838 & 0{,}911
\end{pmatrix}
$$

4. The corresponding equivalent mean value of the load transfer factors $\psi_{FN,ij}$:

   $\bar{\psi}_{FN} = 0{,}8454$

5. Estimation of the equivalent variance and standard deviation:

   $\hat{\psi}_{FN}^2 = 0{,}004077$

   $\hat{\psi}_{FN} = 0{,}064$

6. Determination of the statistical values with consideration of the load transfer for the distribution of the acting load in uncracked concrete $\Delta\tilde{N}$ for the chosen displacement $\Delta s_D = 0{,}6$ mm:

   $\Delta\bar{N} = (1/0{,}8454) \cdot 20{,}94 = 24{,}77\ kN$

   $\Delta\hat{N}^2 = (1/0{,}8454)^2 \cdot 2{,}148 + 0{,}004077 \cdot 20{,}94^2 + 0{,}004077 \cdot 2{,}148 = 4{,}802\ kN^2$

   $\Delta\hat{N} = \sqrt{4{,}802} = 2{,}191\ kN$

7. Determination of the characteristic acting load (95%-quantile) with consideration of the load transfer:

   $\Delta N_{95\%} = \mathrm{LOGNORM.INV}(0{,}95; 3{,}20574; 0{,}08828)^{*)} = 28{,}52\ kN$ (log-normal distribution)

   $m = \ln\left(\Delta\bar{N}^2/\sqrt{\Delta\hat{N}^2 + \Delta\bar{N}^2}\right) = \ln\left(24{,}77^2/\sqrt{2{,}191^2 + 24{,}77^2}\right) = 3{,}20574$

   $s = \sqrt{\ln\left(\left[\Delta\hat{N}/\Delta\bar{N}\right]^2 + 1\right)} = \sqrt{\ln\left([2{,}191/24{,}77]^2 + 1\right)} = 0{,}08828$

8. The required load transfer factor is determined on the level of the 95%-quantile of the acting load:

   $\psi_{FN} = \Delta N_{cal,95\%}\ /\ \Delta N_{95\%} = 23{,}43\ /\ 28{,}52 = 0{,}8214$

*) This Excel function LOGNORM.INV calculates quantiles of the logarithmic normal distribution.

ANNEX D TEST DETAILS

D.1 Test samples, fixtures

Testing shall be performed on fasteners manufactured with the same material batch and production lot. All relevant measured values of the fastener shall be included in the test reports.

The tests for steel failure (tension, shear and combined tension and shear) shall be carried out with the minimum fixture thickness $t_{fix,min}$. The value $t_{fix,min}$ as determined for the use under static loading (see related European Technical Assessment (ETA)) shall be used.

Loosening of the nut or screw shall not occur during testing. If loosening of the nut occurs the fastener cannot be assessed according to this EAD.

D.2 Test details

D.2.1 Tests for steel failure under tension

The tests for fatigue cyclic loading shall be carried out on a single fastener installed in cracked concrete (see also Section D.3.3 and D.6). An example for the load application and displacement measurement without influence of deformation of the test rig is given in Figure D.1.

For test method C the tests for fatigue cyclic loading shall also be carried out on a single fastener installed in uncracked concrete (see also Section D.3.4).

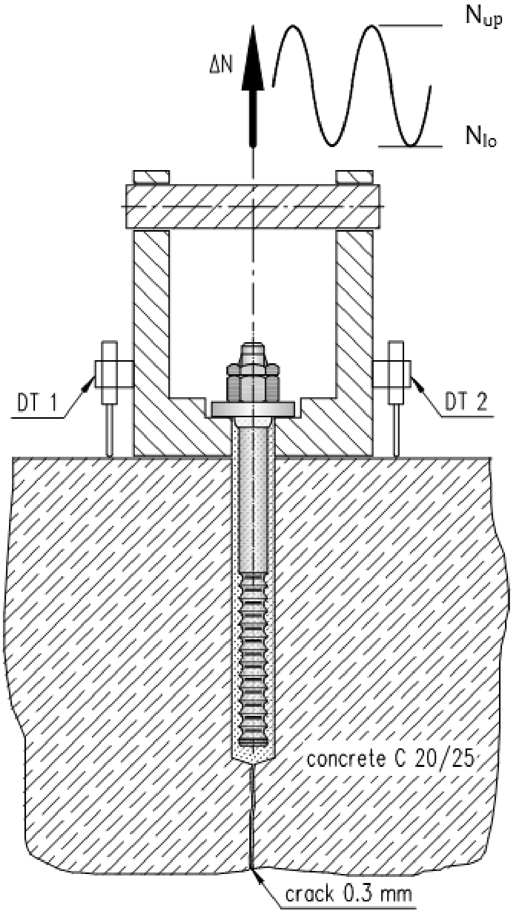


Figure D.1: Example of test setup for steel failure under tension in cracked concrete with displacement transducer (DT)

D.2.2 Tests for steel failure under shear

The tests for fatigue cyclic loading shall be carried out on a single fastener installed in cracked concrete (see also Section D.3.3 and D.6). The crack direction shall correspond to the direction of the shear load ΔV. An example for the load application and displacement measurement without influence of deformation of the test rig is given in Figure D.2.

For test method C the tests for fatigue cyclic loading shall also be carried out on a single fastener installed in uncracked concrete (see also Section D.3.4).

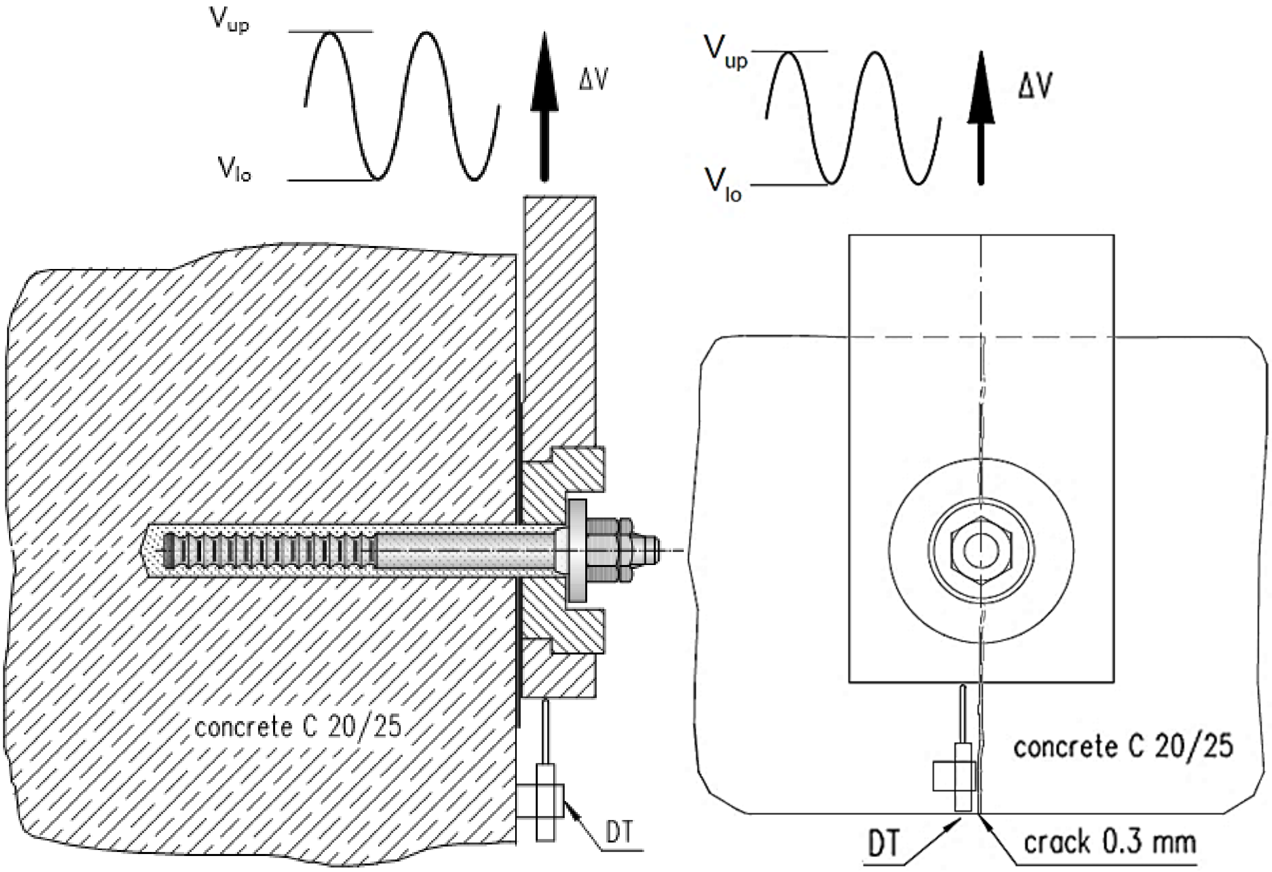


Figure D.2: Example of test setup for steel failure under shear in cracked concrete with displacement transducer (DT)

D.2.3 Tests for steel failure under combined tension and shear

The tests for fatigue cyclic loading shall be carried out on a single fastener installed in cracked concrete (see also Section D.3.3 and D.6). The crack direction shall correspond to the direction of the combined tension and shear load ΔF^{β}. The load shall be applied by one load application acting at the specified angle β to the fastener axis (β for test method A and B see Section 2.2.7, β for test method C between 30° and 60°). An example for the load application without influence of deformation of the test rig is given in Figure D.3. The displacement of the fastener relative to the concrete surface may be measured in the direction of the load. It is recommended to use the internal displacement transducer in the loading unit.

