



EUROPEAN ASSESSMENT DOCUMENT

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ANCHOR CHANNELS

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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.

- (1) 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 Fig. 1.1 to Fig. 1.4. Typical cross sections of channels, types of connections between anchor and channel and anchor types are shown in Fig. 2.8 to Fig. 2.10. 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.
- (2) 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 in contact with the channel (see Fig. 1.1).
- (3) 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.

1.1.1 Channel profile

- (1) The channel profile consists of carbon steel or stainless steel.
- (2) The channel profiles are made by a cold- or hot-forming manufacturing process.
- (3) The channel profile dimensions are limited by the values 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}	$\geq 15 \text{ mm}$ $\leq 51 \text{ mm}$
Channel width b_{ch}	$\geq 25 \text{ mm}$ $\leq 76 \text{ mm}$
channel length l_{ch}	$\geq 100 \text{ mm}$

1.1.2 Anchor - General

- (1) 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.
- (2) The axial distance between the end of the channel and the axis of the nearest anchor, x (see Fig. 1.2), is $\geq 25 \text{ mm}$.
- (3) The axial spacing between anchors, s (see Fig. 1.2), is at least 50 mm. The maximum spacing s , is not larger than $5 \cdot c_{min}$ or 400 mm.
- (4) If more than two anchors are connected to the channel back, their spacing shall be constant.
- (5) This EAD applies to anchors according to 1.1.3 or 1.1.4.

1.1.3 Anchors, that are welded to the channel back

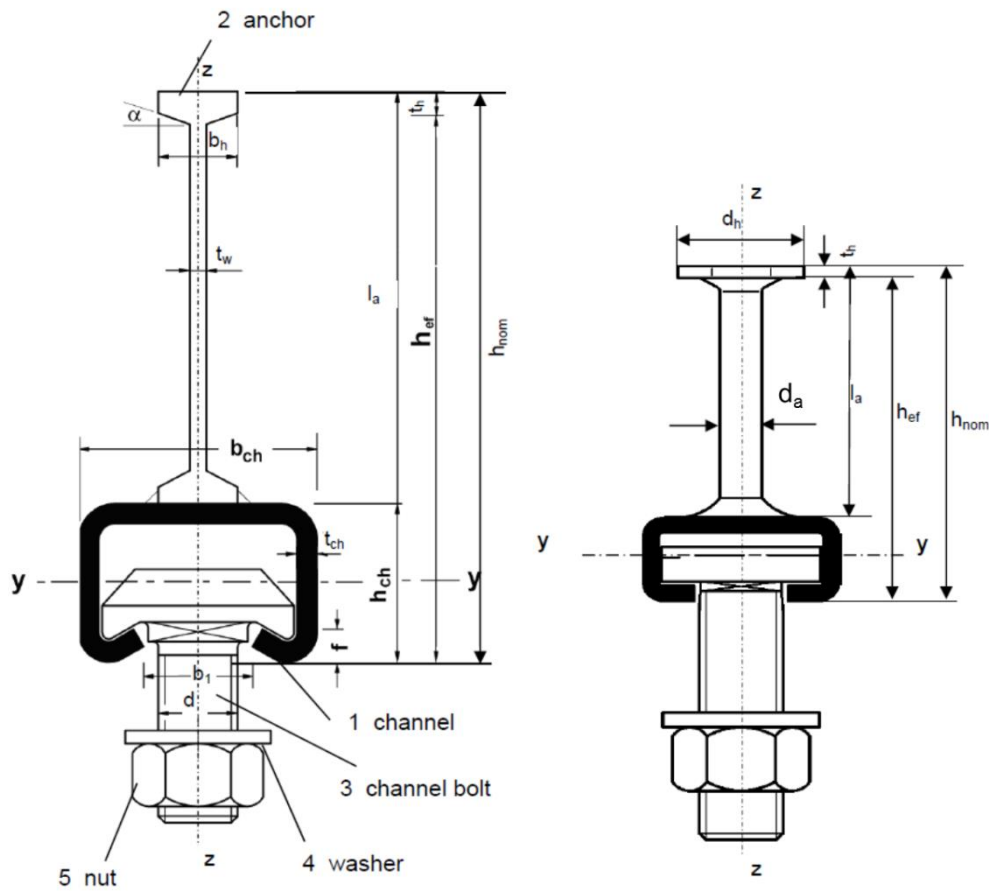
- (1) The anchors consist of I-shaped or T-shaped profiles or round headed anchors. The welding is performed in a plant by an appropriate welding method (method according to EN ISO 4063 [8]).
- (2) I-shaped and T-shaped anchors comply with the following dimensions (compare Fig. 1.1a): length $l_a \geq 60$ mm, web thickness $w \geq 4$ mm, width of anchor head $b_h \geq 14$ mm and width (cutting length) $10 \text{ mm} \leq w_A \leq 50$ mm.
- (3) Round headed anchors comply with the following dimensions (compare Fig. 1.1b): length $l_a \geq 30$ mm, shaft diameter $d_a \geq 5$ mm and head diameter $d_h \geq 12$ mm. The head is forged to the anchor or may consist of a nut, which is fixed non-detachably.

