EUROPEAN ASSESSMENT DOCUMENT

EAD 330008-03-0601

May 2018

ANCHOR CHANNELS

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 OF THE EAD

1.1 Description of the construction product

This European Assessment Document (EAD) covers the system of anchor channels and appropriate channel bolts made of carbon steel or stainless steel.

The construction product (anchor channel) consists of a channel profile with two lips produced of carbon steel or stainless steel and at least two metal anchors on the channel back as illustrated in Figure 1.1 to Figure 1.5. Typical cross sections of channels, types of connections between anchor and channel and anchor types are shown in Figure 2.7 to Figure 2.9. The anchors are made of carbon steel or stainless steel and are fastened on the anchor channel at the manufacturing plant only. As many anchors as desired are fastened to the anchor channel at constant distances. All anchors attached to the anchor channel are of the same type, size and embedment.

The product is described by: (see also Figure 1.1)

- Geometry of anchor channel.
- Moment of inertia I_y
- Dimensions and minimum and maximum spacing of anchors.
- Method of connecting anchors to channel.
- Geometry and type of channel bolts to be used in a certain channel size.
- Spacing of channel bolts.
- Effective embedment depth.
- Constituent materials and appropriate physical properties of anchors, channel and channel bolts including yield and tensile strength, hardness (if applicable), and coatings (if applicable).
- Protective coating of anchor channel or channel bolt (if applicable).

This EAD covers anchor channels with a smooth surface of the channel lips in combination with channel bolts with a smooth surface on the underside of the channel bolt head (see Figure 1.2a)) or notching channel bolts (see Figure 1.2b)) and anchor channels with serrated channel lips in combination with locking channel bolts with matching serrations on the channel bolt head (see Figure 1.2c)).

The materials for the anchor channels are listed in Table 1.2. If the anchor channel consists of components involving different materials, the different materials are noted.

This EAD covers anchor channels with a coefficient of variation of failure loads of 20% at maximum.

The minimum and/or maximum dimensions given in 1.1.1 to 1.1.3 are based on relevance in practice. All assessment methods are developed / adjusted according to these dimensions on experiences and tests. Other dimensions could cause other failure modes, other stiffnesses and other mechanical models which are not assessed according to this EAD.

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

The product is not fully covered by EAD 330008-02-0601. In comparison to EAD 330008-02-0601 the following has been added:

- Serrated channel profile, serrated channel bolt according to Figure 1.2c) and notching channel bolt according to Figure 1.2b),
- Assessment of characteristic resistance for longitudinal shear under static and quasi-static loading,
- Torque tests according to Table A.1, Line S5 on cast-in anchor channels,
- Shear tests according to Table A.1, Line S6 on anchor channels with three anchors,
- Characteristic shear resistance of channel bolt is corrected to $V_{Rk,s} = \alpha_s \cdot A_s \cdot f_{uk,}$
- Section 2.2.27 is completed with material.

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.

1.1.1 Channel profile

The channel profile consists of carbon steel or stainless steel. The channel profiles are made by a cold- or hot-forming manufacturing process.

The channel profile dimensions are given in Table 1.1. The maximum channel length is unlimited.

Table 1.1: Minimum and maximum dimensions of anchor channels covered by this EAD

Channel height h_{ch}	15 mm ≤ h_{ch} ≤ 51 mm
Channel width b_{ch}	25 mm ≤ b_{ch} ≤ 76 mm
Height of notch and serration (definition of difference between smooth channel bolt head and notching channel bolt head and definition of serration – see Figure 1.2)	≥ 0,7 mm

Channels with h_{ch}/h_{ef} > 0,4 and / or b_{ch}/h_{ef} > 0,7 included in this EAD are subject to tension loading only.

1.1.2 Anchors

The anchors are produced from carbon or stainless steel in accordance with Table 1.2. They are welded, bolted or forged to the channel back.

The axial distance between the end of the channel and the axis of the nearest anchor, x (see Figure 1.3), is ≥ 25 mm.

The axial spacing between anchors, s (see Figure 1.3), is at least 50 mm. The maximum spacing s is not larger than 5 c_{min} or 400 mm.

If more than two anchors are connected to the channel back, their spacing is constant.

Round headed anchors comply with the following dimensions (compare Figure 1.1b): length l_a ≥ 30 mm, shaft diameter d_a ≥ 5 mm and head diameter d_h ≥ 12 mm. The head is forged to the anchor or may consist of a nut, which is fixed non-detachably.

<u>Anchors, that are welded to the channel back</u>

The anchors consist of I-shaped or T-shaped profiles or round headed anchors. The welding is performed in a plant by an appropriate welding method (method according to EN ISO 4063[1] [8]).

I-shaped and T-shaped anchors comply with the following dimensions (compare Figure 1.1a): length l_a ≥ 30 mm, web thickness t_w ≥ 4 mm, width of anchor head b_h ≥ 14 mm and width (cutting length) 10 mm ≤ w_A ≤ 50 mm.

<u>Round headed anchors that are forged or bolted to the channel back</u>

The anchors are placed into holes in the back of the channel and connected rigidly.

1.1.3 Channel bolts (hammer-head and hook-head)

The geometry of the channel bolt head fits into the internal shape of the channel.

A marking at the end of the channel bolt shows the correct placement of the channel bolt.

Shape of shaft and thread follows EN ISO 4018 [9].

The indication of the strength class follows EN ISO 898-1 [10] and/or EN ISO 3506-1 [11].

The thread diameter is ≥ 6 mm (M6).

The minimum spacing of channel bolts is $s_{min,cbo}$ = 5 · d.

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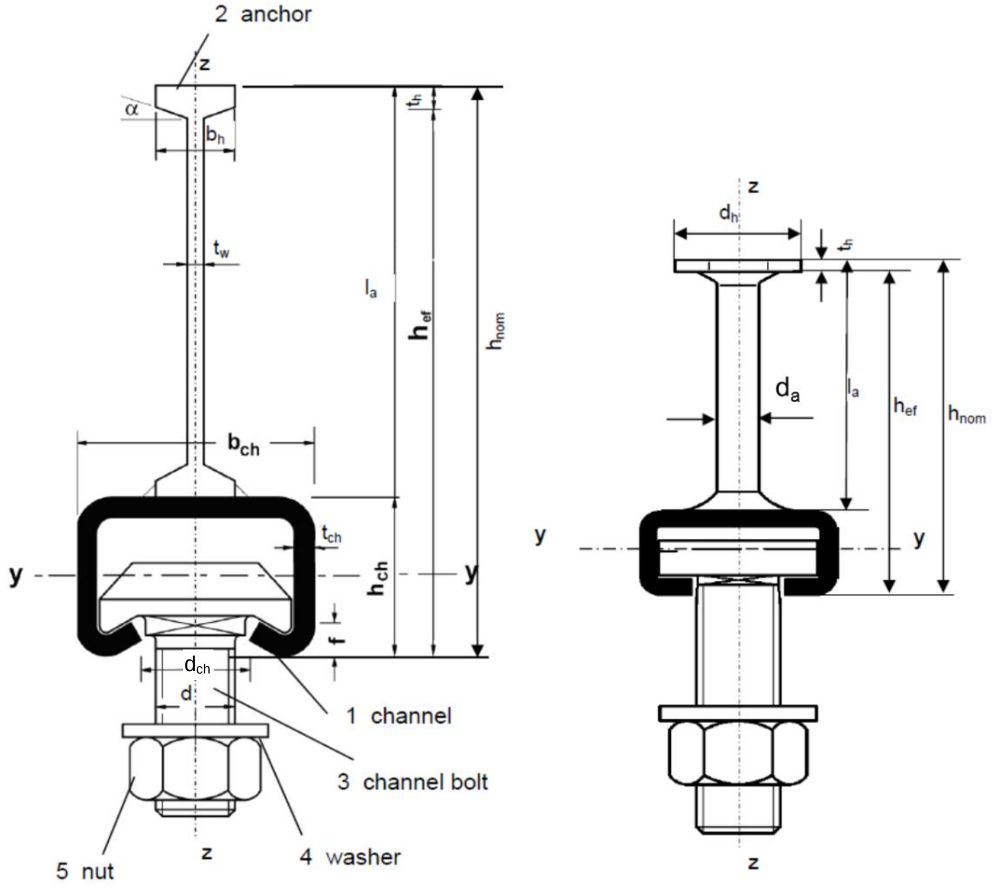
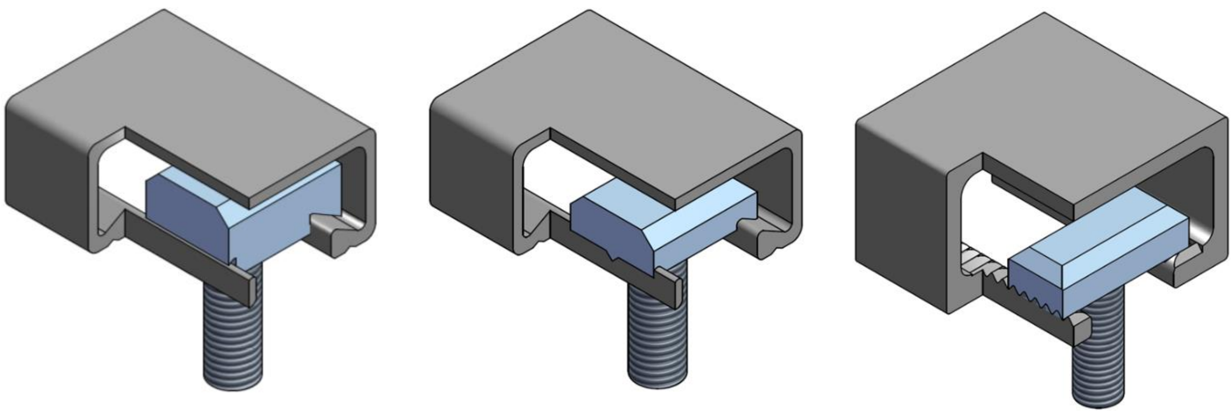
1 All undated references to standards or to EADs in this EAD are to be understood as references to the dated versions listed in clause 4.



a) anchor channel with I-anchor welded to the channel back

b) anchor channel with round anchor

Figure 1.1: Examples of anchor channels with different anchor types



a) anchor channel with smooth surface of the channel lips in combination with a smooth surface on the underside of the channel bolt head

b) anchor channel with smooth surface of the channel lips in combination with a notching channel bolt

c) anchor channel with serrated channel lips in combination with locking channel bolts with matching serrations on the channel bolt head

Figure 1.2:
Examples of anchor channels with different channel profiles and different channel bolt types

Table 1.2: Designations and materials

Part	Designation	Material
1	Channel	Steel according to EN 10025 [6]
		Steel according to EN 10149 [18]
		Steel according to EN 10277-2 [25]
		Stainless steel according to EN 10088 [7]
2	I-Anchor	Steel according to EN 10025 [6]
		Stainless steel according to EN 10088 [7]
	Round anchor	Steel according to EN 10263 [15]
		Steel according to EN 10269 [19]
		Steel according to EN 10277-2 [25]
		Stainless steel according to EN 10088 [7]
		Shaft and thread form following EN ISO 4018 [9]
3	Channel bolt	Carbon steel, 4.6 ≤ strength class ≤ 8.8 according to EN ISO 898-1 [10]
		Stainless steel, 50 ≤ strength class ≤ 70 following EN ISO 3506-1 [11]
		Steel, hardness class ≥ 200 HV according to EN ISO 7089 [20], EN ISO 7090 [26] and EN ISO 7091 [27]
4	Washer	Stainless steel, hardness class ≥ 200 HV according to EN ISO 7089 [20], EN ISO 7090 [26] and EN ISO 7091 [27]
		Steel, strength class 5, 6 or 8, according to EN ISO 898-2 [10]
5	Nut EN ISO 4032 [16] and EN ISO 4034 [17]	Stainless steel, strength class 50 or 70 according to EN ISO 3506-2 [11]

1.2 Information on the intended use of the construction product

1.2.1 Intended use

This EAD covers anchor channels installed in members made of compacted reinforced or unreinforced normal weight concrete of strength classes in the range C12/15 to C90/105 all in accordance with EN 206-1 [12].

For fire resistance this EAD covers anchor channels installed in members made of compacted reinforced normal weight concrete of strength classes in the range C20/25 to C50/60 used for normal structures under fire exposure. This base material, in which the anchor channel shall be anchored, shall have at least the same duration of fire resistance as the anchor channel itself.

Local spalling is possible at fire attack. To avoid any influence of the spalling on the anchorage, the anchor channels are intended to be used only for cases where

- the concrete member is designed according to EN 1992-1-2 [5], and
- where the members are made of concrete with quartzite additives and are protected from direct moisture, or where the moisture content of the concrete is like in dry internal conditions, respectively, and
- where the embedment depth is increased for wet concrete by at least 30 mm compared to the value given in the European Technical Assessment.

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

The anchor channel is intended to be embedded surface-flush in the concrete as illustrated in Figure 1.3.

The anchor channels are intended to be secured at their position during installation such that no movement of the channels will occur during the time of laying the reinforcement and placing and compacting the concrete.

The anchor channels are intended to be used only in concrete which has properly been compacted especially in the region of the anchor channel and under the head of the anchors. The channels are intended to be protected from penetration of concrete into the internal space of the channels.

The anchor channel is intended to be cast in only once.

A fixture is connected to the anchor channel by channel bolts (hammer head or hook head channel bolts) with appropriate hexagon nuts and washers in accordance with Figure 1.3 and Figure 1.4.

The anchor channels are intended to be used with notching channel bolts which are connected to the anchor channel only once. Those channel bolt (marking according to relevant ETA) are oriented perpendicular to the longitudinal channel axis.

For all types of anchor channels the installation torque moment is applied using a calibrated torque wrench with a measuring error of ± 5% of the maximum applied torque moment.

The fixture is in contact with the concrete surface as shown in Figure 1.4a) or is not in contact with the concrete surface (steel-steel contact with no bending of the channel lips during installation) as shown in Figure 1.4b).

In applications according to Figure 1.4a) (fixture in contact with concrete) a clamping force between concrete and fixture is generated by tightening the channel bolt with the installation torque.

In addition, applications according to Figure 1.4b) are possible. In these applications it is assumed that only a clamping force between channel profile and fixture is generated by tightening the channel bolt with the installation torque, because of the direct contact between fixture and channel lips. To ensure the correctness of these assumptions the gap between fixture and concrete surface after installation of the anchor channel and pre-stressing of the channel bolt is sufficiently large taking into account a possible unevenness of the concrete surface. The required gap between fixture and concrete surface is ensured by placing suitable steel parts (e.g. sufficiently large washers) between channel lips and fixture.

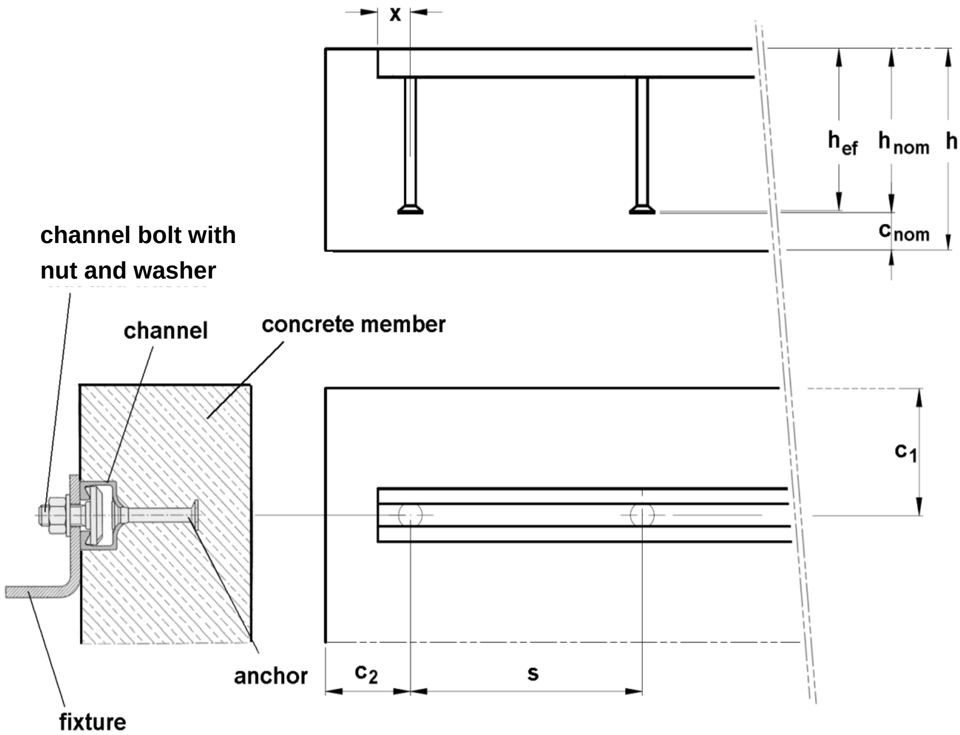
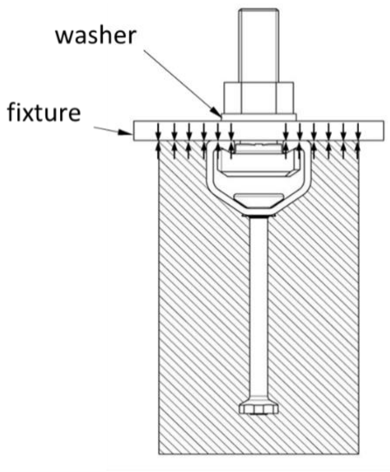
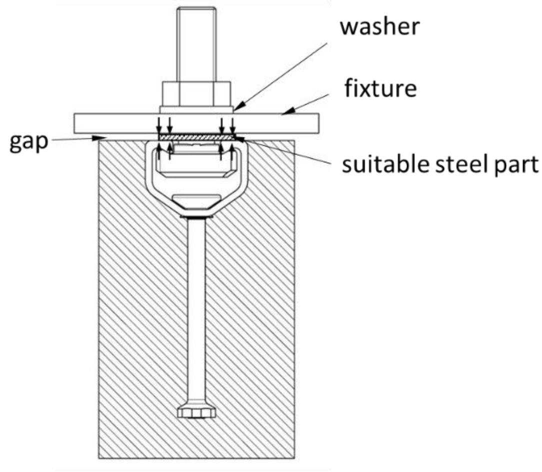


Figure 1.3: Example of an anchor channel embedded in a concrete member



a) General: The fixture is in contact with the channel profile and the concrete surface by tightening with $T_{inst,g}$



b) Steel-to-steel contact: The fixture is not in contact with the concrete surface. The fixture is fastened to the anchor channel by suitable steel part (e.g. washer) by tightening with $T_{inst,s}$ ($T_{inst,s} \geq T_{inst,g}$)

Figure 1.4: Anchor channel embedded in concrete

The distance between two or more anchor channels is such that no spacing between two anchors of neighbouring anchor channels is less than $s_{cr,N}$ (see EN 1992-4 [3], 7.4.1.5).

The anchor channel is anchored in concrete by mechanical interlock between the anchor and the concrete member.

The anchor channel is intended to be used under static or quasi-static loads. The anchor channel is used to transmit tension loads, shear loads perpendicular to the longitudinal channel axis, shear loads acting in the direction of the longitudinal channel axis (only for single-piece channel bolts), or any combination of these loads in accordance with Figure 1.5 into the concrete. Shear loads along the longitudinal axis of the anchor channel are transferred by a positive load transfer mechanism (e.g. mechanical interlock between the channel bolt and the channel profile by notching channel bolts (example see Figure 1.2 b) or by matching serrations between the channel lips and channel bolt (example see Figure 1.2 c)). The shear load is applied without or with lever arm in respect to the concrete surface. Shear loads along the longitudinal axis are only for single- piece channel bolts.

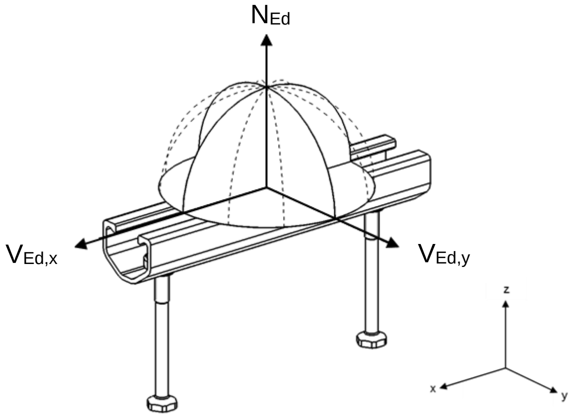
Channels with h_{ch}/h_{ef} > 0,4 and / or b_{ch}/h_{ef} > 0,7 are subject to tension loading only.

The anchor channel is intended to be used also under fatigue loads in combination with or without static or quasi-static loads. The anchor channel is intended to be used to transmit only fatigue tension loads in accordance with Figure 1.5 into the concrete. No static or quasi-static shear or fatigue shear load is intended to be applied in concomitance with a fatigue tension load.

The characteristic fatigue resistances of anchor channels can be given as a continuous function of the fatigue resistance, as a tri-linear function of the fatigue resistance or as a value of the characteristic fatigue limit resistance.

Loads with an arbitrary distance are applied at any position within the outermost anchors of the anchor channel.

Any fixture is fixed to the anchor channel using a channel bolt.



tension load:
z-direction (in direction of anchor)

shear load:
y-direction (perpendicular to longitudinal axis of channel)

shear load:
x-direction (in longitudinal channel axis)

Figure 1.5: Load directions: tension load, shear load and any combinations of these

In this EAD the assessment is made to determine characteristic values of the anchor channel for design according to:

- EN 1992-4 [3] or
- TR 047: Technical Report "Design of Anchor Channels" [4],

and for fatigue loads in combination with

- TR 050: Technical Report "Calculation Method for the Performance of Anchor Channels under fatigue loads" [28]

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 anchor channel for the intended use of 50 years when installed in the works (provided that the anchor channel 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.

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

1.3 Specific terms used in this EAD

The definitions and symbols used in this EAD are given in EN 1992-4 [3] and Technical Report TR 047 "Design of Anchor Channels" [4] and below.

T_{crack}	=	torque moment, at which a hairline crack (crack with a width < 0,1 mm) is observed at least at one anchor		[Nm]
$A_{s,a}$	=	stressed cross section of anchor		[mm^2]
$A_{s,cbo}$	=	stressed cross section of channel bolt		[mm^2]
b_{ch}	=	channel width		[mm]
$b_{cbo,2}$	=	length of head of channel bolt	Fig. 2.5	[mm]
b_h	=	width of the head of the I-anchor	Fig. 1.1	[mm]
c_{nom}	=	concrete cover	Fig. 1.3	[mm]
c_1, c_2	=	edge distances of the anchor	Fig. 1.3	[mm]
c'_1	=	net distance between edge of the concrete member and the anchor channel = c_1 - 0,5b_{ch}		[mm]
d	=	diameter of channel bolt	Fig. 1.1	[mm]
d_a	=	diameter of round anchor		[mm]
d_{ch}	=	width of channel opening		[mm]
d_f	=	diameter of clearance hole in the fixture		[mm]
d_h	=	diameter of round anchor head		[mm]
f	=	height of channel lips		[mm]
f_c	=	concrete compression strength measured on cylinders		[N/mm^2]
f_{ck}	=	characteristic concrete compression strength measured on cylinders		[N/mm^2]
$f_{c,test}$	=	mean concrete compression strength at time of testing		[N/mm^2]
f_{uk}	=	nominal characteristic steel ultimate tensile strength		[N/mm^2]
f_{yk}	=	nominal characteristic steel yield strength		[N/mm^2]
h	=	thickness of concrete member	Fig. 1.3	[mm]
h_{ch}	=	channel height		[mm]
$h_{ef,min}$	=	minimum effective embedment depth		[mm]
h_{nom}	=	distance between concrete surface and end of embedded anchor		[mm]
s	=	spacing of anchors	Fig. 1.3	[mm]
t_h	=	thickness of anchor head		[mm]
t_w	=	web thickness of I-anchor		[mm]
w_A	=	width (cutting length) of I-anchor		[mm]
x	=	end spacing (distance between end of channel and axis of nearest anchor)	Fig. 1.3	[mm]
$c_{cr,N}$	=	characteristic edge distance for ensuring the transmission of the characteristic resistance of a single fastener under tension load		[mm]
$s_{cr,N}$	=	characteristic spacing for ensuring the transmission of the characteristic resistance of a single fastener under tension load (2 $_{cr,N}$)		[mm]
$c_{cr,sp}$	=	characteristic edge distance in case of splitting under load		[mm]
$s_{cr,sp}$	=	characteristic spacing in case of splitting under load (2$c_{cr,sp}$)		[mm]
s_{max}	=	maximum spacing between anchors		[mm]
s_{min}	=	minimum spacing between anchors		[mm]

$s_{min,cbo}$	=	minimum spacing between channel bolts	[mm]
c_{min}	=	minimum edge distance	[mm]
a	=	axis intercept of regression line MV [1]	[-]
a	=	positive dimensionless number for the S/N-curve	[-]
a_k	=	axis intercept of 5%-quantile limit [1]	[-]
$a_{k,red}$	=	axis intercept of reduced 5%-quantile limit [1]	[-]
a_s	=	axis intercept of displacement regression line for one area	[mm]
a_x	=	axis intercept of regression line 2 [1]	[-]
a_y	=	axis intercept of regression line 1 [1]	[-]
b	=	slope of regression line MV [1]	[-]
b	=	positive dimensionless number for the S/N-curve	[-]
b_k	=	slope of 5%-quantile limit [1]	[-]
b_s	=	slope of displacement regression line for one area	[mm]
b_x	=	slope of regression line 2 [1]	[-]
b_y	=	slope of regression line 1 [1]	[-]
e_i	=	residuum [1]	[-]
$k_{h,p,1-\alpha}$	=	statistical tolerance factor; h: total number of fatigue cyclic test results; p: 5%-quantile (p = 0.05); 1 - α: level of confidence of 90% (1 - α = 0.9) (see [22], Table D.3)	[-]
$k_{n,p,1-\alpha}$	=	statistical tolerance factor; n: number of static test results; p: 5%-quantile (p = 0.05); 1 - α: level of confidence of 90% (1 - α = 0.9) (see [22], Table D.3)	[-]
$k_{r,p,1-\alpha}$	=	statistical tolerance factor; r: number of fatigue cyclic test results in finite life fatigue area; p: 5%-quantile (p = 0.05); 1 - α: level of confidence of 90% (1 - α = 0.9) (see [22], Table D.3)	[-]
l	=	attempt with highest load range belonging to fatigue life area	[-]
m	=	attempt with lowest load range belonging to fatigue life area	[-]
h	=	first run-out attempt (test method A2)	[-]
h	=	total number of fatigue cyclic test results (test method A1)	[-]

[1] *value using logarithmic scaling for abscissa (number of cycles n) and ordinate (range of force ΔS)*

n	=	number of cycles	[-]
n_i	=	number of cycles of the cross section for every step i	[-]
n_I	=	number of cycles in cross section n_I	[-]
n_{II}	=	number of cycles in cross section n_{II}	[-]
n_D	=	number of cycles, transition from finite fatigue life to fatigue limit resistance	[-]
$\dot{n}$	=	number of cycles in centroid of test result scatter for one area, regarding the upper limit S_{oi} of a sinusoidal load process	[-]
$\dot{n}_A$	=	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	[-]
$n_{lim,a}$	=	limit number of cycles for test method A2	[-]
$n_{lim,u}$	=	lower limit of the limit number of cycles n_{lim} interval	[-]
$\bar{n}_r$	=	average number of cycles from reference attempts	[-]
$n_{RT,min}$	=	minimum number of cycles for run-out test	[-]
r	=	number of fatigue cyclic test results in finite life fatigue area	[-]
$\hat{s}$	=	standard deviation of static test results	[N]
$\hat{\hat{s}}$	=	average standard deviation	[N]
$\hat{\hat{s}}^2$	=	average variance	[-]
$\hat{\hat{s}}_A$	=	average standard deviation of area A	[N]
$\hat{\hat{s}}_B$	=	average standard deviation of area B	[N]
$\hat{\hat{s}}_C$	=	average standard deviation of area C	[N]
$\hat{\hat{s}}_j$	=	average standard deviation for each three results	[N]
$\hat{\hat{s}}_j^2$	=	average variance for each three results	[-]
$\hat{s}_I$	=	standard deviation in the cross sections n_I	[N]
$\hat{s}_{II}$	=	standard deviation in the cross sections n_{II}	[N]
$\dot{s}_o$	=	displacement in centroid of test result scatter for one area, regarding the upper limit S_{oi} of a sinusoidal load process	[mm]
$s_{o,i}$	=	displacement of the cross section, regarding the upper limit S_{oi} of a sinusoidal load process, for every step i	[mm]
$\overline{S}$	=	mean value of static test results	[N]
S_d	=	design value of static resistance	[N]
S_k	=	characteristic static resistance	[N]
S_{oi}	=	upper level of the sinusoidal course	[N]
$\hat{s}_r$	=	average standard deviation from reference attempts	[N]
S_u	=	lower level of the sinusoidal course	[N]

x	=	x-value of experimental pair of values [2]	[-]
$\dot{x}$	=	x-value of the centroid of test result scatter [2]	[-]
x_I	=	number of cycles in cross section n_I [2]	[-]
x_{II}	=	number of cycles in cross section n_{II} [2]	[-]
x_D	=	number of cycles, transition from finite fatigue life to fatigue limit resistance [2]	[-]
y	=	y-value of experimental pair of values [2]	[-]
$\dot{y}$	=	y-value of the centroid of test result scatter [2]	[-]
$y_{I,95\%}$	=	95%-quantile (load range) in cross section n_I [2]	[-]
$y_{II,95\%}$	=	95%-quantile (load range) in cross section n_{II} [2]	[-]
$y_{I,k}$	=	5%-quantile (load range) in cross section n_I [2]	[-]
$y_{II,k}$	=	5%-quantile (load range) in cross section n_{II} [2]	[-]
$y_{I,k,red}$	=	reduced 5%-quantile (load range) in cross section n_I [2]	[-]
y_D	=	characteristic fatigue limit resistance [2]	[-]
γ_M	=	material safety factor for static resistance	[-]
$\gamma_{M,fat}$	=	material safety factor for fatigue resistance	[-]
$\gamma_{M,fat,n}$	=	material safety factor for fatigue resistance in the transition area from the static resistance to the fatigue limit resistance	[-]
Δ_S	=	distance between the load levels	[N]
ΔS	=	mean load range for fatigue resistance	[N]
$\Delta\overline{S}$	=	load range of average regression line	[N]
$\Delta\dot{S}$	=	load range of the centroid of test result scatter	[N]
ΔS_a	=	load level of attempt a for quality control	[N]
$\Delta\bar{\dot{S}}_A$	=	mean value of area A	[N]
$\Delta\dot{S}_{A,5\%}$	=	5%-quantile of area A	[N]
ΔS_b	=	load level of attempt b for quality control	[N]
$\Delta\bar{\dot{S}}_B$	=	mean value of area B	[N]
$\Delta\dot{S}_{B,5\%}$	=	5%-quantile of area B	[N]
ΔS_c	=	load level of attempt c for quality control	[N]
$\Delta\bar{\dot{S}}_C$	=	mean value of area C	[N]
$\Delta\dot{S}_{C,5\%}$	=	5%-quantile of area C	[N]

[2] *logarithmic value*

$\Delta\bar{S}_I$	=	load range of average regression line in cross section n_I	[N]
$\Delta\bar{S}_{II}$	=	load range of average regression line in cross section n_{II}	[N]
$\Delta\bar{S}_D$	=	mean load range of fatigue limit resistance	[N]
ΔS_{fail}	=	failed or damaged specimen with lowest load range	[N]
$\Delta\bar{\dot{S}}_j$	=	mean value of the cross section for every step j	[N]
$\Delta\dot{S}_{j,5\%}$	=	5%-quantile in cross section n_j	[N]
$\Delta S_{I,5\%}$	=	load range of 5%-quantile in cross section n_I	[N]
$\Delta S_{II,5\%}$	=	load range of 5%-quantile in cross section n_{II}	[N]
$\Delta S_{I,95\%}$	=	load range of 95%-quantile in cross section n_I	[N]
$\Delta S_{I,95\%}$	=	load range of 95%-quantile in cross section n_{II}	[N]
$\Delta S_{I,d}$	=	design value in cross section n_I	[N]
$\Delta S_{I,k}$	=	characteristic fatigue resistance in cross section n_I	[N]
$\Delta S_{II,k}$	=	characteristic fatigue resistance in cross section n_{II}	[N]
$\Delta S_{I,k,red}$	=	reduced characteristic fatigue resistance in cross section n_I	[N]
$\Delta S_{D,d}$	=	design value of fatigue limit resistance	[N]
$\Delta S_{D,k}$	=	characteristic fatigue limit resistance	[N]
$\Delta S_D^{\approx}$	=	estimated value of the fatigue limit resistance	[N]
ΔS_i	=	load level of the cross section for every step i	[N]
$\Delta\bar{S}_i$	=	mean value of the cross section for every step i	[N]
ΔS_{RT}	=	load level for run-out test	[N]
$\Delta\Delta S_i$	=	residual of the cross section for every step i	[N]
η_A	=	reduction factor for mean load range of fatigue limit resistance	[-]
η_I	=	factor for determination of v_I	[-]
η_{II}	=	factor for determination of v_{II}	[-]
$\eta_{I,b}$	=	multiplier for determination of v_I	[-]
$\eta_{II,b}$	=	multiplier for determination of v_{II}	[-]
$\eta_{I,red}$	=	reduction factor for 5%-quantile in cross section n_I	[-]
$\eta_{I,\dot{v}}$	=	multiplicand for determination of v_I	[-]
$\eta_{II,\dot{v}}$	=	multiplicand for determination of v_{II}	[-]
$\dot{v}$	=	average coefficient of variation	[%]
v_I	=	coefficient of variation in cross section n_I	[%]
v_{II}	=	coefficient of variation in cross section n_{II}	[%]

2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

2.1 Essential characteristics of the product

Table 2.1 shows how the performance of the anchor channel is assessed in relation to the essential characteristics.

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

No	Essential characteristic	Assessment method	Expression of product performance
	Basic Works Requirement 1: Mechanical resistance and stability		
Characteristic resistance under static and quasi-static tension loading			
1	Resistance to steel failure of anchors	2.2.1	Level $N_{Rk,s,a}$
2	Resistance to steel failure of the connection between anchors and channel	2.2.2	Level $N_{Rk,s,c}$
3	Resistance to steel failure of channel lips and subsequently pull-out of channel bolt	2.2.3	Level $N^0_{Rk,s,l}$; $s_{l,N}$
4	Resistance to steel failure of channel bolt	2.2.4	Level $N_{Rk,s}$
5	Resistance to steel failure by exceeding the bending strength of the channel	2.2.5	Level $M_{Rk,s,flex}$; s_{max}
6	Maximum installation torque moment to avoid damage during installation	2.2.6	Level $T_{inst,g}$; $(T_{inst,s})$
7	Resistance to pull-out failure of the anchor	2.2.7	Level $N_{Rk,p}$
8	Resistance to concrete cone failure	2.2.8	Level $k_{cr,N}$; $k_{ucr,N}$; h_{ef}
9	Minimum edge distances, spacing and member thickness to avoid concrete splitting during installation	2.2.9	Level s_{min}; c_{min}; h_{min}
10	Characteristic edge distance and spacing to avoid splitting of concrete under load	2.2.10	Level $s_{cr,sp}$; $c_{cr,sp}$
11	Resistance to blowout failure - bearing area of anchor head	2.2.11	Level A_h
Characteristic resistance under static and quasi-static shear loading			
12	Resistance to steel failure of channel bolt under shear loading without lever arm	2.2.12	Level $V_{Rk,s}$
13	Resistance to steel failure by bending of the channel bolt under shear load with lever arm	2.2.13	Level $M^0_{Rk,s}$
14	Resistance to steel failure of channel lips, steel failure of connection between anchor and channel or steel failure of anchor (shear load in transverse direction)	2.2.14	Level $V^0_{Rk,s,l,y}$; $s_{l,V}$; $V_{Rk,s,c,y}$; $V_{Rk,s,a,y}$
15	Resistance to steel failure of connection between channel lips and channel bolt (shear load in longitudinal channel axis)	2.2.15	Level $V_{Rk,s,l,x}$

No	Essential characteristic	Assessment method	Expression of product performance
16	Factor for sensitivity to installation	2.2.16	Level γ_{inst}
17	Resistance to steel failure of the anchor	2.2.17	Level $V_{Rk,s,a,x}$
18	Resistance to steel failure of connection between anchor and channel	2.2.18	Level $V_{Rk,s,c,x}$
19	Resistance to concrete pry-out failure	2.2.19	Level k_8
20	Resistance to concrete edge failure	2.2.20	Level $k_{cr,V}$; $k_{ucr,V}$
Characteristic resistance under combined static and quasi-static tension and shear loading			
21	Resistance to steel failure of the anchor channel	2.2.21	Level k_{13}; k_{14}
Characteristic resistance under fatigue tension loading			
22	Fatigue resistance to steel failure of the whole system (continuous or tri-linear function)	2.2.22 or	Level $\Delta N_{Rk,s,0,n}$ (n = 1 to n = ∞)
23	Fatigue limit resistance to steel failure of the whole system	2.2.23	Level $\Delta N_{Rk,s,0,\infty}$
24	Fatigue resistance to concrete related failure (exponential function)	2.2.24 or	Level $\Delta N_{Rk,c,0,n}$ $\Delta N_{Rk,p,0,n}$ (n = 1 to n = ∞)
25	Fatigue limit resistance to concrete related failure	2.2.25	Level $\Delta N_{Rk,c,0,\infty}$ $\Delta N_{Rk,p,0,\infty}$
26	Displacements	2.2.26	Level δ_{N0}, $\delta_{N\infty}$, $\delta_{V,y,0}$, $\delta_{V,y,\infty}$, $\delta_{V,x,0}$, $\delta_{V,x,\infty}$
Basic Works Requirement 2: Safety in case of fire			
27	Reaction to fire	2.2.28	Class
28	Resistance to fire	2.2.29	Level $N_{Rk,s,fi}$; $V_{Rk,s,fi}$
Aspects of durability			
29	Durability	2.2.27	Description

For the determination of the characteristic fatigue resistances of anchor channels, one of the following test methods can be chosen:

- Test method A1, which corresponds to the so-called Interactive Method and is meant to provide a continuous function of the fatigue resistance, is described in Annex C.
- Test method A2, which is meant to provide a tri-linear function of the fatigue resistance, is described in Annex D.
- Test method B (simple), which only provides the value of the characteristic fatigue limit resistance, is described in Annex E.