For test method C the tests for fatigue cyclic loading shall also be carried out on a single fastener installed in uncracked concrete (see also Section D.3.4).

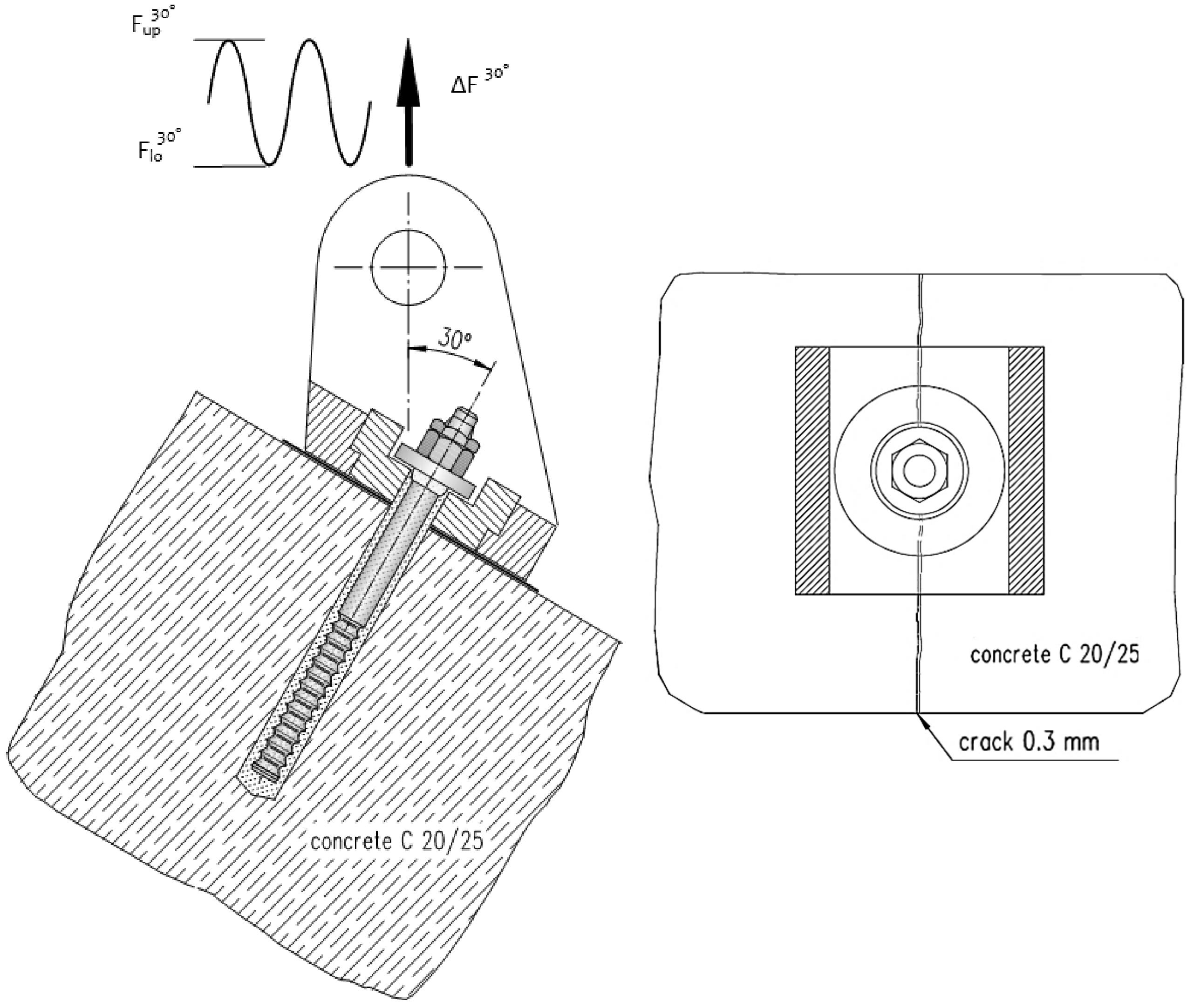


Figure D.3: Example of test setup for steel failure under combined tension and shear in cracked concrete

D.2.4 Tests for concrete cone failure under tension

The tests for static and fatigue cyclic loading shall be carried out on a quadruple fastener group installed in uncracked concrete with the minimum anchor spacing s_{min} to avoid steel failure. The value s_{min} as determined for the use under static loading (see related European Technical Assessment (ETA)) shall be used. The fasteners of a group shall be connected by a rigid fixture. The tension load shall be applied centrally to the fixture. The connection between the fixture and the load cell shall be hinged to permit differential fastener displacements. An example for the load application without influence of deformation of the test rig is given in Figure D.5.

The displacement of the fastener group relative to the concrete surface may be measured e.g. by use of the internal displacement transducer (as mean displacement) or e.g. at a distance of ≥ 1,5 · h_{ef} of the outermost fasteners, for example by use of transducers measuring the displacement of the fixture.

In order to avoid splitting of the concrete specimens during static or fatigue cyclic loading a high degree of reinforcement in combination with small reinforcement diameters shall be installed into the concrete specimens. Furthermore the reinforcement shall not affect the test results and fastener performance. An example of the reinforcement layout designed for four tests in a concrete specimen is given in Figure D.4. The circular reinforcement around the fastener group shall be arranged conical with a base circle diameter larger than or equal to 4,5 · h_{ef} + s_{min} and a slope of about 35°. The reinforcement diameters of the reinforcement cage shall not be larger than or equal to 10 mm.