1.1.4 Round headed anchors that are forged or bolted to the channel back.

- (1) The anchors comply with the dimensions given in 1.1.3 (3).
- (2) The anchors are placed into holes in the back of the channel and connected rigidly.

1.1.5 Channel bolts (hammer-head and hook-head channel bolts)

- (1) The geometry of the channel bolt head fits into the internal shape of the channel.
- (2) A marking at the end of the channel bolt shows the correct placement of the channel bolt.
- (3) Shape of shaft and thread follows EN ISO 4018 [9].
- (4) The indication of the strength class shall follows EN ISO 898-1 [10] and/or EN ISO 3506-1 [11].
- (5) The thread diameter is ≥ 6 mm (M6).



- a) anchor channel with I-anchor welded to the channel back. b) anchor channel with round anchor welded to the channel back.

Fig. 1.1: Examples of anchor channels with corresponding channel bolt

Table 1.2: Designations and materials

Part	Designation	Material
1	Channel	Steel acc. to EN 10025 [6]
		Steel acc. to EN 10149 [18]
		Stainless steel acc. to EN 10088 [7]
2	I-Anchor	Steel acc. to EN 10025 [6]
		Stainless steel acc. to EN 10088 [7]
	Round anchor	Steel acc. to DIN 17111 [14]
		Steel acc. to EN 10263 [15]
		Steel acc. to EN 10269 [19]
		Stainless steel acc. to EN 10088 [7]
3	Channel bolt	Shaft and thread form following EN ISO 4018 [9]
		Carbon steel, $4.6 \leq \text{strength class} \leq 8.8$ acc. to EN ISO 898 [10]
		Stainless steel, $50 \leq \text{strength class} \leq 70$ following EN ISO 3506 [11]
4	Washer	Steel, hardness class ≥ 200 HV acc. to EN ISO 7089 [20], EN ISO 7090 [26] and EN ISO 7091 [20]
		Stainless steel, hardness class ≥ 200 HV acc. to EN ISO 7089 [20], EN ISO 7090 [26] and EN ISO 7091 [20]
5	Nut EN ISO 4032 [16] and EN ISO 4034 [17]	Steel, strength class 5, 6 or 8, acc. to EN ISO 898-2 [10]
		Stainless steel, strength class 50 or 70 acc. to EN ISO 3506-2 [11]

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

The product is not fully covered by the following harmonised technical specification:
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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.

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

1.2 Information on the intended use of the construction product

1.2.1 Intended use

- (1) This EAD covers anchor channels installed in members made of compacted normal weight concrete of strength classes in the range C12/15 to C90/105 all in accordance with EN 206-1. The anchor channel is intended to be used in cracked and non-cracked concrete.
- (2) The anchor channel is embedded surface-flush in the concrete as illustrated in Fig. 1.2. 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 Fig. 1.2 and Fig. 1.3. The installation is described in the manufacturer's product installation instruction. Manufacturer's Product Installation Instructions (MPII) are clear and provide all necessary information for a safe installation.
- (3) The fixture is in contact with the concrete surface as shown in Fig. 1.3 a) or is not in contact with the concrete surface (steel-steel contact with no bending of the channel lips during installation) as shown in Fig. 1.3 b).
- (4) In applications according to Fig. 1.3 a) (fixture in contact with concrete) a clamping force between concrete and fixture is generated by tightening the channel bolt with the installation torque.
- (5) In applications according to Fig. 1.3 b) 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 prestressing 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.
- (6) Applications acc. to Fig. 1.3 a) and b) may have different values of T_{inst} . To report the installation torque T_{inst} acc. to Fig. 1.3 a) is mandatory and acc. Fig. 1.3 b) is optional.