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

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

2.2.1 Characteristic resistance to steel failure of anchors under static and quasi-static tension loading

The characteristic resistance $N_{Rk,s,a}$ of an anchor shall be determined according to Equation (2.1).

$N_{Rk,s,a}$	=	$A_{s,a} \cdot f_{uk}$	[N]	(2.1)
$A_{s,a}$	=	stressed cross section of anchor	[mm²]	
f_{uk}	=	nominal characteristic steel ultimate tensile strength of anchor	[N/mm²]	

2.2.2 Characteristic resistance to steel failure of the connection between anchor and channel under static and quasi-static tension loading

For connections with fillet welds the characteristic resistance $N_{Rk,s,c}$ is determined according to EN 1993-1-8, Chapter 4.5.3 [21] as follows, if all provisions for fillet welds according to EN 1993-1-8, Chapter 4 [21] are fulfilled:

$N_{Rk,s,c}$	=	$\min\left(f_u \cdot \frac{A_w}{\beta_w}\ ;\ 0{,}9\, f_u \cdot A_w\right)$	[N]	(2.2a)
f_u	=	Nominal ultimate tensile strength of the weaker part joined	[N]	
A_w	=	Design throat area according to [21], Chapter 4.5.3.2	[mm²]	
β_w	=	appropriate correlation factor taken from [21], Table 4.1	[-]	

For other connections and if the characteristic resistance $N_{Rk,s,c}$ cannot be determined according to EN 1993-1-8, Chapter 4.5.3 [21] tests according to Table A.1, line S1 shall be performed to determine the characteristic resistance for failure of the connection between channel and anchor. All anchor channel sizes with all anchor types specified by the manufacturer and all materials shall be tested.

Test conditions:

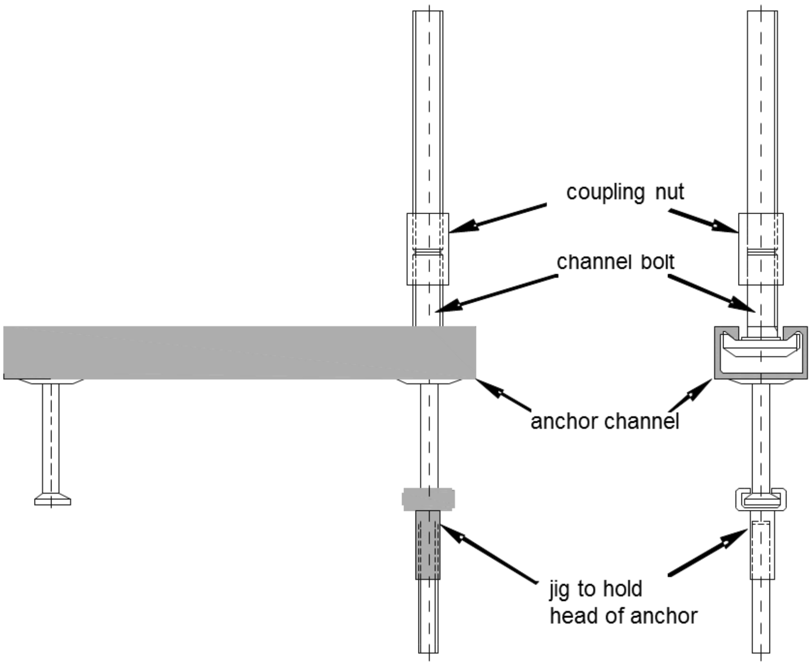
The tests shall be carried out on anchor channels not cast into concrete with the load applied through a channel bolt aligned with an anchor. The edge distance from the end of the anchor channel to the tested anchor shall be x_{min} on one side. The largest channel bolt with the maximum strength specified for the tested anchor channel may be used to avoid failure of the channel bolt. A typical test setup is shown in Figure 2.1.

In case of anchor channels with a smooth surface of the channel lips in combination with channel bolts with a smooth surface on the underside of the channel bolt head and anchor channels with serrated lips in combination with locking channel bolts with matching serrations on the cannel bolt head, the tests may be performed with or without fixture.

In case of anchor channels with a smooth surface of the channel lips in combination with notching channel bolts, the tests shall be performed with fixture.

If a fixture is used, the pretension shall be applied in accordance to Section A.2.

If the test is performed with anchor channels with a smooth surface of the channel lips in combination with channel bolts with a smooth surface on the underside of the channel bolt head and anchor or connection failure occurs in all tests, recognition for the use of notching channel bolts in combination with anchor channels with a smooth surface of the channel lips shall be included without further testing.



Side view of the channel cross section of the channel

Figure 2.1: Tension test setup for testing anchor channels in a universal testing machine.

Assessment:

The characteristic resistance, $N_{Rk,s,c}$ shall be determined according to following Equation taking into account the actual dimensions and actual steel strengths.

$$N_{Rk,s,c} = N_{Rk,s,c,test} \cdot \frac{f_{uk}}{f_{u,test}} \cdot \frac{t_{ch,nom}}{t_{ch,test}} \quad [N] \qquad (2.2b)$$

$N_{Rk,s,c,test}$	=	5%-fractile of the ultimate loads measured in test series S1 according to Table A.1	[N]
f_{uk}	=	nominal characteristic steel ultimate tensile strength of channel	[N/mm²]
$f_{u,test}$	=	actual steel ultimate tensile strength of channel back $f_{u,test} \geq f_{uk}$	[N/mm²]
$t_{ch,nom}$	=	nominal thickness of channel back or channel lip depending on the failure mode	[mm]
$t_{ch,test}$	=	actual thickness of channel back or channel lips depending on the failure mode	[mm]

2.2.3 Characteristic resistance to steel failure of channel lips and subsequently pull-out of channel bolt under static and quasi-static tension loading

Determination of the characteristic resistance of the channel against bending and local rupture of the channel lips.

No tests are required if the following conditions are fulfilled:

- In test series S1 according to Table A.1, using a channel bolt with the smallest head size and maximum steel strength, steel failure of a part of the anchor channel other than the channel bolt is observed.
- The 5%-fractile of the ultimate loads observed in test series S1 ($N_{Rk,s,c,test}$) is used as $N^0_{Rk,s,l,test}$ to calculate the characteristic resistance of the channel lips $N^0_{Rk,s,l}$ according to (2.2).

If these conditions are not fulfilled tests according to Table A.1, line S2 shall be performed. All channel sizes with all materials specified by the manufacturer shall be tested. The channel bolt with the smallest head size and maximum steel strength that, when tested, still results in steel failure of a part of the anchor channel other than the channel bolt shall be used. If the largest channel bolt with the smallest head still results in bolt failure, the bolt failure load shall be taken as load corresponding to lip failure.

Test conditions:

The tests may be performed either on channels not cast into concrete a) or channels cast into concrete b).

a) The test may be performed as described in 2.2.2 with a channel bolt with the smallest head size and maximum steel strength that, when tested, still results in steel failure of a part of the anchor channel other than the channel bolt.

b) Test may be performed according to Table A.1, line S2 with anchor channels with two anchors embedded in non-cracked concrete C20/25. The edge distance from the end of the channel to the tested anchor (see Fig. 1.3) shall be x_{min} according to the specific product. The anchor spacing shall be s ≥ s_{min} where s_{min} according to the specific product and given in the ETA but is not less than 100 mm. Insert the channel bolt over one anchor.

   In case of anchor channels with a smooth surface of the channel lips in combination with channel bolts with a smooth surface on the underside of the channel bolt head and anchor channels with serrated lips in combination with locking channel bolts with matching serrations on the channel bolt head, the tests may be performed with or without fixture.

   In case of anchor channels with a smooth surface of the channel lips in combination with notching channel bolts, the tests shall be performed with fixture.

   If a fixture is used, it shall have the following dimensions: width = b_{ch}, length = $3b_{ch}$, thickness = d_f. The fixture shall be shimmed with steel strips having a thickness = 3,0 mm located on each side of the anchor channel (similar to Figure 2.3). The diameter of the hole in the fixture shall be approximately 10 percent larger than the diameter of the shaft of the channel bolt. The channel bolt shall be pre-tensioned in accordance with Section A.2.

   The test shall be conducted with a test rig as shown in Figure 2.1 b, however the support spacing may be reduced to ≥ h_{ef}. Direct contact between the test rig and the channel is not allowed. Report load-displacement curve, failure load and failure mode of each test.

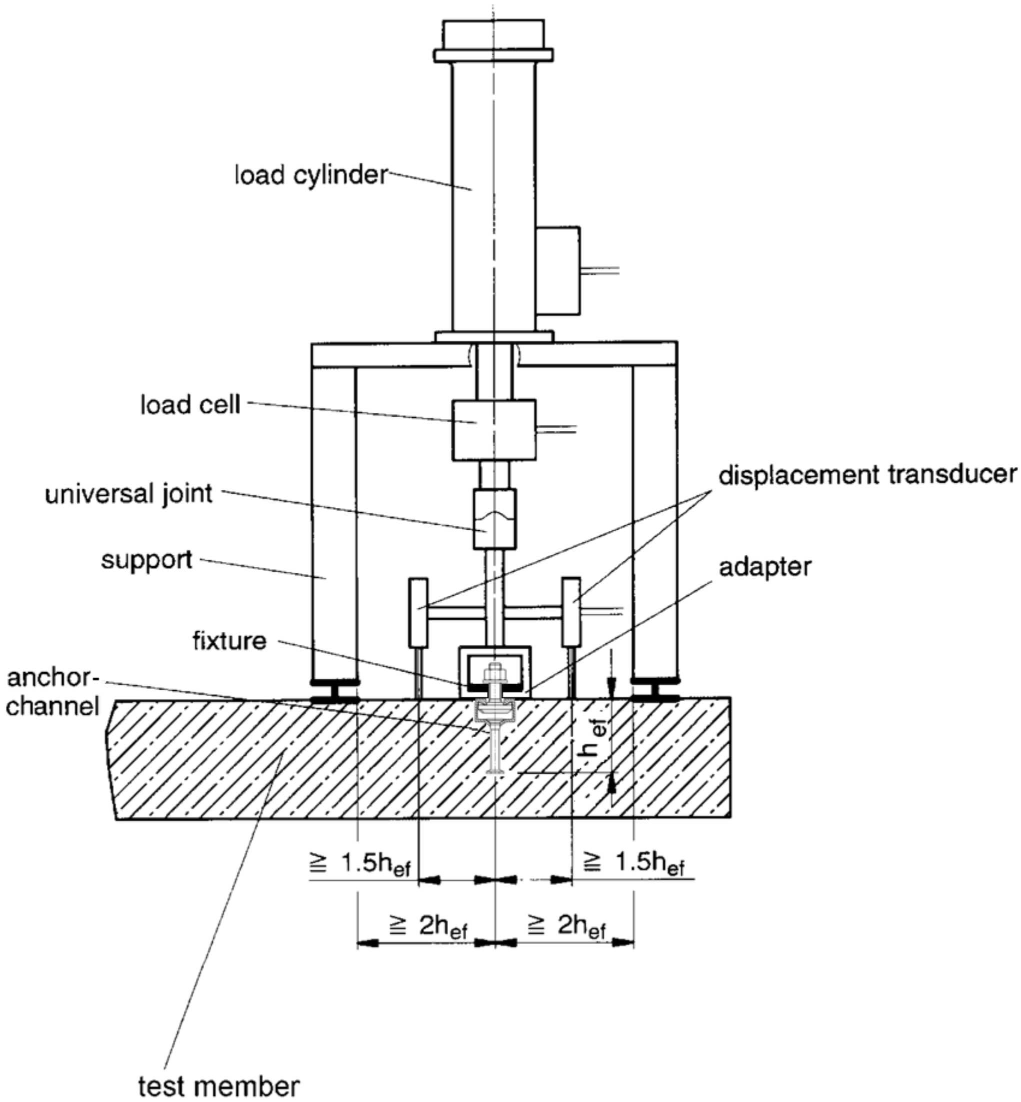


Figure 2.1 b: Example of a tension test rig for unconfined tests

Assessment:

If test series S2 of Table A.1 has not been performed, the characteristic resistance of the channel lips shall be taken as $N_{Rk,s,c}$ (see 2.2.2).

If test series S2 of Table A.1 has been performed, the characteristic resistance $N^0_{Rk,s,l}$ shall be determined according to Equation (2.3) taking into account the actual dimensions and actual steel strength.

$$N^0_{Rk,s,l} = N^0_{Rk,s,l,test} \cdot \frac{f_{uk}}{f_{u,test}} \cdot \frac{t_{ch,nom}}{t_{ch,test}} \quad [N] \qquad (2.3)$$

$N^0_{Rk,s,l,test}$	=	5%-fractile of the ultimate loads measured in test series S2 according to Table A.1	[N]
f_{uk}	=	nominal characteristic tensile strength of channel	[N/mm²]
$f_{u,test}$	=	actual steel ultimate tensile strength of channel back $f_{u,test} \geq f_{uk}$	[N/mm²]
$t_{ch,nom}$	=	nominal thickness of channel back or channel lip depending on the failure mode	[mm]
$t_{ch,test}$	=	actual thickness of channel back or channel lips depending on the failure mode	[mm]

If the thickness of the channel lips varies as a function of the distance from the end of the lips the nominal and actual thickness of the channel back may be used in Equation (2.3) instead of the thickness of the channel lips.

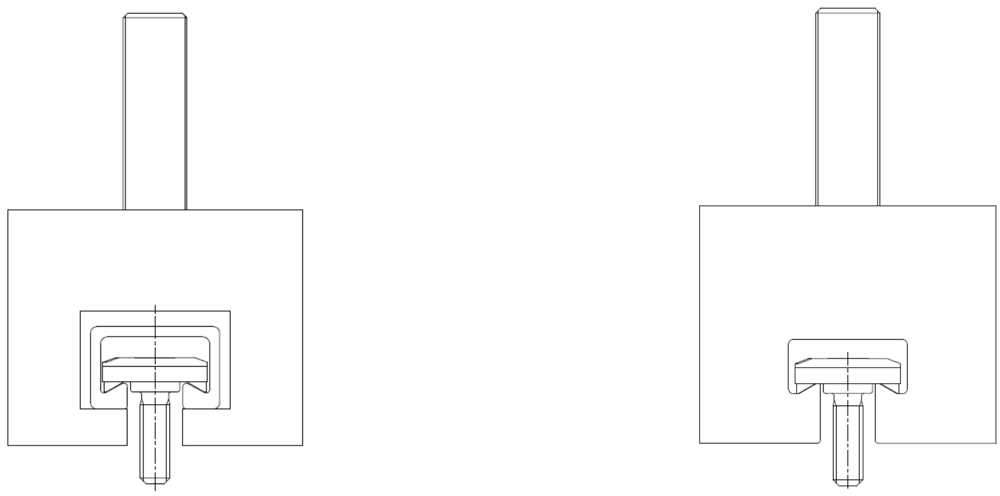
Currently, no tests are available to determine $s_{l,N}$. $s_{l,N}$ shall be taken as 2 · b_{ch}.

2.2.4 Characteristic resistance to steel failure of channel bolt under static and quasi-static tension loading

Perform the tests according to Table A.1, line S3. Channel bolts of all materials shall be tested. Channel bolts with the smallest ratio of head thickness multiplied by the width of the channel bolt head to cross section of channel bolt shaft for a given channel size shall be used as components of the test specimens. Additionally at the option of the manufacturer, in case of failure of the bolt head, the channel bolt with the next larger ratio head thickness multiplied by the width of channel bolt head to cross section of channel bolt shaft may be tested until failure of the channel bolt shaft is observed. If it is not obvious which channel bolt is unfavourable, all channel bolt sizes shall be tested.

Test conditions:

The test is carried out on anchor channels not cast into concrete. The channel bolts may be tested in a channel section that is sufficiently restraint to cause failure of the channel bolt (see Figure 2.2 a)). Alternatively, channel bolts may be tested in a steel template (see Figure 2.2 b)) which shall represent the inner profile of the channels (angle of channel lips and width of slot). If the channel bolt is intended to be used for different channel sizes, conduct the tests in the channel profile (see Figure 2.2 a)) or template (see Figure 2.2 b)) with the maximum width of the slot. Insert the channel bolt in the channel profile or template respectively, and apply the tension load with a coupling nut to avoid thread failure. No fixture or washer between the coupling nut and the steel template or channel section shall be used. Report the failure load and failure mode of each test.



a) Test of channel bolt in a channel section which is restraint to avoid lip failure

b) Test in a steel template

Figure 2.2: Tests on channel bolts

Assessment:

In case of failure of the shaft of the channel bolt the value $N_{Rk,s}$ shall be calculated according to Equation (2.4). The 5%-fractile of the measured failure loads for bolt failure (not converted) shall be larger than $N_{Rk,s}$.

$N_{Rk,s}$	=	$A_{s,cbo} \cdot f_{uk} \leq N_{Rk,s,test}$	[N]	(2.4)
$A_{s,cbo}$	=	stressed cross section of channel bolt	[mm²]	
f_{uk}	=	nominal characteristic tensile strength of channel bolt shaft	[N/mm²]	
$N_{Rk,s,test}$	=	5%-fractile of the ultimate loads measured in test series S3 according to Table A.1, not converted	[N]	

In case of failure of the channel bolt head the characteristic resistance $N_{Rk,s}$ shall be calculated according to Equation (2.5) taking into account the actual steel strength.

$N_{Rk,s}$	=	$N_{Rk,s,test} \cdot \frac{f_{uk}}{f_{u,test}}$	[N]	(2.5)
$N_{Rk,s,test}$	=	see Equation (2.4)	[N]	
f_{uk}	=	nominal characteristic tensile strength of channel bolt shaft	[N/mm²]	
$f_{u,test}$	=	actual steel ultimate tensile strength of channel bolt shaft $f_{u,test} \geq f_{uk}$	[N/mm²]	

The smaller of the values calculated according to Equation (2.4) and (2.5) shall be reported as $N_{Rk,s}$ in the ETA.

2.2.5 Characteristic resistance to steel failure by exceeding the bending strength of the channel under static and quasi-static tension loading

Determination of the characteristic resistance in case of bending failure of the channel taking into account the restraint of the deformation of the outer channel ends by the concrete.

No tests are required if a degree of restraint $\alpha_r = 4$ (simply supported beam) is considered.

Optional perform tests according to Table A.1, line S4, if a degree of restraint $4 < \alpha_r \leq 8$ is aimed for. The tests shall be performed with all sizes and materials of anchor channels. Anchor channels with two anchors with a maximum spacing as given in the ETA and with an anchor type that provides the highest anchor strength shall be tested. Use a channel bolt which provides the highest channel bolt yield strength for the tested channel size.

If for an anchor channel size the characteristic resistance for bending failure of the channel, $N_{Rk,s,flex}$, computed in accordance with Equation (2.6) is smaller than the characteristic resistance $N_{Rk,s,l}$ for lip failure evaluated in accordance with 2.2.3, additional tests with this anchor channel size shall be performed with s < s_{max}.

The anchor spacing in these tests shall be chosen such that the characteristic resistances for the failure modes "bending of channel" and "local failure of channel lips" are about equal.

$N_{Rk,s,flex}$	=	$\alpha_r \cdot W_{pl,y,nom} \cdot f_{yk} / s_{min}$	[N]	(2.6)
α_r	=	degree of constraint evaluated according to Equation (2.7) from the failure loads measured in test series S4 according to Table A.1 with anchor channels with s = s_{max}	[-]	
$W_{pl,y,nom}$	=	plastic section modulus around y-axis (see Figure 1.1) computed with nominal channel dimensions.	[mm³]	
f_{yk}	=	nominal characteristic yield strength of the channel	[N/mm²]	
s_{min}	=	minimum anchor spacing according to the specific product	[mm]	

Test conditions:

The tests shall be performed with anchor channels with the minimum end distance x_{min} embedded in uncracked concrete. A channel bolt shall be inserted midway between the anchors. Apply a tension load via the channel bolt shaft until failure of the anchor channel. Report the failure load, the failure mode and the load-displacement curve of each test.

In case of anchor channels with a smooth surface of the channel lips in combination with channel bolts with a smooth surface on the underside of the channel bolt head and anchor channels with serrated lips in combination with locking channel bolts with matching serrations on the channel bolt head, the tests may be performed with or without fixture.

In case of anchor channels with a smooth surface of the channel lips in combination with notching channel bolts, the tests shall be performed with fixture.

If a fixture is used, it shall have the following dimensions: width = b_{ch}, length = b_{ch}, thickness = d_f. The diameter of the hole in the fixture d_f shall be according EN 1992-4 [3], Table 6.1 resp. Table A.2 of this EAD. The channel bolt shall be pre-tensioned in accordance with Section A.2.

Assessment:

If no tests have been performed the restraint factor shall be taken as $\alpha_r = 4.0$.

The degree of constraint shall be calculated from the 5%-fractile of the measured ultimate loads according to Equation (2.7), taking account of the actual yield steel strength and the actual dimensions.

α_r	=	$\frac{N_{Rk,s,test} \cdot s_{test}}{W_{pl,y,act} \cdot f_{y.test}}$	[-]	(2.7)
$N_{Rk,s,test}$	=	5%-fractile of the ultimate loads measured in test series S4 of Table A.1	[N]	
s_{test}	=	spacing of anchors in tests	[mm]	
$W_{pl,y,at}$	=	plastic section modulus of the tested channel around the y-axis (see Figure 1.1) computed with actual channel dimensions	[mm³]	
$f_{y,test}$	=	actual mean yield strength of the channel back	[N/mm²]	

The value of α_r calculated according to Equation (2.7) shall be rounded down to the nearest multiple of 0.1. It shall be taken not smaller than 4 (valid for a beam on two supports) and not larger than 8 (valid for a beam with full restraint on both ends).

The reference characteristic bending moment $M_{Rk,s,flex}$ of the channel shall be determined according to Equation (2.8).

$M_{Rk,s,flex}$	=	$\frac{\alpha_r}{4} \cdot M_{pl}$	[Nm]	(2.8)
α_r	=	value computed according to Equation 2.7	[-]	
M_{pl}	=	$W_{pl,y,nom} \cdot f_{yk}$	[Nm]	(2.9)
$W_{pl,y,nom}$	=	plastic section modulus of the channel around the y-axis (see Figure 1.1) computed with nominal channel dimensions	[mm³]	
f_{yk}	=	nominal characteristic yield strength of channel	[N/mm²]	

The maximum spacing between anchors s_{max} shall be shall be stated in the ETA for each channel size.

2.2.6 Maximum installation torque moment to avoid damage during installation

Determination of the maximum installation torque moment that can be applied without inducing damage to the channel bolt and/or channel and/or anchor and/or concrete.

No torque tests are required with channel bolts without lubricants or friction-reducing coatings if the pre-stressing force N_{calc} is calculated according to Equation (2.10) with k = 0,15 (Case 1).

Optional torque tests with channel bolts of all sizes and materials and coatings in channels of all sizes and materials specified for the tested channel bolt can be performed according to Table A.1, line S5.

If the results of torque tests with the most unfavourable combination material and coating are assessed and the resulting maximum installation torque moment is given in the ETA for all variants only the most unfavourable variant need to be tested. If the most unfavourable combination cannot be established channel bolts with all materials and coatings shall be tested (Case 2).

Only the smallest, medium and largest diameters of channel bolts need to be tested in anchor channels with the medium size of the range of anchor channels specified by the manufacturer for the tested channel bolts, if the pre-stressing force N_{calc} for the not tested sizes is calculated according to Equation (2.10) with k = min (0,2; k_{test}) (Case 3).

Test conditions:

The tests may be performed on channels not casted into concrete. If the specified torque moment of the channel bolt does not fulfil the conditions in Equation (2.13) and respectively Equation (2.14), additional tests on anchor channels embedded in concrete are permitted to be performed. In this case test all anchor channels made from all materials using channel bolts of all materials and coatings specified for the tested anchor channel that does not fulfil the requirements of Equation (2.13) and respectively Equation (2.14).

It shall be allowed to measure the anchor forces by strain gauges or by load cell in test C1 of Table A.1 if the test requirements for both test series are fulfilled.

<u>Tests on channels not cast into concrete:</u>

A test set-up similar to the one shown in Figure 2.3 a shall be used. Double-side abrasive paper of sufficient roughness shall be placed between washer and test fixture to prevent rotation of the washer relative to the fixture during application of the torque. The diameter of the clearance hole in the fixture shall correspond to the value given in EN 1992-4 [3], Table 6.1 resp. Table A.2 of this EAD. Apply torque up to a torque moment T ≥ 1,3 · T_{inst} (with T_{inst} as maximum of $T_{inst,g}$ given by the manufacturer for applications according to Figure 1.4a) and $T_{inst,s}$ given by the manufacturer for applications according to Figure 1.4b) additional). If no T_{inst} is given by the manufacturer, $T_{inst,g}$ = $T_{inst,s}$ = 2 Nm shall be used.

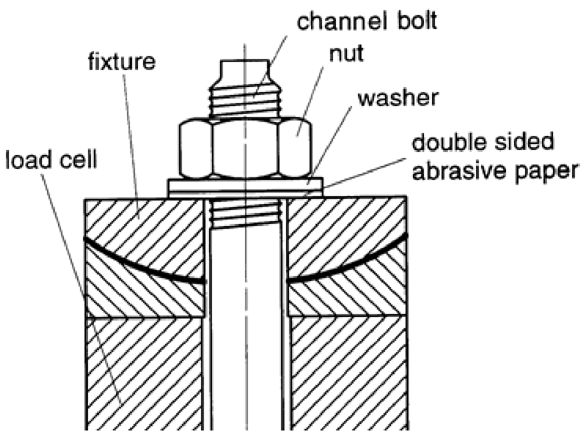


Figure 2.3 a: Example for detail of torque test (schematic)

Results of tests: $N_{test,i,bolt}$ $(1{,}0\ T_{inst,g})$ and $N_{test,i,bolt}$ $(1{,}3\ \ max\ (T_{inst,g\ ;}\ T_{inst,s)}))$

Assumption: $N_{test,i,anchor}$ $(1{,}0\ T_{inst,g})$ = $N_{test,i,bolt}(1{,}0\ T_{inst,g})$

Tests on channels cast into concrete:

The tests shall be carried out on anchor channels with two anchors cast into non-cracked concrete C20/25. The spacing of the anchors shall correspond to the maximum value (s_{max}) and the distance between the end of the channel and the anchor axis to the minimum value (x_{min}) specified by the manufacturer for the tested channel size. The edge distance shall be large enough to avoid an edge influenced failure.

The anchor channel shall be installed flush with the concrete surface. A fixture with the following dimensions shall be used: width = $3b_{ch}$, length = $3b_{ch}$, thickness = d_f. The diameter of the hole d_f in the fixture shall be according EN 1992-4 [3], Table 6.1 resp. Table A.2 of this EAD. To ensure introduction of a tension load into the anchor during torqueing, the fixture shall be placed on two steel strips (width = $2b_{ch}$, length = $3b_{ch}$, thickness = 3,0 mm) located on each side of the anchor channel (see Figure 2.3 b).

Double-side abrasive paper of sufficient roughness shall be placed between washer and fixture to prevent rotation of the washer relative to the test fixture during the application of torque. Other methods of preventing rotation of the washer shall be permitted provided it can be shown that they do not affect the test result. To reduce adhesion and/or friction between steel parts of the anchor channel and concrete, the outside of the channel and the anchor shall be greased before casting.

Insert a channel bolt over one anchor. Apply increasing torque up to a torque moment T ≥ 1,3 · $T_{inst,g}$ given by the manufacturer for applications according to Figure 1.4a) and record the torque, the corresponding induced tension in the channel bolt and in the anchor as well as the number of revolutions of the nut. The tension force in the anchor may be measured by using strain gauges (see Figure 2.3 b) or load cells (see Figure 2.3 c). Two strain gauges should be applied to the anchor as close to the channel as possible in which the strain is measured.

The tension force in the anchor is calculated via this measured strain and the cross section and E-Modulus of the anchor at that place, where the strain gauges are applied. Alternatively, the tension forces in the anchor may be measured by a load cell placed below the anchor. In this case the anchor may be extended beyond the concrete member by welding or by using a coupler. Use a spherical washer in combination with the load cell to prevent introduction of bending stresses in the anchor. However, it must be demonstrated, that no additional slip is generated by extending the anchor and anchoring the anchor on the load cell.

Plot the measured tension forces in the channel bolt and in the anchor as a function of the applied torque moment as well as a function of the displacement of the channel bolt head, evaluated from the measured revolutions of the nut.

Results of tests: $N_{test,i,bolt}$ (1,3 $T_{inst,g}$) and $N_{test,i,anchor}$ (1,3 $T_{inst,g}$)

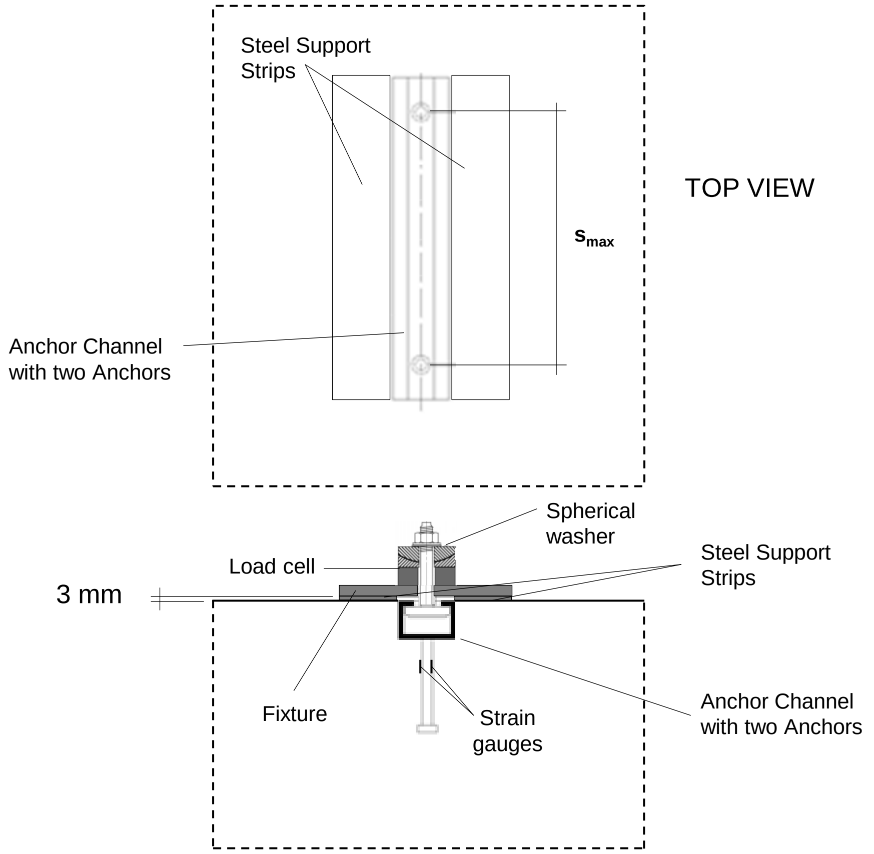


Figure 2.3 b: Test setup for tests (using strain gauges) in accordance to Table A.1, Line S5

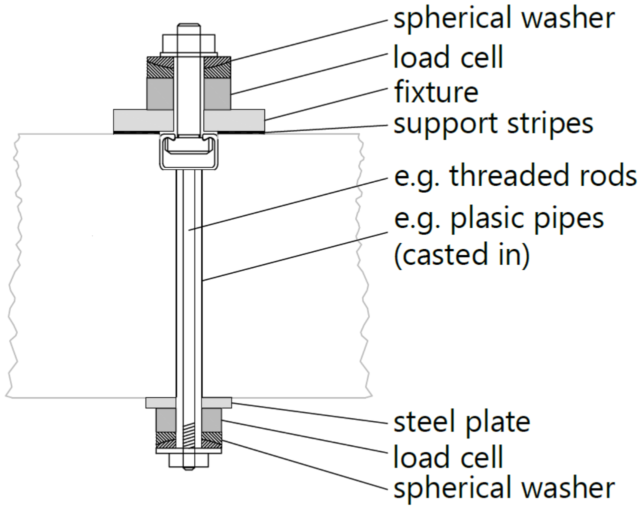


Figure 2.3 c: Test setup for tests (using load cells) in accordance to Table A.1, Line S5

Assessment:

For not tested sizes calculate the pre-stressing force, N_{calc}, according to Equation (2.10):

N_{calc}	=	$\frac{\alpha \cdot T_{inst}}{k \cdot d}$	[N]	(2.10)
N_{calc}	=	calculated pre-stressing force at T = α· T_{inst}	[N]	
α	=	1,0 for assessment of concrete failure according to Equation (2.14)		
	=	1,3 for assessment of steel according to Equations (2.13) or for assessment of concrete failure according to Equation (2.15)		
T_{inst}	=	installation torque moment specified by the manufacturer $T_{inst,g}$ in general for applications according to Figure 1.4a) $T_{inst,s}$ in addition for applications according to Figure 1.4b)	[Nmm]	
k	=	friction factor to be taken as lower bound value (5%-fractile)	[-]	
	=	0,15 — for Case 1 (without tests)		
	=	min (0,2; k_{test}) — for Case 3 (for sizes without tests, with k_{test} according to Equation (2.11) resulting from the tested sizes)		
d	=	diameter of the channel bolt shaft	[mm]	

For tested sizes (Case 2 and tested sizes of Case 3) calculate friction factor k_{test} according to Equation (2.11) and the pre-stressing force, $N_{95\%,test}$ according to Equation (2.12):

k_{test}	=	$k_{test,m} \cdot (1 - k_s \cdot v_{test})$	[N]	(2.11)
$k_{test,m}$	=	mean of the values $k_{test,i}$ calculated according to Equation (2.12)	[N]	

with:

$k_{test,i}$	=	$\frac{\alpha \cdot T_{inst}}{N_{test,i} \cdot d}$		
$N_{test,i}$	=	pre-stressing force at T = $\alpha \cdot T_{inst}$ measured in test i	[N]	
α, T_{inst}, d		see Equation (2.10)		
k_s ,v_{test}		see Equation (A.5)		

$N_{95\%,test}$	=	$N_{m,test} \cdot (1 + k_s \cdot v_{test})$	[N]	(2.12)
$N_{m,test}$	=	mean pre-stressing force at T = $\alpha \cdot T_{inst}$	[N]	
α, T_{inst}		see Equation (2.10)		
$k_{s,}$ v_{test}		see Equation (A.5)		

Following conditions shall be fulfilled:

For all tests and calculations (steel failure of channel bolt):

$$N_{95\%,test}(T = 1{,}3\ T_{inst}) \quad \text{or} \quad N_{calc}\ (T = 1{,}3\ T_{inst}) \quad \leq \quad N_{Rk,s} \cdot \frac{f_{yk}}{f_{uk}} \tag{2.13}$$

$N_{95\%,test}$ pre-stressing force on channel bolt

$N_{Rk,s}$ according to 2.2.4

$T_{inst} = max\ (T_{inst,g}\ ;\ T_{inst,s})$

For tests with channels not cast in concrete (steel failure of anchor channel and concrete failure):

$$N_{95\%,test}\ (T = 1{,}0\ T_{inst,g}) \quad \text{or} \quad N_{calc}\ (T = 1{,}0\ T_{inst,g}) \quad \leq \quad N_{Rk,s,a} \quad \text{according to 2.2.1} \tag{2.14}$$

$\leq \quad N_{Rk,s,c}$ according to 2.2.2

$\leq \quad N^0_{Rk,s,l}$ according to 2.2.3

$\leq \quad N_{Rk,p}$ according to 2.2.7

$N_{95\%,test}$ pre-stressing force on channel bolt

Exception: For anchor channels with an embedment depth $h_{ef} \geq 90$ mm, assessment of the pre-stressing force with respect to the pull-out strength is not required.

For tests with channels cast in concrete (steel failure of anchor channel and concrete failure):

$$N_{95\%,test}\ (T = 1{,}3\ T_{inst,g}) \quad \text{or} \quad N_{calc}\ (T = 1{,}3\ T_{inst,g}) \quad \leq \quad N_{Rk,s,a} \quad \text{according to 2.2.1} \tag{2.15}$$

$\leq \quad N_{Rk,s,c}$ according to 2.2.2

$\leq \quad N^0_{Rk,s,l}$ according to 2.2.3

$\leq \quad N_{Rk,p}$ according to 2.2.7

$N_{95\%,test}$ pre-stressing force on the anchor

Exception: For anchor channels with an embedment depth $h_{ef} \geq 90$ mm, assessment of the pre-stressing force with respect to the pull-out strength is not required.