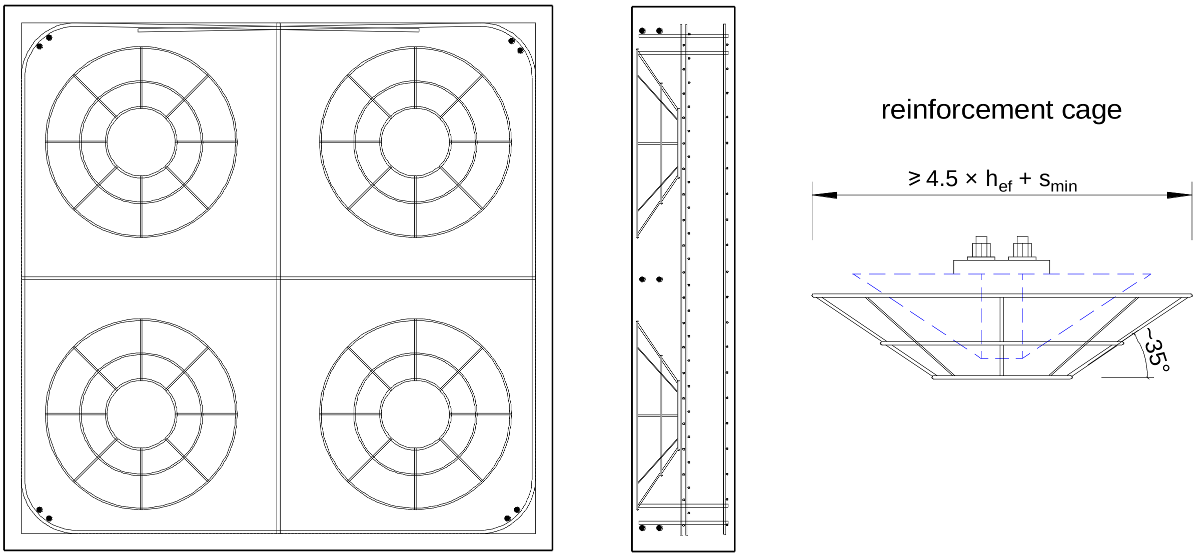


Figure D.4: Example of the reinforcement layout for concrete cone failure tests

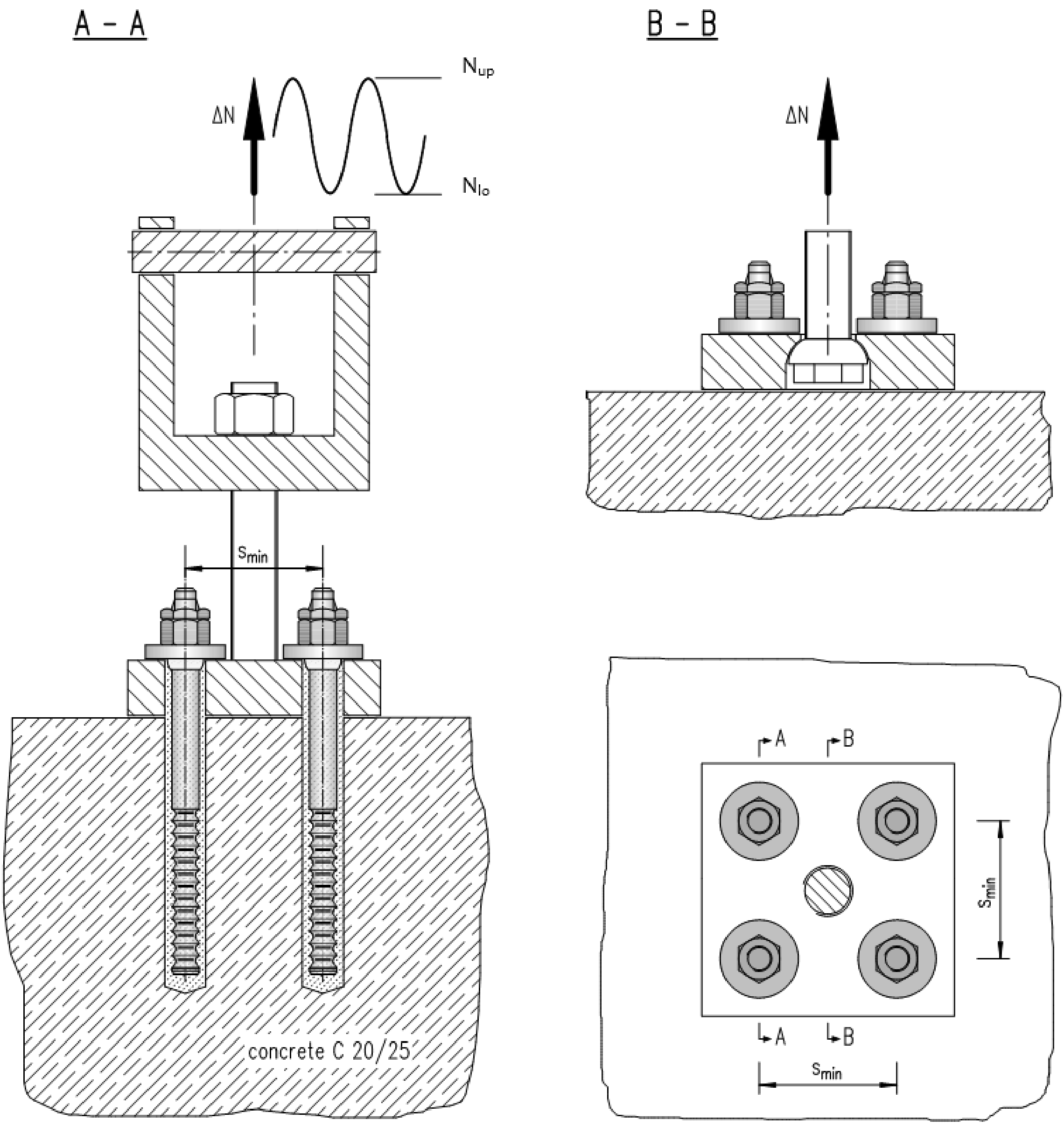


Figure D.5: Example of test setup for concrete cone failure under tension in uncracked concrete

D.2.5 Tests for concrete edge failure under shear

The tests for static and fatigue cyclic loading shall be carried out on a double fastener group at the edge of test member installed in uncracked concrete with the minimum anchor spacing s_{min} and the minimum edge distance c_{min} to avoid steel failure. The values c_{min} and s_{min} are already specified in the European Technical Assessment (ETA) on the basis of [1], [2]. The two fasteners shall be installed parallel to the edge and connected by a rigid fixture and the shear load shall be applied at the centre. The test arrangement shall simulate a hinged connection, so that the two fasteners are loaded equally. An example for the load application and displacement measurement without influence of deformation of the test rig is given in Figure D.6.

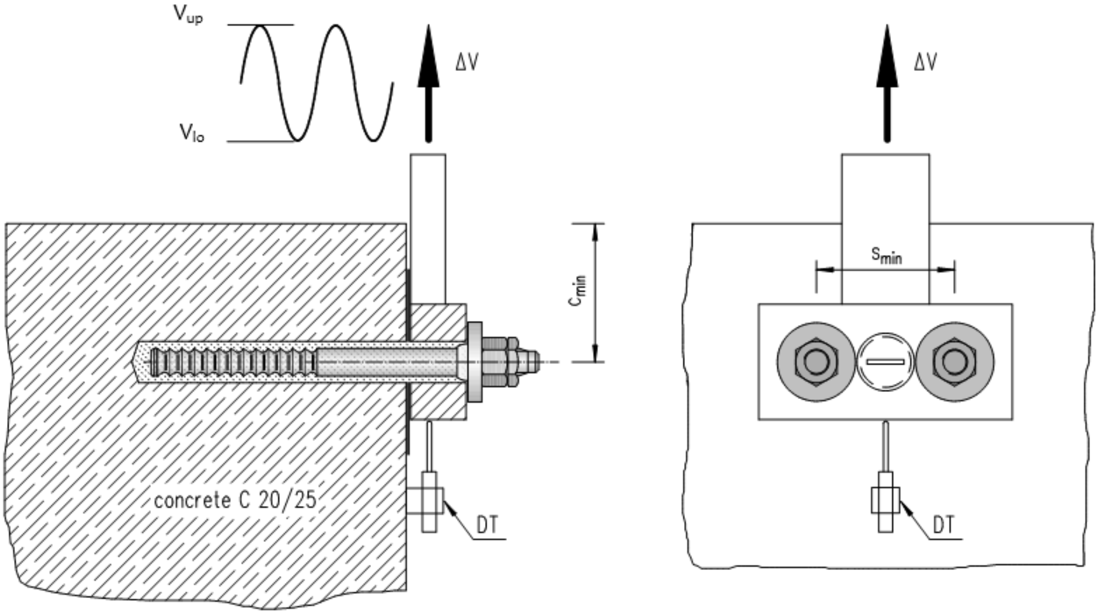


Figure D.6: Example of test setup for concrete edge failure under shear in uncracked concrete

D.2.6 Tests for shear and combined tension and shear tests

In order to avoid friction between the loading fixture and the surrounding concrete, a thin layer of friction-reducing material (e.g., PTFE layer) with a maximum thickness of 2 mm shall be placed between the loading fixture and the surrounding concrete.

D.2.7 Conditions for all tension tests

All boreholes shall be drilled with a scheduled inclined position of at least 3° (see Figure D.7) to consider this possible misalignment during installation as a negative acting factor. The inclination of the anchor shall correspond to the crack direction.

If the tests for test method C are performed without any inclination a reduction factor of 0,75 shall be taken into account.

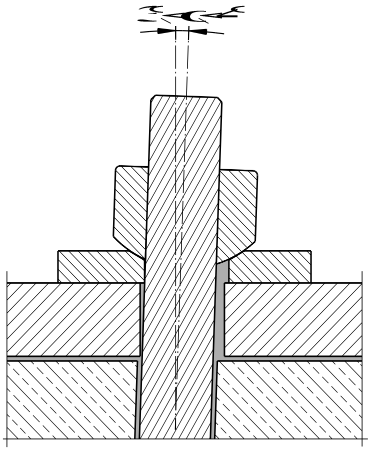


Figure D.7: Inclined position of at least 3° for tension tests

D.2.8 Details for all tests

In all tests, apply the required installation torque, T_{inst}, specified in the manufacturer's product installation instructions (MPII) using a calibrated torque wrench having a measuring error within ±5% of the specified torque.

After a minimum of ten minutes after the initial application of T_{inst}, loosen the nut and re-apply torque as follows: 5 Nm ≤ $0{,}2 \cdot T_{inst}$.

When performing run-out tests on second (higher) load level, re-application of torque to the system shall not be permitted.

The installation torque, T_{inst}, used for testing shall be given in the relevant ETA.

The test setups shall include moment hinges on two positions to avoid eccentricities at the point at which load is introduced. Examples of the principle structure are shown in Figure D.8. The maximum length of the tension rods including the loading fixture between the point of load application and the load cell shall be equal to or smaller than 0,8 m for tension and combined tension and shear setups and equal to or smaller than 1,1 m for shear setups. The minimum dimensions (width / diameter) of the tension rods shall be equal to or larger than 24 mm.

If the conditions above are not fulfilled, the connection between the point of load application and the load cell shall have an eigenfrequency of f ≥ 400 Hz. This eigenfrequency is comparable to the conditions in the paragraph before.

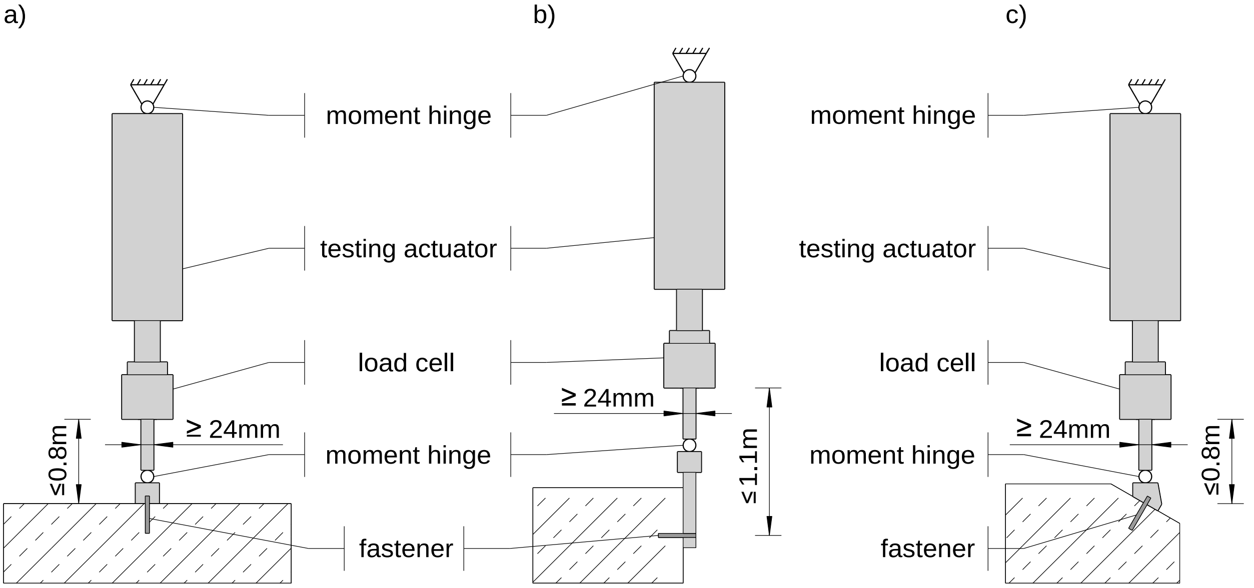


Figure D.8: Examples of tension a), shear b) and combined tension and shear c) test setups including two moment hinges and dimensions of tension rods

In tests with tension loads of single fasteners it is necessary for experimental reasons, to initiate the forces over a pendulum rod to the fastener. In this load initiation, the conditions are more favourable than in most of practical applications. This difference is taken into account with a reduction factor of 0,92 = 1 / 1,087 (see [10]), while the load levels of single fastener test results are multiplied by the factor 0,92.

The tests shall be conducted as unconfined tests (Exception tests for bond fatigue resistance according to test method C) in accordance with Section D.4.1. For tension load tests the support reactions (e.g. test stand) shall be located entirely on the concrete surface in order to avoid bending of the concrete specimens during fatigue cyclic loading.

Additionally the support reactions shall not affect the concrete break-out bodies when performing concrete failure tests. For this reason the clear distance between the support reaction and a fastener (single fastener) or the outer fastener (fastener group) respectively shall be at least $2 \cdot h_{ef}$ (tension test) or $2 \cdot c_{min}$ (shear test at the edge with load applied towards the edge, see Figure D.6).

Tests for bond fatigue resistance according to test method C are performed as confined tests in accordance with Section D.4.2.

The samples shall be tested to failure.

Test method A and B: In case of fatigue-tested specimen without rupture, the tests shall be stopped. The fastener shall be re-loaded at a higher stress range until failure occurs (see Annexes A and B for additional details).

The fastener shall be loaded with a sinusoidal load process according Figure D.9.

Test method A and B: All fastener sizes with all steel qualities/properties and coatings specified by the manufacturer shall be tested.

The pulsating load has to be controlled in accordance with Figure D.9, where F_{lo} shall be equal to the smallest operable load, but larger than zero and $F_{up} = F_{lo} + \Delta F$. F_{lo} shall be kept constant throughout the entire test program.

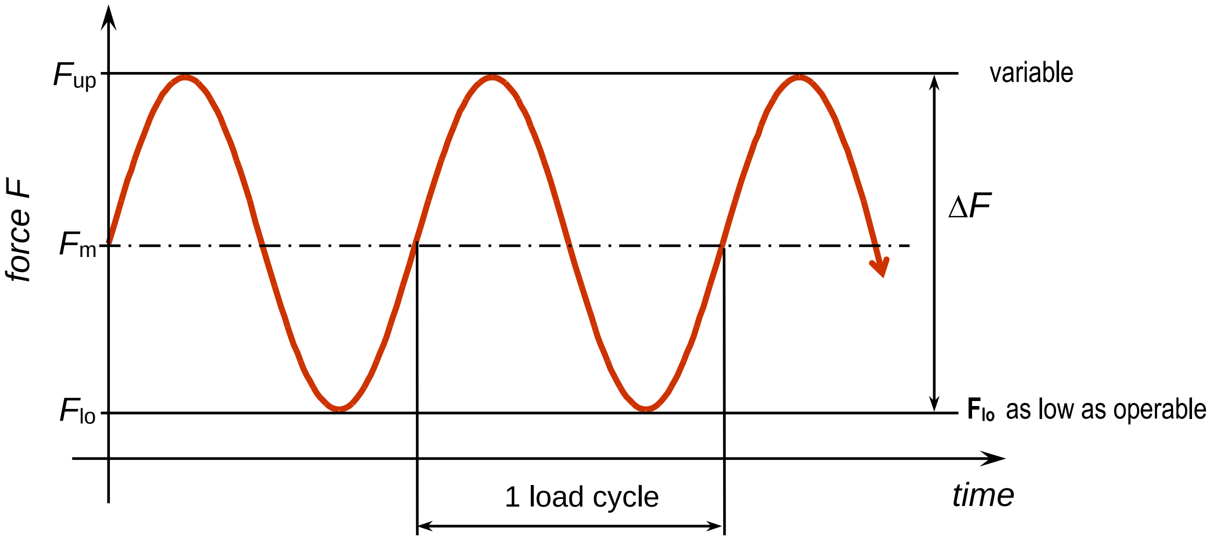


Figure D.9: Example of fatigue cyclic loading protocol

The testing frequency shall be between 0,1 Hz and 20 Hz. The low frequencies (0,1 Hz to 5 Hz) may be used for high stress ranges near the static resistance resulting in large plastic deformations.

The fatigue cyclic force range shall be varied when performing tests according to test method A (see Annex A for additional details).

In the static tests, the load displacement functions shall be continuously recorded and the failure mode shall be given.

In the fatigue cyclic tests, the number of cycles at failure and the failure mode shall be given. In addition, the following values shall be continuously recorded:

- Displacements corresponding to the maximum load as a function of the number of cycles n
- Elapsed time and number of cycles
- F_{lo} and s_{lo} (minimum force and corresponding displacement)
- F_{up} and s_{up} (maximum force and corresponding displacement)
- Loosing of the nut or screw shall be monitored during testing

It is recommended to record at least 50 measured values per cycle.

The measurement frequency must be able to measure the minimum and maximum force and displacement values correct (e. g. by using the Nyquist-Shannon sampling theorem).

In the test reports, all information described above, in addition to all other relevant installation parameters (e.g., T_{inst}) shall be provided.

D.3 Test members

D.3.1 Concrete composition

The test members shall comply with the following:

Aggregates shall be of natural occurrence (i.e. non-artificial) and with a grading curve falling within the boundaries given in Figure D.10. The maximum aggregate size shall be 16 mm or 20 mm. The aggregate density shall be between 2.0 and 3.0 t/m^3 (see EN 206:2013 + A1:2016 [4]).

The boundaries reported in Figure D.10 are valid for aggregate with a maximum size of 16 mm. For different values of maximum aggregate sizes, different boundaries may be adopted, if previously agreed with the responsible TAB.