Overview tests and assessment:

Case	**Assess-ment of Part**	**Test (Sizes etc.)**	**Test condi-tions**	T_{inst}	**Factor for** T_{inst}	**Friction factor**	**Pre-stressing force**	**Assess-ment**
Case 1	bolt	no	-	$max\ (T_{inst,g}\,;T_{inst,s})$	α = 1,3	k = 0,15	N_{calc} (2.10)	(2.13)
	anchor	no	-	$T_{inst,g}$	α = 1,0	k = 0,15	N_{calc} (2.10)	(2.14)
Case 2	bolt	all	not cast in	$max\ (T_{inst,g}\,;T_{inst,s})$	α = 1,3	Not relevant	$N_{95\%,test,bolt}$ (2.12)	(2.13)
	anchor	all	not cast in	$T_{inst,g}$	α = 1,0	Not relevant	$N_{95\%,anchor}$ = $N_{95\%,test,bolt}$ (2.12)	(2.14)
	anchor alter-natively	all	cast in	$T_{inst,g}$	α = 1,3	Not relevant	$N_{95\%,test,anchor}$ (2.12)	(2.15) substitute (2.14)
Case 3	bolt	s/m/l	not cast in	$max\ (T_{inst,g}\,;T_{inst,s})$	α = 1,3	Not relevant	$N_{95\%,test,bolt}$ (2.12)	(2.13)
	bolt	not tested sizes	-	$max\ (T_{inst,g}\,;T_{inst,s})$	α = 1,3	k = min (0,2; k_{test} (2.11) of tested sizes)	N_{calc} (2.10)	(2.13)
	anchor	s/m/l	not cast in	$T_{inst,g}$	α = 1,0	Not relevant	$N_{95\%,anchor}$ = $N_{95\%,test,bolt}$ (2.12)	(2.14)
	anchor	not tested sizes	-	$T_{inst,g}$	α = 1,0	k = min (0,2; k_{test} of tested sizes)	N_{calc} (2.10)	(2.14)
	anchor alter-natively	s/m/l [1)]	cast in	$T_{inst,g}$	α = 1,3	Not relevant	$N_{95\%,test,anchor}$ (2.12)	(2.15) substitute (2.14)
	anchor alter-natively	not tested sizes	-	$T_{inst,g}$	α = 1,3	k = min (0,2; k_{test} of tested sizes)	N_{calc} (2.10)	(2.15) substitute (2.14)

1) If Equation (2.15) is fulfilled for the largest size (maximum torque moment) the result may be used for small and medium sizes.

If the conditions according to Equations (2.14) and (2.15) are not fulfilled, then the installation torque moment shall be reduced until the conditions are fulfilled.

The installation torque moment $T_{inst,g}$ for general application and steel-steel contact $T_{inst,s}$ that fulfils the above conditions, is stated in the ETA for each size, kind of manufacturing, material and coating of the channel bolt if applicable and each size and material of the channel if applicable.

2.2.7 Characteristic resistance to concrete pull-out failure of the anchor under static and quasi-static tension loading

The characteristic resistance $N_{Rk,p}$ for pull-out failure shall be calculated according to Equation (2.16).

$N_{Rk,p}$	=	$k_2 \cdot A_h \cdot f_{ck}$	[N]	(2.16)
k_2	=	7,5 in cracked concrete, 10,5 in non-cracked concrete		
f_{ck}	=	nominal characteristic compressive cylinder strength (150 mm diameter by 300 mm cylinder)	[N/mm²]	
A_h	=	projected load bearing area of the head of the anchor	[mm²]	

For round headed anchors, the projected load bearing area of the head can be calculated according to:

$$A_h = \frac{\pi}{4} \cdot (d_h^2 - d_a^2) \qquad (2.16a)$$

with: $d_h \le 6\,t_h + d_a$

For I - anchors, the projected load bearing area of the head can be calculated according to:

$$A_h = w_a \cdot (b_h - t_w) \qquad (2.16b)$$

with: $b_h \le 6\,t_h + t_w$

The characteristic resistance $N_{Rk,p}$ for pull-out failure as a function of the concrete compressive strength shall be stated in the ETA for each anchor channel size.

2.2.8 Characteristic resistance to concrete cone failure under static and quasi-static tension loading

The values $k_{cr,N}$ and $k_{ucr,N}$ are calculated according to Equation (2.17) and Equation (2.18)

$k_{cr,N}$	=	$\alpha_{ch,N} \cdot 8{,}9$	for cracked concrete	[-]	(2.17)
$k_{ucr,N}$	=	$\alpha_{ch,N} \cdot 12{,}7$	for uncracked concrete	[-]	(2.18)
$\alpha_{ch,N}$	=	$\left(\frac{h_{ef}}{180}\right)^{0,15} \le 1{,}0$	if $\frac{h_{ch}}{h_{ef}} \le 0{,}4$ and $\frac{b_{ch}}{h_{ef}} \le 0{,}7$	[-]	(2.19)
$\alpha_{ch,N}$	=	1,0	if $\frac{h_{ch}}{h_{ef}} > 0{,}4$ and/or $\frac{b_{ch}}{h_{ef}} > 0{,}7$	[-]	(2.20)

The decisive effective embedment depth h_{ef} is stated in the ETA as follows:

For anchor channels with $h_{ch}/h_{ef} \le 0{,}4$ and $b_{ch}/h_{ef} \le 0{,}7$: $h_{ef} = h_{nom} - t_h$ (see Figure 1.1)

For anchor channels with $h_{ch}/h_{ef} > 0{,}4$ and $b_{ch}/h_{ef} > 0{,}7$: $h_{ef}^* = h_{nom} - t_h - h_{ch}$

2.2.9 Minimum edge distance, spacing and member thickness to avoid splitting of concrete during installation

Tests shall be performed with anchor channels embedded in uncracked concrete according to Table A.1, line C1 with each channel size. The most unfavourable combination of material, kind of manufacturing, coating, and diameter of channel bolt shall be tested that result in the highest pre-stressing force.

If for one channel size different anchors are specified, the anchor with the smallest head shall be used to generate the highest splitting forces.

If the specified minimum edge distance and minimum anchor spacing are independent of the channel bolt size, only tests with the channel bolt with the largest diameter have to be conducted. If the specified minimum edge distance and minimum anchor spacing depend on the channel bolt size additional tests with channel bolts with a smaller diameter are required.

Exception: Only the smallest, medium and largest channel sizes need to be tested, if:

a) The value γ_{inst} to be applied in Equation (2.24) is increased by 30%; and

b) The ratio of the pre-stressing force $N_{95\%}$ to the area $A_c = c_{min} \cdot s_{min}$ of the intermediate untested channel sizes shall not exceed 1.1 times the ratio corresponding to the next largest and next smallest tested channel sizes, whereby $N_{95\%}$ is calculated according to Equation (2.10) with $T = T_{inst,g}$ and k as determined in accordance with 2.2.6.

   For calculating $N_{95\%}$ of the tested channel sizes the value T_{inst} to be inserted in Equation (2.10) may be replaced by $T_{inst,adm}$ according to Equation (2.21).

$T_{inst,adm}$	=	$T_{inst,g} \cdot \gamma / \gamma_{req}$	[Nm]	(2.21)
γ	=	$T_{crack,5\%} \cdot \left(f_{ck} / f_{c,test}\right)^{0,5} / T_{inst,g}$	[-]	(2.22)
$T_{crack,5\%}$	=	5%-fractile of the torque moments T_{crack} calculated according to Equation (2.23)	[Nm]	
T_{crack}	=	torque moment at which a hairline crack (crack with a width < 0,1 mm) is observed.	[Nm]	
f_{ck}	=	20 N/mm²		
$f_{c,test}$	=	concrete compression strengths at time of testing measured on cylinder $f_{c,test} \geq f_{ck}$	[N/mm²]	
T_{inst}	=	Installation torque moment specified by the manufacturer and given in the ETA for applications according to Figure 1.4a) (fixture in contact with the concrete)	[Nm]	
γ_{req}	=	$1,3 \cdot \gamma_{inst}$	[-]	
γ_{inst}	=	see Equation (2.24)		
$T_{crack,5\%}$	=	$T_{crack,m} \cdot (1 - k_s \cdot v_{test})$	[Nm]	(2.23)
$T_{crack,m}$	=	mean value of torque moment at which a hairline crack (crack with a width < 0,1 mm) is observed.	[Nm]	
k_s , v_{test}		See Equation (A.5)		

Test conditions:

Anchor channels with two anchors at minimum spacing according to the specific product shall be cast into concrete members with the minimum specified member depth at the minimum edge distance specified by the manufacturer.

If the minimum member depth is not specified by the manufacturer, min. h = max. h_{ef} + t_h + c_{nom}. If the minimum edge distance is not specified by the manufacturer, min. c = $c_{cr,N}$ according to EN 1992-4 [3], Equation (7.63a).

The anchor channel shall be installed surface flush at the top face of the concrete member during concrete placement and parallel to the edge of the concrete member. The distance between the outer anchors of two anchor channels in the direction of the longitudinal channel axis shall be at least $3h_{ef}$. A fixture with the following dimensions shall be used:

width = b_{ch} + $3d_f$, length = s_{min} + $3d_f$, thickness t_{fix} = d_f with d_f = diameter of the hole in the fixture

To ensure introduction of a tension load into the anchor during torqueing, the fixture shall be placed on two steel strips (width = d_f, length = s_{min} + $3d_f$, thickness = 3 mm) located on each side of the anchor channel (see Figure 2.4). The anchor channel is loaded by the application of a torque to two channel bolts located directly above the anchors.

Apply a torque alternately to the two channel bolts in steps of 0,2 $T_{inst,g}$ until failure (cracks in concrete) or until the channel lips are in contact with the fixture). After each step of applied torque check the concrete member for cracks. Record the number of revolutions per step of applied torque, the torque T_{crack} at which hairline crack is observed for at least at one anchor and the maximum torque T_u that can be applied to both channel bolts ($T_{inst,g}$ for applications according to Figure 1.4a).

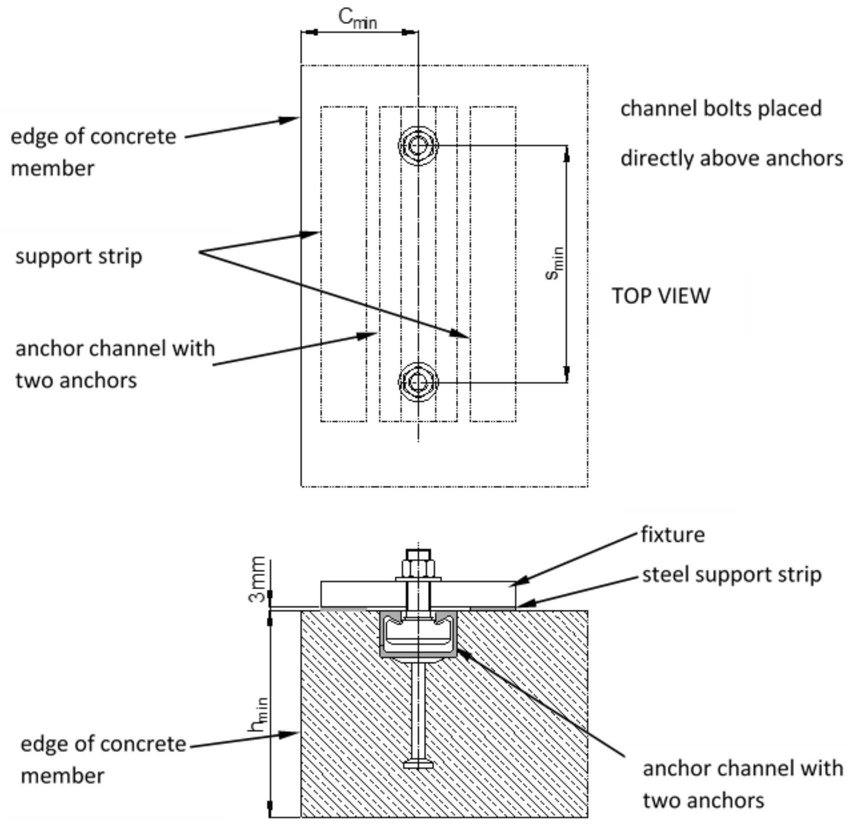


Figure 2.4: Test setup for tests in accordance with Table A.1, line C1

Assessment:

If tests with all channel sizes have been performed, the 5%-fractile $T_{crack,5\%}$ of the torque moments T_{crack} calculated according to Equation (2.23) shall fulfil Equation (2.24).

$T_{crack,5\%}$	≥	$\gamma_{inst} \cdot T_{inst,g} \cdot \left(f_{c,test} / f_{ck}\right)^{0,5}$	[Nm]	(2.24)
γ_{inst}	=	1,3 for anchorages in cracked concrete 1,7 for anchorages in uncracked concrete	[-]	

$T_{crack,5\%}$, $T_{inst,g}$, $f_{c,test}$, f_{ck} see Equation (2.22) and (2.23)

If Equation (2.24) is not fulfilled, either $T_{inst,g}$ shall be reduced or the tests shall be repeated with a larger edge distance or spacing or in test members with a larger minimum member depth until Equation (2.24) is fulfilled.

The minimum spacing, s_{min}, the minimum edge distances, c_{min}, the minimum thickness of the concrete member, h_{min} and the installation torque moment $T_{inst,g}$ shall be stated in the ETA for each channel size and channel bolt.

2.2.10 Characteristic edge distance and spacing to avoid splitting of concrete under load

The values $s_{cr,sp}$ and $c_{cr,sp}$ are calculated according to Equation (2.25) and Equation (2.26).

$s_{cr,sp}$	=	$2 \cdot c_{cr,sp}$	[mm]	(2.25)
$c_{cr,sp}$	=	$3 \cdot h_{ef}$	[mm]	(2.26)

The values $s_{cr,sp}$ is valid for the minimum member thickness h_{min} = h_{ef} + t_h + c_{nom}.

The characteristic edge distance $c_{cr,sp}$ and the characteristic spacing $s_{cr,sp}$shall be stated in the ETA for each channel size.

2.2.11 Resistance to blowout failure - Bearing area of the anchor head

Determination of bearing area of the anchor head to determine the characteristic resistance to blow out failure according.

(1)	circular shaped heads	according EN 1992-4, (7.12)				
(2)	I-anchor	A_h	=	$(b_h - t_w) \cdot w_A$	[mm²]	(2.26a)

The bearing area of the anchor head A_h shall be specified according to the specific product and shall be stated in the ETA for each anchor type and size.

2.2.12 Characteristic resistance to steel failure of channel bolt under static and quasi-static shear loading in transverse direction without lever arm

The characteristic resistance for steel failure of the channel bolt under shear loading without lever arm $V_{Rk,s}$ shall be calculated according to following Equation.

$V_{Rk,s}$	=	$\alpha_s \cdot A_s \cdot f_{uk}$	[N]	(2.27)
α_s	=	0,6 for f_{uk} < 800 N/mm² or f_{yk} / f_{uk} < 0,8	[-]	
	=	0,5 for f_{uk} ≥ 800 N/mm² or f_{yk} / f_{uk} ≥ 0,8		
A_s	=	stressed cross section of the channel bolt	[mm]	
f_{uk}	=	nominal characteristic steel ultimate tensile strength of channel bolt	[N/mm²]	

The characteristic resistances, $V_{Rk,s}$ of all channel bolt sizes in all materials and steel grades shall be given in the ETA.

2.2.13 Characteristic resistance to steel failure by bending of the channel bolt under static and quasi-static loading in transverse direction with lever arm

Characteristic resistance to steel failure by bending of the channel bolt under static and quasi-static loading in transverse direction with lever arm
The characteristic bending resistance $M^0_{Rk,s}$ of the channel bolt shall be determined according to Equation (2.28).

$$M^0_{Rk,s} = 1{,}2 \cdot W_{el} \cdot f_{uk} \leq 0{,}5 \cdot N^0_{Rk,s,l} \cdot a \leq 0{,}5 \cdot N_{Rk,s} \cdot a \quad \text{[Nmm]} \qquad (2.28)$$

W_{el}	=	elastic section modulus of channel bolt calculated with the equivalent diameter of the stressed cross section	[mm³]
f_{uk}	=	nominal characteristic tensile strength of channel bolt shaft	[N/mm²]
$N_{Rk,s,l}$	=	characteristic resistance of channel lips, see 2.2.3	[N]
$N_{Rk,s}$	=	characteristic resistance of channel bolt see 2.2.4	[N]

$$a = \frac{1}{3}\left(b_{cbo,2} + d_{w,2} + d_{ch}\right) \quad \text{[mm]} \qquad (2.29)$$

	=	internal lever arm	[mm]
$b_{cbo,2}$	=	length of channel bolt head	[mm]
$d_{w,2}$	=	outer diameter of washer	[mm]
d_{ch}	=	width of channel opening	[mm]

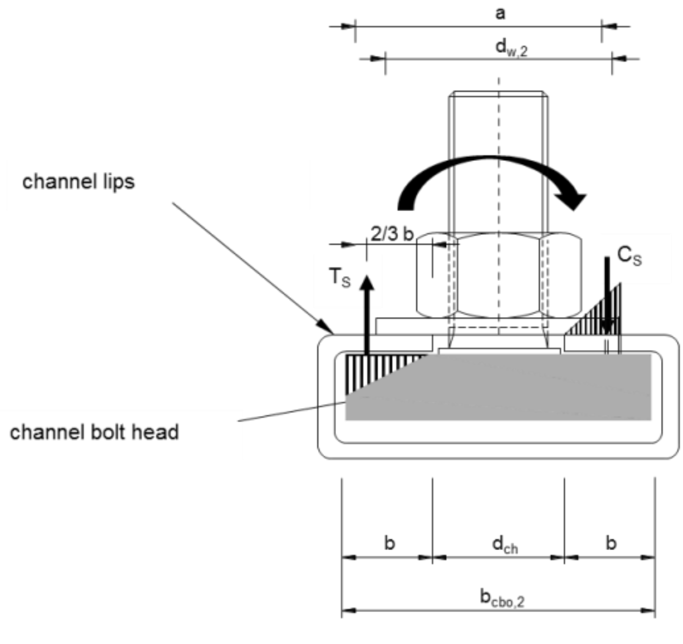


Figure 2.5: Statically system for calculating the forces on the channel lips generated by a bending moment on the channel bolt

2.2.14 Characteristic resistance to local steel failure of channel lips, steel failure of connection between anchor and channel or steel failure of anchor under static and quasi-static loading in transverse direction

Determination of the characteristic resistance of the channel under shear loading in case of bending and local failure of the channel lips, failure of the connection between anchor and channel or failure of the anchor without influence of concrete edges.

No tests are required if $V^0_{Rk,s,l,y} = V_{Rk,s,c,y} = V_{Rk,s,a,y} = min\ (N^0_{Rk,s,l}; N_{Rk,s,c};\ N_{Rk,s,a})$

Tests according to Table A.1, line S6 are required, if $V^0_{Rk,s,l,y} > N^0_{Rk,s,l}$ and/or $V_{Rk,s,c,y} > N_{Rk,s,c}$ and/or $V_{Rk,s,a,y} > N_{Rk,s,a}$ is applied for. All anchor channel sizes and steel types shall be tested. If different anchor types are specified by the manufacturer, test anchor channels with those anchor type that results in the minimum anchor failure load or minimum failure load of the connection between anchor and channel, whichever is less.

Test conditions:

The tests shall be performed according to Figure 2.10 on anchor channels cast into concrete with two anchors with the maximum anchor spacing specified by the manufacturer. Place a PTFE layer (or other friction limiting material of similar friction coefficient) over the entire contact area between fixture, concrete surface and channel profile.

The channel bolt with the smallest head size and maximum ultimate steel strength that, when tested, still results in steel failure of a part of the anchor channel other than the channel bolt shall be used.

In one test series (test series S6a), the channel bolt shall be inserted in the channel over one anchor and shall be pre-tensioned in accordance with A.2**.** In a second test series (test series S6b), the channel bolt shall be positioned midway between the two anchors and pre-tensioned in accordance with A.2**.** The minimum characteristic failure load derived from the two test series is decisive. If the largest channel bolt size results in bolt failure, the bolt failure load shall be used in the assessment.

Apply a shear load to the channel bolt until failure. Record the applied shear load, the corresponding displacement of the anchor channel at the point of load application, the ultimate load and the failure mode.

To measure the static shear strength of the anchor or the connection between anchor and channel it shall be permitted to perform additional tests on anchor channels with 3 anchors with the maximum anchor spacing embedded in concrete. Place a PTFE layer (or other friction limiting material of similar friction coefficient) over the entire contact area between fixture, concrete surface and channel profile. Connect the channel with the fixture by at least 2 channel bolt with a centre-to-centre distance ≥ 3·d. The channel bolts shall be arranged symmetrically to the middle anchor. Apply a shear load to the fixture using a rod that is connected at the middle of the fixture. If 2 or more channel bolts are used, it shall be ensured that the shear load applied to the fixture is distributed equally to the channel bolts.

Assessment:

The characteristic resistance of the channel lips, $V^0_{Rk,s,l,y}$ shall be determined according to Equation (2.30) taking into account the actual steel ultimate tensile strength and the actual dimensions.

$$V^0_{Rk,s,l,y} = V^0_{Rk,s,l,y,test} \cdot \frac{f_{uk}}{f_{u,test}} \cdot \frac{t_{ch,nom}}{t_{ch,test}} \quad [N] \qquad (2.30)$$

$V^0_{Rk,s,l,y,test}$	=	5%-fractile of the ultimate loads measured in test series S6 according to Table A.1	[N]
f_{uk}	=	nominal characteristic steel ultimate tensile strength of channel	[N/mm²]
$f_{u,test}$	=	actual steel ultimate tensile strength of channel back $f_{u,test} \geq f_{uk}$	[N/mm²]
$t_{ch,nom}$	=	nominal thickness of channel back or channel lip depending on the failure mode	[mm]
$t_{ch,test}$	=	actual thickness of channel back or channel lips depending on the failure mode	[mm]

Where the results derived from tests with channel bolts inserted over one anchor and tests with channel bolts positioned midway between the anchors are statistically equivalent, the test results may be combined.

Note: Statistically equivalent means that the ultimate loads of both test series are in the same scatter band and the 5%-fractile of the ultimate loads may be calculated from both test series together.

The characteristic resistances for failure of the connection between anchor and channel and for failure of the anchor may be taken as $V_{Rk,s,c,y}$ = $V_{Rk,s,a,y}$ = $V^0_{Rk,s,l,y}$ and shall be stated in the ETA.

If additional tests with anchor channels with 3 anchors have been performed, the shear resistance of the middle anchor calculated according to 6.3.3 (2) [3] from the 5% fractile of the failure loads converted according to Equation 2.30 shall be denoted as $V_{Rk,s,c,y}$ = $V_{Rk,s,a,y}$.

Currently, no tests are available to determine $s_{l,V}$. $s_{l,V}$ shall be taken as 2 b_{ch}.

2.2.15 Characteristic resistance to steel failure of connection between channel lips and channel bolt under static and quasi-static shear loading in longitudinal channel axis

All channel sizes and steel types specified by the manufacturer shall be tested. Test all types of channel bolts and sizes specified for a particular channel size.

Test results for the smallest channel size can be applied to a range of anchor channel sizes provided all of the following criteria are satisfied:

a. The channel bolt used for all channel sizes of that range of anchor channels is of constant dimensions including serration or notch, specified steel strength, coating, thread type, and manufacture; and

b. For anchor channels with smooth channel lips, the shape (see Figure 2.6), specified steel strength, and manufacture of the channel lips is constant across all channel sizes of that range of anchor channels; and

c. For anchor channels with serrated lips, the shape (see Figure 2.6), specified steel strength, and manufacture of the channel lips, including the shape and dimensions of the serrations, is constant across all channel sizes of that range of channels.

In this case, the value of $V_{Rk,s,l,x}$ shall be constant for all channel sizes.

Test results for one channel bolt size can be applied to a range of channel bolt sizes to be used with a single channel size provided all of the following criteria are satisfied:

a. The dimension of the channel bolt head and the diameter of the tested channel bolt including serration or notch is the smallest of all channel bolts of that range of channel bolts; and

b. The specified steel strength of the tested channel bolt is equal to or less than the specified steel strength of all channel bolts of that range of channel bolts.

In this case, the value of $V_{Rk,s,l,x}$ shall be constant for all channel bolt sizes.

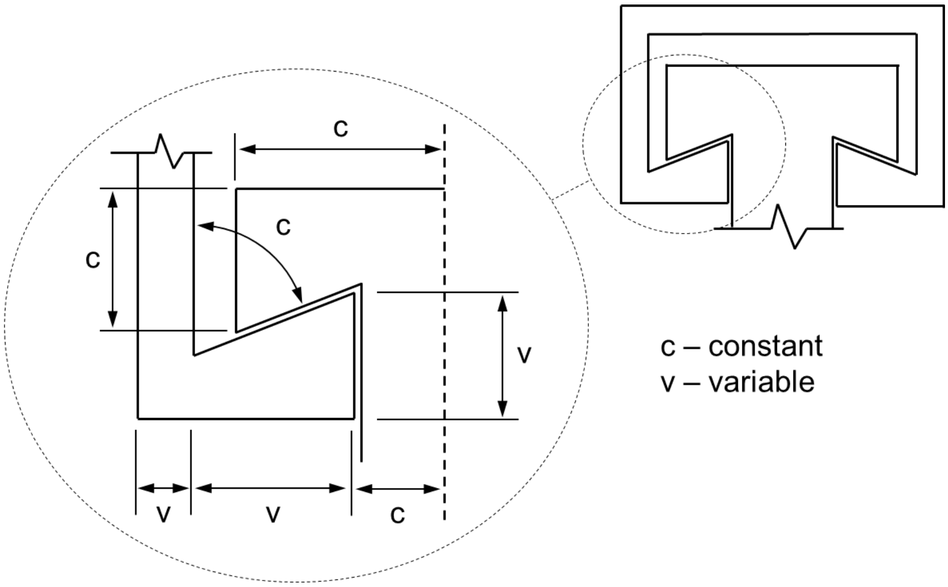


Figure 2.6: Grouping by anchor channel shape

Test conditions:

The tests (test series S7) shall be performed on anchor channels cast into concrete with two anchors with the maximum anchor spacing and a distance between the end of the channel and the anchor axis to the minimum value specified by the manufacturer for the tested channel size. Place a PTFE layer (or other friction limiting material of similar friction coefficient) over the entire contact area between fixture and concrete surface as well as between fixture and channel profile. Insert a channel bolt over one anchor and pretension it in accordance with Section A.2.

Apply a shear load towards the free edge of the channel to the channel bolt in longitudinal channel axis until failure. Record the peak shear load, the corresponding displacement of the anchor channel at the point of load application and the failure mode.

Assessment:

The characteristic resistance of the channel lips, $V_{Rk,s,l,x}$ shall be determined according to Equation (2.31) taking into account the actual steel strength.

$$V_{Rk,s,l,x} = V_{Rk,s,l,x,test} \cdot \frac{f_{uk}}{f_{u,test}} \quad \text{[N]} \tag{2.31}$$

$V_{Rk,s,l,x,test}$	=	5%-fractile of the ultimate loads measured in test series S7 according to Table C.1	[N]
f_{uk}	=	nominal characteristic tensile strength of channel	[N/mm²]
$f_{u,test}$	=	actual steel ultimate tensile strength of channel back $f_{u,test} \geq f_{uk}$	[N/mm²]

2.2.16 Factor for sensitivity to installation

Determination of factor for sensitivity to installation of anchor channels under shear load acting in the direction of the longitudinal axis of the channel. In this context, the sensitivity to the degree of the conversion of torque to tension force on the channel bolt (test series S8) and on inaccuracies in the placement of the channel such as recessed anchor channels (test series S9) are considered.

Test conditions:

The tests of test series S8 shall be performed according to Section 2.2.15. However, the channel bolt shall be pre-stressed with only 50% of the installation torque $T_{inst} = min\,(T_{inst,g};\, T_{inst,s})$ specified in the manufacturer's installation instructions using a calibrated torque wrench having a measuring error within ±5 percent of the specified torque. If no T_{inst} is given by the manufacturer, $T_{inst,g}$ = $T_{inst,s}$ = 2 Nm shall be used.

If these tests are performed with 0,5 $T_{inst,s}$ only, this $T_{inst,s}$ shall be given in the ETA for this type of anchor channel. After a minimum of ten minutes after the initial application of 0,5 T_{inst}, the test shall be started.

The tests of test series S9 shall be performed according to Section 2.2.15. However, steel support strips with a thickness = 3,0 mm (as illustrated in Figure 2.3) shall be placed between fixture and concrete surface. Place a PTFE layer (or other friction limiting material of similar friction coefficient) over the entire contact area between fixture and steel support strips.

Assessment:

The characteristic resistance of the channel lips, $V_{Rk,s,l,x,S8}$ and $V_{Rk,s,l,x,S9}$ shall be determined according to Equation (2.31) taking into account the actual steel strength.

The reduction factor α_{inst} accounting for the sensitivity to installation shall be determined according to Equation (2.32).

$$\alpha_{inst} = min\,(V_{Rk,s,l,x,S8}\,;\, V_{Rk,s,l,x,S9}) \,/\, V_{Rk,s,l,x,S7} \quad [-] \qquad (2.32)$$

$V_{Rk,s,l,x,S7}$ = According to Equation (2.31) [N]

It shall be permitted to evaluate the value α_{inst} on the basis of mean converted peak loads, provided that:

a. the difference in the number of replicates in the test series to be compared is not greater than five; and

b. the coefficient of variation of the converted peak loads measured in tests S8 and S9 is less than or equal to the coefficient of variation of the converted peak loads in tests S7 or less than or equal to 10%.

The factor γ_{inst} shall be determined according to Table 2.2 by comparing the factor α_{inst} according to Equation (2.32) with the value of req. α_{inst}.

Table 2.2: Values of req. α_{inst} in the sensitivity to installation tests

factor γ_{inst}	req. α_{inst} for tests according to Table A.1, test series S8 and S9
1,0	≥ 0,95
1,2	0,95 > α_{inst} ≥ 0,80
1,4	α_{inst} < 0,80

For anchor channels with α_{inst} < 0,70 the characteristic resistance $V_{Rk,s,l,x}$ evaluated in accordance with Section 2.2.15 shall be multiplied by the ratio (α_{inst} /0,7) ≤ 1. This reduced value $V_{Rk,s,l,x}$ shall be reported in the ETA.

2.2.17 Characteristic resistance to steel failure of the anchor under static and quasi-static loading in longitudinal channel axis

The characteristic resistance of an anchor in x-direction, $V_{Rk,s,a,x}$, shall be determined according to Equation (2.33).

$V_{Rk,s,a,x}$	=	$\alpha_s \cdot A_s \cdot f_{uk}$	[N]	(2.33)
α_s	=	0,6 for f_{uk} < 800 N/mm² and f_{yk} / f_{uk} < 0,8	[-]	
	=	0,5 for f_{uk} ≥ 800 N/mm² or f_{yk} / f_{uk} ≥ 0,8		
A_s	=	stressed cross section of anchor	[mm²]	
f_{uk}	=	nominal characteristic steel ultimate tensile strength of anchor	[N/mm²]	

2.2.18 Characteristic resistance to steel failure of connection between anchor and channel under static and quasi-static loading in longitudinal channel axis

The characteristic resistance of the connection between anchor and channel in x-direction, $V_{Rk,s,c,x}$, shall be determined according to Equation (2.34)

$V_{Rk,s,c,x}$	=	$\alpha_s \cdot N_{Rk,s,c}$	[N]	(2.34)
α_s	=	0,6 for f_{uk} < 800 N/mm² and f_{yk} / f_{uk} < 0,8	[-]	
	=	0,5 for f_{uk} ≥ 800 N/mm² or f_{yk} / f_{uk} ≥ 0,8		
$N_{Rk,s,c}$	=	Characteristic resistance to steel failure of connection between anchor and channel	[N]	

2.2.19 Characteristic resistance to concrete pry-out failure under static and quasi-static shear loading

Determination of the factor k_8 used in the EN 1992-4 [3] or Technical Report TR 047 "Design of Anchor Channels" [4] for calculation of the characteristic resistance to pry-out failure under shear loading.

The value k_8 shall be taken as:

k_8 = 1,0 for anchor channels with h_{ef} < 60 mm

k_8 = 2,0 for anchor channels with h_{ef} ≥ 60 mm

The value k_8 shall be given in the ETA for each channel size.

2.2.20 Characteristic resistance to concrete edge failure under static and quasi-static shear loading (anchor channel parallel to the edge)

Determination of the channel factors $k_{cr,V}$ and $k_{ucr,V}$ used in EN 1992-4 [3] or Technical Report TR 047 "Design of Anchor Channels" [4] for the calculation of the characteristic concrete edge resistance under shear load.

No tests are required, if the factors $k_{cr,V}$ = 4,5 and $k_{ucr,V}$ = 6,3 are given for all types and sizes of anchor channels applied for and if channels are used with $h_{ch}/h_{ef} \leq 0,4$ and $b_{ch}/h_{ef} \leq 0,7$.

Note: Channels with $h_{ch}/h_{ef} > 0,4$ and / or $b_{ch}/h_{ef} > 0,7$ included in this EAD subject to tension loading only (see 1.1.1 and 1.2.1).

If $k_{cr,V}$ > 4,5 is applied for, the tests according to Table A.1, line C2 shall be performed. All anchor channel profiles, sizes, anchor types and anchor connection types for which an ETA is applied for shall be tested.

It shall be permitted to use grouping to reduce the test program. Where grouping is used, the tests shall be performed with the smallest anchor channel of a group of anchor channels for which the channel factor $k_{cr,V}$ and $k_{ucr,V}$ shall apply. If several types of anchors are specified for a given channel size, anchor channels with anchors that provide the least shear resistance shall be tested. If this anchor cannot be established, test anchor channels with all anchor types. Use anchor channels with the lowest specified steel strength. Anchor channels shall be grouped according to the following principles:

1. The exterior profile of the channel and the attached anchor is not varied as the anchor channel size increases. See Figure 2.7 for typical anchor channel profiles.

2. The anchor type (round, I-profile, other) and orientation is constant (see Figure 2.8).

3. The connection type and manufacturing method is constant (see Figure 2.9).

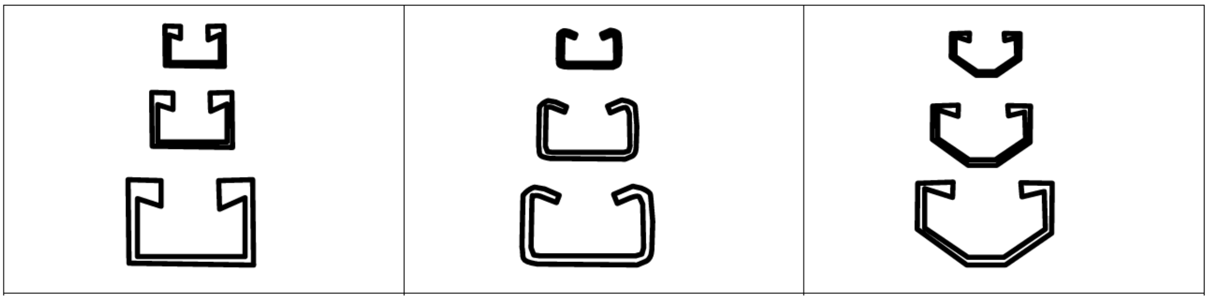
4. For round anchors, the anchor shaft and head of the anchor channels in the group are equal to or greater than that used with the smallest anchor channel of the group. For I or T-profiles, the cross-sectional areas of the web and the flanges of the anchor channels in the group are equal to or greater than that used with the smallest anchor channel of the group.

5. The height of the channel, the distance from the end of the channel to the centre line of the anchors, the embedment depth of the anchors, and the calculated value of the moment of inertia, I_z, of the channel profile around the z-axis (see Figure 1.1) of the anchor channels in the group are equal to or greater than the values associated with the smallest anchor channel of the group.

6. The nominal characteristic steel strength f_{uk} and the nominal characteristic yield strength f_{yk} associated with the anchor channels in the group are equal to or greater than the values associated with the smallest anchor channel of the group.

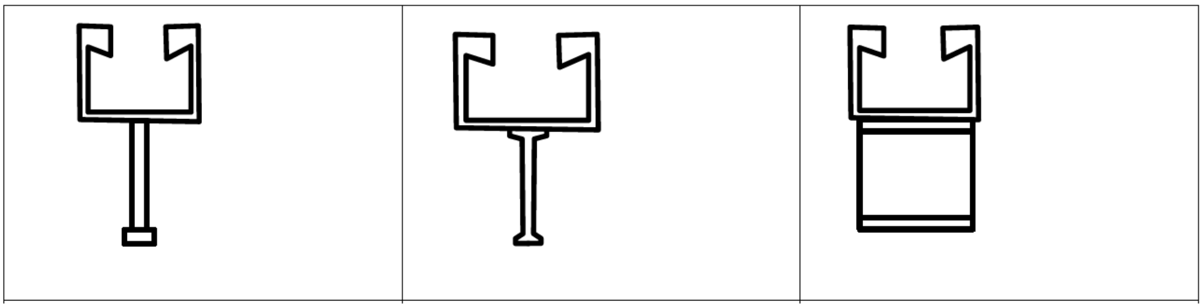
7. The ratio c'_1/c_1 at $c_1 = c_{1,min}$ of the anchor channels in the group is equal to or larger than the ratio corresponding to the smallest anchor channel of the group (see Figure 1.3).

8. The edge distance, c'_1, associated with the anchor channels in the group is equal to or larger than the value corresponding to the smallest anchor channel of the group.



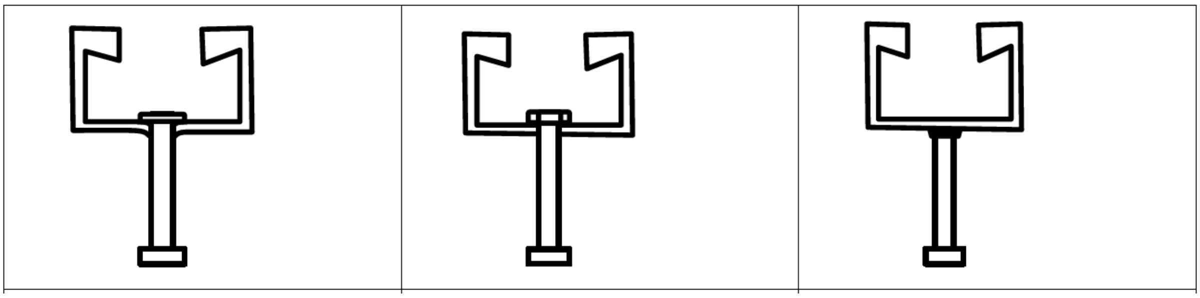
Hot-rolled rectangular | Cold-formed rectangular | Cold-formed non-rectangular

Figure 2.7: Anchor channel grouping by profile



Round Anchors | I-profile orientation A | I-profile orientation B

Figure 2.8: Anchor channel grouping by anchor type



Forged anchor connection | Bolted anchor connection | Welded anchor connection

Figure 2.9: Anchor channel grouping by connection type

Test conditions:

Cast anchor channels with two anchors parallel to the edge of a concrete member. The spacing of the anchors shall correspond to the maximum value and the distance between the end of the channel and the anchor axis to the minimum value specified by the manufacturer for the tested channel size.

The member thickness shall be large enough to avoid an influence on the failure load ($h > h_{cr,V}$). The edge distance shall be the minimum edge distance applied for by the manufacturer for the tested channel size. Steel failure of the anchor channel or the channel bolt should be avoided.

Place a PTFE layer (or other friction- limiting material of similar friction coefficient) over the entire contact area between fixture, concrete surface, and channel profile.

Two channel bolts shall be inserted in the channel directly over the anchors and shall be pre-stressed in accordance with Section A.2. Apply shear load to the two channel bolts perpendicular to the longitudinal axis of the anchor channel. The shear loads applied to the two channel bolts shall be equal.

The clear distance between the support reaction and any loaded anchor shall be greater than or equal to $2,5 \cdot c_1$. The shear force shall be applied at the centre of the fixture (distance between applied shear force and concrete surface $0,5 \cdot t_{fix}$) (see Figure 2.10).

The thickness of the fixture in the immediate vicinity of the tested anchor channel shall be equal to or greater than the diameter of the used channel bolt ($t_{fix} \geq d$). Lift-up of the fixture due to a displacement of the anchor channel shall not be restraint.

The diameter of the clearance hole in the fixture shall be taken according to EN 1992-4 [3], Table 6.1 resp. Table A.2 of this EAD.

A typical test setup is shown in Figure 2.10.

Increase the shear-load until failure. Record the applied shear-load, the displacement of the anchor channel at the locations of the applied shear-load, any cracks in the concrete, the failure load and the failure mode.

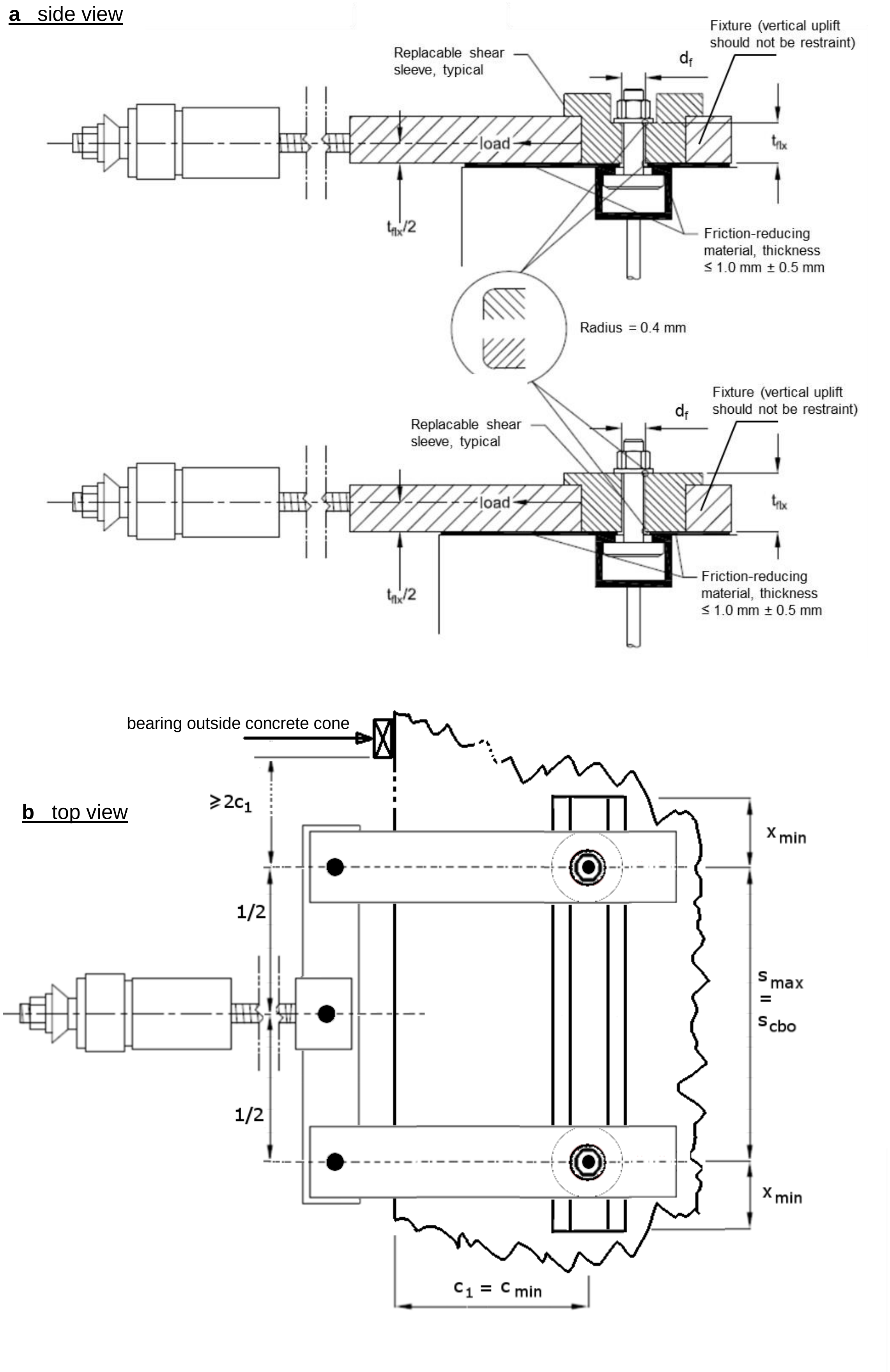


Figure 2.10: Example of shear plate with sleeves and required location of the applied shear-load for test series C2 of Table A.1

Assessment of test results:

The factor $k_{cr,V}$ shall be computed according to Equation (2.35).

$$k_{cr,V} = \frac{min.\left(0{,}75 \cdot V_{u,m,test}\,;\, V_{Rk,test}\right)}{{f_{c,test}}^{0,5} \cdot c_1^{4/3} \cdot \psi_{ch,s,V}} \cdot \frac{1}{1{,}4} \leq 7{,}5 \quad [-] \qquad (2.35)$$

(cracked concrete without reinforcement)

$V_{u,m,test}$	=	mean value of the failure loads applied to one anchor measured in test series C2 of Table A.1	[N]
$V_{Rk,test}$	=	5 % fractile of the failure loads applied to one anchor measured in test series C2 of Table A.1	[N]
$f_{c,test}$	=	actual concrete compressive strength of the test member at time of testing measured on cylinders	[N/mm²]
c_1	=	actual edge distance of the anchor channel in the tests	[mm]
$\psi_{ch,s,V}$	=	factor to take into account the influence of neighbouring anchors on the concrete edge failure load calculated according to Equation (2.36)	[-]

$$\psi_{ch,s,V} = \frac{1}{1 + \left(1 - \frac{s}{s_{cr,V}}\right)^{1,5}} \quad [-] \qquad (2.36)$$

s	=	actual anchor spacing in the tests	[mm]
$s_{cr,V}$	=	$4\,c_1 + 2\,b_{ch}$	[mm]

The factor $k_{cr,V}$ according to Equation (2.35) shall be stated in steps of 0,1 and shall be rounded down to the nearest 0,1.

The factor $k_{ucr,V}$ shall be computed according to Equation (2.37).

$$k_{ucr,V} = k_{cr,V} \cdot 1{,}4 \quad [-] \qquad (2.37)$$

(uncracked concrete without reinforcement)

$k_{cr,V}$	=	Rounded value according to Equation (2.35)	[-]

The factors $k_{cr,V}$ and $k_{ucr,V}$ determined as described above shall be stated in the ETA for each channel size.

2.2.21 Steel failure of anchor channel due to combined static and quasi-static tension and shear loads on anchor channels embedded in concrete

The values k_{13} and k_{14} are selected from EN 1992-4, 7.4.3.1 [3] based on input values established according to this EAD.

2.2.22 Characteristic fatigue resistance to steel failure of the whole system under fatigue cyclic tension loading – Test method A1, A2

Determination of the characteristic resistance for any steel failure of the whole system (anchor, connection anchor/channel, flexure channel lips, channel bolt, flexure channel).

The tests shall be performed according to Section B.2, Figure B.1, and Figure B.2.

Reference tests for steel failure under tension (Table B.1, lines FR1 and FR2)

For the determination of the characteristic static (or, equivalently, fatigue) resistance for n=1 cycles, testing in accordance with Table B.1, lines FR1 and FR2 shall be performed. All channel bolts, channels, connection types, and anchor sizes with all materials and coatings specified by the manufacturer shall be tested.

Test conditions:

The anchor channels shall be loaded in position 1 (test series FR1) and position 2 (test series FR2) until failure. In position 1, the channel bolt shall be inserted in the channel midway between the two anchors and, in position 2, over one anchor. The minimum failure load derived from the two loading positions shall be used to determine the characteristic tension fatigue resistance for n=1 cycles (Final tests).

For the determination of the characteristic static (or, equivalently, fatigue) resistance for n=1 cycles at least five tests are required for the unfavourable load position. For each position testing shall be performed three test results at least. If three results for each positions are available, the unfavourable position may be identified. The remaining two tests shall be performed only for the unfavourable load position.

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

The value of $N_{Rk,s}$ shall be used for the determination of the characteristic fatigue resistance functions.

Pre-tests for steel failure under fatigue cyclic tension (Table B.1, lines FP1 and FP2)

Determination of the unfavourable loading position for fatigue loading. The unfavourable loading position for fatigue cyclic loading is defined as the one providing the lowest number of load cycles to failure for a given load level.

For the determination of the unfavourable loading position for fatigue loading, pre- tests according to Table B.1, lines FP1 and FP2 shall be performed. All channel bolts, channels, connection types, and anchor sizes with all materials and coatings specified by the manufacturer shall be tested.

Test conditions:

The tests shall be performed according to Section B.2, Figure B.1, and Figure B.2.

The anchor channels shall be loaded in position 1 (test series FP1) and position 2 (test series FP2) with a sinusoidal load process according to Figure 2.11 until failure. In position 1, the channel bolt shall be inserted in the channel midway between the two anchors and, in position 2, over one anchor. The minimum failure load derived from the two loading positions shall be used to determine the characteristic tension fatigue resistance for n=1 cycles (Final tests).

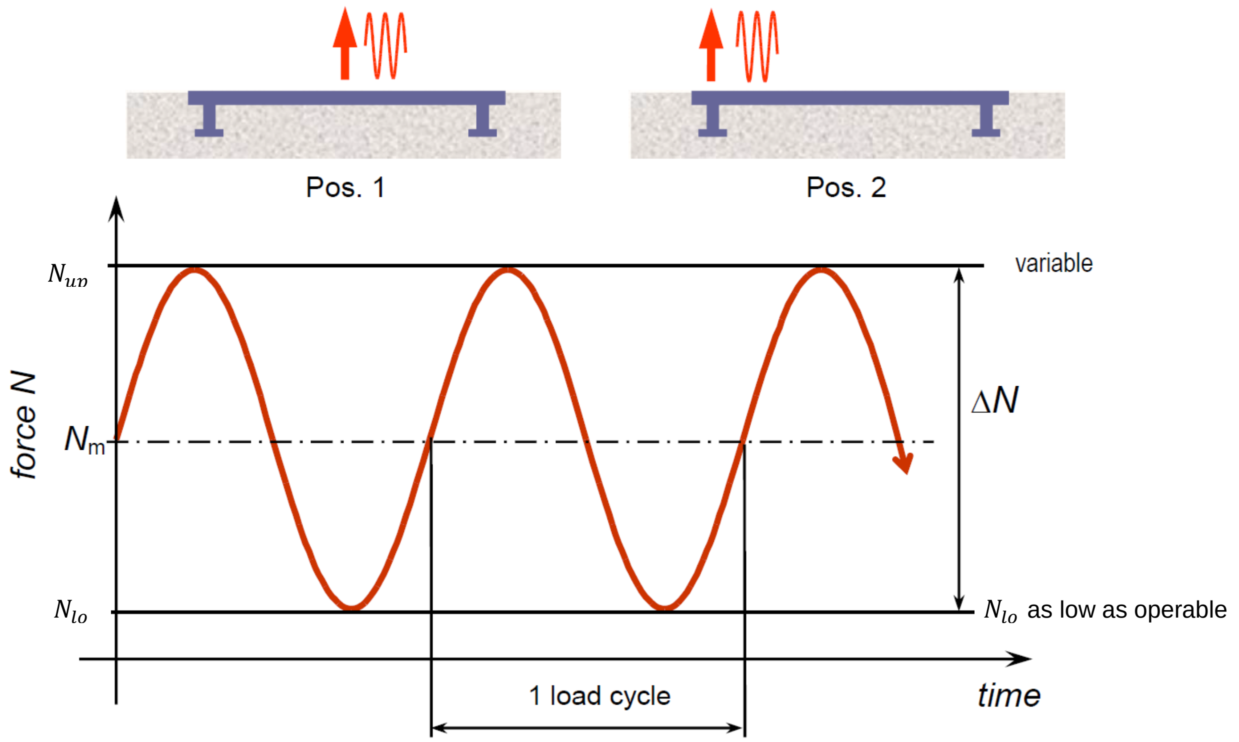


Figure 2.11: Load positions and example of fatigue cyclic loading protocol

For Method A1 (Annex C, Continuous function):

The results of the pre-tests shall be used to determine two preliminary fatigue resistance functions (Position 1 and 2) and, thus, the unfavourable loading position for the final tests for steel failure.

For the determination of the preliminary fatigue resistance functions, tests in Position 1 and Position 2 shall be performed with identical fatigue cyclic load levels (see Figure 2.13 and Figure 2.14).

If the preliminary fatigue resistance functions do not show any crossing point between testing in Position 1 and Position 2 (see Figure 2.13), final tests shall be performed only in the unfavourable loading Position 1 or 2.

If the pre-test results show a crossing point between testing in Position 1 and Position 2 (see Figure 2.14), final tests shall be performed in Position 1 and/or Position 2 depending on the location of the crossing point.

The determination of the final fatigue resistance function shall only take into account those test and pre-test results performed in the unfavourable loading position(s) (see Figure 2.12).

Additional information on the determination of the preliminary and final fatigue resistance functions is included in Annex C.

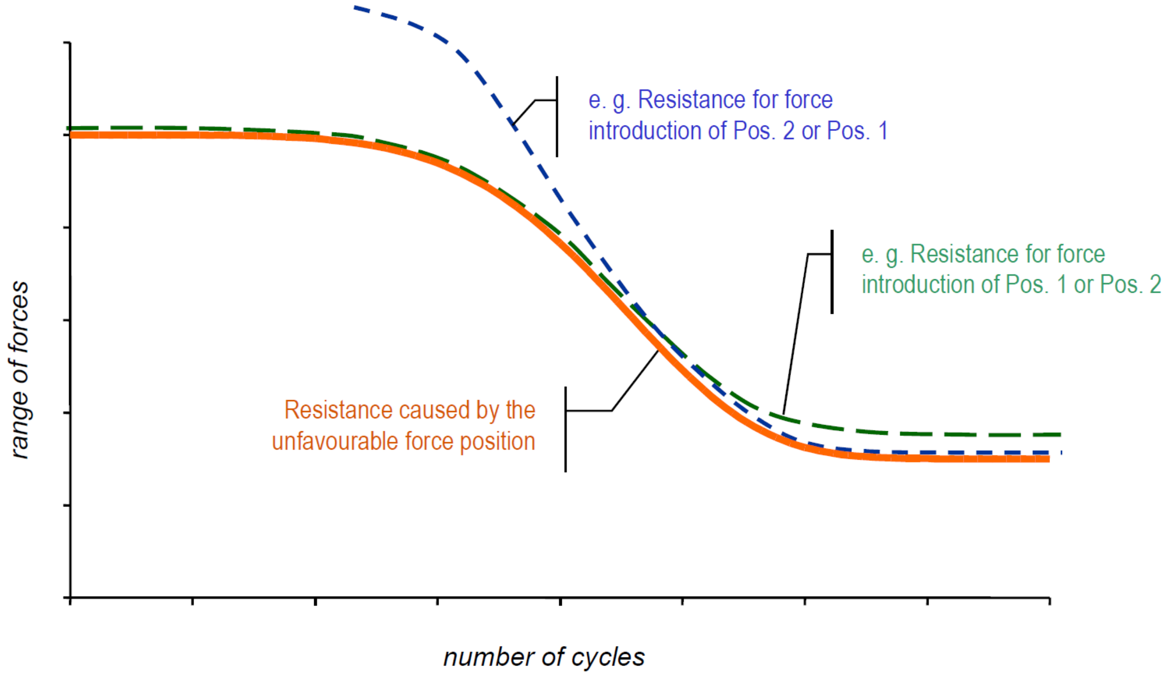


Figure 2.12: Example for the determination of the fatigue failure function depending on the unfavourable load position (test method A1)

For Method A2 (Annex D, Tri-linear function):

The tri-linear approach does not allow the determination of preliminary fatigue resistance functions as per Method A1. Therefore, the results of the pre-tests shall be used only to determine the (unfavourable) loading position (1 or 2) for the final tests for steel failure.

For the determination of the unfavourable loading position, tests in Position 1 and Position 2 shall be performed with identical fatigue cyclic load levels (see Figure 2.13 and Figure 2.14).

If the pre-test results do not show any crossing point between testing in Position 1 and Position 2 (see Figure 2.13), final tests shall be performed only in the unfavourable loading Position 1 or 2.

If the pre-test results show a crossing point between testing in Position 1 and Position 2 (see Figure 2.14), final tests shall be performed in Position 1 and/or Position 2 depending on the location of the crossing point.

The determination of the final tri-linear fatigue resistance function shall only take into account those test and pre-test results performed in the unfavourable loading position(s).

Additional information on the assessment of the pre-tests and the determination of the final tri- linear fatigue resistance function is included in Annex D.

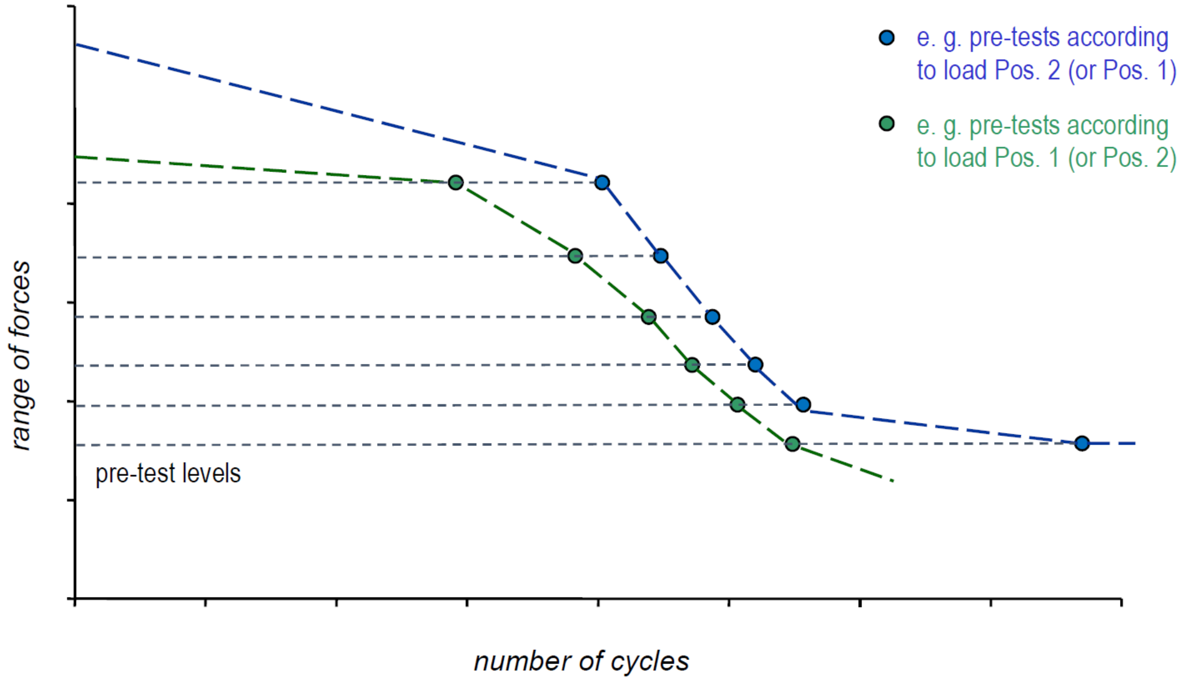


Figure 2.13: Example for the determination of the unfavourable load position - no crossing observed during pre-testing in Position 1 and Position 2

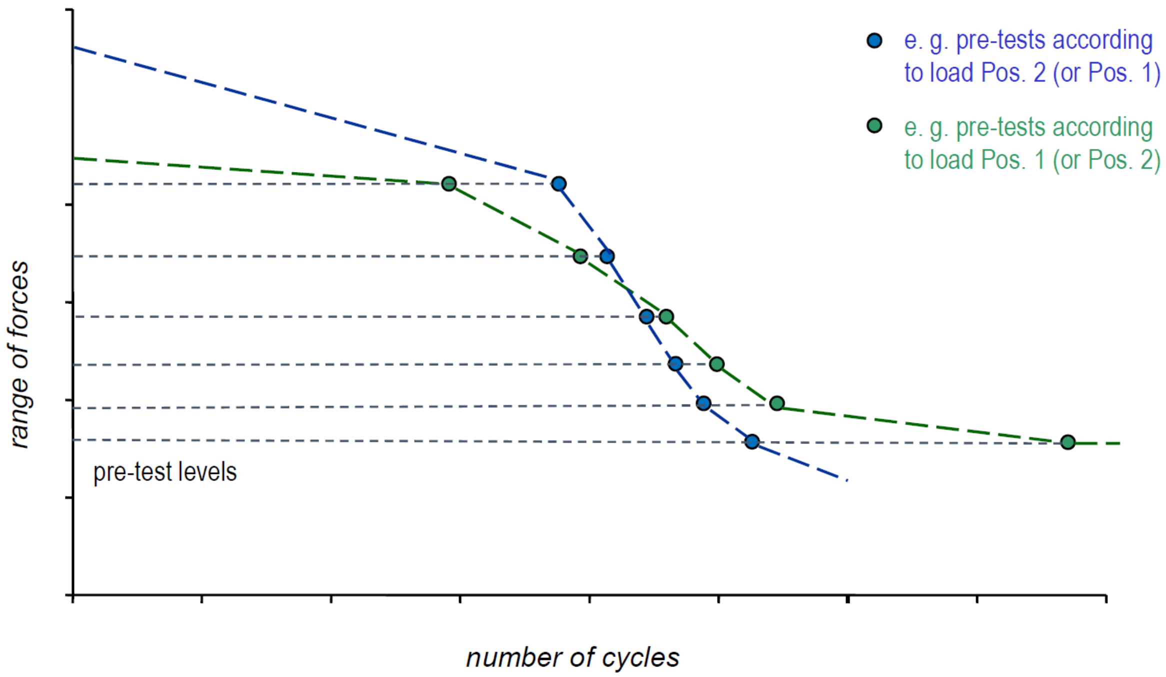


Figure 2.14: Example for the determination of the unfavourable load position - crossing observed during pre-testing in Position 1 and Position 2

<u>Final tests for steel failure under fatigue cyclic tension</u> (Table B.1, lines F1)

Determination of the final characteristic fatigue resistance functions for any steel failure of the whole system (anchor, connection anchor/channel, flexure channel lips, channel bolt, flexure channel) as a function of the number of load cycles, n.

For the determination of the final characteristic fatigue resistance functions, testing in accordance with Table B.1 (test method A1 or A2, test series F1) shall be performed. All channel bolts, channels, connection types, and anchor sizes with all materials and coatings specified by the manufacturer shall be tested.

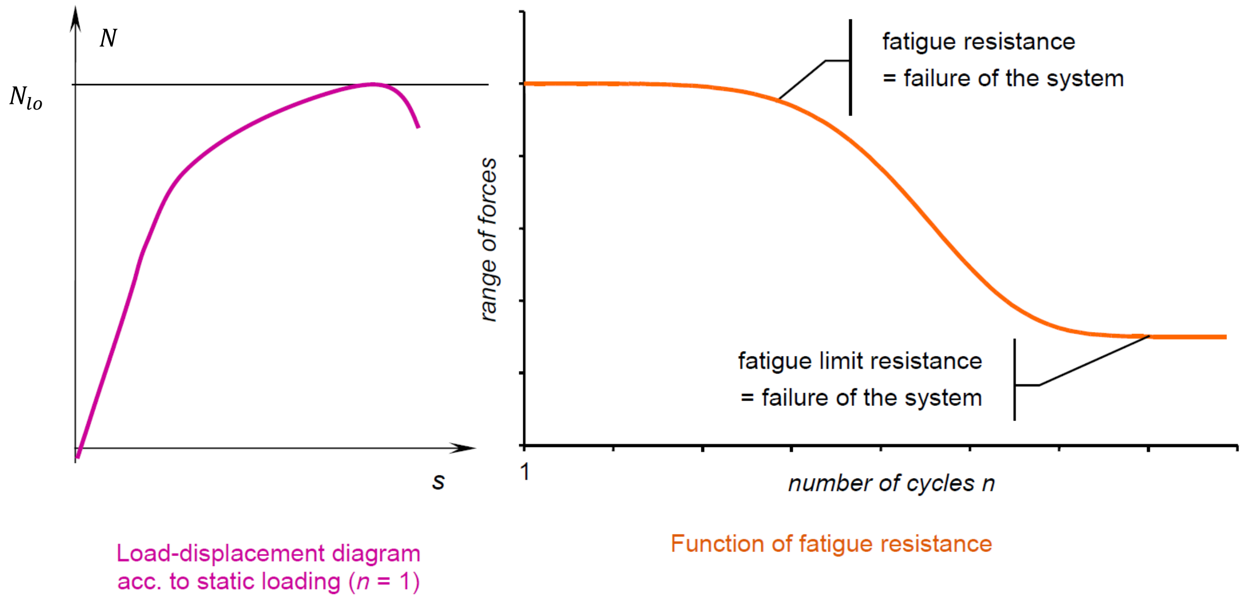
Test conditions:

The anchor channels shall be loaded in the unfavourable load position, as determined in pre-tests with a sinusoidal load process. Additional information on the testing and loading requirements is included in Annexes C and D.

The assessment method shall be given in the relevant ETA. The assessment method applies to anchorage in normal weight concrete of C20/25 to C90/105 according to EN 206-1 [12].

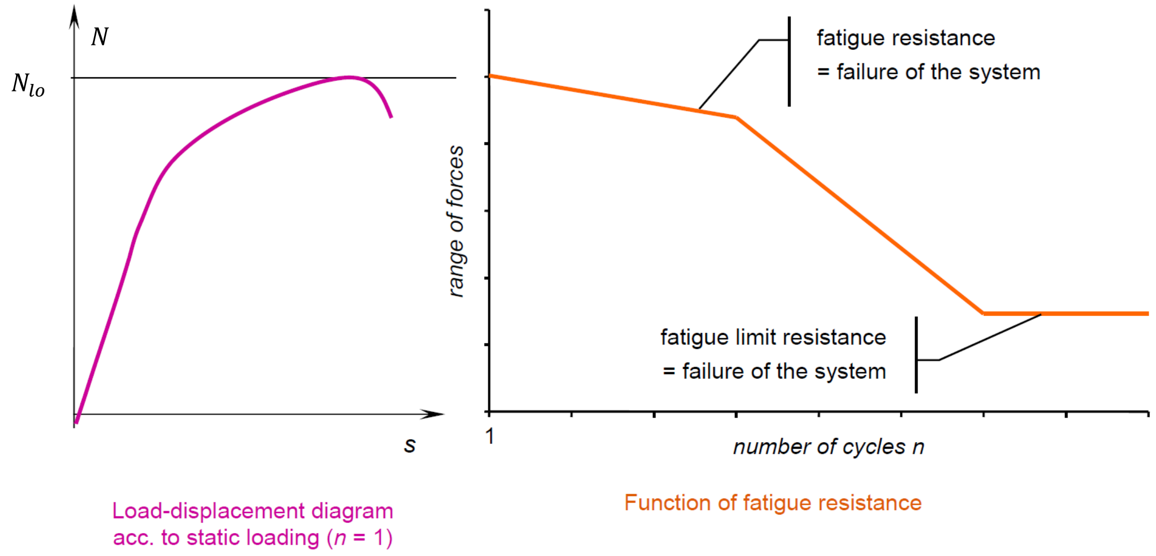
The number of cycles to failure, n, for each range of force ΔN shall be determined through testing.

The test results shall be used for the determination of the fatigue resistance functions (see Figure 2.15 (Method A1) and Figure 2.16 (Method A2)).



N_{lo} static load resistance

Figure 2.15: Example of a fatigue resistance function based on failure of the system (test method A1)



N_{lo} static load resistance

Figure 2.16: Example of a fatigue resistance function based on failure of the system (test method A2)

Tests which are stopped without failure and started again with a higher stress range may be included in the final evaluation (Reference Annexes C and D for additional information).

All tests according to Table B.1, which belong to the unfavourable decisive load position shall be used for the evaluation of the final fatigue resistance functions.

The characteristic fatigue resistance functions are determined by statistical evaluation (Figure 2.17 (Method A1) or Figure 2.18 (Method A2)) based on the 5%-quantile (5%-fractile) with a confidence level of 90%:

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

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

The minimum of the characteristic resistance $N_{Rk,s}$ of the anchor channel for n=1 cycles as determined from test series FR1 and FR2 according Table B.1 the characteristic resistances $N_{Rk,s,a}$, $N_{Rk,s,c}$, $N^0_{Rk,s,l}$, $N_{Rk,s}$, and $N_{Rk,s,flex}$ as determined in static tension tests in accordance with this EAD shall be taken as the characteristic fatigue resistance for n = 1 cycles.

If the characteristic resistance $N_{Rk,s}$ of the anchor channel for n=1 cycles as determined from test series FR1 and FR2 according Table B.1 is larger than the characteristic resistances $N_{Rk,s,a}$, $N_{Rk,s,c}$, $N^0_{Rk,s,l}$, $N_{Rk,s}$, and $N_{Rk,s,flex}$ as determined in static tension tests in accordance with this EAD, the characteristic fatigue resistance functions shall be reduced using the following reduction factors ($\eta_{k,red}$):

- For the fatigue limit resistance, $\eta_{k,red,\infty} = 1{,}0$
- In the transition zone between n = 1 and the fatigue limit resistance

$$\eta_{k,red,n} = \eta_{k,red,\infty} + (\eta_{k,red} - \eta_{k,red,\infty}) \cdot (\Delta N_{Rk,n} - \Delta N_{Rk,\infty}) / (N_{Rk,s} - \Delta N_{Rk,\infty}) \quad [-] \quad (2.38)$$

$N_{Rk,s}$ = characteristic value of static resistance as determined from tests series FR1 and FR2

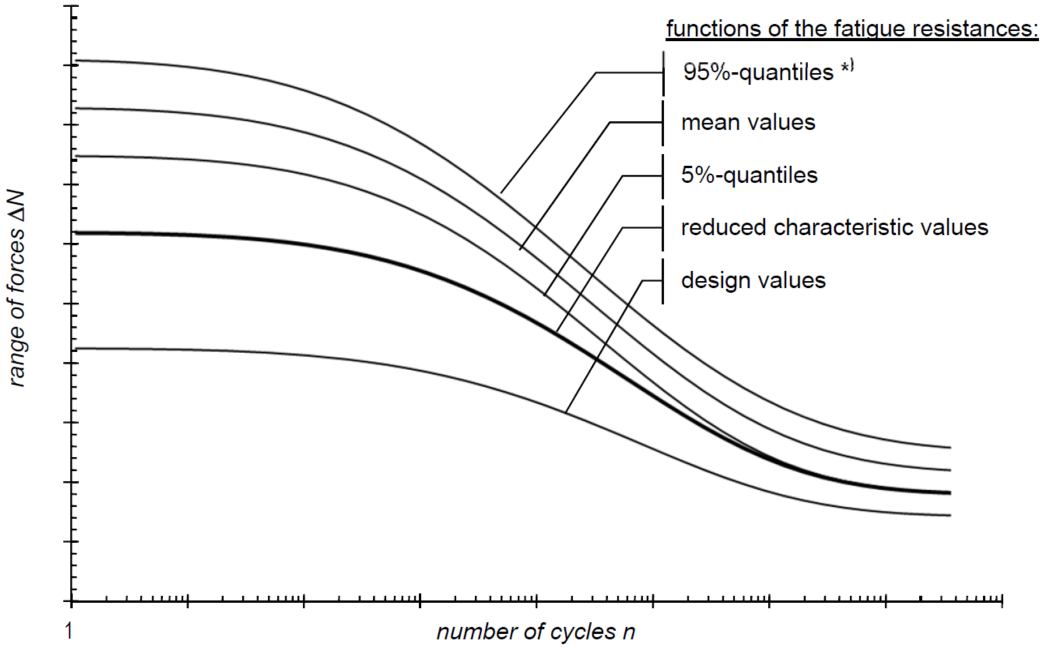
$\Delta N_{Rk,n}$ = characteristic value of fatigue resistance under fatigue cyclic loading after n load cycles

$\Delta N_{Rk,\infty}$ = characteristic value of fatigue limit resistance under fatigue cyclic loading

$$\eta_{k,red} = N_{Rk,s} \,/\, min\,(N_{Rk,s,a}\,, N_{Rk,s,c}\,, N^0_{Rk,s,l}, N_{Rk,s}\,, N_{Rk,s,flex}) \quad [-] \quad (2.39)$$

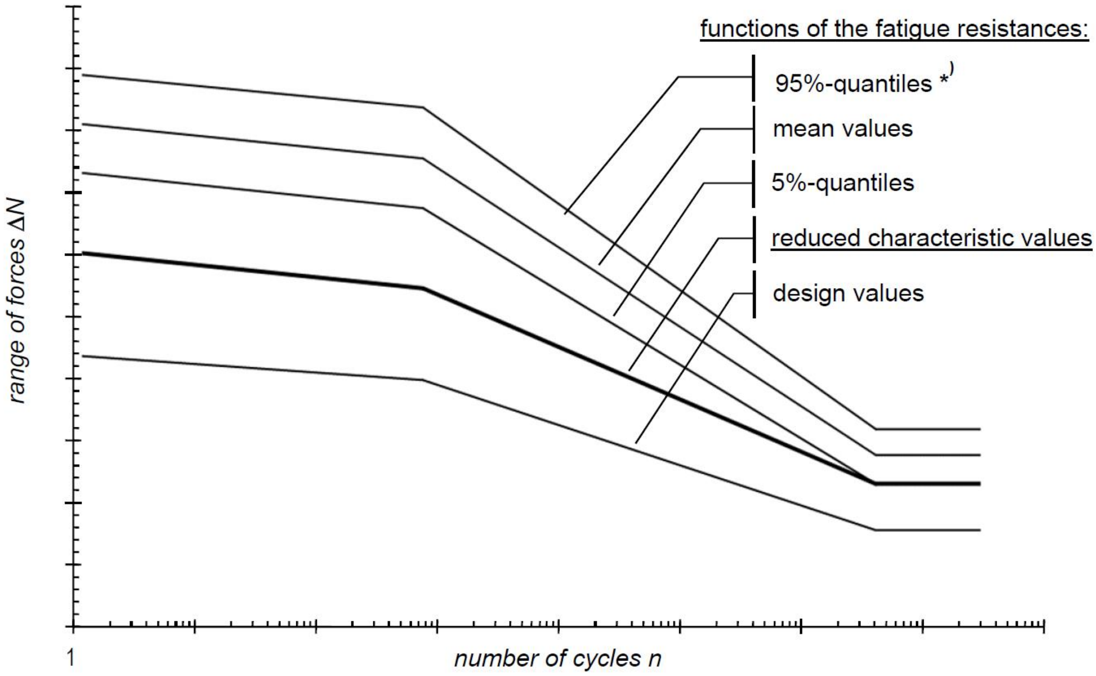
Note that the fatigue resistance corresponds to the failure of the system and not to its yield strength (see Figure 2.15 and 2.16).

The test reports shall include all the relevant information regarding the fatigue resistance functions (i.e., calibration of analytical parameters, equations, slopes of straight lines, etc.).



*) optional

Figure 2.17: Example of characteristic and design fatigue resistance functions (test method A1)



*) optional

Figure 2.18: Example of characteristic and design fatigue resistance functions (test method A2)

2.2.23 Characteristic fatigue limit resistance to steel failure of the whole system under fatigue cyclic tension loading – Test method B

The tests shall be performed according to Section B.2, Figure B.1, and Figure B.2.

Final tests for steel failure under fatigue cyclic tension (Table B.2, lines F3 and F4)

Determination of the characteristic fatigue limit resistance for any steel failure of the whole system (anchor, connection anchor/channel, flexure channel lips, channel bolt, flexure channel) at a pre-defined number of load cycles, n_{lim}.

For the determination of the characteristic fatigue limit resistance final tests according to Table B.2 (test method B, test series F3 and F4) shall be performed. All channel bolts, channels, connection types, and anchor sizes with all materials and coatings specified by the manufacturer shall be tested.

Test conditions:

The anchor channels shall be loaded in Position 1 and Position 2 with a sinusoidal load process. The applied fatigue cyclic load level shall be identical for both Position 1 and Position 2.

The assessment method shall the methods outlined in Technical Report TR 050 "Calculation Method for the Performance of Anchor Channels under fatigue loads" [28] and shall be given in the relevant ETA. The assessment method applies to anchorage in normal weight concrete of C20/25 to C90/105 according to EN 206-1 [12].

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.

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

- no steel failure occurs for all tests in Position 1 and Position 2.
- 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 E.
- run-out 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 is not permitted to combine results from tests performed at different load levels.