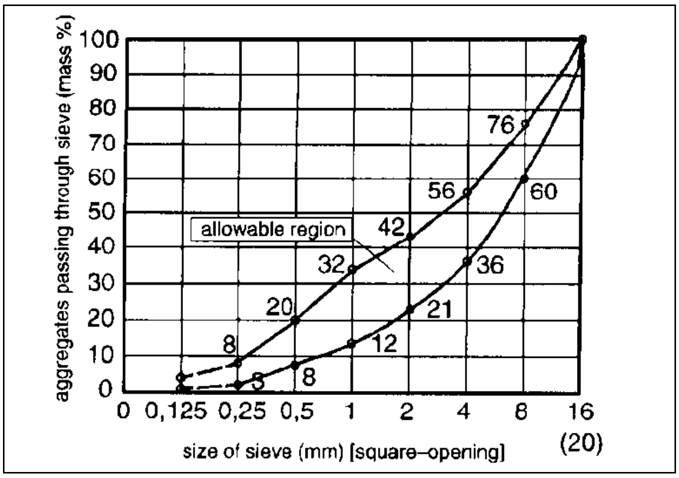


Figure D.10: Admissible region for the grading curve

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 [6]).

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

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

D.3.2 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 N/mm^2 (cylinder: diameter 150 mm, height 300 mm)
	f_{cube}	=	25-35 N/mm^2 (cube:150 x 150 x 150 mm)
C50/60	f_c	=	50-60 N/mm^2 (cylinder: diameter 150 mm, height 300 mm)
	f_{cube}	=	60-70 N/mm^2 (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 $$f_c = \frac{1}{1{,}25} f_{cube} \tag{D.1}$$

C50/60 $$f_c = \frac{1}{1{,}20} f_{cube} \tag{D.2}$$

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

$$f_{cube100} = \frac{1}{0{,}95} f_{cube} \tag{D.3}$$

$$f_{cube} = \frac{1}{0{,}95} f_{cube200} \tag{D.4}$$

$f_{cube} = f_{core100}$ (according to EN 13791:2007 [7], section 7.1) (D.5)

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.

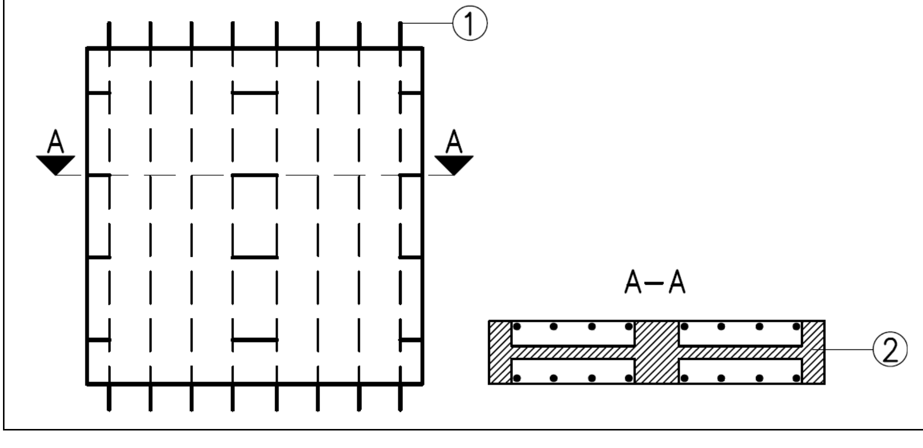
The concrete strength at a certain age shall be measured on at least 3 specimens. The mean value of the measurements governs.

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

D.3.3 Test members for tests in cracked concrete

The tests are carried out on test members with unidirectional cracks. The crack width shall be approximately constant throughout the member thickness. The thickness of the test member shall be $h \geq 2\ h_{ef}$ but at least 100 mm. To control cracking, so-called 'crack-formers' may be built into the member, provided they are not situated near the anchorage zone. An example for a test member is given in Figure D.11.

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



1 reinforcement

2 crack inducers

Figure D.11: Example of a test member for fasteners tested in cracked concrete

D.3.4 Test members for tests in uncracked concrete

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

D.3.5 Casting and curing of test members

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

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

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

D.4 Test setup (general)

D.4.1 Unconfined test setup

Unconfined tests allow an unrestricted formation of the rupture concrete cone. An example for an unconfined test setup is shown in Figure D.12.

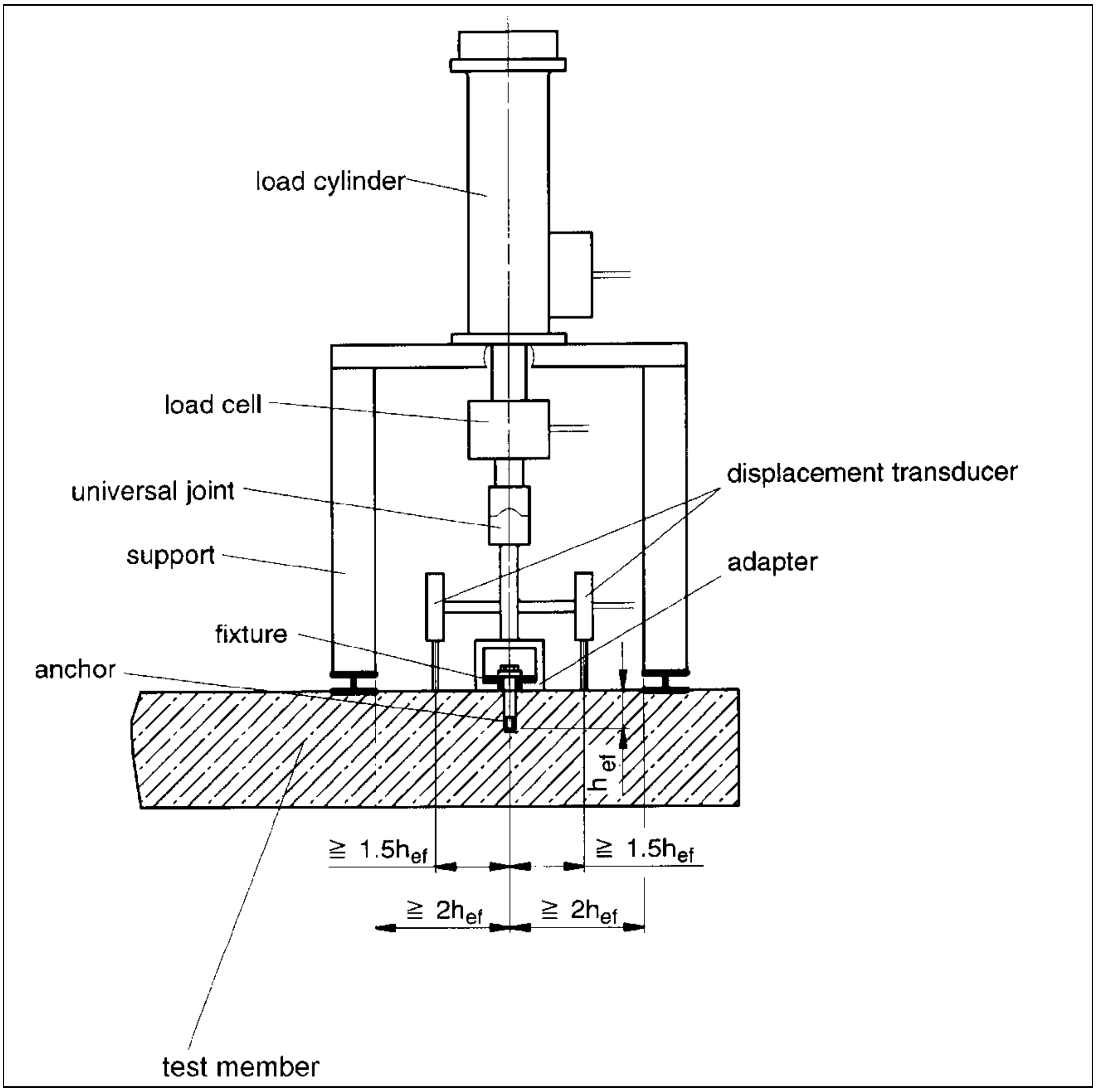


Figure D.12: Example of a tension test rig for unconfined tests

D.4.2 Confined test setup

Confined tests are performed when concrete cone failure shall be excluded (e.g. for bond resistance of bonded fasteners). In confined tests concrete cone failure is eliminated by transferring the reaction force close to the fastener into the concrete.

An example of the test setup is shown in Figure D.13. The rig / steel plate shall be stiff and the area of support large to avoid high compression of the concrete. Recommendation: compression strength under the steel plate < 0,7 of the concrete compression strength.