The characteristic fatigue limit resistance is calculated in accordance with the Annex E.

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

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

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

Reference tests for steel failure under fatigue cyclic tension (Table B.2, lines FR3 and FR4)

Determination of the minimum number of load cycles for run-out tests for any steel failure of the whole system (anchor, connection anchor/channel, flexure channel lips, channel bolt, flexure channel).

For the determination of the minimum number of load cycles for run-out tests reference tests according to Table B.2 (test method B, test series FR3 and FR4) shall be performed. All channels, connection types, and anchor sizes with all materials and coatings specified by the manufacturer shall be tested.

Test conditions:

The anchor channels shall be loaded in Position 1 and Position 2 with a sinusoidal load process.

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

All tests according to Table B.2, series FR3 and FR4, 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 E.

2.2.24 Characteristic fatigue resistance to concrete related failure of the whole system under fatigue cyclic tension loading

Determination of the characteristic resistance for any concrete related failure mode (concrete cone, pull-out)

The characteristic concrete cone fatigue resistance, $\Delta N_{Rk,c,0,n}$, for fatigue loads as a function of the number of cycles, n, can be calculated as follows:

$$\Delta N_{Rk,c,0,n} = \eta_{k,c,fat} \cdot N_{Rk,c} \quad \text{[N]} \quad (2.40)$$

$$\eta_{k,c,fat} = 1{,}108 \cdot n^{-0{,}0444} \geq 0{,}5 \quad (2.41)$$

The characteristic pull-out fatigue resistance, $\Delta N_{Rk,p,0,n}$, can be calculated following:

$$\Delta N_{Rk,p,0,n} = \eta_{k,p,fat} \cdot N_{Rk,p} \quad \text{[N]} \quad (2.42)$$

$$\eta_{k,p,fat} = \eta_{k,c,fat}$$

2.2.25 Characteristic fatigue limit resistance to concrete related failure of the whole system under fatigue cyclic tension loading

Determination of the characteristic resistance for any concrete related failure (concrete cone, pull-out)

The characteristic concrete cone fatigue and pull-out fatigue resistances under fatigue cyclic tension can be calculated as follows:

$$\Delta N_{Rk,c,0,\infty} = 0{,}5 \cdot N_{Rk,c} \quad \text{[N]} \quad (2.43)$$

$$\Delta N_{Rk,p,0,\infty} = 0{,}5 \cdot N_{Rk,p} \quad \text{[N]} \quad (2.44)$$

2.2.26 Displacements

The characteristic displacements for short-term and quasi-permanent loading are specified for the tension load N and shear load V in accordance with following equations:

$$N = N_{Rk} / (\gamma_F \cdot \gamma_M) \quad \text{[N]} \quad (2.45)$$

$$V = V_{Rk} / (\gamma_F \cdot \gamma_M) \quad \text{[N]} \quad (2.46)$$

N_{Rk}	=	characteristic resistance to tension load
V_{Rk}	=	characteristic resistance to shear load
γ_F	=	partial safety factor for actions = 1,4
γ_M	=	partial safety factor for material according EN 1992-4 [3] or Technical Report TR 047 "Design of Anchor Channels" [4]

The displacements δ_{N0} $\delta_{V,y,0}$ and $\delta_{V,x,0}$ under short-term loading are evaluated from test series Table A.1, lines S4, S6 and S8. The value derived should correspond to the mean value of these test series. The displacements (in mm) should be rounded to one position after decimal point.

The displacements $\delta_{N\infty}$ under long-term tension loading are assumed to be approximately equal to 2,0-times the value δ_{N0}.

The displacements $\delta_{V,y,\infty}$ respectively $\delta_{V,x,\infty}$ under long-term shear loading are assumed to be approximately equal to 1,5-times the value $\delta_{V,y,0}$ respectively $\delta_{V,x,0}$.

Under shear loading, the displacements might increase due to a gap between fixture and anchor channel.

It shall be stated clearly in the ETA if this gap is taken into account in the assessment.

2.2.27 Durability

Supporting evidence that corrosion will not occur is not required if the anchor channels (anchor, channel profile, channel bolt, washer, hexagonal nut) are protected against corrosion, as set out below:

(1) Anchor channels intended for use in structures subject to dry, internal conditions:

No special corrosion protection is necessary for anchor channels.

(2) Anchor channels for use in structures subject to internal conditions with usual humidity (e.g. kitchen, bath- and laundry in residential buildings, exceptional permanently damp conditions and application under water):

Anchor channels made of steel material 1.0038 or 1.0044 according to EN 10025-2 [6], 1.0976 or 1.0979 according to EN 10149-1 and -2 [18], 1.0213, 1.0214, 1.1132, 1.5525 or 1.5535 according to EN 10263-2, -3, and -4 [15], 1.5523 according to EN 10269 [19] or 1.0401 according to EN 10277-2 [25] hot dip galvanized according to EN ISO 1461 [23] or EN ISO 10684 [24] with at least 50 µm thickness are considered to have sufficient durability.

(3) Anchor channels for use according EN 1993-1-4 [1], Annex A:

Anchor channels made of stainless steel according to EN 1993-1-4 [1], Annex A, Table A.3 and A.4 are considered to have sufficient durability.

Anchor channels with channel profiles, channel bolt, washer and nut made of stainless steel of corrosion resistance class III and anchors made of stainless steel of corrosion resistance class II may be used as anchor channels of corrosion resistance class III, if

- the anchor channel is loaded by static or quasi-static action only,
- the anchors are welded to the channel back (top of the anchor protected by channel profile),
- the concrete cover of the anchor is more than 22 mm and there are no tempering colors in the area of the concrete cover.

(4) Anchor channels for use according EN 1993-1-4 [1], Annex A without chlorides:

Channels profiles, channel bolts, washers and hexagonal nuts made of stainless steel according EN 1993-1-4 [1], Annex A, Table A.3 with anchors made of steel material 1.0038 according to EN 10025-2 [6] are considered to have sufficient durability, if the anchors are welded to the channel back (top of the anchor protected by channel profile) and the concrete cover of the anchor is more than 50 mm if the tempering colours are removed. If tempering colours are not removed the concrete cover is 100 mm.

2.2.28 Reaction to fire

The anchor channel (including bolts) is considered to satisfy the requirements for performance class A1 of the characteristic reaction to fire in accordance with the EC Decision 96/603/EC (as amended) without the need for testing on the basis of it fulfilling the conditions set out in that Decision and its intended use being covered by that Decision.

Therefore the performance of the product is class A1.

2.2.29 Resistance to fire

The assessment of an anchor channel for use in a system that is required to provide a specific fire resistance class shall be determined according to Annex F subjected to the following conditions:

The determination of the duration of the fire resistance is according to the conditions given in EN 1363-1 [2] using the "Standard Temperature/Time Curve" (STC).

In general, the duration of the fire resistance of anchor channels depends mainly on the configuration of the structure itself (base materials, anchor channels including the fixture). It is not possible to classify an anchor channel for its fire resistance. This evaluation concept includes the behaviour of the anchor channel in concrete and the parts outside the concrete. The influence of the fixation is considered unfavourable.

The fire resistance to steel failure may only be determined by testing under tension load. The resistances to steel failure under tension load may be used as the resistances under shear load. For determining the stress according to Annex F the cross section of the channel bolt shall be used.

Fire resistance performance cannot be claimed for individual products only, since it is a characteristic of a complete system.

The characteristic values of resistances are determined as follows:

$N_{Rk,s,fi,30}$	=	$\sigma_{Rk,s,fi,30} \cdot \pi \cdot d^2 /4$	[N]	(2.47a)
$N_{Rk,s,fi,60}$	=	$\sigma_{Rk,s,fi,60} \cdot \pi \cdot d^2 /4$	[N]	(2.47b)
$N_{Rk,s,fi,90}$	=	$\sigma_{Rk,s,fi,90} \cdot \pi \cdot d^2 /4$	[N]	(2.47c)
$N_{Rk,s,fi,120}$	=	$\sigma_{Rk,s,fi,120} \cdot \pi \cdot d^2 /4$	[N]	(2.47d)
$V_{Rk,s,fi,30}$	=	$N_{Rk,s,fi,30}$	[N]	(2.48a)
$V_{Rk,s,fi,60}$	=	$N_{Rk,s,fi,60}$	[N]	(2.48b)
$V_{Rk,s,fi,90}$	=	$N_{Rk,s,fi,90}$	[N]	(2.48c)
$V_{Rk,s,fi,120}$	=	$N_{Rk,s,fi,120}$	[N]	(2.48d)

$\sigma_{Rk,s,fi,30}$	Characteristic steel stress according to Annex F, F.2.3 for a duration of fire resistance of 30 min	[N/mm^2]
$\sigma_{Rk,s,fi,60}$	Characteristic steel stress according to Annex F, F.2.3 for a duration of fire resistance of 60 min	[N/mm^2]
$\sigma_{Rk,s,fi,90}$	Characteristic steel stress according to Annex F, F.2.3 for a duration of fire resistance of 90 min	[N/mm^2]
$\sigma_{Rk,s,fi,120}$	Characteristic steel stress according to Annex F, F.2.3 for a duration of fire resistance of 120 min	[N/mm^2]
d	diameter of channel bolt	[mm^2]

3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

3.1 System of assessment and verification of constancy of performance to be applied

For the products covered by this EAD the applicable European legal act is Commission Decision 2000/273/EC.

The system is 1.

Note: Anchor channels were previously called "Channel bars".

3.2 Tasks of the manufacturer

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

Table 3.1 gives guidance; the control plan depends on the individual manufacturing process and has to be established between TAB, notified body and manufacturer for each product.

Table 3.1 Control plan for the manufacturer; cornerstones

<table>
<tr><th>No</th><th>Subject/type of control</th><th>Test or control method</th><th>Criteria, if any</th><th>Minimum number of samples</th><th>Minimum frequency of control</th></tr>
<tr><td colspan="6">Factory production control (FPC)
[including testing of samples taken at the factory in accordance with a prescribed test plan]</td></tr>
<tr><td colspan="6">Raw material</td></tr>
<tr><td>1</td><td>Material and material properties of channel</td><td>Inspection certificate 3.1 according to EN 10204 [13]</td><td rowspan="3">Control plan</td><td rowspan="3">1</td><td rowspan="3">Each manufac-turing batch</td></tr>
<tr><td>2</td><td>Material and material properties of anchor</td><td>Test report 2.2 according to EN 10204 [13]</td></tr>
<tr><td>3</td><td>Dimensions and material properties of channel bolts</td><td>Inspection certificate 3.1 according to EN 10204 [13]1)</td></tr>
<tr><td colspan="6">For the welding of the anchors on the channel back the manufacturer shall possess the corresponding recognition for the intended welding process.
1) This does not apply, if tension tests with channel bolts according to line 7 are carried out</td></tr>
</table>

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Tests after production steps					
4	Determination of the functional measurements (thickness, width, height and opening) of the channels and dimensions of the anchors	Gauge	Control plan	3 [2)]	2000 consecutive meter of the anchor channels resp. per 10000 short anchor channels resp. once per production week
5	Checking the thickness of the weld, lengths of the weld, anchor widths	Gauge		3 [2)]	
6	Determination of the ultimate load of the anchor channels not cast into concrete by centric tension tests loaded in the line of the axis of the anchor via anchor and channel. The load shall be transferred into the channel by a load-carrying device with the corresponding geometry of appropriate heads of channel bolts.	Section A2		3 [2)]	
7 [3)]	Determination of the ultimate load of the channel bolts by centric tension tests loaded in the line of the axis of the channel bolt. The load shall be transferred into the head of the bolt by a load-carrying device with the corresponding geometry of appropriate channel profiles. The test shall be carried out for each channel bolt, each channel profile and each type of material of the channel bolt	Section A2		3	
8	Determination of the ultimate load of the anchor channels and channel bolts by shear tests loaded in the line of the axis of the channel profile. The load shall be transferred into the bolt by a fixture. The test shall be carried out for each channel bolt, each channel profile and each type of material of the channel bolt only if shear load acting in the direction of the longitudinal channel axis the is assessed	Section A2		3	
9	Determination of the thickness of the corrosion protection	Visual, measurement		3 [2)]	
10	Characteristic steel fatigue resistance for test method A1 and A2	tests under different fatigue cyclic load levels [4) 7)]	[5)]	3 (1 per load level)	1/material batch
11	Characteristic steel fatigue resistance for test method B	tests on load level ΔS_D [7)]	[6)]	3	

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control

2) for each channel profile, each anchor and each type of material of channel profile and anchor

3) alternatively if inspection certificate 3.1 is not available resp. the characteristic resistance due to steel failure of the channel bolts does not comply to material properties according to EN ISO 898-1 and EN ISO 3506-1

4) The load levels are determined as follows:

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

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

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

5) 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.

6) 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}.

7) Tests shall be performed with the smallest channel bolt.

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 anchor channels are laid down in Table 3.2.

Table 3.2 Control plan for the notified body; cornerstones

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

1) If the product criteria in Table 3.1 are observed, it is not necessary to monitor specific stages of production.

4 REFERENCE DOCUMENTS

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

[2] EN 1363-1:2012 Fire resistance tests - Part 1: General Requirements

[3] EN 1992-4:2018 Eurocode 2: Design of concrete structures; Part 4: Design of fastenings for use in concrete;

[4] EOTA TR 047:2018-01 Technical Report 047, "Design of Anchor Channels"

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

[6] EN 10025-1+2:2005 Hot rolled products of structural steels. Part 1: General technical delivery conditions; Part 2: Technical delivery conditions for non-alloy structural steels;

[7] EN 10088-1, 3, 4+5:2009 Stainless steels Part 1: List of stainless steels, Part 3: Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes;

[8] EN ISO 4063:2010 Welding and allied processes – Nomenclature of processes and reference numbers;

[9] EN ISO 4018:2011 Hexagon head screws – Product grade C;

[10] EN ISO 898-1+2:2013 Mechanical properties of fasteners made of carbon steel and alloy steel. Part 1: Bolts, channel bolts and studs with specified property classes –Coarse thread and fine pitch thread; 2013. Part 2: Nuts with specified property classes-Coarse thread and fine pitch thread, 2012;

[11] EN ISO 3506-1+2:2009 Mechanical properties of corrosion-resistant stainless steel fasteners. Part 1: Bolts, channel bolts and studs, Part 2: Nuts;

[12] EN 206-1+A1+A2:2000 Concrete. Part 1: Specification, performance, production and conformity;

[13] EN 10204:2004 Metallic products - Types of inspection documents;

[14] ISO 6783:1982 Coarse aggregates for concrete; Determination of particle density and water absorption; Hydrostatic balance method

[15] EN 10263-2, -3 + 4:2017 Steel rod, bars and wire for cold heading and cold extrusion

Part 2: Technical delivery conditions for steels not intended for heat treatment after cold working

Part 3: Technical delivery conditions for case hardening steels

Part 4: Technical delivery conditions for quenching and tempering;

[16] EN ISO 4032:2012 Hexagon regular nuts (style 1) – Product grades A and B;

[17] EN ISO 4034:2012 Hexagon regular nuts (style 1) - Product grade C;

[18] EN 10149-1+2:2013 Hot-rolled flat products made of high yield strength steels for cold forming. Part 1: General technical delivery conditions; Part 2: Technical delivery conditions for thermomechanically rolled steels;

[19] EN 10269:2013 Steels and nickel alloys for fasteners with specified elevated and/or low temperature properties;

[20] EN ISO 7089:2000 Plain washers – Normal series – Product grade A;

[21] EN 1993-1-8:2005+AC:2009 Eurocode 3: Design of steel structures - Part 1-8: Design of joints

[22] ISO 16269-6:2005 Statistical interpretation of data – Part 6: Determination of statistical tolerance intervals

[23] EN ISO 1461:2009 Hot dip galvanized coatings on fabricated iron and steel articles-Specifications and test methods;

[24] EN ISO 10684:2004+AC:2009 Fasteners – Hot dip galvanized coatings;

[25] EN 10277-2:2008 Bright steel products – Technical delivery conditions

Part 2: Steels for general engineering purposes;

[26] EN ISO 7090:2000 Plain washers, chamfered – Normal series – Product grade A;

[27] EN ISO 7091:2000 Plain washers – Normal series – Product grade C;

[28] EOTA TR 050:2018-10 Technical Report 050, "Calculation Method for the Performance of Anchor Channels under fatigue loads"

[29] EN 13791:2007 Assessment of in-situ compressive strength in structures and precast concrete components

[30] EN 197-1:2011 Cement - Part 1: Composition, specifications and conformity criteria for common cements

ANNEX A RESISTANCE UNDER STATIC AND QUASI-STATIC LOADING - GENERAL ASPECTS OF TESTS AND ASSESSMENT

A.1 Test program for resistances under static and quasi-static load

Tests shall be done according to Table A.1.

Table A.1 Tests under static or quasi-static actions (tension and shear)

N°	Tests according to the following sections	Concrete	Δw [mm]	Number of tests	Channel	Anchor	Material	Channel bolt Ø	Channel bolt Quality
Steel failure under tension load									
S1	2.2.2 Channel / anchor	—	—	≥ 5[1)]	all	all	all	2.2.2	
S2	2.2.3 Failure of channel lips, pull-out channel bolt [2),10)]	— C20/25	— 0	≥ 5[1)]	all	all	all	2.2.3	
S3	2.2.4 Channel bolt head	—	—	≥ 5	2.2.4	—	all	2.2.4	
S4	2.2.5 Bending strength of channel [3)]	C20/25	0	≥ 5	all	2.2.5	all	2.2.5	
S5	2.2.6 Torque tests [4)]	see 2.2.6	—	≥ 5	all	2.2.6	all	all	all
Concrete failure under tension load									
C1	2.2.9 Splitting failure due to installation[5)] c = c_{min}, s = s_{min}, h = h_{min}	C20/25	0	≥ 5	all	2.2.9			
Steel failure under shear load acting perpendicular to the longitudinal channel axis									
S6a	2.2.14 Bending or failure of channel lips, connection anchor/channel or anchor[7)]	C20/25	0	≥ 5[1),8)]	all	2.2.14	all	2.2.14	
S6b				≥ 5[1),9)]					
Concrete failure under shear load									
C2	2.2.20 Concrete edge failure[11)] c = c_{min}; s = s_{max}	C20/25	0	≥ 5	2.2.20			2.2.20	
Steel failure under shear load acting in longitudinal channel axis [6)]									
S7	2.2.15 Connection between channel lips and channel bolt	C20/25	0	≥ 5	2.2.15				
S8	2.2.16 Connection between channel lips and channel bolt – influence of level of pre-stressing force	C20/25	0	≥ 5	2.2.16				
S9	2.2.16 Connection between channel lips and channel bolt – influence of channel below concrete surface	C20/25	0	≥ 5	2.2.16				

Footnotes to Table A.1:

1) If the coefficient of variation of the failure loads is v ≤ 5%, the number of tests can be reduced to n= 3.

2) The tests may also be performed in non-cracked concrete C20/25 (2.2.3).

3) Tests are only necessary if restraint of channels embedded in concrete shall be taken into account ($\alpha_r > 4$, 2.2.5).

4) The test program may be reduced, if the conditions in 2.2.6 are fulfilled.

5) The test program may be reduced, if the conditions in 2.2.9 are fulfilled.

6) In tests for a range of anchor channels according to 2.2.15 subjected to longitudinal shear, channel bolts from the same production lot shall be used for Line S5 and Line S7 to S9

7) Tests may be omitted if the conditions in 2.2.14 are fulfilled.

8) Five tests need to be conducted with the channel bolt positioned over an anchor.

9) Five tests with the channel bolt positioned midway between the two anchors.

10) Tests may be omitted if conditions in 2.2.3 are observed.

11) Tests may be omitted if the profile factors $k_{cr,V}$=4,5 and $k_{ucr,V}$= 6,3 are given in the ETA.

A.2 Test details for resistances under static and quasi-static load

A.2.1 Test members

The concrete test member shall be manufactured in accordance with EN 206-1 [12].

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 A.1. The maximum aggregate size shall be 16 mm or 20 mm. The aggregate density shall be between 2.0 and 3.0 t/m^3 (see EN 206 [12] and ISO 6783 [14]).

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

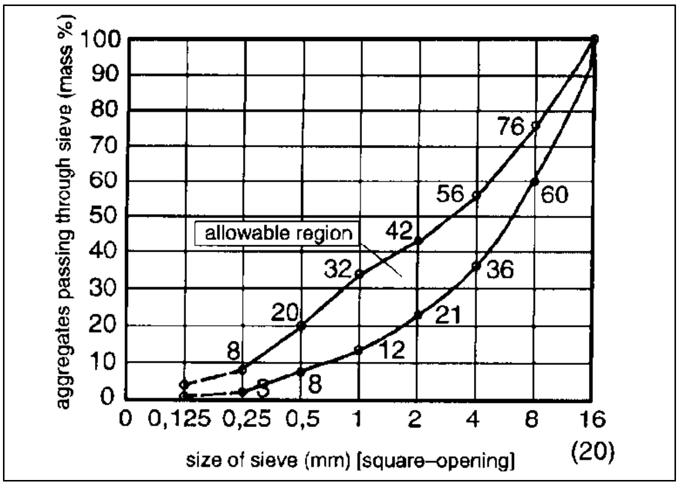


Figure A.1 Admissible region for the grading curve

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 [30])

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.

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

C20/25 f_c = 20-30 MPa (cylinder: diameter 150 mm, height 300 mm)

f_{cube} = 25-35 MPa (cube:150 x 150 x 150 mm)

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 $$f_c = \frac{1}{1{,}25} f_{cube} \qquad \text{(A.1)}$$

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

$$f_{cube100} = \frac{1}{0{,}95} f_{cube} \qquad \text{(A.2)}$$

$$f_{cube} = \frac{1}{0{,}95} f_{cube200} \qquad \text{(A.3)}$$

$f_{cube} = f_{core100}$ (according to EN 13791 [29], section 7.1) (A.4)

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.

The concrete control specimens shall be tested on the same day as the anchor channels 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 anchor channels tests, e.g. at the beginning and at the end of the tests. In this case the concrete strength at the time of testing can be determined by interpolation.

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

If, when evaluating the test results, there should be doubts whether the strength of the control specimens represents the concrete strength of the test members, at least three cores of 100 mm diameter shall be taken from the test members outside the zones where the concrete has been damaged in the tests, and tested in compression. The cores shall be cut to a height equal to their diameter, and the surfaces to which the compression loads are applied shall be ground or capped. The compressive strength measured on these cores may be converted into the strength of cubes by equation (A.4).

The tests are carried out in uncracked unreinforced concrete 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 anchor channel 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°.

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 anchor channel the concrete shall be at least 21 days old.

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

A.2.2 Test setup

A.2.2.1 General

The test program for the assessment of the performance of the anchor channels in relation to the essential characteristics consists of service condition tests and reliability tests. The purpose of the service condition tests is to determine the basic technical data required to predict the performance of the anchor channels under service conditions and derive corresponding design information. The purpose of the reliability tests is to determine various effects for the relevant application range according to the intended use.

A.2.2.2 Test equipment

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

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

For unconfined tests the test rigs shall allow the formation of an unrestricted rupture cone. For this reason the distance between the support reaction and an anchor shall be at least 2 h_{ef} (tension test) as shown in Figure 2.1 b or 2 c_1 (shear test at the edge with load applied towards the edge, with c_1 = edge distance in load direction) as shown in Figure 2.10.

During all shear tests S6 to S9 and C2 according to Tab. A.1, the load shall be applied to the channel bolt(s) by a fixture that does not fail nor plasticise during tests. During tension tests S1 and S3 the load shall be applied directly to the channel bolt. During tension tests S2 and S4 the load shall be applied to the channel bolt by a fixture or directly to the channel bolt according to section 2.2.3 and 2.2.5 subject to the type of contact surface of channel lips and channel bolt head (smooth, serrated or notching). During torsion tests a fixture has to be used.

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

During tension tests the load shall be applied concentrically to the channel bolt. To achieve this, hinges shall be incorporated between the loading device and the anchor channel. Requirements for the diameter of the clearance hole of the fixture may be given in the EADs. An example of a tension test rig is illustrated in Figure 2.1 b.

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

The test arrangement shall simulate a hinged connection so that the 2 channel bolts are loaded equally.

An example of a shear test rig is illustrated in Figure 2.10. As there is a lever arm between the applied load and the support reaction, the test member is stressed by a torsion moment. This shall be taken up by additional reaction forces placed sufficiently far away from the anchor channel.

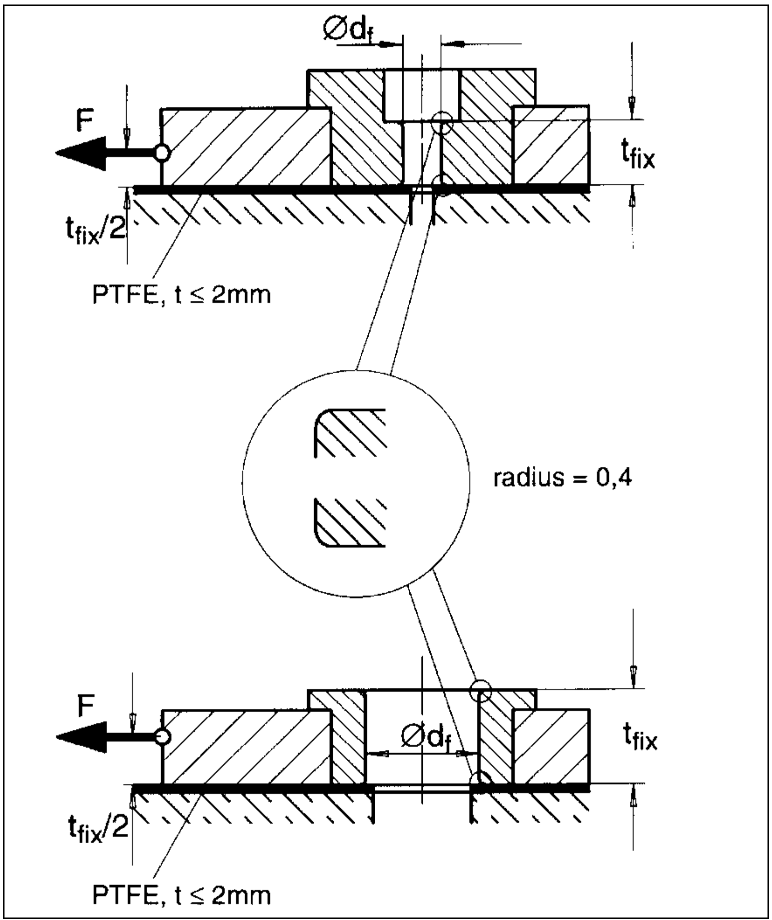


Figure A.2 Examples of shear test sleeves

A.2.2.3 Test procedure

Anchor channels shall be installed in the test member in accordance with the manufacturer´s product installation instructions (MPII) in a formed face of the concrete or in concrete with a trowelled finish, except where special conditions are specified in the EAD for the test series. Nuts and washers not supplied with the channel bolt shall conform to the specifications of the manufacturer. The anchor channel shall be placed such that the behaviour is not influenced by reinforcement, see A.2.1. The concrete shall be properly compacted especially in the area of the anchor channels and in the area of the head of the anchors.

The hole clearance according to Table A.2 is used in tests if the appropriate section refer to.

Table A.2 Hole clearance (Dimension in mm)

1	diameter of channel bolt d	6	8	10	12	14	16	18	20	22	24	27	30	>30
2	diameter d_f of clearance hole in the fixture	7	9	12	14	16	18	20	22	24	26	30	33	d + 3

In tests with anchor channels embedded in concrete except without fixture according to section 2.2.3, 2.2.5 and except with fixture 2.2.15 and 2.2.16 apply the installation torque $T_{inst,g}$ specified in the manufacturer's installation instructions using a calibrated torque wrench having a measuring error within ± 5% of the specified torque, if not noted otherwise for a specific test series. After a minimum of ten minutes after the initial application of $T_{inst,g}$, loosen the nut of the channel bolt and re-apply torque to a level of 0,5 $T_{inst,g}$.

In tests with anchor channels not embedded in concrete, the channel bolts shall not be pre-stressed, if not noted otherwise for a specific test series.

In shear tests after installation, the channel bolts are connected to the test rig without gap between the channel bolt and the interchangeable sleeve in the loading plate and is then loaded to failure. The displacements of the channel bolt relative to the concrete shall be measured in the direction of the load application, e.g. by use of a displacement transducer fixed behind the channel bolt (seen from the direction of load application) on the concrete.

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

For each individual test the peak load shall be determined, the failure mode shall be given and the shear mean displacement of the fixture relative to the concrete outside the rupture cone shall be recorded continuously, if not noted otherwise with a specific test series.

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

A.3 General assessing methods for resistances under static and quasi-static load

The 5%-fractile of the ultimate loads of a test series shall be calculated according to statistical methods for a confidence level of 90%. In general a normal distribution and an unknown standard deviation shall be assumed.

$$F_{5\%} = F_m \cdot (1 - k_s \cdot v_{test}) \quad [N] \qquad (A.5)$$

F_m = mean failure load of a test series

k_s = statistical tolerance factor corresponding to a 5 percent probability of non-exceedance with a confidence of 90%, in general derived from a Gaussian distribution for which the population standard deviation is unknown, values for specific sample sizes n may be taken from ISO 16269-6 [22], Table D.

v_{test} = coefficient of variation of failure loads of a test series

The test results shall be converted to the nominal values (strength and dimensions).

The characteristic resistances N_{Rk} and V_{Rk} evaluated from the results of tests shall be rounded down in 0,1 kN steps.

ANNEX B RESISTANCE UNDER FATIGUE CYCLIC TENSION LOADING – GENERAL ASPECTS OF TESTS

B.1 Test program for resistances under fatigue cyclic tension loading

Table B.1: Tests under fatigue cyclic tension loading: Test methods A1 and A2

N°	Tests according to the section 2.2.22	Concrete	Load position	Minimum number of tests	Channel size	Anchor size	Anchor Channel Material	Anchor Channel Coating	Connection anchor/channel type	Channel bolt diameter	Channel bolt Material	Channel bolt Coating
Reference tests for steel failure												
FR1	any steel failure of the whole system (anchor, connection anchor/ channel, flexure channel lips, channel bolt, flexure channel)	C20/25	Pos.1	3(+2) 2)	all	all	all	all	all	all 1)	all 1)	all
FR2		C20/25	Pos.2	3(+2) 2)	all	all	all	all	all	all 1)	all 1)	all
Pre-tests tests for steel failure												
FP1	Unfavourable position of the load subject to the number of cycles	C20/25	Pos.1	6 3)	all	all	all	all	all	all 1)	all 1)	all
FP2		C20/25	Pos.2	6 3)	all	all	all	all	all	all 1)	all 1)	all
Final tests for steel failure												
F1	any steel failure of the whole system (anchor, connection anchor/ channel, flexure channel lips, channel bolt, flexure channel)	C20/25	Pos.1 and/or Pos.2	20	all	all	all	all 5)	all	all 1)	all 1)	all 4)

1) Only channel bolts with the smallest head size and providing the lowest characteristic static tension resistance as determined in Section 2.2.4 of this EAD may be tested if the resulting fatigue resistance is applied to all other channel bolt sizes and types with all materials specified by the manufacturer. In case of locking channel bolts in combination with non-serrated anchor channels, test all channel bolt sizes. The channel bolt size, type, steel strength, and coating in combination with the anchor channel sizes and types used for testing shall be specified in the ETA.

2) For the unfavourable load position two remaining tests shall be performed.

3) Results of the pre-tests performed on the unfavourable (decisive) load position shall be used in combination with the final tests for steel failure.

4) Only channel bolts providing the lowest resistances as determined in reference tests and pre-tests may be tested if the resulting static and fatigue resistance are applied to all other channel bolt coatings specified by the manufacturer.

5) Only anchor channels providing the lowest resistances as determined in reference tests and pre-tests may be tested if the resulting static and fatigue resistance are applied to all other anchor channel coatings specified by the manufacturer.

Table B.2: Tests under fatigue cyclic tension loading: Test method B

N°	Tests according to section 2.2.23	Concrete	Load position	Minimum number of tests	Channel size	Anchor size	Anchor Channel Material	Anchor Channel Coating	Connection anchor/channel type	Channel bolt diameter	Channel bolt Material	Channel bolt Coating
Final tests for steel failure												
F3	any steel failure of the whole system (anchor, connection anchor/ channel, flexure channel lips, channel bolt, flexure channel)	C20/25	Pos. 1	3	all	all	all	all	all	all [1)]	all [1)]	all
F4		C20/25	Pos. 2	3	all	all	all	all	all	all [1)]	all [1)]	all
Reference tests for steel failure												
FR3	any steel failure of the whole system (anchor, connection anchor/ channel, flexure channel lips, channel bolt, flexure channel)	C20/25	Pos. 1	3	all	all	all	all	all	all [1)]	all [1)]	all
FR4		C20/25	Pos. 2	3	all	all	all	all	all	all [1)]	all [1)]	all

1) The same conditions as per Table B.1, Footnote 1) shall be applied.

B.2 Test details for resistances under fatigue cyclic tension loading

The characteristic resistances for tension under fatigue cyclic loading are determined by tests within the context of this section of the EAD and/or following Annex A.

The concrete specimens for the tests are to be manufactured in accordance with Annex A and EN 206-1 [12]. The concrete strength is to be determined in accordance with Annex A. The tests are to be carried out under laboratory conditions.

The tests shall only be carried out on the final products supplied to the market, inclusive, for example, coating for corrosion resistance and/or with holes for fixing the anchor channel to the frame work. Testing shall be performed on anchor channels manufactured with the same material batch and production lot. Before testing, it shall be verified that the dimensions of all parts (channel, anchor, channel bolts), materials, thickness of any coating, marking, used for testing are within the manufacturer's specifications observing the tolerances. All the relevant information shall be included in the test reports.

The tests shall be carried out on anchor channels with two anchors cast in non-cracked concrete according to Figure B.1.

The spacing between the anchors, s, must be equal to the maximum value, s_{max}, if these tests are applied for other anchor channels of the same size with different spacing.

The end spacing, x, must be equal to the minimum value, x_{min}, if these tests are applied for other anchor channels of the same size with different end spacing.

In order to avoid the transfer of unintended forces to the base material, a clear gap of at least 3 mm shall be placed between the end of the channel profile and the concrete (this will allow the forces to be transferred only by the anchors). It shall be ensured that the concrete specimens remain uncracked throughout the tests (e.g., sufficient edge distance and member thickness should be guaranteed).

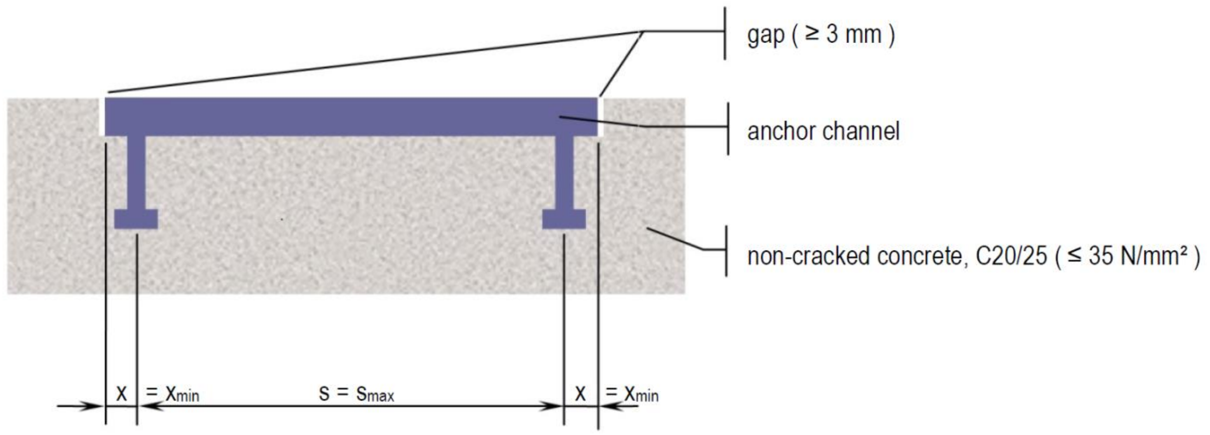


Figure B.1: Test specimen (sample)

In order to avoid bonding between the anchor channel profile and the surrounding concrete, a thin layer of debonding material (e. g., release lube, machine grease) shall be applied on the external surface of each anchor channel profile side before concreting.

The anchor channels shall be fastened such that they cannot be moved during placing and compacting of the concrete. The concrete shall be properly compacted in the area of the channels and under the head of the anchors.

The loading fixture may be in contact with the concrete surface (general contact condition) or may not be in contact with the concrete surface (steel-steel contact condition) as shown in Figure 1.4. For this purpose the provisions according to Section 1.2.1 shall be adhered to.

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

For steel-steel contact: After a minimum of ten minutes after the initial application of $T_{inst,s}$, loosen the nut of the channel bolt and re-apply torque to a maximum level of 0,5 $T_{inst,s}$. This testing procedure allows qualification only for steel-to steel contact conditions.

For general contact: After a minimum of ten minutes after the initial application of $T_{inst,g}$, loosen the nut of the channel bolt and install the channel bolt with a finger-tight condition. If 0,2 $T_{inst,g}$ is lower than or equal to 5 Nm, the finger-tight installation torque shall be equal to 5 Nm. If 0,2 $T_{inst,g}$ is larger than or equal to 10 Nm, the finger-tight installation torque shall be equal to 10 Nm. If 0,2 $T_{inst,g}$ is between 5 Nm and 10 Nm, the finger-tight installation torque shall be equal to 0,2 $T_{inst,g}$. This testing procedure allows assessment for all applicable installation conditions (i.e., steel-to-concrete, steel- to-steel, etc.).

For all contact conditions: Torque on anchor channels for run-out tests on second (higher) load levels is not reapplied.

The installation torque moment, T_{inst}, and the contact condition used for testing shall be given in the relevant ETA. For tests performed with a finger-tight condition, the installation torque, T_{inst}, to be reported in the ETA shall correspond to the minimum installation torque specified in the manufacturer's published installation instructions.