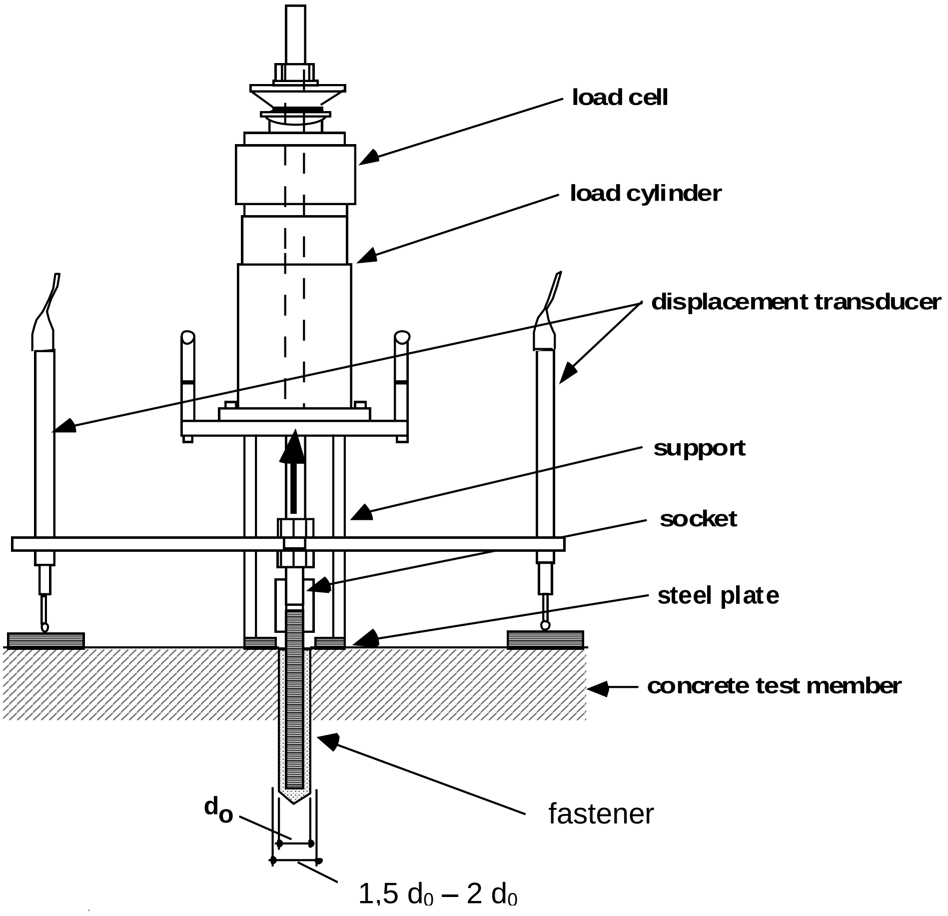


Figure D.13: Example of a tension test rig for confined tests

D.5 Details for the installation of the fastener

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

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).

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

The diameter of the cutting edges as a function of the nominal drill bit diameter is given in Figure D.14. 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 can 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.

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

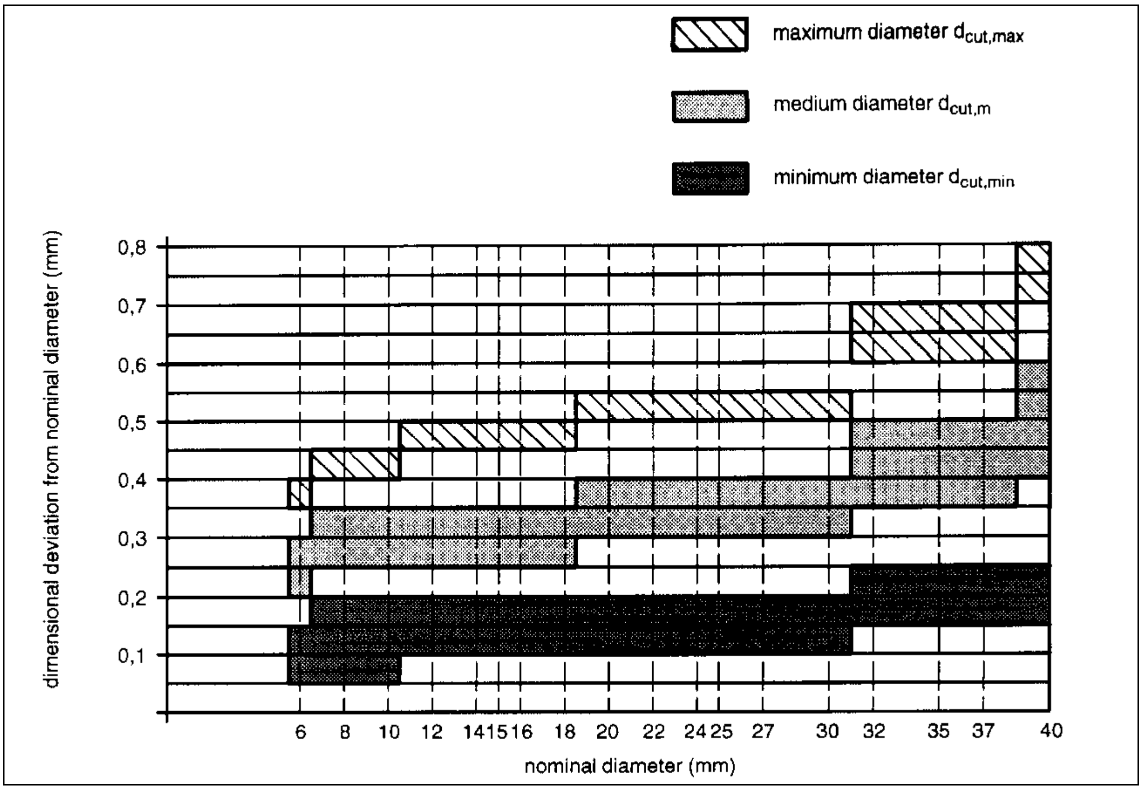


Figure D.14: Cutting diameter of hard metal hammer-drill bits

D.6 Details for tests in cracked concrete

The tests in cracked concrete are undertaken in unidirectional cracks. The required crack width Δw is given in Table A.1, Table B.1, Table C.1 or Table E1. Δw is the difference between the crack width when loading the fastener and the crack width at fastener installation. After installation of the fastener the crack is widened to the required crack width while the fastener is unloaded. The initial crack width shall be set to within +10 % of the specified value. However, the mean value of a series shall reflect the specified value.

Use one-sided tolerance for crack width.

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

- at a constant width, for example, by means of a servo system, or
- limited to a width close to the initial value by means of appropriate 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.

ANNEX E TEST METHOD C TO DETERMINE THE LINEARIZED CHARACTERISTIC FATIGUE RESISTANCE

E.1 Test program

The characteristic fatigue resistance function (test method C) shall be determined by testing performed in accordance with Table E.1. All tests are performed in concrete of strength class C20/25.

Table E.1:Test method C: Required tests under static and fatigue cyclic loading for bonded fastener

N°	Tests according to Sections	Crack width Δw [mm]	Load direction	Minimum number of tests	Fastener Size 3)	Mortar	Embedment depth h_{ef}	Remarks
	Tension							
FE.1	2.2.15 Reference tests for steel failure 6)	0	0°	5	all	all	≥8d	single fastener
FE.2	2.2.15 Fatigue tests for steel failure	0	0°	15	all	all	≥8d	single fastener
FE.3	2.2.15 Reference tests for steel failure 6)	0,3	0°	5	all	all	≥8d	single fastener
FE.4	2.2.15 Fatigue tests for steel failure	0,3	0°	15	all	all	≥8d	single fastener
FE.5	2.2.16 Reference tests for concrete failure 1)	0	0°	5	all	4)	min	group of 4 fasteners
FE.6	2.2.16 Fatigue tests for concrete failure 1)	0	0°	15	all	4)	min	group of 4 fasteners
FE.7	2.2.16 Reference tests for concrete failure 1)	0,3	0°	5	all	4)	min	group of 4 fasteners
FE.8	2.2.16 Fatigue tests for concrete failure 1)	0,3	0°	15	all	4)	min	group of 4 fasteners
FE.9	2.2.17 Reference tests for bond failure	0	0°	5	max	all	min	single fastener
FE.10	2.2.17 Fatigue tests for bond failure	0	0°	15	max	all	min	single fastener
FE.11	2.2.17 Reference tests for bond failure	0,3	0°	5	max	all	min	single fastener
FE.12	2.2.17 Fatigue tests for bond failure	0,3	0°	15	max	all	min	single fastener
	Shear							
FE.13	2.2.18 Reference tests for steel failure	0	90°	5	all	all	≥8d	single fastener
FE.14	2.2.18 Fatigue tests for steel failure	0	90°	15	all	all	≥8d	single fastener
FE.15	2.2.18 Reference tests for steel failure	0,3	90°	5	all	all	≥8d	single fastener
FE.16	2.2.18 Fatigue tests for steel failure	0,3	90°	15	all	all	≥8d	single fastener
FE.17	2.2.19 Reference tests for concrete edge failure 2)	0	90°	5	min5)	4)	min	group of 2 fasteners
FE.18	2.2.19 Fatigue tests for concrete edge failure 2)	0	90°	15	min5)	4)	min	group of 2 fasteners
FE.19	2.2.20 Reference tests for concrete pry-out failure 2)	0	90°	5	min5)	all	min	group of 2 fasteners
FE.20	2.2.20 Fatigue tests for concrete pry-out failure 2)	0	90°	15	min5)	all	min	group of 2 fasteners
	Combined tension and shear							
FE.21	2.2.21 Fatigue tests for steel failure	0	β	10	all	all	≥8d	single fastener
FE.22	2.2.21 Fatigue tests for steel failure	0,3	β	10	all	all	≥8d	single fastener

Table E.2: Test method C: Required tests under static and fatigue cyclic loading for torque controlled expansion fastener (bolt type with external thread)

N°	Tests according to Sections	Crack width Δw [mm]	Load direction	Minimum number of tests	Fastener Size [3]	Embedment depth h_{ef}	Remarks
	Tension						
FE.1	2.2.15 Reference tests for steel failure	0	0°	5	all	max	single fastener
FE.2	2.2.15 Fatigue tests for steel failure	0	0°	15	all	max	single fastener
FE.3	2.2.15 Reference tests for steel failure	0,3	0°	5	all	max	single fastener
FE.4	2.2.15 Fatigue tests for steel failure	0,3	0°	15	all	max	single fastener
FE.5	2.2.16 Reference tests for concrete failure [1]	0	0°	5	all	min	group of 4 fasteners
FE.6	2.2.16 Fatigue tests for concrete failure [1]	0	0°	15	all	min	group of 4 fasteners
FE.7	2.2.16 Reference tests for concrete failure [1]	0,3	0°	5	all	min	group of 4 fasteners
FE.8	2.2.16 Fatigue tests for concrete failure [1]	0,3	0°	15	all	min	group of 4 fasteners
FE.9	2.2.17 Reference tests for pull-out failure [1]	0	0°	5	all	min	single fastener
FE.10	2.2.17 Fatigue tests for pull-out failure [1]	0	0°	15	all	min	single fastener
FE.11	2.2.17 Reference tests for pull-out failure [1]	0,3	0°	5	all	min	single fastener
FE.12	2.2.17 Fatigue tests for pull-out failure [1]	0,3	0°	15	all	min	single fastener
	Shear						
FE.13	2.2.18 Reference tests for steel failure	0	90°	5	all	max	single fastener
FE.14	2.2.18 Fatigue tests for steel failure	0	90°	15	all	max	single fastener
FE.15	2.2.18 Reference tests for steel failure	0,3	90°	5	all	max	single fastener
FE.16	2.2.18 Fatigue tests for steel failure	0,3	90°	15	all	max	single fastener
FE.17	2.2.19 Reference tests for concrete edge failure [2]	0	90°	5	min[5]	min	group of 2 fasteners
FE.18	2.2.19 Fatigue tests for concrete edge failure [2]	0	90°	15	min[5]	min	group of 2 fasteners
FE.19	2.2.20 Reference tests for concrete pry-out failure [2]	0	90°	5	min[5]	min	group of 2 fasteners
FE.20	2.2.20 Fatigue tests for concrete pry-out failure [2]	0	90°	15	min[5]	min	group of 2 fasteners
	Combined tension and shear						
FE.21	2.2.21 Fatigue tests for steel failure	0	β	10	all	max	single fastener
FE.22	2.2.21 Fatigue tests for steel failure	0,3	β	10	all	max	single fastener

Footnotes to Table E.1 and E.2:

[1] No tests are required, if the reduction factor for characteristic fatigue resistance for concrete cone failure is calculated according to Equation (2.5).

[2] No tests are required, if the reduction factor for characteristic fatigue resistance for concrete edge failure is calculated according to Equation (2.11).

[3] Fastener size may be reduced if statistically equivalence is given

[4] Mortar with highest strength

[5] Minimum size without steel failure

[6] $F_{k,ref}$ may be calculated according to EAD 330499-01-0601 [2], Equation (2.1) by using the steel strength of threaded rods which are used in tests FE.2

The total number of tests of fasteners having a uniform cross section with variable embedment depths can be reduced, if the resulting fatigue resistance of the smallest embedment depth is applied to all other fastener embedment depths specified by the manufacturer.

If the fastener is intended to be used with different drilling methods as specified by the manufacturer, the tests summarized in Table E.1 shall be performed separately for each drilling method. The number of tests can be reduced if the results fit within the other tests.

If the fastener is produced in with different steel qualities as specified by the manufacturer, the tests summarized in Table E.1 shall be performed with the steel of lowest rupture elongation and strength. Otherwise the tests summarized in Table E.1 shall be performed for all steel qualities. The number of tests can be reduced if the results fit within the other tests.

Tests summarized in Table E.1 shall be performed for all coatings specified by the manufacturer. The number of tests can be reduced if the results fit within the other tests.

Distribution of the tests:

The test shall be performed in a way that the fatigue test fail between n = 10.000 and n = $1 \cdot 10^6$ load cycles for carbon steel and between n = 10.000 and n = $1 \cdot 10^7$ load cycles for stainless steel.

The fatigue tests must be distributed in a way that 6 to 8 tests shall fail between 10^4 and 10^5 load cycles, about 6 to 8 tests shall fail between 10^5 and $1 \cdot 10^6$ under tension load and between 10^5 and $5 \cdot 10^5$ under shear load. For stainless steel 2 tests shall fail between $2 \cdot 10^6$ and $1 \cdot 10^7$.

Reduction of the necessary test numbers of fatigue tests:

If the fatigue tests regarding steel failure for different sizes are statistical equivalent (based on the stress at the cross section) the number of tests for the other sizes can be reduced to 5. The results can be assessed using a joint evaluation with at least 20 tests in total. For the joint evaluation the assessment according to E.3.2 is done for the stress at the cross section $\Delta\sigma_k$ instead of ΔF_k.

If the test results in crack concrete are statistically equivalent with the test results in uncracked concrete the number of tests in cracked concrete can be reduced to 5.

If the test results for different tested mortars are statistically equivalent the tests can be performed with the most unfavourable mortar. For each mortar at least 5 tests shall be performed.

Minimum 20 tests in total shall be performed. For cracked and uncracked concrete minimum 5 tests for each size and mortar shall be performed.

Determine statistically equivalence:

The determination of statistically equivalence is performed using the quantiles-lines using and the 90% confidence levels. Statistically equivalence is sufficient if the results of different diameters and mortars or the results in cracked and uncracked concrete are within the range between the 5%-quantile-line and the 95%-quantile-line (prediction band) of the unfavourable or leading investigated size or mortar (largest amount of test results) in uncracked concrete.

The lowest 5%-quantile level shall be taken at the unfavourable condition with respect to size, mortar type or cracked and uncracked concrete. Therefore the scatter band of the test results shall be taken into account and the comparison of the different sizes, mortars or concrete state (cracked / uncracked) can be done using stresses instead of forces.

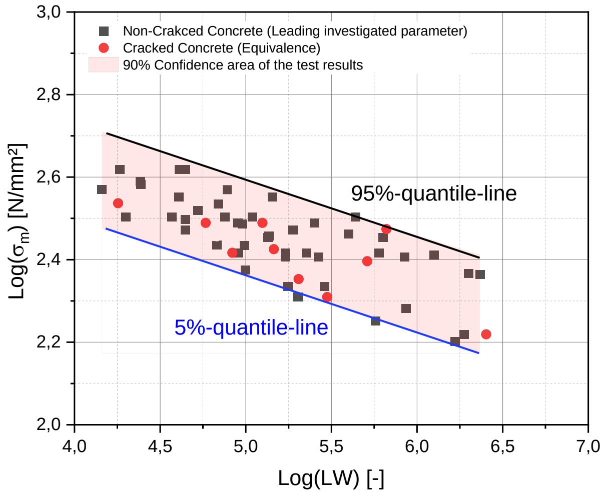
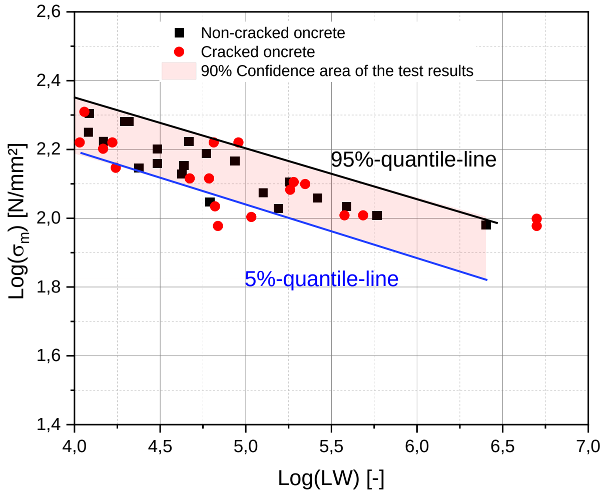
Statistically equivalence is given	
Statistically equivalence is not given	

Figure E.1: Example for statistically equivalence or no statistically equivalence

E.2 Basics

The force-controlled periodic loading with sinusoidal course is used as the most disadvantageous case (practical application) of the test specimen.