The test setup shall include moment hinges on two positions to avoid eccentricities and resulting shear forces at the point at which load is introduced. An example of the principle structure is shown in Figure B.2. The maximum length of the tension rod including the loading fixture between the point of load application and the load cell shall be equal to or smaller than 0,6 m. The maximum and minimum dimensions of the tension rod and loading fixture are shown in Figure B.2 and shall be adhered to.

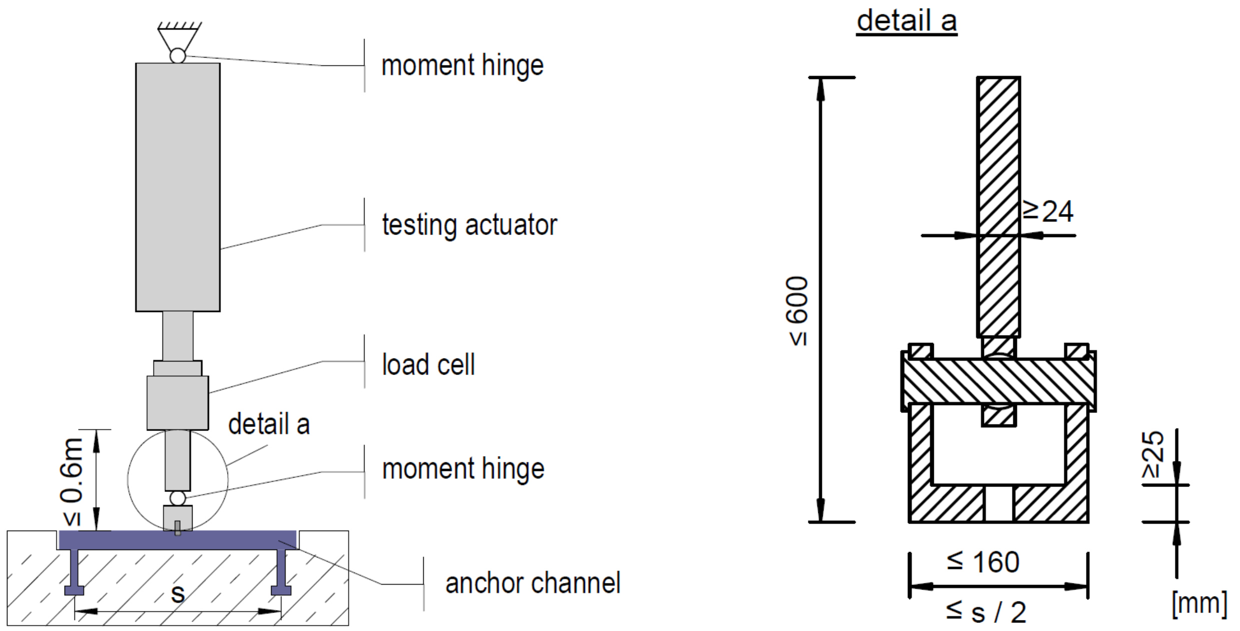


Figure B.2: Example of test setup including two moment hinges and dimensions of tension rod and loading fixture

The tests shall be conducted as unconfined tension tests in accordance with Figure 2.1 b. 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. Direct contact between the test stand and the channel profile is not permitted.

Testing shall be performed according to Table B.1 or Table B.2 and the following sections. The samples shall be tested to failure.

In case of fatigue-tested specimen without rupture, the tests shall be stopped and started at a higher stress range again until failure occurs (see Test methods A1, A2 and B for additional details).

The anchor channel shall be loaded with a sinusoidal load process according Figure 2.11.

All channel bolt sizes and types with all materials and coatings specified by the manufacturer shall be tested. Exceptions to the general cases compare Table B.1 Footnote [1)].

The load has to be controlled in accordance with Figure 2.11, where N_u shall be equal to the smallest operable load and $N_o = N_u + \Delta N$. N_u shall be kept constant throughout the entire test program.

The testing frequency shall be chosen to be between 0.1 to 20 Hz. It is recommended to adopt low frequencies for high stress ranges resulting in large plastic deformations.

The fatigue cyclic force range shall be varied according to the selected method of testing and evaluation.

An example for the load application and displacement measurement without influence of deformation of the test rig is given in Figure B.3.

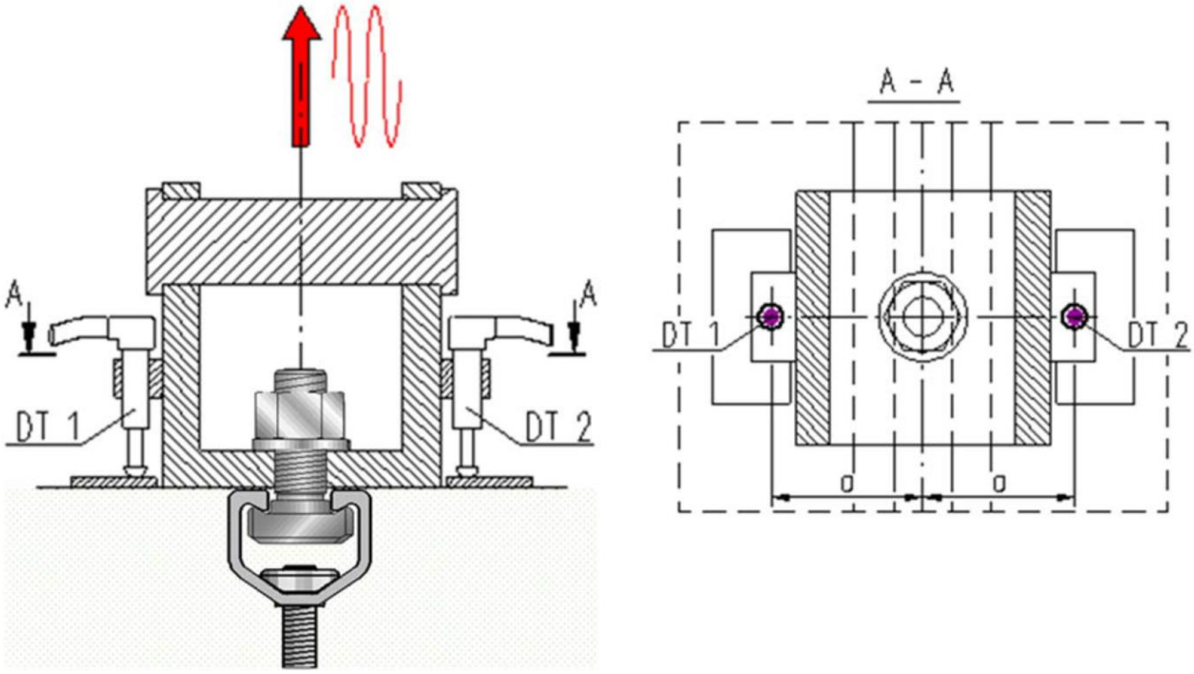


Figure B.3: Example of test setup with displacement transducer (DT)

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 and described in the test report:

- Displacements corresponding to the maximum load as a function of the number of cycles, n
- Elapsed time and number of cycles
- N_u and s_u (minimum force and corresponding displacement)
- N_o and s_o (maximum force and corresponding displacement)

In addition to the values mentioned above all other relevant installation parameters (e.g., T_{inst}, contact condition, etc.), shall be provided.

ANNEX C RESISTANCE UNDER FATIGUE CYCLIC TENSION LOADING – ASSESSMENT: INTERACTIVE METHOD (METHOD A1)

C.1 Basics

The force-controlled periodic loading with sinusoidal course should be used for 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 should 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 (assessment 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 Interactive Method 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.

C.2 Procedure steps

C.2.1 Determination of the characteristic static resistance

For the determination of the characteristic static resistance S_k at least five tests $(n \geq 5)$ are required for the unfavourable load position (see Figure 2.11). For each position testing shall be performed up to three test results, afterward the unfavourable position may be identified. The remaining two tests shall be performed only for the unfavourable load position.

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 followed:

$$S_k = \overline{S} - k_{n,p,1-\alpha} \cdot \hat{s} \qquad \text{(C.1)}$$

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

C.2.2 Determination of the unfavourable loading position for fatigue loading

For the determination of the unfavourable loading position six tests in Position 1 and Position 2 shall be performed with identical fatigue cyclic load levels for each position (see Figure 2.11).

The fatigue cyclic load levels correspond to the first six load levels of Section C.2.3, i.e. for the unfavourable position, and are used to determine the preliminary average function and the preliminary characteristic fatigue resistance function. Therefore testing is continued with the seventh attempt in Section C.2.3.

C.2.3 Planning of the fatigue cyclic load levels

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

$$\Delta S_i = S_{oi} - S_u \qquad \text{(C.3)}$$

The lower level of the sinusoidal course, S_u, is equal for all fatigue cyclic load levels and should be kept to a minimum.

Results from testing with only one cycle, i.e. under quasi-static loading, already exist (see Section C.2.1). These results will be included later in the evaluation. The first attempt under fatigue cyclic loading with constant load range is carried out on a level close to the elastic limit of the specimen/system made of steel.

After the first attempt, 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 ranges for hot-rolled and cold-formed anchor channels may be used based on the static mean resistance $\overline{S}$.

Hot-rolled: $\Delta S_D^{\approx} \approx (0.10, \ldots, 0.30) \cdot \overline{S}$

Cold-formed: $\Delta S_D^{\approx} \approx (0.05, \ldots, 0.20) \cdot \overline{S}$

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

The fourth attempt 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 attempt, without distinction between failed and run-out specimens (see Section C.2.5 and C.2.6).

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

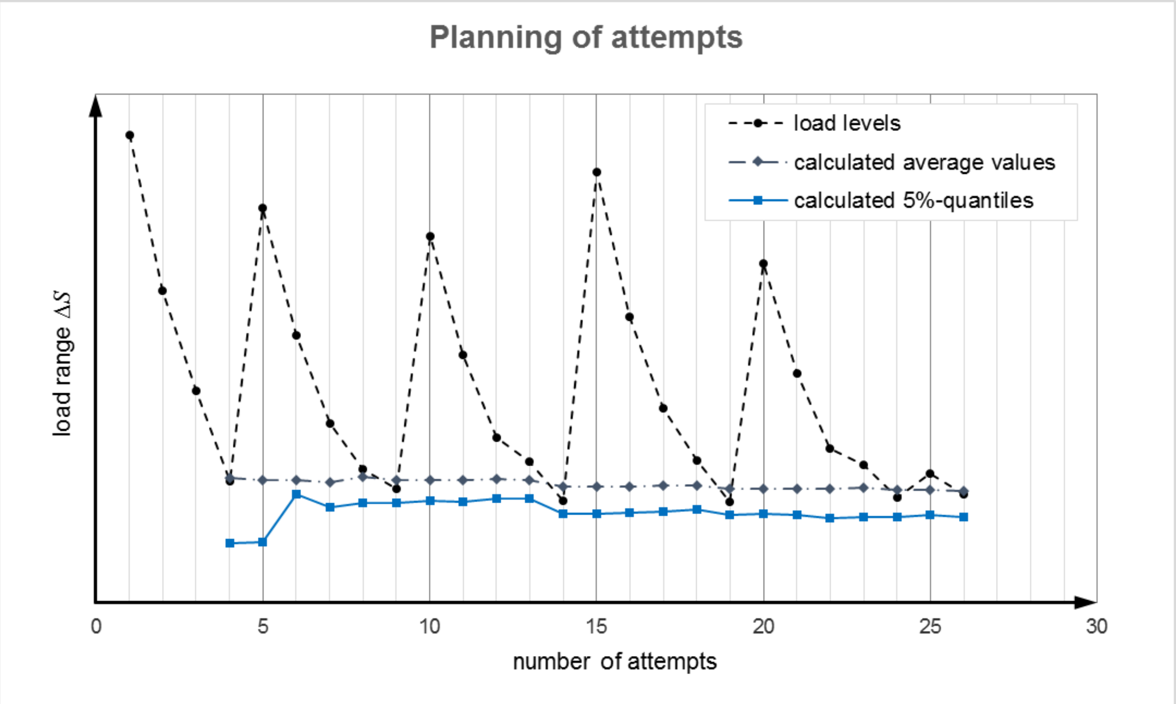


Figure C.1: Planning of attempts – average values and 5%-quantiles apply to the fatigue limit resistance

The further course of experimental design is detailed shown in Figure C.1. The analysis is carried out after each attempt 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 attempt on high stress level. As a rule, testing may be stopped after 24 attempts because calculated results have stabilized. The stabilization of fatigue limit resistance is shown in Figure C.1.

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

C.2.4 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 5·10^6 ≤ n_{lim} ≤ 8·10^6 (carbon steel) respectively 7·10^6 ≤ n_{lim} ≤ 10^7 (stainless steel).

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

For the assessment of the stabilization, regarding the upper limit S_{oi} 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 2·10^6 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 C.2). If no stabilization occur the next higher areas (B and C) are compared with each other. This is continued until the upper limit of each respective interval is reached.

Note: If, during the measurement recording large variance of the measured values occur and the evaluation provides inconclusive results, then the specimen is always charged to the upper limit of the respective interval. In this case the only criterion for a „real" run-out is the run-out test, provided that no damage has occurred.

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

Centroid of test result scatter for one area:

$$\dot{s}_o = \frac{1}{m}\sum_{i=1}^{m} s_{o,i} \qquad \text{(C.4)}$$

$$\dot{n} = \frac{1}{m}\sum_{i=1}^{m} n_i \qquad \text{(C.5)}$$

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

Regression line:

$$s_o = a_s + b_s n \qquad \text{(C.6)}$$

$$a_s = \dot{s}_o - b_s\dot{n} \qquad \text{(C.7)}$$

$$b_s = \frac{\sum_{i=1}^{m}(n_i - \dot{n})\left(s_{o,i} - \dot{s}_o\right)}{\sum_{i=1}^{m}(n_i - \dot{n})^2} \qquad \text{(C.8)}$$

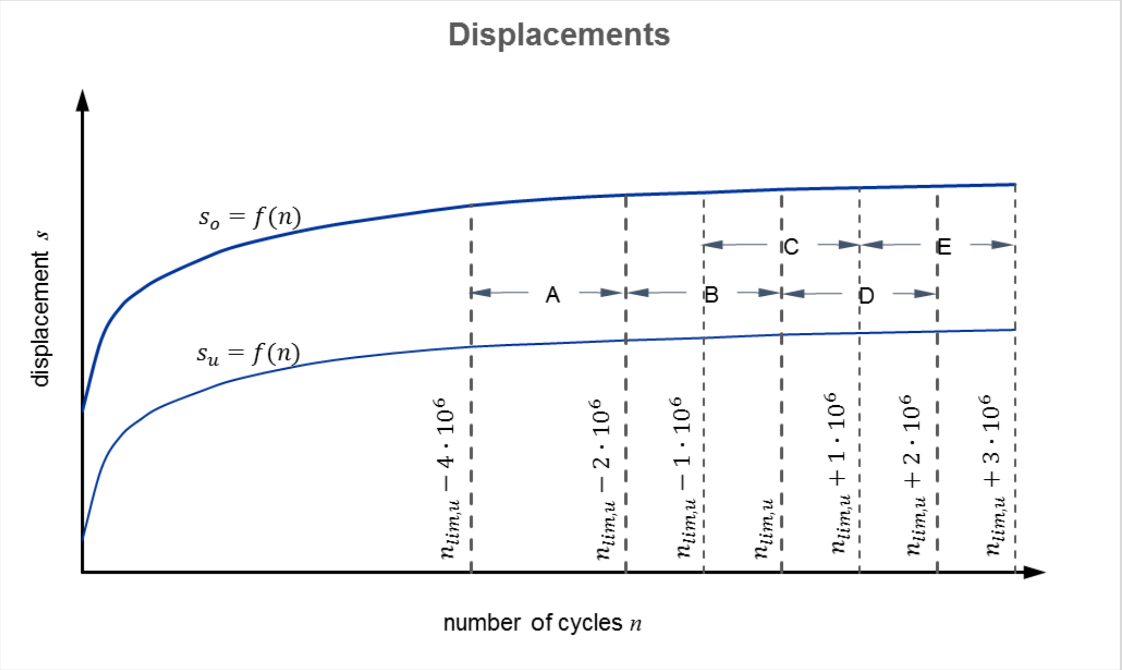


Figure C.2: Stabilization of deformations of a run-out

Specimen reaching $n \geq n_{lim}$ without failure, are to be tested again with the stress range ΔS_{RT} until failure occur. 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 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 C.2.5) and characteristic resistance functions (Section C.2.6). Results of run out tests performed on their second load level are required only to verify that damage to the specimens has not occurred 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 C.3) and is calculated as follows:

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

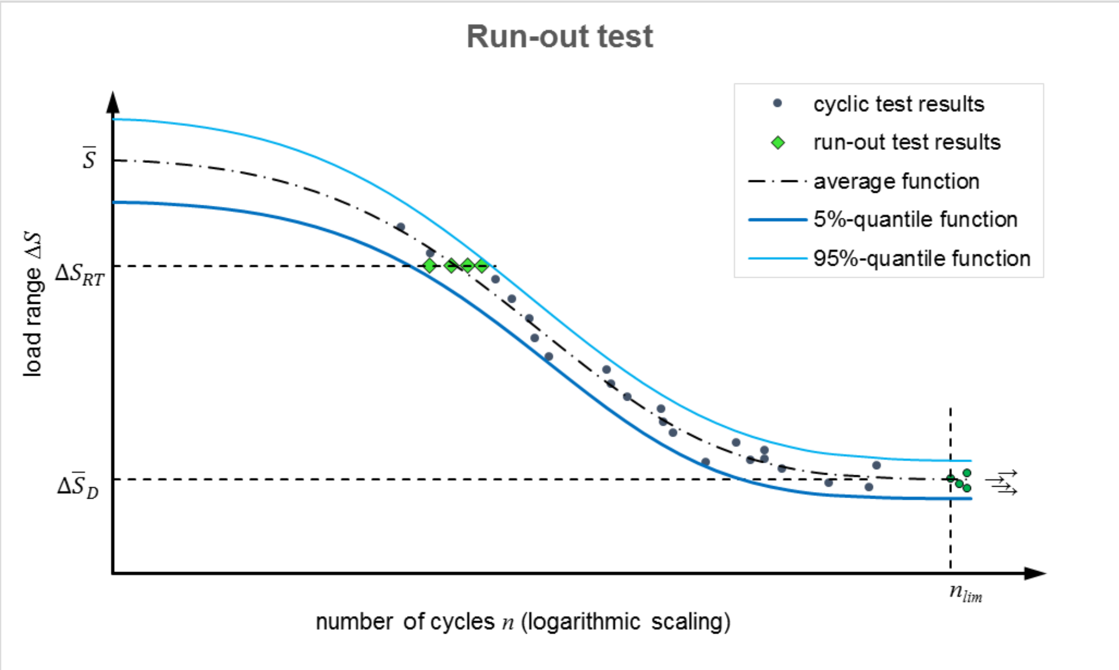


Figure C.3: Load level for run-out test (general)

If the pre-test results show a crossing point between testing in Position 1 and Position 2 (see Figure 2.14) and a run-out specimen on first load level is performed in unfavourable position (e.g. Pos. 1), then the run-out test results on second load level shall be assigned to the same position (e.g. Pos. 1). If the second load level belongs to the range identified for the favourable position (e.g. Pos. 1), then the scatter band on load level ΔS_{RT} determined for the unfavourable position (e.g. Pos. 2) shall be transferred to the favourable position (e.g. Pos. 1) as shown in Figure C.4. Once the scatter band is transferred, then the same conditions shall be applied for the run-out test assessment.

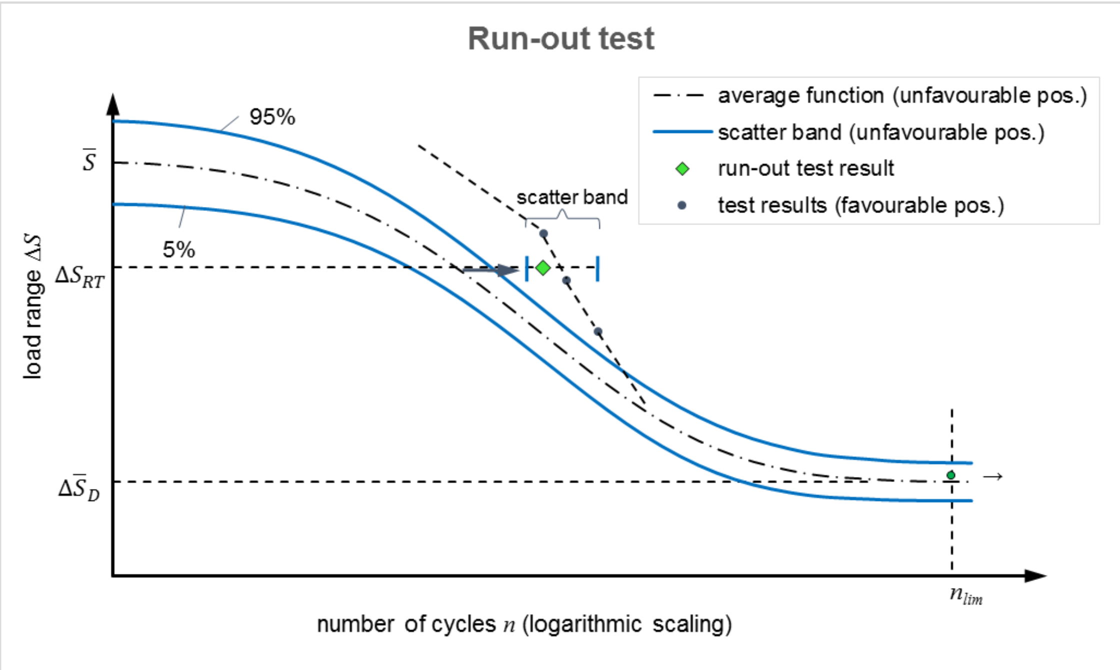


Figure C.4: Transfer of the scatter band (unfavourable position) to the favourable position

C.2.5 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 (C.10) according to the principles of the least squares method. The free parameters a, b 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 centerline of the fatigue resistance (see Figure C.5).

$$\Delta\bar{S} = \Delta\bar{S}_D + (\bar{S} - S_u - \Delta\bar{S}_D) \cdot a^{(\lg n)^b} \quad \text{(C.10)}$$

a, b = positive dimensionless numbers for the average function, where $a < 1.0$

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 reference tests according to Table B.1, line FR1 and FR2

S_u = lower limit of fatigue cyclic loads

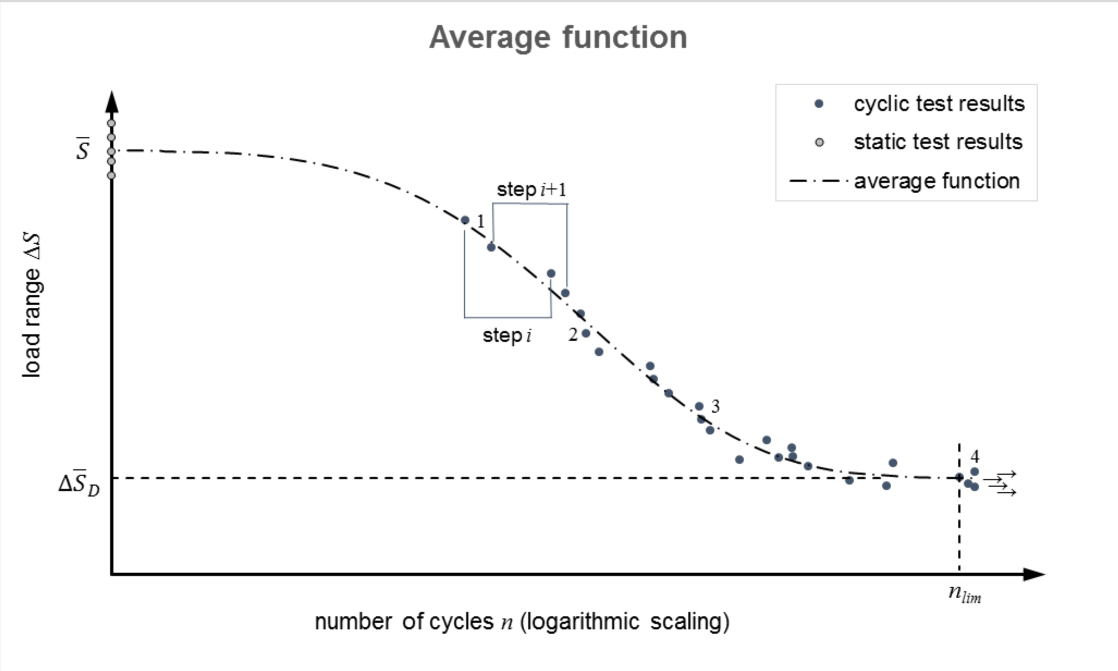


Figure C.5: Tests results and average function of fatigue resistance

C.2.6 Determination of the characteristic fatigue resistance

For the statistical evaluation three juxtaposed results are considered.

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. In the next step $i + 1$ the following pair of values with next higher number of cycles is taken into account and the pair of values with smallest number of cycles of step i is disregarded (see Figure C.5). This gives also the standard deviation, which is valid for these three values. 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 values and residuals are calculated:

   $\Delta\bar{S}_i$ = mean value of the cross section for every step i according to equation (C.9)

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

   $$\Delta\Delta S_i = \Delta S_i - \Delta\overline{S}_i\,, i = 1, \dots, h \qquad \text{(C.11)}$$

   where

   h = total number of available fatigue cyclic test results

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

   $$\hat{s}_j^2 = \frac{((\Delta\Delta S_i)^2 + (\Delta\Delta S_{i+1})^2 + (\Delta\Delta S_{i+2})^2) \cdot h}{3 \cdot (h-3)}, j = 1, \dots, h-2 \qquad \text{(C .12)}$$

   $$\hat{s}_j = \sqrt{\hat{s}_j^2} \qquad \text{(C .13)}$$

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

   $\Delta\bar{\dot{S}}_j$ = mean value of the cross section for every step j according to equation (C.9)

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

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

   $$\Delta\dot{S}_{j,5\%} = \Delta\bar{\dot{S}}_j - k_{h,p,1-\alpha} \cdot \hat{s}_j, j = 1, \dots, h-2 \qquad \text{(C.15)}$$

   $k_{h,p,1-\alpha}$ = statistical tolerance factor [22]; h: total number of available fatigue cyclic test results; p: 5%-quantile; $(p = 0.05)$; $1 - \alpha$: level of confidence of 90% $(1 - \alpha = 0.9)$

The course of the 5%-quantiles is calculated using equation (C.16) according to the principles of the least squares method (ref. Equation (C .10)). An example of the 5%-quantile function is shown in Figure C.6.

$$\Delta S_k = \Delta S_{D,k} + (S_k - S_u - \Delta S_{D,k}) \cdot a^{(\lg n)^b} \qquad \text{(C.16)}$$

a, b = 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 reference tests according to Table B.1, line FR1 and FR2

S_u = lower limit of fatigue cyclic loads

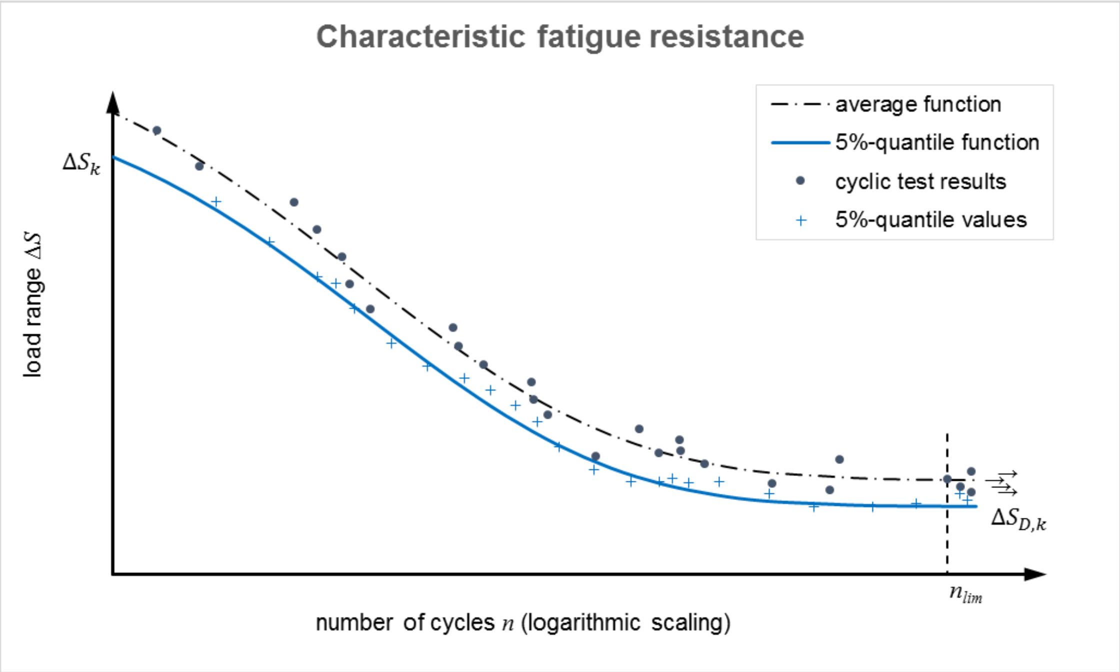


Figure C.6: Tests results, average function and 5%-quantile after regression analysis

C.2.7 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 C.7):

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

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

$\Delta\bar{\dot{S}}_A$ = mean value of area A according to equation (C.10)

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

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

Area B – first half quantity of the fatigue cyclic test results ($0.5h$):

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

$\Delta\bar{\dot{S}}_B$ = mean value of area B according to equation (C.10)

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

$$\hat{\dot{s}}_B = \sqrt{\frac{\left(\sum_{i=1}^{0.5h}(\Delta\Delta S_i)^2\right) \cdot h}{0.5h \cdot (h-3)}} \tag{C.22}$$

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 ($0.5h$):

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

$\Delta\bar{\dot{S}}_C$ = mean value of area C according to equation (C.10)

where $\dot{n}_C = 10^{\left(\left(\sum_{i=1}^{0.5h} \lg n_i\right)/0.5h\right)}$ (C.24)

$$\hat{\dot{s}}_C = \sqrt{\frac{\left(\sum_{i=1}^{0.5h}(\Delta\Delta S_i)^2\right) \cdot h}{0.5h \cdot (h-3)}} \tag{C.25}$$

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 value in the centroid $\dot{n}_A$:

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

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

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

If these four calculated values lie above the characteristic fatigue resistance or at the same level, the control is passed. Otherwise the characteristic fatigue resistance shall be reduced to the level of the four calculated values. 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.

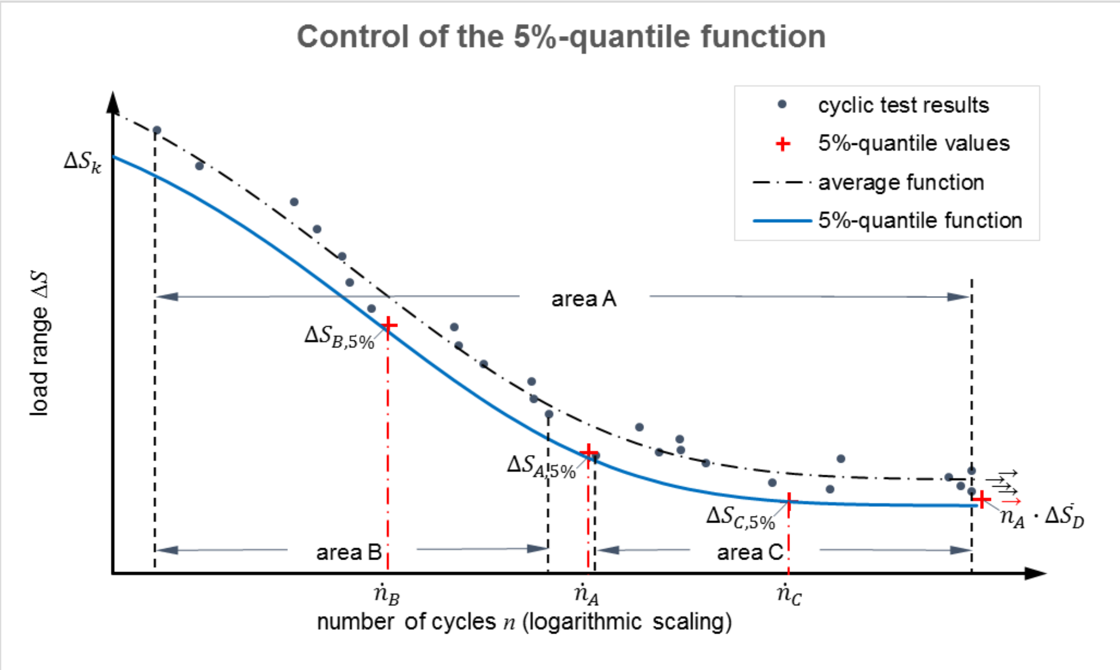


Figure C.7: Control of the characteristic fatigue resistance

ANNEX D RESISTANCE UNDER FATIGUE CYCLIC TENSION LOADING – ASSESSMENT: TRI-LINEAR FUNCTION (METHOD A2)

D.1 Basics

The method is based on the assumption that, using logarithmic scaling for abscissa (number of cycles n) and ordinate (range of stress or force ΔS) in a fatigue strength diagram (S/N-diagram), the part of the function in the finite life fatigue resistance range displays a nearly linear characteristic.

This method builds up on following experiences made by using the Interactive Method:

- Distribution of test results along the whole S/N-curve
- Determination of the limit number of cycles
- Second fatigue cyclic test of undamaged specimen at higher stress level (run-out test)
- Criteria for defining the fatigue strength resistance

Further assumptions based on the Interactive Method relate to the test options:

- The force-controlled periodic loading with sinusoidal course should be used for 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 should 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 (assessment 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 used capital letter S in this Annex shall be replaced by the letter N for tension loads.

D.2 Procedure steps

D.2.1 Determination of the characteristic static resistance

For the determination of the characteristic static resistance S_k at least five tests ($n \geq 5$) are required for the unfavourable load position (see Figure 2.11). For each position testing shall be performed up to three test results, afterward the unfavourable position may be identified. The remaining two tests shall be performed only for the unfavourable load position.

For the determination of the static, finite life fatigue and fatigue limit 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 followed:

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

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

D.2.2 Determination of the unfavourable loading position for fatigue loading

For the determination of the unfavourable loading position six tests in Position 1 and Position 2 shall be performed with identical fatigue cyclic load levels for each position (see Figure 2.11).

The fatigue cyclic load levels ΔS_i correspond to six load levels used to determine the finite life fatigue resistance. Tests which belong to the unfavourable decisive load position shall be included in the final evaluation (see Section D.2.3). The load levels are calculated as follows (for the determination of ΔS_1 and Δ_S, see Section D.2.3):

Load level 1: $\Delta S_2 = 10^{\lg \Delta S_2}$ where $\lg \Delta S_2 = \lg \Delta S_1 - \Delta_S$

Load level 2: $\Delta S_7 = 10^{\lg \Delta S_7}$ where $\lg \Delta S_7 = \lg \Delta S_1 - 6\Delta_S$

Load level 3: $\Delta S_{11} = 10^{\lg \Delta S_{11}}$ where $\lg \Delta S_{11} = \lg \Delta S_1 - 10\Delta_S$

Load level 4: $\Delta S_{15} = 10^{\lg \Delta S_{15}}$ where $\lg \Delta S_{15} = \lg \Delta S_1 - 14\Delta_S$

Load level 5: $\Delta S_{17} = 10^{\lg \Delta S_{17}}$ where $\lg \Delta S_{17} = \lg \Delta S_1 - 16\Delta_S$

Load level 6: $\Delta S_{19} = 10^{\lg \Delta S_{19}}$ where $\lg \Delta S_{19} = \lg \Delta S_1 - 18\Delta_S$

D.2.3 Planning of the fatigue cyclic load levels at the finite life fatigue resistance range

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

$$\Delta S_i = S_{oi} - S_u \quad \text{(D.3)}$$

The lower level of the sinusoidal course S_u is equal for all fatigue cyclic load levels and should be kept to a minimum.

For further planning of the 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 ranges for hot-rolled and cold-formed anchor channels may be used subject to the static mean resistance $\overline{S}$.

Hot-rolled: $\Delta S_D^{\approx} \approx (0.10, \ldots, 0.30) \cdot \overline{S}$

Cold-formed: $\Delta S_D^{\approx} \approx (0.05, \ldots, 0.20) \cdot \overline{S}$

It follows the determination of the distance Δ_S between the load levels. The constant value is due to the difference between the first load level and estimated fatigue limit resistance. The characteristic static resistance and estimated fatigue limit resistance refer to the unfavourable loading position.

$$\Delta_S = 0.05 \cdot (\lg\Delta S_1 - \lg\Delta S_D^{\approx}) \quad \text{(D.4)}$$

$$\Delta S_1 = S_k - S_u \quad \longrightarrow \quad \lg\Delta S_1 \quad \text{(D.5)}$$

$$\Delta S_D^{\approx} \quad \longrightarrow \quad \lg\Delta S_D^{\approx}$$

The load levels are calculated as follows:

Attempt 1: ΔS_1

Attempt 2: $\Delta S_2 = 10^{\lg \Delta S_2}$ where $\lg \Delta S_2 = \lg \Delta S_1 - \Delta_S$

Attempt 3: $\Delta S_3 = 10^{\lg \Delta S_3}$ where $\lg \Delta S_3 = \lg \Delta S_1 - 2\Delta_S$

Attempt 4: $\Delta S_4 = 10^{\lg \Delta S_4}$ where $\lg \Delta S_4 = \lg \Delta S_1 - 3\Delta_S$

…………………………………………………………………………………..