The repeated loads consist of a constant lower stress level and an upper stress level with same algebraic sign (no alternating actions) and are applied on the specimen until fatigue failure.

Tests which are stopped without failure shall not be included in the final evaluation.

Only tests failed after 10^6 load cycles (carbon steel) and after 10^7 (stainless steel) under tension and after 500.000 load cycles (carbon steel) and after 10^7 (stainless steel) under shear shall be taken into account if the regression curve is unfavourable under this assumption.

Tests failed before 10.000 load cycles under tension or shear load shall be taken into account if the regression curve is unfavourable under this assumption.

Method C comes up with a linearized function of the fatigue resistance depending on the number of load cycles.

The total function exists of 4 lines:

- The upper horizontal level is the characteristic fatigue resistance ΔF_k (n = $1 \cdot 10^4$)
- The first slope m_1 (up to n = $5 \cdot 10^6$) is determined as given in section E.3
- The second slope m_2 (between n = $5 \cdot 10^6$ and n = $1 \cdot 10^8$) is calculated as given in section E.3. The slope is reduced depending on the slope m_1.
- The lower horizontal level is the limit characteristic resistance $\Delta F_{k,\infty}$ ($n = \infty$)

The used capital letter F in this Annex shall be replaced by the letter N for tension loads, V for shear loads and F^{β} for combined tension and shear loads, σ for stress at the cross section, τ for bond strength at the effective embedment depth, respectively.

E.3 Procedure steps

E.3.1 Determination of the characteristic static resistance

The characteristic static resistance is determined according to A.3.1

$F_{k,ref} = S_k$

where: S_k according to Equation (A.1)

E.3.2 Determination of the characteristic fatigue resistance

The number of cycles to failure n for each range of force ΔF shall be determined through testing. The test results shall be used for the determination of the fatigue resistance function.

The characteristic fatigue resistance function is determined by statistical evaluation based on the 5%-quantile with a confidence level of 90%

The procedure is summarized as given:

1. Linear regression of the test data on log-log scale is performed employing the method of least squares. The regression line is given with Equation (E.3):

$$y_i = a_m + b_m \cdot x_i \qquad \text{(E.3)}$$

where:

y_i Variable of the regression curve as the logarithm applied fatigue load range for test result i

= $\log \Delta F_i$

x_i Variable of the regression curve as the number of observed load cycles for test result i

= $\log n_i$

a_m, b_m Regression parameter for the average function, see Equations (E.4) and (E.5)

n_i Number of cycles for test result i

ΔF_i Load range of fatigue resistance for test result i

The parameters a_m and b_m are obtained from the condition that the sum of the squares of residuals is minimum:

$$b_m = \frac{\sum x_i\, y_i - m \cdot (\sum \bar{x})\, (\sum \bar{y})}{\sum x_i^2 - m \cdot \sum(\bar{x})^2} \tag{E.4}$$

$$a_m = \bar{y} - b_m \cdot \bar{x} \tag{E.5}$$

where:

$a_m, b_m,\ x_i, y_i$	see Equation (E.3)
m	Number of test results
$\bar{y}$ and $\bar{x}$	Mean values of y_i and x_i respectively

2. The standard deviation is estimated as:

$$s = \sqrt{\frac{S_{yy} - b_m \cdot S_{xy}}{m - 2}} \tag{E.6}$$

where:

$$S_{yy} = \sum y_i^2 - \frac{1}{m} (\sum y_i)^2 \tag{E.7}$$

$$S_{xy} = \sum x_i\, y_i - \frac{1}{m} (\sum x_i \sum y_i) \tag{E.8}$$

x_i, y_i	see Equation (E.3)
b_m	Regression parameter for the average function, see Equation (E.4)
m	Number of test results

3. The lower confidence limit is evaluated using the 5%-quantile value of the regression line.

The characteristic fatigue resistance is calculated using the following equation:

$$log\,(\Delta F_{k,n}) = a_m + b_m \cdot log\,(n) - k \cdot s \tag{E.9}$$

where:

$\Delta F_{k,n}$	characteristic fatigue resistance for n load cycles
n	Number of load cycles
a_m, b_m	see Equation (E.4) and (E.5)
k	statistical factor for a confidence level of 90% and unknown standard deviation = $k_{n-u,p,1-\alpha}$ according to Table A.2 or [1]
s	standard deviation, see Equation (E.6)

If a test result is below the calculated characteristic regression curve the curve shall be shifted in a way that the curve runs through the lowest value.

4. The assessment of the characteristic resistance for fatigue loading is performed using a four-linear curve in the double logarithmic scale (see Figure E.2).

   4a. The characteristic fatigue resistances for n = 1·10⁴ to n = 5·10⁶ load cycles are derived from test results as follows:

$$\Delta F_{k.n} = 10^{\left(a + b \cdot \log(\mathrm{n})\right)} \tag{E.10}$$

where:

$$a = \left(\frac{k \cdot s - a_m}{b_m}\right) \tag{E.11}$$

$$b = \left(\frac{1}{b_m}\right) \tag{E.12}$$

$\Delta F_{k,n}$	characteristic fatigue resistance for n load cycles
n	Number of load cycles
a_m, b_m	see Equation (E.4) and (E.5)
k, s	see Equation (E.9)

   4b. For n = 5 · 10⁶ load cycles the characteristic resistance is calculated as following:

$$\Delta F_{k.5 \cdot 10^6} = 10^{\left(a + b \cdot \log\left(5 \cdot 10^6\right)\right)} \tag{E.13}$$

where

a, b = see Equation (E.11) and (E.12)

   4c. For n > 5·10⁶ load cycles the slope of the curve is reduced depending on the slope of the determined curve up to 5 million cycles. The slope is expressed as m_1 up to n = 5·10⁶ cycles and as m_2 for n > 5·10⁶ cycles.

   The characteristic fatigue resistances for n > 5·10⁶ load cycles and n < 1·10⁸ cycles is calculated as following:

$$\Delta F_{k.n} = 10^{\left(\log \Delta F_{k.5 \cdot 10^6} + \frac{\log(n) - 6.7}{m_2}\right)} \tag{E.14}$$

where:

$$m_2 = 2 \cdot m_1 - 1 = \frac{2}{b} - 1 \tag{E.15}$$

$$m_1 = \frac{1}{b} \tag{E.16}$$

b	see Equation (E.12)
$\Delta F_{k,n}$	characteristic fatigue resistance for n load cycles
n	Number of load cycles
m_1	slope up to 5·10⁶ load cycles
m_2	slope for more than 5·10⁶ load cycles and less than 10⁸ load cycles

   4d. For n > 1·10⁸ a horizontal line is applied using the value that was calculated for n = 1·10⁸.

   4e For n < 1·10⁴ a horizontal line is applied using the value that was calculated for n = 1·10⁴.

An example of the determination is given in following figure.

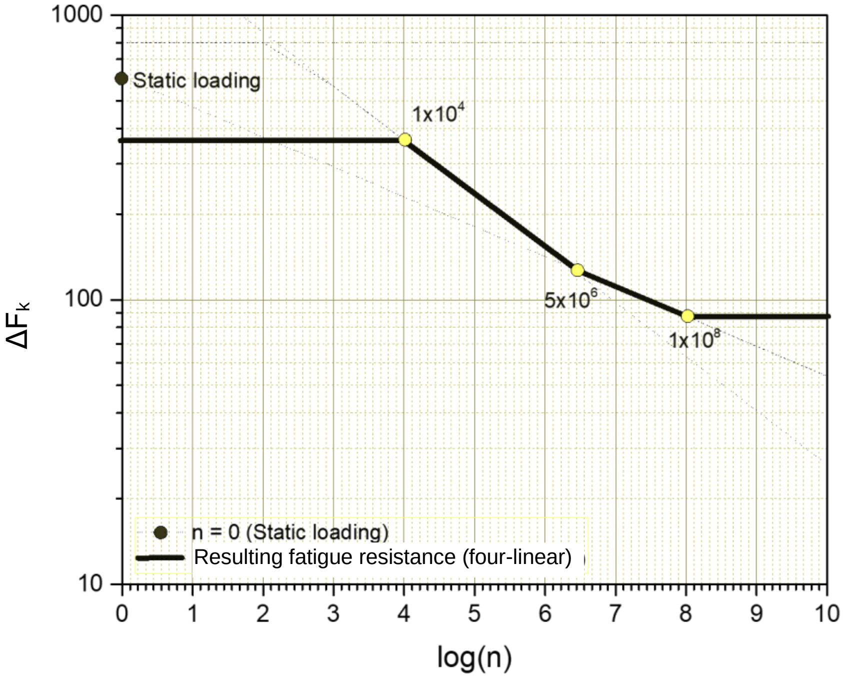


Figure E.2: Schematic four-linear fatigue resistance ΔF_k for log(n) number of cycles