Attempt h: $\Delta S_h = 10^{\lg \Delta S_h}$ where $\lg \Delta S_h = \lg \Delta S_1 - (h-1)\Delta_S$ (D.6)

In the case that the result of attempt h does not fit into the linear area of the finite life fatigue range, a first evaluation has to be conducted according to steps D.2.4 and D.2.5. Afterward the limit number of cycles n_{lim} for attempt h shall be determined by step D.2.6. If attempt h reaches the limit number of cycles and passes the run-out test, then it is considered as a „real" run-out specimen on the first load level (see step D.2.6).

D.2.4 Linear regression analysis

The determination of the regression lines includes only attempts which fits to the linear area of the finite life fatigue range. This means attempts in the low or high cycle fatigue area are not taken into account. Table D.1 contains attempts from l to m ($l \geq 1$ and $m < h$) with the load level ΔS_i and the number of cycles n_i, whereby $i = 1, \dots, r$ and $r = m - l + 1$. These r different specimen belong to the finite life fatigue range and are used to determine the centroid of test result scatter.

Table D.1: Treatment of experimental results

i	Load level	Number of cycles	y	x
l	ΔS_l	n_l	$y_l = lg\,\Delta S_l$	$x_l = lg\,n_l$
$l+1$	ΔS_{l+1}	n_{l+1}	$y_{l+1} = lg\,\Delta S_{l+1}$	$x_{l+1} = lg\,n_{l+1}$
...	...	...	...	...
m	ΔS_m	n_m	$y_l = lg\,\Delta S_m$	$x_m = lg\,n_m$
Centroid of test result scatter:			$\dot{y} = \frac{1}{r}\sum_{i=l}^{m} y_i$ (D.7)	$\dot{x} = \frac{1}{r}\sum_{i=l}^{m} x_i$ (D.8)

Using simple linear regression the experimental values (x_i, y_i) are to see in following context:

$$y_i = a + bx_i + e_i \qquad \text{(D.9)}$$

The residual e_i of the representative sample is the difference between regression line $a + bx_i$ and measured values y_i. The objective is to find a regression line which lies optimal in the test result scatter, so that the difference between regression line and the values is the smallest possible. The regression line will be adjusted by the least squares method.

Account should be taken of the random variables X and Y. These are to be determined with two mutually independent regression lines (see Figure D.1). The first for the assumed linear dependency $y = a_y + b_y x$ for line 1 according to (D.10) and (D.11), the second for the assumed dependency $x = a_x + b_x y$ for line 2 according to (D.12) and (D.13). These two regression lines have the slopes b_y and $1/b_x$ and cross each other at the centroid of the test result scatter. The parameters a_y/a_x and b_y/b_x are determined by the following equations:

Regression line 1:

$$a_y = \dot{y} - b_y \dot{x} \qquad \text{(D.10)} \qquad\qquad b_y = \frac{\sum_{i=l}^{m}(x_i - \dot{x})(y_i - \dot{y})}{\sum_{i=l}^{m}(x_i - \dot{x})^2} \qquad \text{(D.11)}$$

Regression line 2:

$$a_x = \dot{x} - b_x \dot{y} \qquad \text{(D.12)} \qquad\qquad b_x = \frac{\sum_{i=l}^{m}(x_i - \dot{x})(y_i - \dot{y})}{\sum_{i=l}^{m}(y_i - \dot{y})^2} \qquad \text{(D.13)}$$

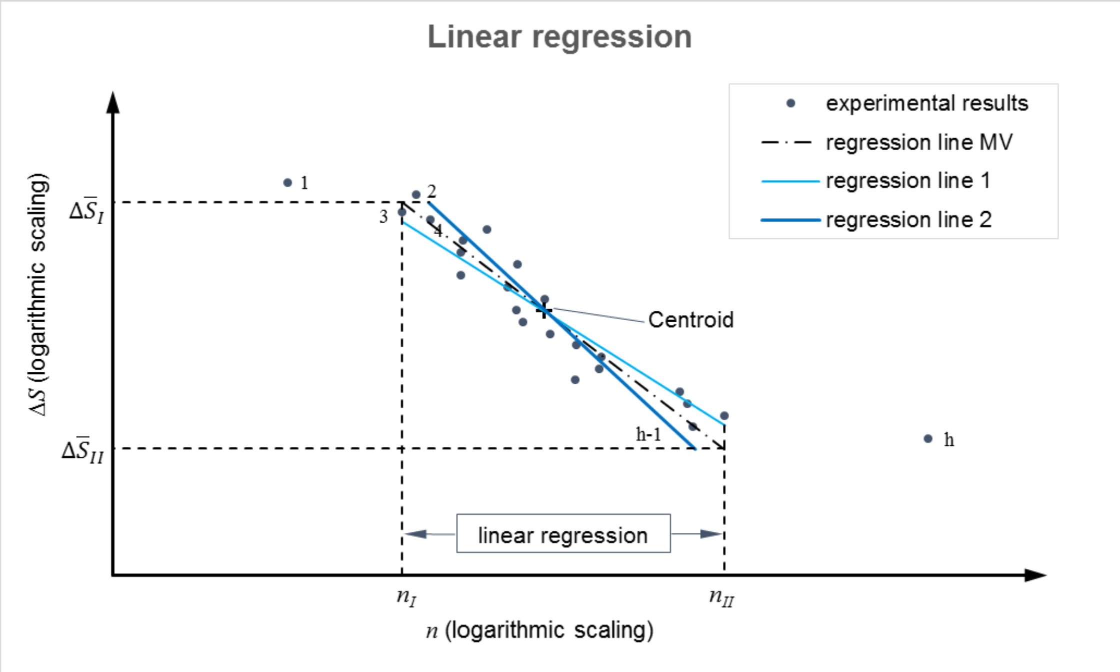


Figure D.1: Regression analysis with two mutually independent regression lines

To keep the variation of the value b as small as possible for different representative samples and thus to get best reproducibility, the average function ("MV" in Figure D.1) is replaced by the straight line $y = a + bx$, which is crossing the centroid of the test result scatter with a mean slope b. The parameters are calculated as follows:

Regression line MV (average function):

$$a = \dot{y} - b\dot{x} \qquad \text{(D.14)} \qquad\qquad b = \left(b_y + \frac{1}{b_x}\right) / \, 2 \qquad \text{(D.15)}$$

If a specimen fails on the first load level during the determination of the characteristic fatigue limit resistance $\Delta S_{D,k}$ (see Section D.2.7) and falls in to the linear area of the finite life fatigue range, then it is necessary to repeat the regression analysis. This specimen below the level of attempt h complements the finite life fatigue range and corrects the regression line course. In the second evaluation $r > m - l + 1$ result-value pairs are used to determine the centroid of test result scatter (see Table D.1).

The determination of specimen belonging to the finite life fatigue range is conducted by using the following procedure. In the first step ten experimental results are selected and statistically evaluated, i.e. regression line and characteristic lines (see Section D.2.5) are determined (see example in Figure D.2). These ten results correspond to the fifth to fourteenth load level (ΔS_5 to ΔS_{14}).

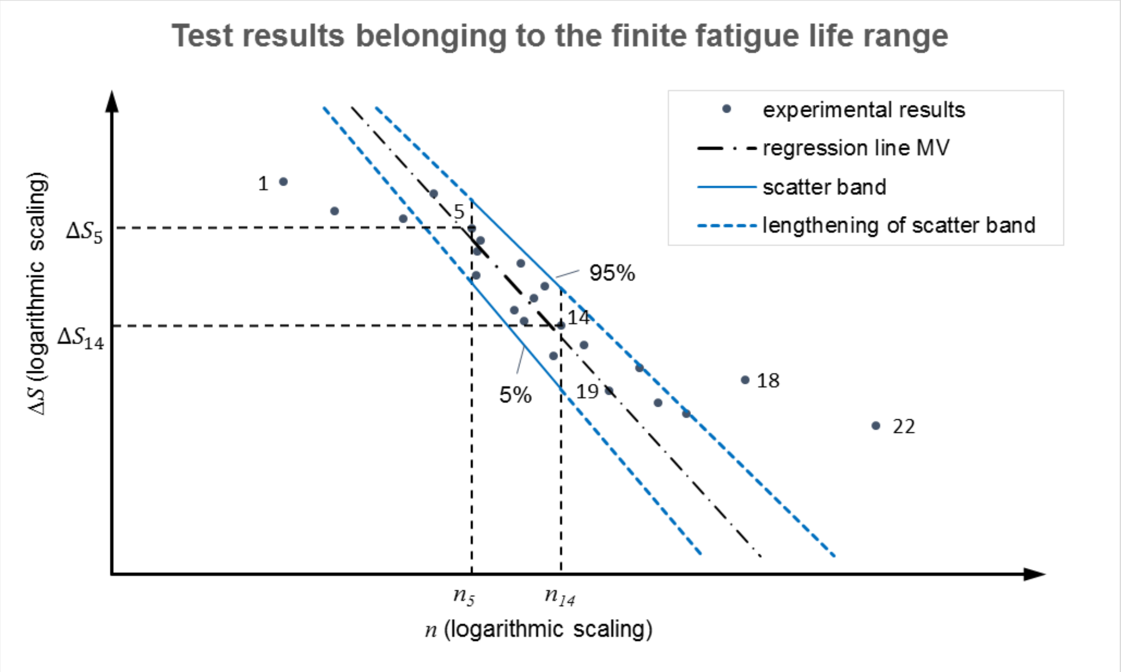


Figure D.2: Result after first evaluation including ten test results (example)

The fifth load level has been chosen as the start value, because several simulations have shown that results with smaller load levels may fall in to the low cycle area and to ensure that only test results belonging to the finite fatigue life area are included in the first evaluation. Moreover, ten results provide a sufficient basis for a good first evaluation.

After the first evaluation a further test result of the remaining attempts is added by two criteria. The first criterion specifies the test result with the smallest squared residual, which corresponds to attempt 19 in the example shown in Figure D.2. If attempt 19 is within the scatter band (blue lines), then the second criteria is also fulfilled. This procedure is repeated for each attempt as long as both criteria (smallest squared residual and allocation within the scatter band) are not fulfilled. Figure D.3 shows the end result after evaluation of each attempt. In this case four test results (1, 3, 18 and 22) are outside the scatter band and therefore not belonging to the finite fatigue life area. The evaluation is completed and test results belonging to the finite fatigue life area are defined.

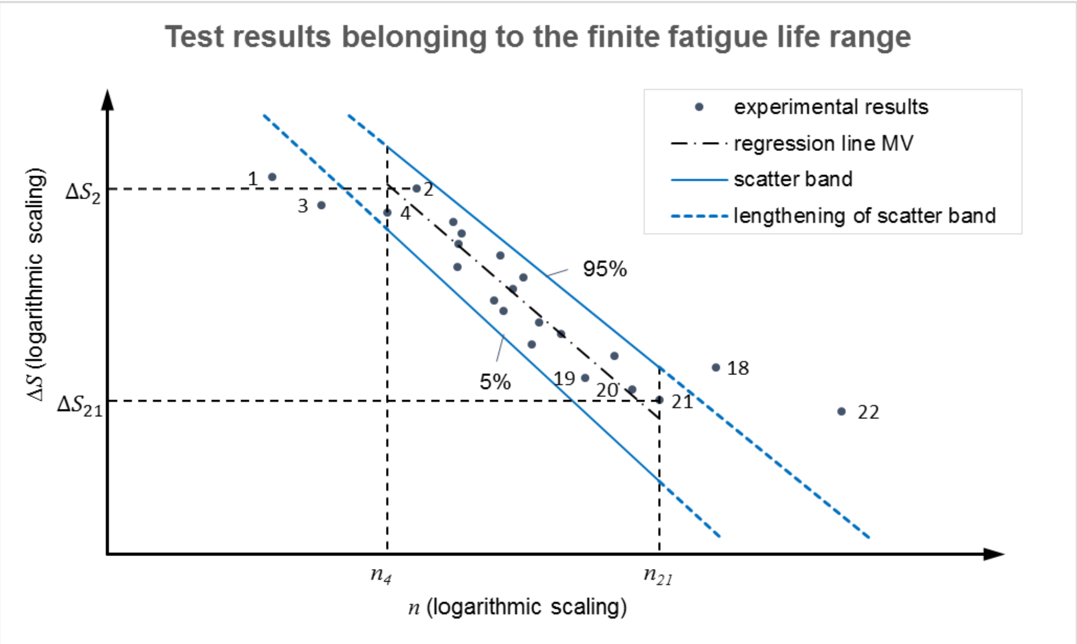


Figure D.3: End result with defined specimen belonging to the finite fatigue life area (example)

D.2.5 Determination of the characteristic fatigue resistance in the finite fatigue life area

The determination of the characteristic fatigue resistance is carried out on the finite fatigue life area limits, i.e. in the cross sections n_I and n_{II} (see Figure D.4). For the statistical evaluation, which is calculated with non-logarithmic values, the average of the standard deviation (variation of fatigue resistance in the finite fatigue life area) is calculated in the following three steps:

1. The regression line $y = a + bx$ will be rearranged to:

$$\Delta\overline{S} = 10^{y} = 10^{(a+bx)} \qquad \text{(D.16)}$$

2. For the crossing sections x_i following average values and residuals are determined:

$$\Delta\overline{S}_i = 10^{(a+bx_i)}\,, i = 1, \dots, r \qquad \text{(D.17)}$$

$$\Delta\Delta S_i = \Delta S_i - \Delta\overline{S}_i\,, i = 1, \dots, r \qquad \text{(D.18)}$$

3. Estimation of the average variance and average standard deviation:

$$\hat{\dot{s}}^2 = \frac{\sum_{i=1}^{r}(\Delta\Delta S_i)^2}{r-1} \qquad \text{(D.19)}$$

$$\hat{\dot{s}} = \sqrt{\hat{\dot{s}}^2} \qquad \text{(D.20)}$$

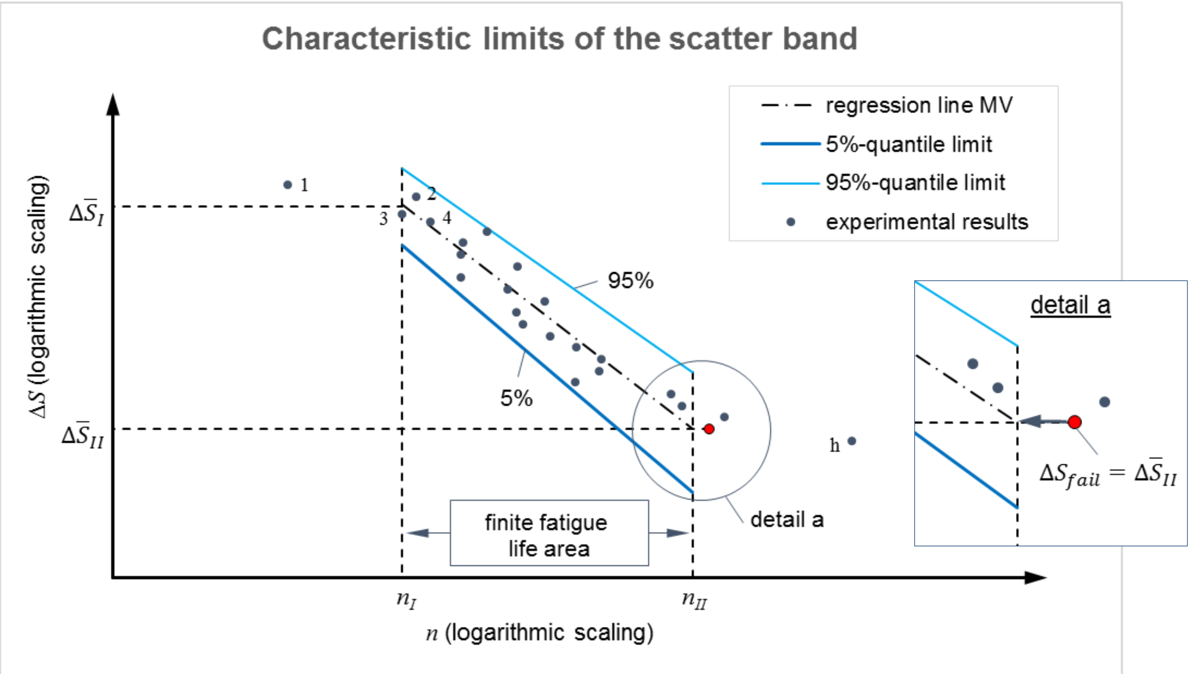


Figure D.4: Scatter band including lower 5%- and upper 95%-quantile limit

In the following steps four to seven the characteristic values, which form the scatter band, are calculated. Whereat the lower limit of the scatter band corresponds to the 5%-quantile and the upper limit to the 95%-quantile.

4. The average coefficient of variation $\dot{v}$ may be determined by means of the average standard deviation $\hat{\dot{s}}$ in cross section $\dot{x}$ (centroid):

$$\dot{v} = \hat{\dot{s}} / \Delta\dot{S} \qquad \text{(D.21)}$$

$$\Delta\dot{S} = 10^{\dot{y}} \qquad \text{(D.22)}$$

5. The mean values in cross sections n_I and n_{II} are calculated as follows:

   Section n_I:

   $$\Delta\overline{S}_I = 10^{(a+bx_I)} \quad \text{(D.23)}$$

   $x_I = \min(x_i)\,, i = 1, \dots, r$

   Section n_{II}:

   $$\Delta\overline{S}_{II} = \Delta S_{fail} = 10^{(a+bx_{II})} \quad \text{(D.24)}$$

   $$x_{II} = \left(y_{fail} - a\right)/b \quad \text{(D.25)}$$

   where $y_{fail} = \lg \Delta S_{fail}$

   $\Delta S_{fail} \triangleq$ failed or damaged specimen with lowest load range

6. Calculating standard deviations $\hat{s}_I$ and $\hat{s}_{II}$ in the cross sections n_I and n_{II} following values v_I and v_{II} are determined at first:

   Section n_I:

   $$\hat{s}_I = v_I \cdot \Delta\overline{S}_I \quad \text{(D.26)}$$

   $$v_I = \eta_I \cdot \dot{v} \quad \text{(D.27)}$$

   $$\eta_I = \eta_{I,b} \cdot \eta_{I,\dot{v}} \Leftarrow \eta_{I,b} = 0.05 \cdot b + 0.11 \Leftarrow \eta_{I,\dot{v}} = -14 \cdot \dot{v} + 10 \quad \text{(D.28)}$$

   Section n_{II}:

   $$\hat{s}_{II} = v_{II} \cdot \Delta\overline{S}_{II} \quad \text{(D.29)}$$

   $$v_{II} = \eta_{II} \cdot \dot{v} \quad \text{(D.30)}$$

   $$\eta_{II} = \eta_{II,b} \cdot \eta_{II,\dot{v}} \Leftarrow \eta_{II,b} = 1.32 \cdot b + 1.66 \Leftarrow \eta_{II,\dot{v}} = 0.22 + 1.18 \cdot 0.26^{(3.6 \cdot \dot{v})^{1.3}} \quad \text{(D.31)}$$

7. The characteristic fatigue resistances on the finite fatigue life area limits are calculated as p-quantiles on a level of confidence of 90% $(1 - \alpha = 0.9)$ by using the normal distribution. The linear path of the characteristic value of fatigue resistance corresponds to the 5%-quantile when using logarithmic scaling of abscissa and ordinate $(y = a_k + b_k x)$ and is given through a straight connection of $(n_I,\ \Delta S_{I,k})$ and $(n_{II},\ \Delta S_{II,k})$. The 5%-quantiles in the cross sections n_I and n_{II} are calculated as follows:

   $$\Delta S_{I,k} = \Delta S_{I,5\%} = \Delta\overline{S}_I - k_{r,p,1-\alpha} \cdot \hat{s}_I \quad \text{(D.32)}$$

   $$\Delta S_{II,k} = \Delta S_{II,5\%} = \Delta\overline{S}_{II} - k_{r,p,1-\alpha} \cdot \hat{s}_{II} \quad \text{(D.33)}$$

   Parameters of 5%-quantile limit:

   $$a_k = y_{I,k} - b_k \cdot x_I \quad \text{(D.34)}$$

   $$b_k = \left(y_{I,k} - y_{II,k}\right) / \left(x_I - x_{II}\right) \quad \text{(D.35)}$$

   where $y_{I,k} = \lg \Delta S_{I,k}$, $y_{II,k} = \lg \Delta S_{II,k}$

8. Similar to the 5%-quantile limit the upper 95%-quantile limit is a straight connection of $(n_I,\ \Delta S_{I,95\%})$ and $(n_{II},\ \Delta S_{II,95\%})$.

   $$\Delta S_{I,95\%} = \Delta\overline{S}_I + k_{r,p,1-\alpha} \cdot \hat{s}_I \quad \text{(D.36)}$$

   $$\Delta S_{II,95\%} = \Delta\overline{S}_{II} + k_{r,p,1-\alpha} \cdot \hat{s}_{II} \quad \text{(D.37)}$$

   Parameters of 95%-quantile limit:

   $$a_{95\%} = y_{I,95\%} - b_{95\%} \cdot x_I \quad \text{(D.38)}$$

   $$b_{95\%} = \left(y_{I,95\%} - y_{II,95\%}\right) / \left(x_I - x_{II}\right) \quad \text{(D.39)}$$

   where $y_{I,95\%} = \lg \Delta S_{I,95\%}$, $y_{II,95\%} = \lg \Delta S_{II,95\%}$

D.2.6 Determination of the limit number of cycles and load level for run-out test

The limit number of cycles n_{lim} is defined as the intersection of an extension of the 95%-quantile and the level of the characteristic value $\Delta S_{II,k}$ (see Figure D.5). If the calculated value is outside the interval 5·10⁶ ≤ $n_{lim,a}$ ≤ 8·10⁶ (carbon steel) respectively 7·10⁶ ≤ $n_{lim,a}$ ≤ 10⁷ (stainless steel) the limit number of cycles is allocated to the lower or upper limit of the respective interval.

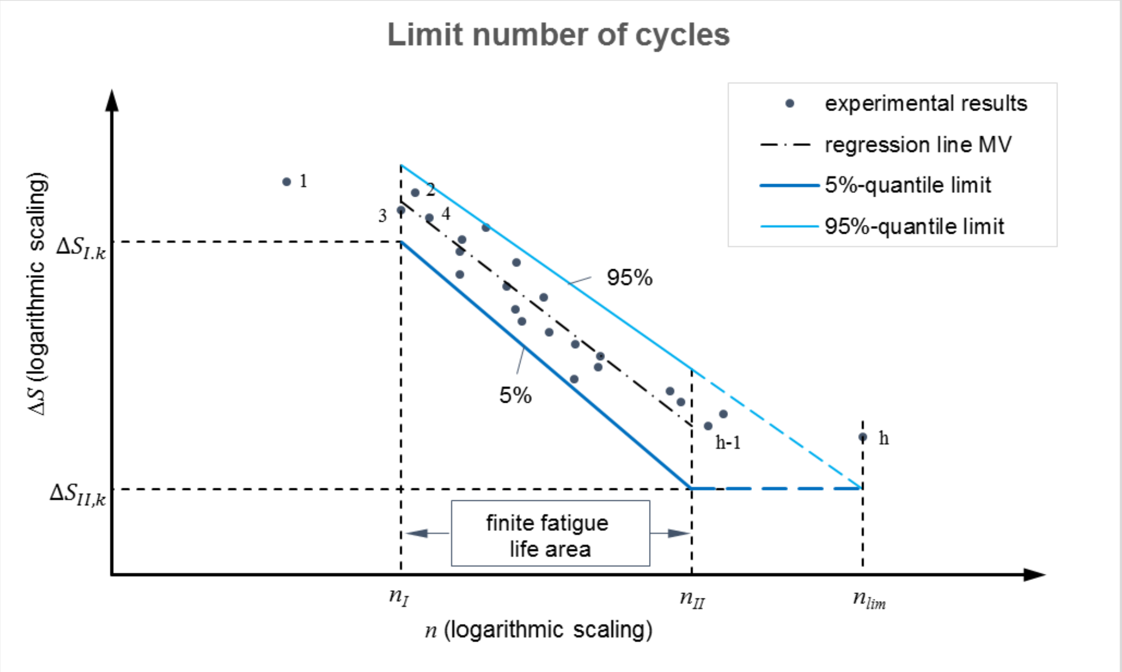


Figure D.5: Determination of the limit number of cycles n_{lim}

The assessment of the stabilization of deformations starts once the allocated limit number of cycles $n_{lim,a}$, which lies within the respective interval, is reached. If a stabilization is detected at the allocated limit number of cycles, then the limit number of cycles n_{lim} is assigned to the value $n_{lim,a}$. If no stabilization is detected, then the limit number of cycles has to be increased.

For the assessment of the stabilization, regarding the upper limit S_{oi} 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 2·10⁶ 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 D.6). If no stabilization occur the next higher areas (B and C) are compared with each other. This is continued until the upper limit of each respective interval is reached.

Note: If, during the measurement recording large variance of the measured values occur and the evaluation provides inconclusive results, then the specimen is always charged to the upper limit of the respective interval. In this case the only criterion for a „real" run-out is the run-out test, provided that no damage has occurred.

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

Centroid of test result scatter for one area:

$$\dot{s}_o = \frac{1}{m}\sum_{i=1}^{m} s_{o,i} \quad \text{(D.40)} \qquad \dot{n} = \frac{1}{m}\sum_{i=1}^{m} n_i \quad \text{(D.41)}$$

where $s_{o,i}$ = Displacement of the cross section, regarding the upper limit S_{oi} of a sinusoidal load process, for every step i

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

m = number of measured values ($m \geq 80$)

Regression line:

$$s_o = a_s + b_s n \quad \text{(D.42)}$$

$$a_s = \dot{s}_o - b_s \dot{n} \quad \text{(D.43)} \qquad b_s = \frac{\sum_{i=1}^{m}(n_i - \dot{n})(s_{o,i} - \dot{s}_o)}{\sum_{i=1}^{m}(n_i - \dot{n})^2} \quad \text{(D.44)}$$

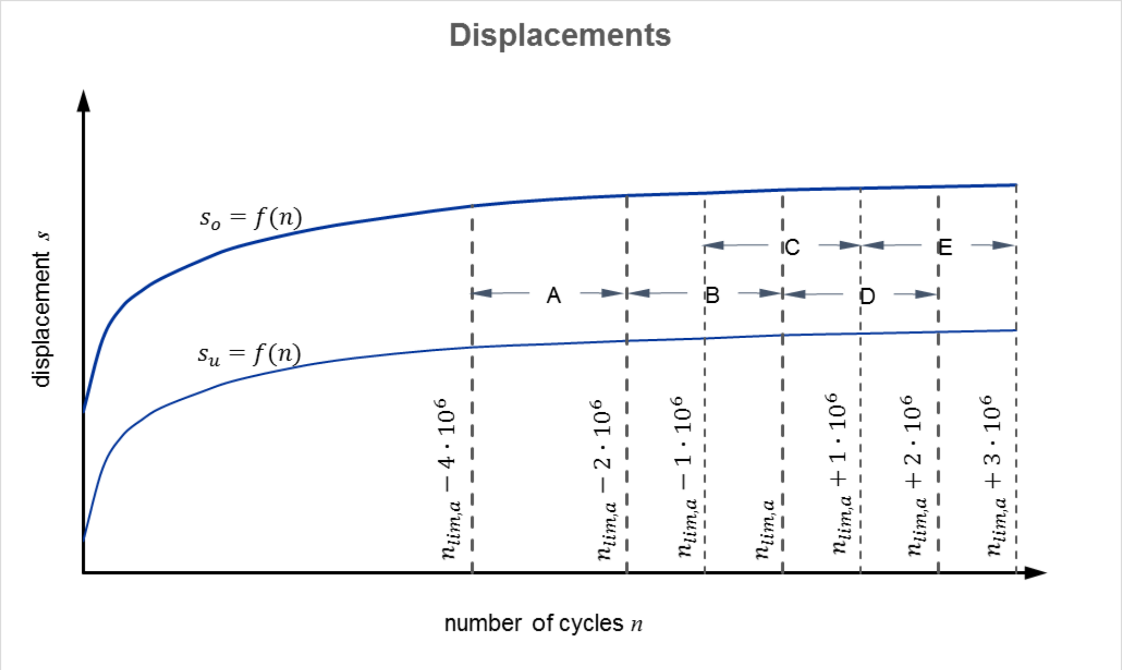


Figure D.6: Stabilization of deformations of a run-out

Specimen reaching $n \geq n_{lim}$ without failure, are to be tested again with the stress range ΔS_{RT} until failure occur. 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 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. Results of run out tests performed on their second load level are required only to verify that damage to the specimens has not occurred 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 D.7) and is calculated as follows:

$$\Delta S_{RT} \approx \Delta \overline{S}_I - \left(\Delta \overline{S}_I - \Delta \overline{S}_{II}\right) / 3 \quad \text{(D.45)}$$

If the pre-test results show a crossing point between testing in Position 1 and Position 2 (see Figure 2.14) and a run-out specimen on first load level is performed in unfavourable position (e.g. Pos. 1), then the run-out test results on second load level shall be assigned to the same position. If the second load level belongs to the range identified for the favourable position, then the scatter band on load level ΔS_{RT} determined for the unfavourable position shall be transferred to the favourable position as shown in Figure C.4. Once the scatter band is transferred, then the same conditions shall be applied for the run-out test assessment.

D.2.7 Determination of the characteristic fatigue limit resistance

The determination of the characteristic fatigue limit resistance $\Delta S_{D,k}$ starts with the first run-out ΔS_h (see Fig. D.7 – case 1). If a „real" run-out specimen is proved under this load level then the load levels for following tests will be reduced continuously. Therefore the range between ΔS_h and the characteristic fatigue resistance $\Delta S_{II,k}$ is divided into three parts, thus three load levels with equal distances arise. The characteristic fatigue limit resistance $\Delta S_{D,k}$ may be determined when all four specimen are considered as „real" run-out specimen without failed test results in between. The level of $\Delta S_{D,k}$ is defined with $k_{r,p,1-\alpha} \cdot \hat{s}_{II}$-distance down from the level of failed ($\triangleq \Delta S_{fail}$ case 1 - example 1) or damaged specimen with the smallest load range. For this level of the characteristic value statistical analyses were performed with many random simulations and have shown that this rule leads to a confidence level of 90% for the 5%-quantile of the fatigue limit capacity.

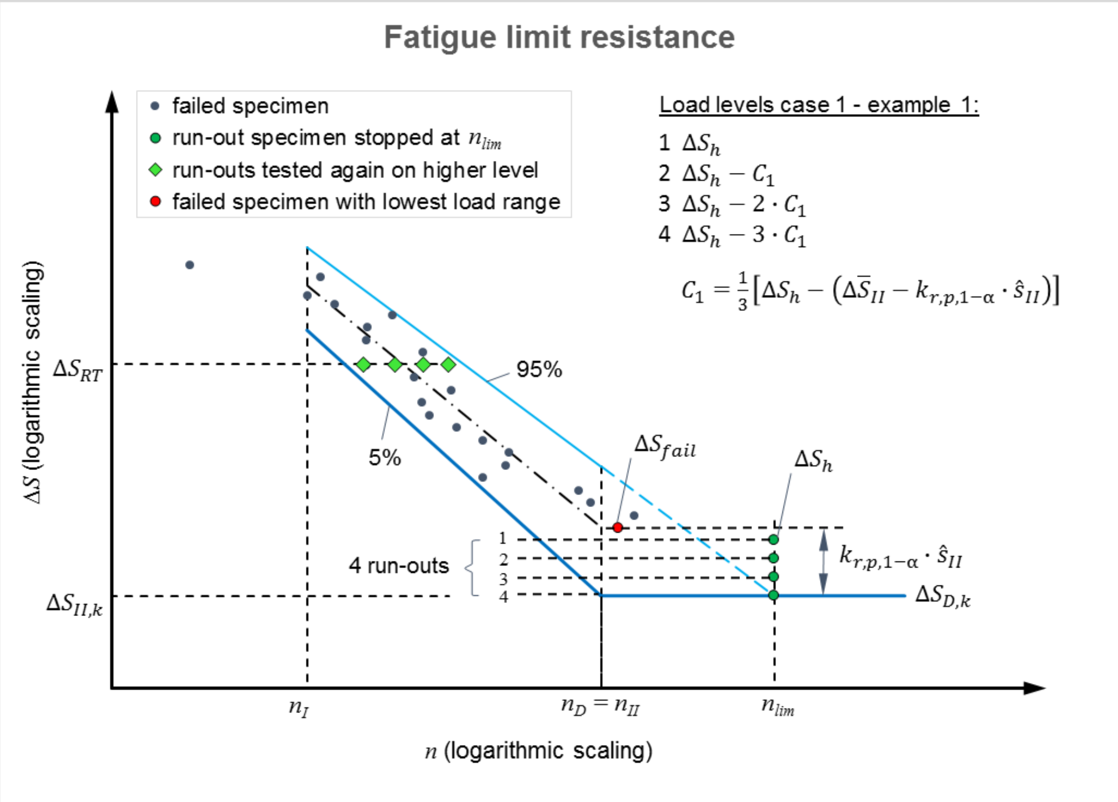


Figure D.7: Determination of the characteristic fatigue limit resistance (case 1: example 1)

In case two a specimen below the first run-out ΔS_h has failed ($\triangleq \Delta S_{fail}$ case 2 - example 1) or do not passes the run-out test. The parameters of cross section n_{II} (see Section D.2.5) and the limit number of cycles (see Section D.2.6) have to be determined again. In the range between failed or damaged specimen and the characteristic fatigue resistance $\Delta S_{II,k}$ four testing levels with equal distances are determined (see Figure D.8). If all four specimen are considered as „real" run-out specimen, then the characteristic fatigue limit resistance $\Delta S_{D,k}$ is defined with $k_{r,p,1-\alpha} \cdot \hat{s}_{II}$-distance down from the level of failed or damaged specimen with the smallest load range.

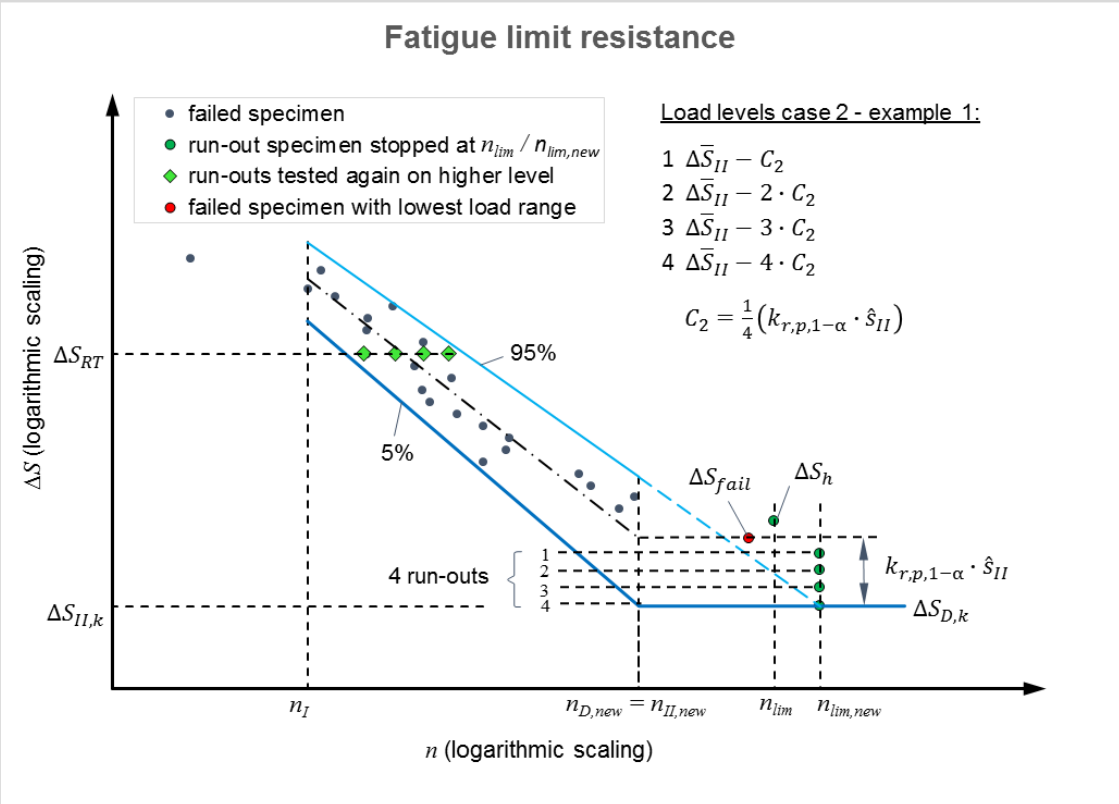


Figure D.8: Determination of the characteristic fatigue limit resistance (case 2: example 1)

In example two of case two a specimen below the first run-out ΔS_h has failed ($\triangleq \Delta S_{fail}$ case 2 example 2) and falls into the finite fatigue life area (see Figure D.9). The parameters of finite fatigue life area (see Section D.2.4 and D.2.5) and the limit number of cycles (see Section D.2.6) have to be determined again and testing for determination of the fatigue limit resistance needs to re-start following the rules of case two.

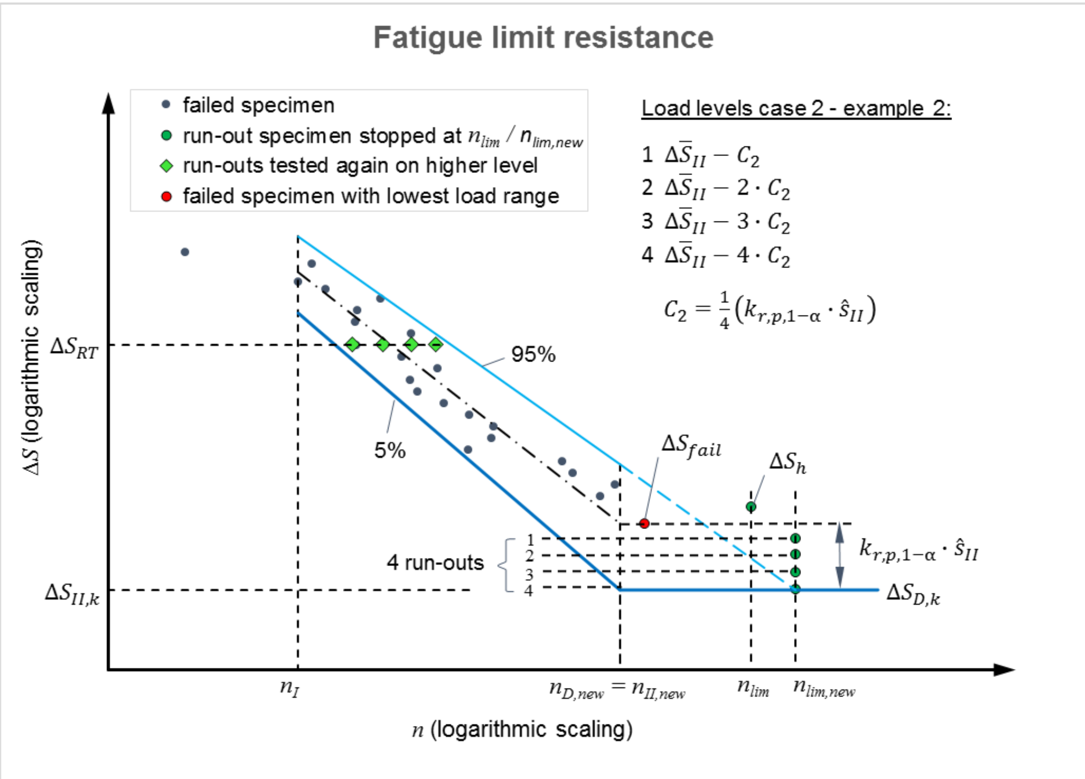


Figure D.9: Determination of the characteristic fatigue limit resistance (case 2: example 2)

D.2.8 Reduction of the finite fatigue life resistance

After determining the finite fatigue and fatigue limit resistances the characteristic resistance $\Delta S_{I,k}$ in cross section n_I is reduced by the factor $n_{I,red}$ to achieve the required level of confidence. It is calculated by following equations:

$$\Delta S_{I,k,red} = 10^{y_{I,k,red}} \quad \text{(D.46)}$$

$$y_{I,k,red} = \eta_{I,red} \cdot y_{I,k} \quad \text{(D.47)}$$

where $\eta_{I,red} = 1 - 0{,}03 \cdot \Delta\dot{S} \,/\, \Delta\overline{S}_I$ (D.48)

$y_{I,k} = \lg \Delta S_{I,k}$

This leads to the following parameters of the characteristic limit in the finite fatigue life area:

$$a_{k,red} = y_{I,k,red} - b_k \cdot x_I \quad \text{(D.49)}$$

The number of cycles $n_{D,red}$, i.e. the transition from finite fatigue life to fatigue limit resistance is calculated as follows:

$$n_{D,red} = 10^{x_{D,red}} \quad \text{(D.50)}$$

$$x_{D,red} = \frac{y_D - a_{k,red}}{b_k} \quad \text{(D.51)}$$

where $y_D = lg\, \Delta S_{D,k}$

The characteristic limit in the finite fatigue life area is shifted by the amount of reduction in parallel downwards (see Figure D.10).

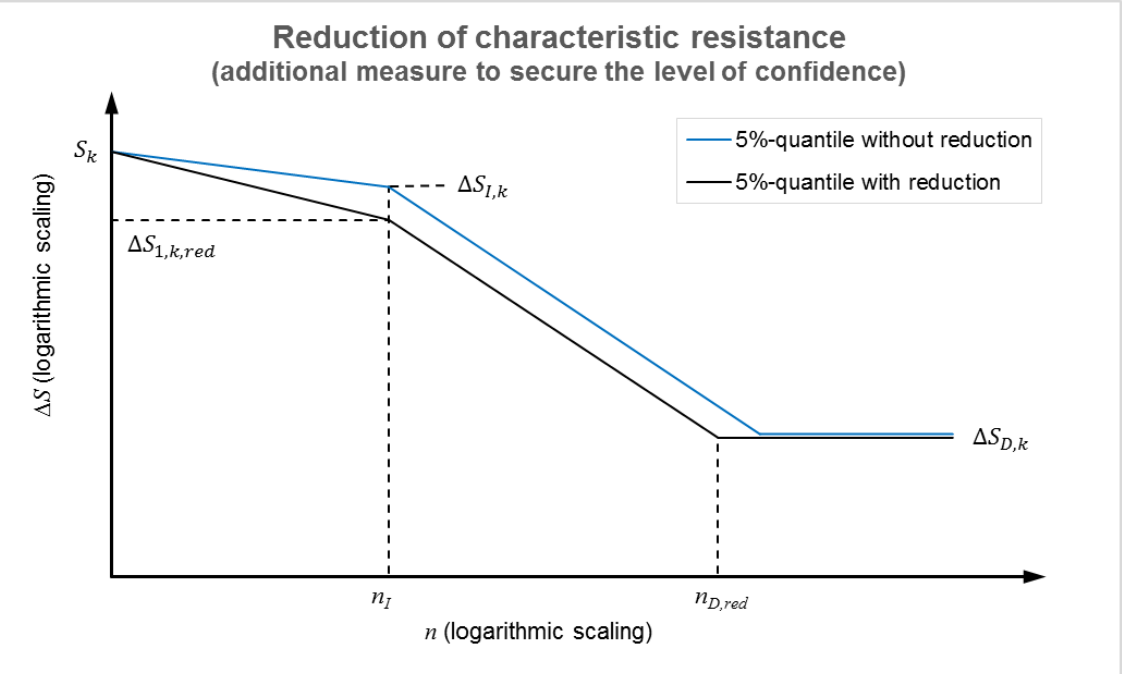
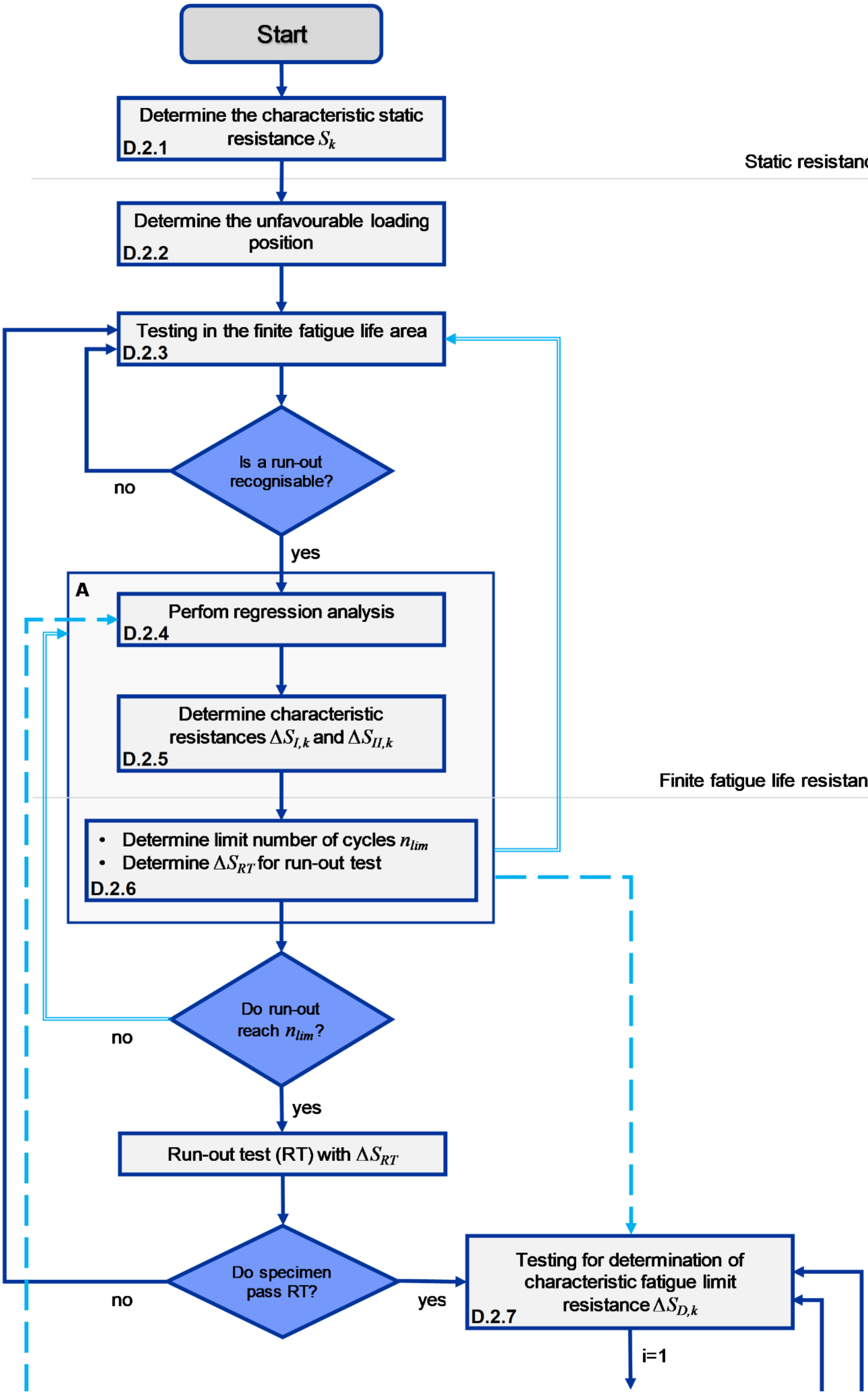
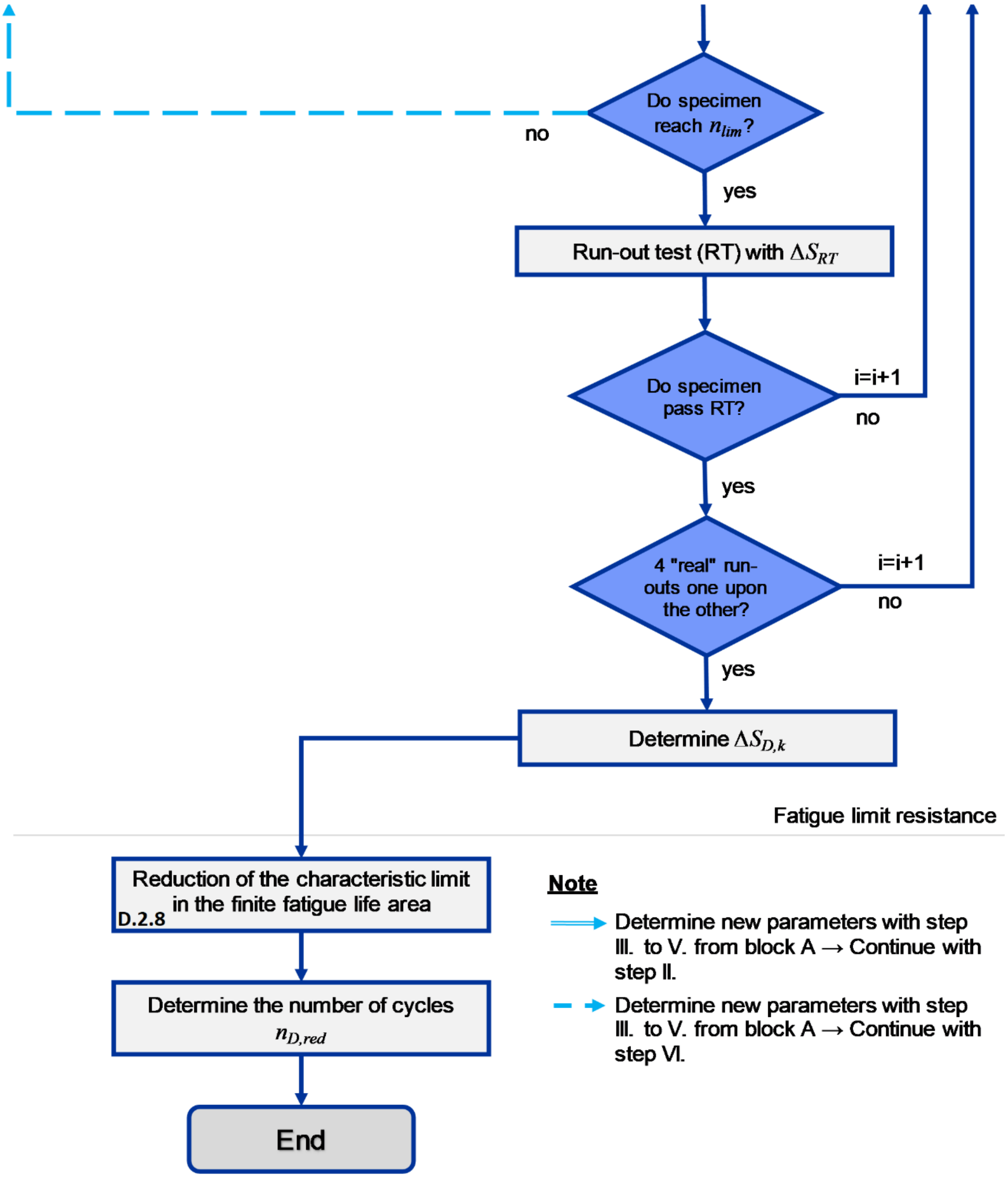


Figure D.10: **Reduction of characteristic fatigue resistance**

D.2.9 Flow chart for tri-linear method




Do specimen reach n_{lim}?
no
yes
Run-out test (RT) with ΔS_{RT}
Do specimen pass RT?
i=i+1
no
yes
4 "real" run-outs one upon the other?
i=i+1
no
yes
Determine $\Delta S_{D,k}$
Fatigue limit resistance
Reduction of the characteristic limit in the finite fatigue life area
D.2.8
Determine the number of cycles $n_{D,red}$
End
Note
Determine new parameters with step III. to V. from block A → Continue with step II.
Determine new parameters with step III. to V. from block A → Continue with step VI.

ANNEX E RESISTANCE UNDER FATIGUE CYCLIC TENSION LOADING – ASSESSMENT: CHARACTERISTIC FATIGUE LIMIT RESISTANCE (METHOD B)

E.1 Basics

The force-controlled periodic loading with sinusoidal course should be used for 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 should 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 (assessment 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.

E.2 Procedure steps

E.2.1 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 ranges for hot-rolled and cold-formed anchor channels 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.

Hot-rolled: $\Delta S_D^{\approx} \approx (0.10, \ldots ,0.30) \cdot \overline{S}$

Cold-formed: $\Delta S_D^{\approx} \approx (0.05, \ldots ,0.20) \cdot \overline{S}$

The load level for reference attempts corresponds to the load level ΔS_{RT} (see Section E.2.2).

E.2.2 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 $5 \cdot 10^6 \leq n_{lim} \leq 8 \cdot 10^6$ (carbon steel) respectively $7 \cdot 10^6 \leq n_{lim} \leq 10^7$ (stainless steel).

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 $n_{lim,u}$ of the respective interval. If no stabilization is detected, then the limit number of cycles has to be increased.

For the assessment of the stabilization, regarding the upper limit S_{oi} 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 E.1). If no stabilization occur the next higher areas (B and C) are compared with each other. This is continued until the upper limit of each respective interval is reached.

Note: If, during the measurement recording large variance of the measured values occur and the evaluation provides inconclusive results, then the specimen is always charged to the upper limit of the respective interval. In this case the only criterion for a „real" run-out is the run-out test, provided that no damage has occurred.

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

Centroid of test result scatter for one area:

$$\dot{s}_o = \frac{1}{m}\sum_{i=1}^{m} s_{o,i} \quad \text{(E.1)} \qquad \dot{n} = \frac{1}{m}\sum_{i=1}^{m} n_i \quad \text{(E.2)}$$

where $s_{o,i}$ = Displacement of the cross section, regarding the upper limit S_{oi} of a sinusoidal load process, for every step i

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

m = number of measured values ($m \geq 80$)

Regression line:

$$s_o = a_s + b_s n \quad \text{(E.3)}$$

$$a_s = \dot{s}_o - b_s\dot{n} \quad \text{(E.4)} \qquad b_s = \frac{\sum_{i=1}^{m}(n_i - \dot{n})(s_{o,i} - \dot{s}_o)}{\sum_{i=1}^{m}(n_i - \dot{n})^2} \quad \text{(E.5)}$$

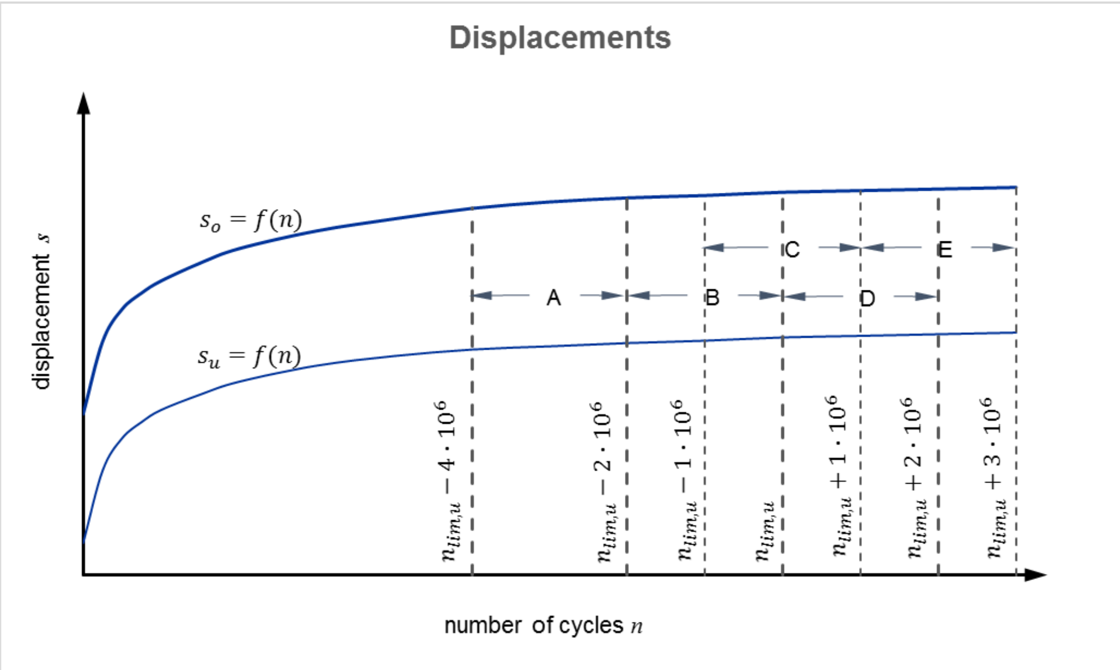


Figure E.1: Stabilization of deformations of a run-out

Specimen reaching $n \geq n_{lim}$ without failure, are to be tested again with the stress range ΔS_{RT} until failure occur. 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 number of cycles on the second load level exceed the minimum number of cycles $n_{RT,min}$ (see Section E.2.3). 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. This second test is to be set on the lower limit of the upper third of the finite fatigue life area (see Figure E.2) and is calculated as follows:

$$\Delta S_{RT} = \bar{S} - (\bar{S} - \Delta S_D)\,/\,3 \quad \text{(E.6)}$$

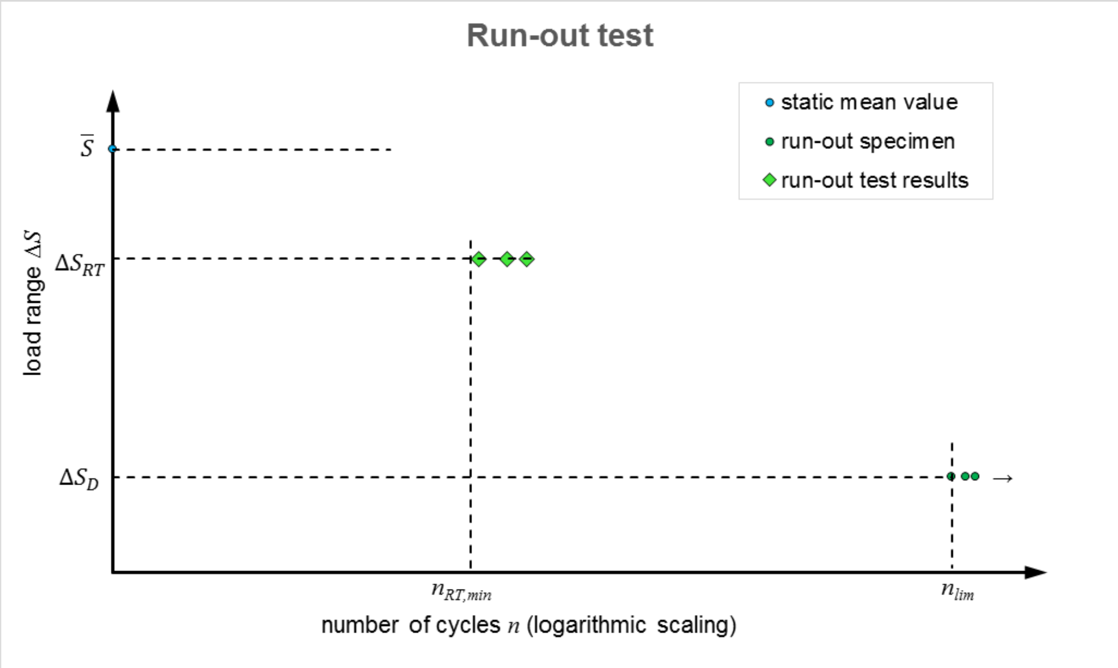


Figure E.2: Load level for run-out test

E.2.3 Reference attempts for determination of the minimum number of cycles for run-out test

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

$$n_{RT,min} = \bar{n}_r - 2 \cdot \hat{s}_r \tag{E.7}$$

$$\bar{n}_r = 10^{((\lg n_1 + \lg n_2 + \lg n_3)/3)} \tag{E.8}$$

$$\hat{s}_r = \sqrt{\frac{\sum_{i=1}^{3} (\bar{n}_r - \lg n_i)^2}{2}} \tag{E.9}$$

where n_i = number of cycles of the cross section for every step i

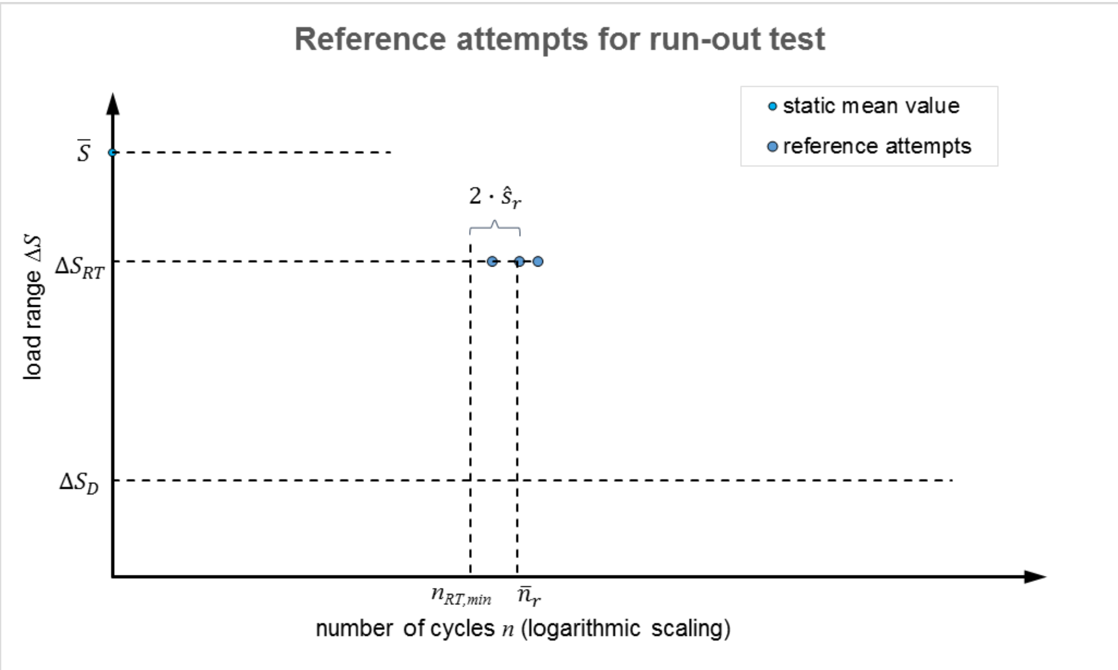


Figure E.3: Minimum number of cycles for run-out test

E.2.4 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:

$$\Delta S_{D,k} = 0.6 \cdot \Delta S_D \quad \text{(E.10)}$$

ANNEX F TEST DETAILSAND ASSESSMENT OF ANCHOR CHANNELS IN CONCRETE CONCERNING RESISTANCE TO FIRE

F.1 General

The resistances under tension and shear load due to steel failure cannot be individually achieved by calculation due to failure of multiple steel parts and multiple locations. Therefore the design resistances under tension and shear load due to steel failure are evaluated according to Annex F, section F.2 in a series of tension tests as a minimum of those failure modes and locations.

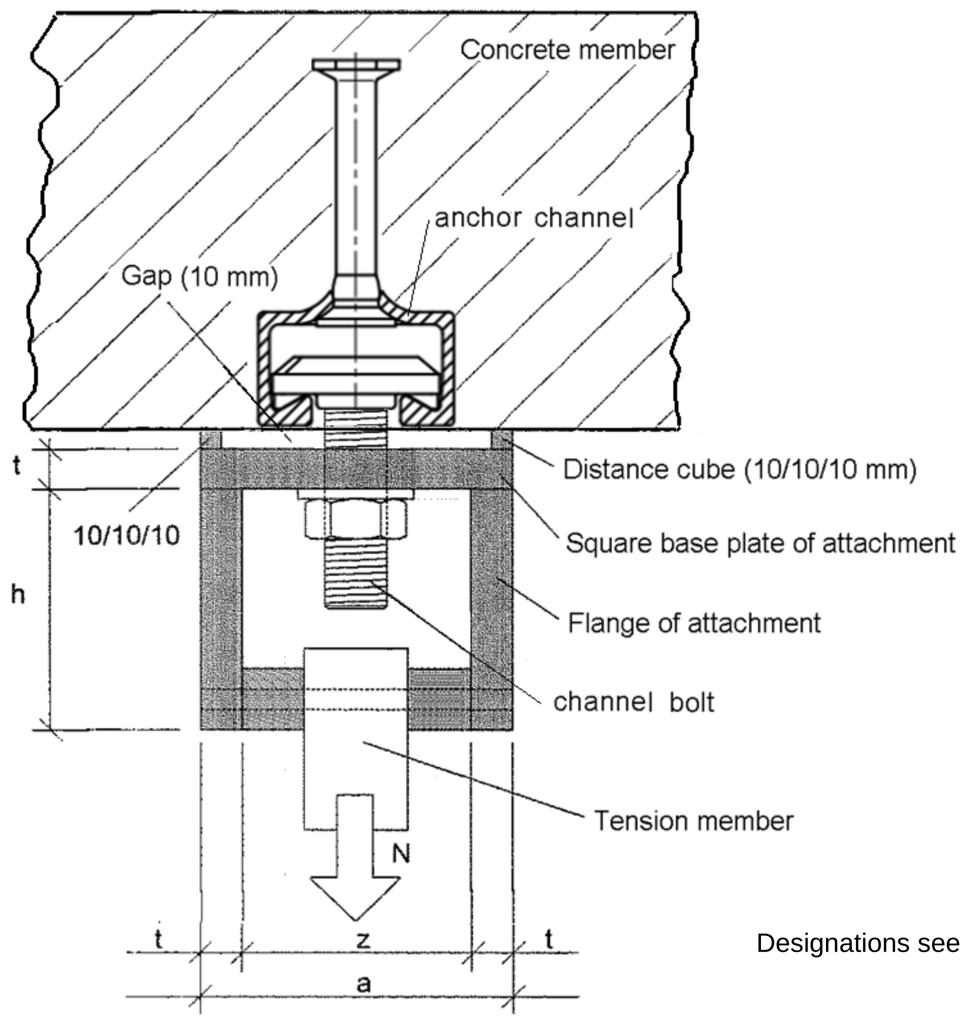
The determination is valid for unprotected anchor channels.

F.2 Experimental determination of the duration of the fire resistance of anchor channels due to steel failure under tension load

The anchor channel has to be set according to the manufacturer's product installation instructions (MPII) and pre-stressed with the installation torque $T_{inst,g}$, the torque has to be reduced to $0.5 \times T_{inst}$ after 10 min.

F.2.1 Test setup

The tests for the determination of the carrying capacity under steel failure have to be carried out in uncracked concrete using an unloaded slab. The principle test setup can be seen in Figure F1.



Designations see Table F.1

Figure F.1 Test setup for the determination of the steel failure under fire exposure and tension load

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

Table F.1 Dimensions of the fixture during the test under fire exposure

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

Anchor channels with two or more anchors may be used.

The anchor channels shall be used with the minimum end spacing x_{min} and the maximum spacing s_{max} of the anchors.

The anchor channel shall be basically loaded in mid span.

F.2.2 Test procedure

The channel bolt has to be loaded in tension during the test under fire exposure via the fixture which is defined in Table F.1. The fire tests have to be carried out according to EN 1363-1 [2].

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

F.2.3 Assessment

From the fire tests pair of variates [test load F / duration of failure t_u] shall be determined (existing test results in cracked concrete can be taken into account for the evaluation, if the failure appeared after more than 60 min). The test loads F shall be converted into steel stresses σ_s and drawn for each channel bolt size in a diagram depending on the determined fire resistance duration t_u (see Figure F.2). By linear regression of the pair of variates σ_s / (1/t_u) (see Figure F.3) the formula (mean value curve) according to (F.1) shall be determined.

The test results should represent the regression curve according to Figure F.2. Clouds of similar test results cannot be used for the determination of the regression curve. If the channel bolt and the anchor channel do not fail during the test, the result cannot be used for determination of the regression curve according to Figure F.2.

$$\sigma_{s1} = p_1 + p_2 / t_u \qquad \text{(F.1)}$$

The mean value curve according to (F.1) shall be reduced with an additional factor $p_3 < 1$ in such a way, that the curve runs through the pair of variates of the most unfavourable test result. As a result the lower limit value curve according to (F.2) is obtained.

$$\sigma_{s2} = p_3 \bullet (p_1 + p_2 / t_u) \qquad \text{(F.2)}$$

The characteristic steel stress for a duration of fire resistance of 60 min, 90 min and 120 min. can be calculated by (F.2) as follows:

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

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

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

Using the two pair of variates t_u = 60min / $\sigma_{Rk,s,fi(60min)}$ and t_u = 90min / $\sigma_{Rk,s,fi(90min)}$ the following linear equation can be derived:

$$\sigma_{s3} = p_4 - p_5 \bullet t_u \quad (F.3)$$

The characteristic steel stress for a duration of fire resistance of 30 min can be calculated by (F.3) as follows:

$$\sigma_{Rk,s,fi(30)} = p_4 - p_5 \bullet 30min$$

If there are tests carried out with two channel bolt sizes for one anchor channel size only (d_1 and d_2), the characteristic steel stress for intermediate sizes ($d_1 \le d \le d_2$) can be calculated by linear interpolation without additional tests only (see Figure F.4), if the ratio of the steel strength $\sigma_{Rk,s,d2}$ / $\sigma_{Rk,s,d1}$ is not larger than about 2, channel bolt heads are identical and channel bolt failure is decisive for both. For channel bolt sizes d > d_2, the characteristic steel stress calculated for d_2 can be taken, if channel bolt heads are identical and channel bolt failure is decisive for both.

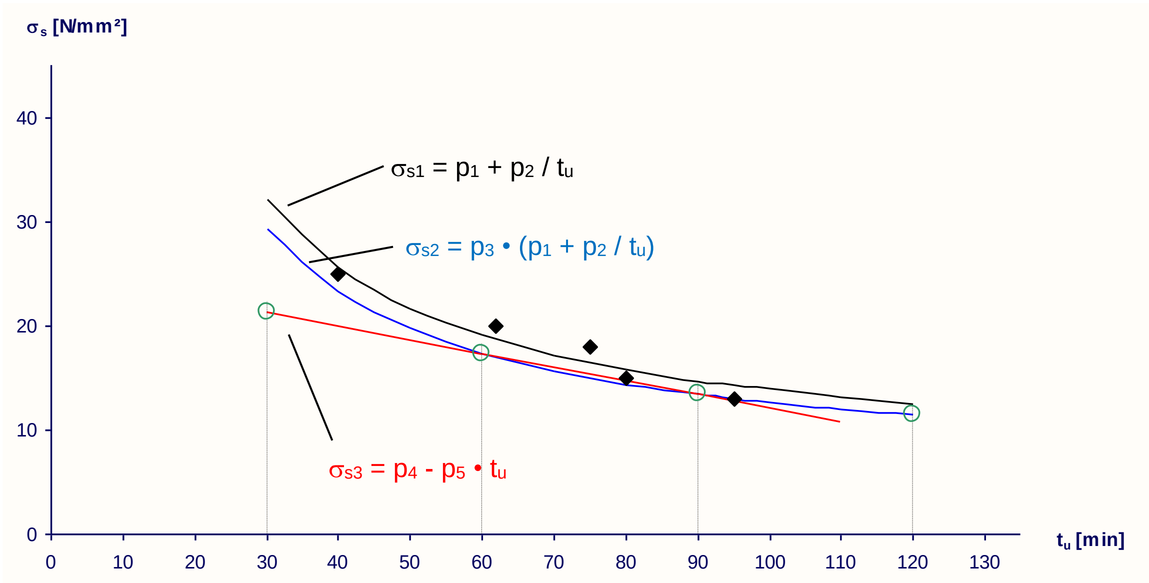


Figure F.2 Determination of the characteristic steel stress

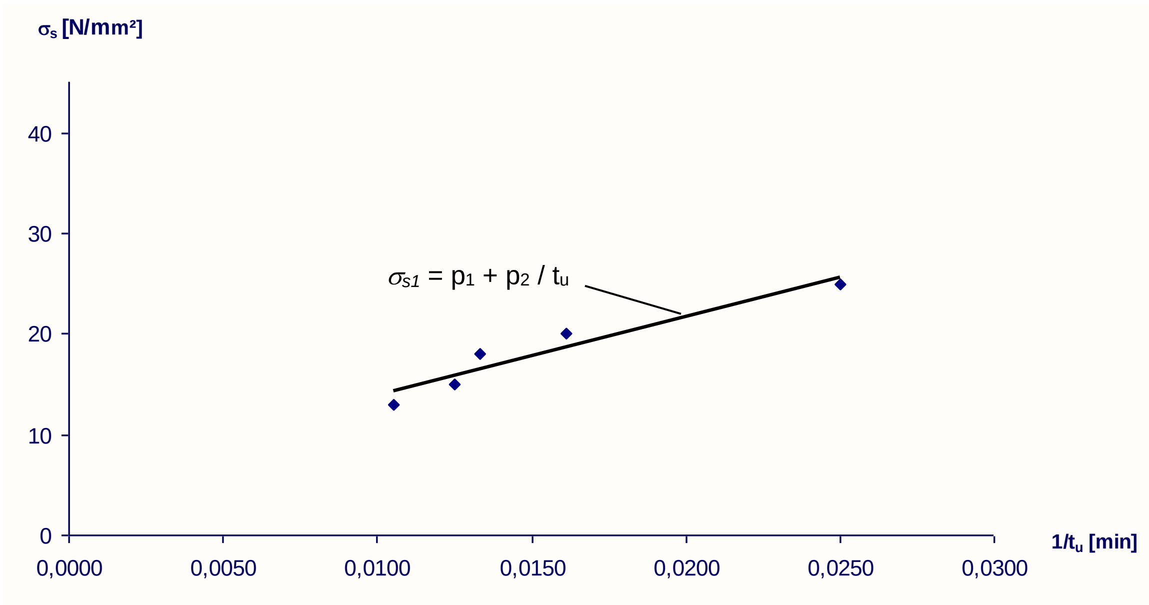


Figure F.3 Determination of the regression equation

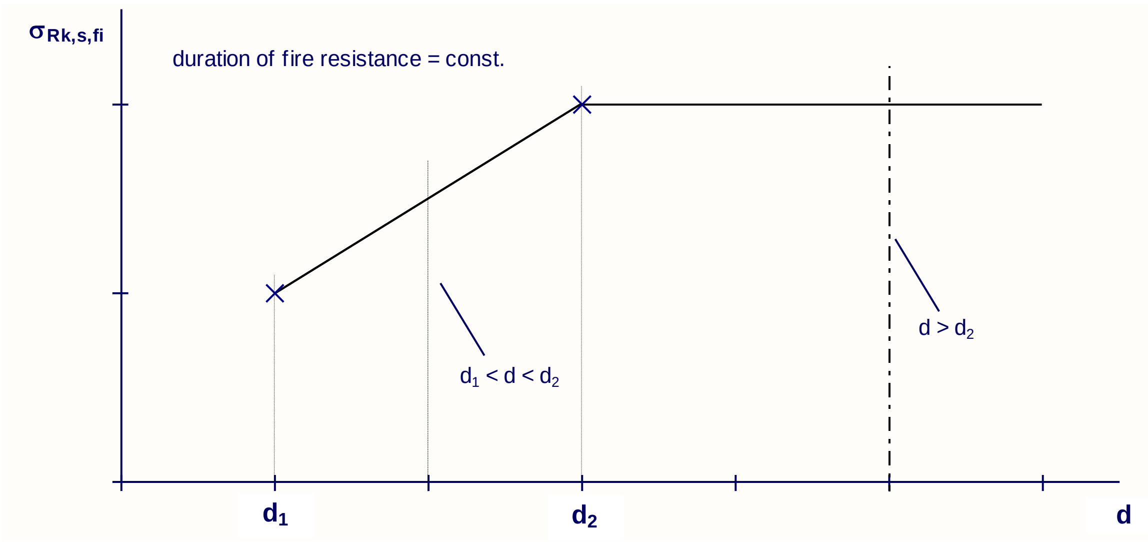


Figure F.4 Interpolation of intermediate sizes

The resistances to steel failure under tension load may be used as the resistances under shear load.