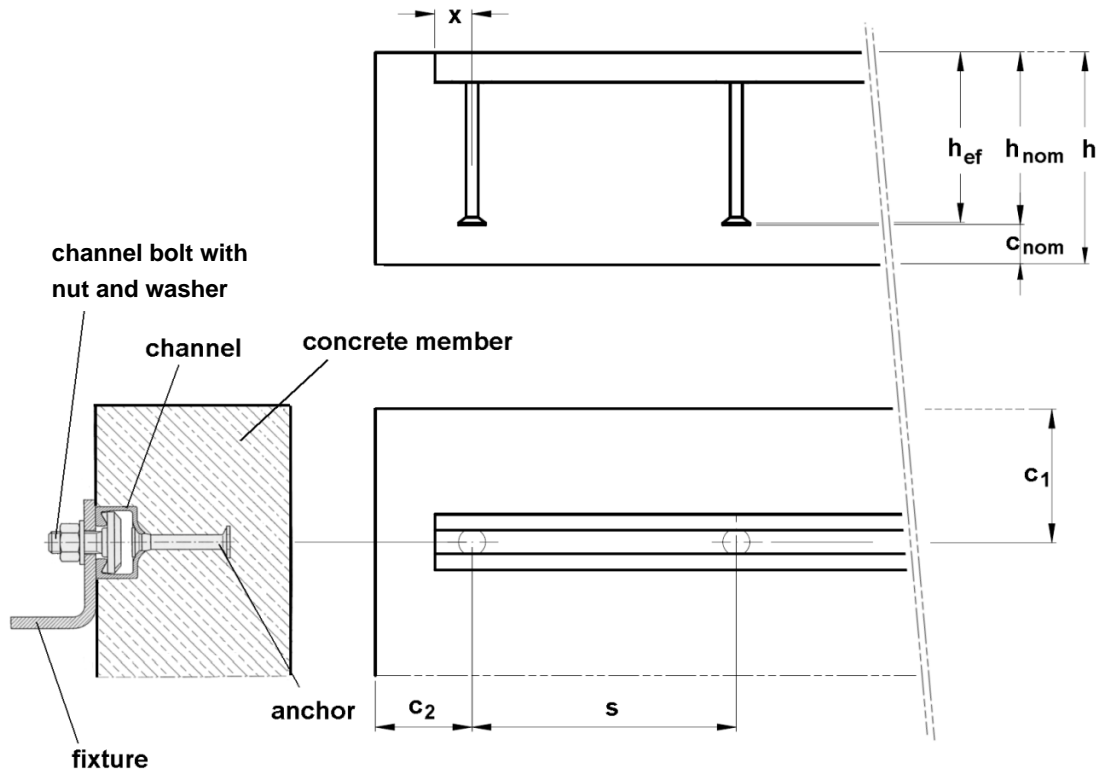


Fig. 1.2: Example of an anchor channel embedded in a concrete member

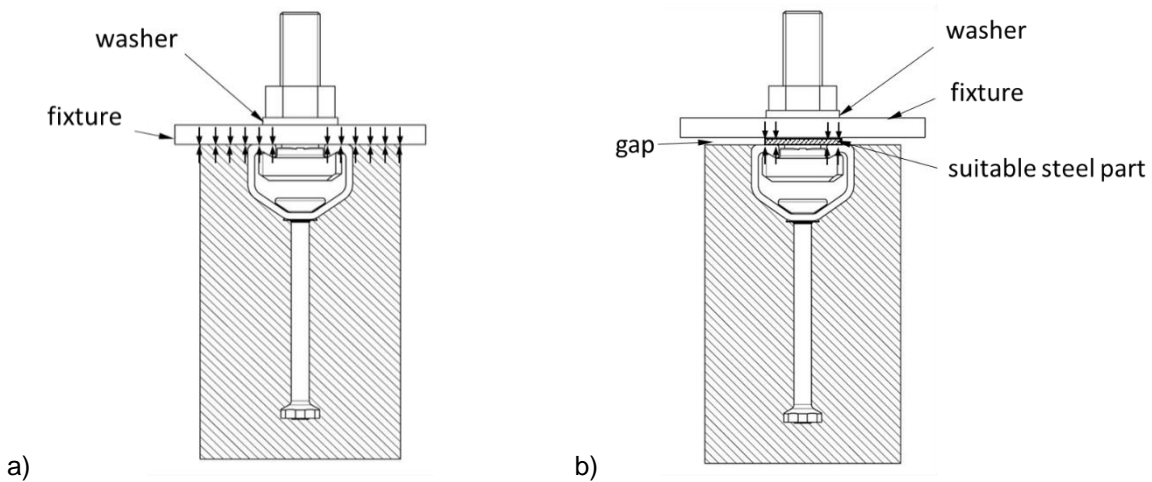


Fig. 1.3: Anchor channel embedded in concrete

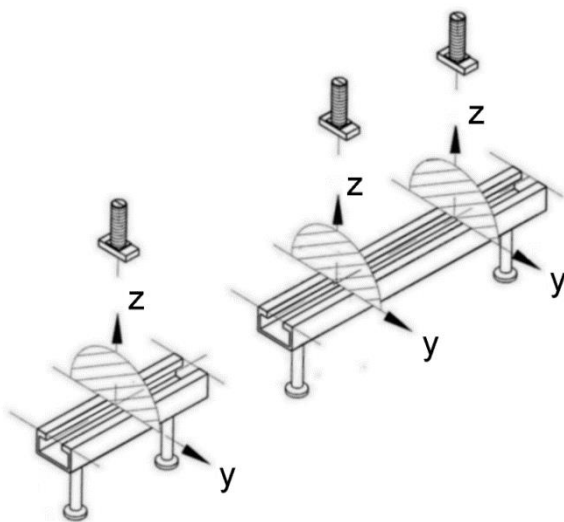
a) General: The fixture is fastened to the concrete or to the anchor channel respectively fastened to concrete and anchor channel.

b) Steel to steel contact: The fixture is fastened to the anchor channel by suitable steel part (e.g. washer).

- (7) The distance between two or more anchor channels is in such a way that no spacing between two anchors of neighboring anchor channels is less than $s_{cr,N}$.
- (8) The anchor channel is anchored in concrete by mechanical interlock between the anchor and the concrete member.
- (9) This EAD covers anchor channel under static or quasi-static loads. The anchor channel is used to transmit tensile loads, shear loads perpendicular to the longitudinal channel axis or any

combination of these loads in accordance with Fig. 1.4 into the concrete. The shear load is applied without or with lever arm in respect to the concrete surface.

- (10) This EAD covers also anchor channel under fatigue loads in combination with or without static or quasi-static loads. The anchor channel is used to transmit only tensile fatigue loads in accordance with Fig. 1.4 into the concrete. No static or quasi-static shear or fatigue shear load may be applied in concomitance with a fatigue tension load. A pre-condition for the assessment of anchor channels under fatigue loads is the complete assessment of the anchor channels under static loading.
- (11) Loads with an arbitrary distance are applied at any position within the outermost anchors of the anchor channel.
- (12) Any fixture is fixed to the anchor channel using a channel bolt.



tension load: z-direction
shear load: y-direction

Fig. 1.4: Admissible load directions covered by this EAD: tension loads, shear load perpendicular to the longitudinal axis of the anchor channel only and any combination of these loads.

- (13) This EAD provides assessment methods resulting in performance consistent with
 - EN 1992-4 [3] or
 - Technical Report "Calculation Method for the Performance of Anchor Channels" [4]
 and for fatigue loads in combination with
 - Technical Report "Calculation Method for the Performance of Anchor Channels under fatigue loads" [28]

Note 1: Since EN 1992-4 has not yet been published the TR "Calculation Method for the Performance of Anchor Channels" is intended to bridge the time span until the publication of EN 1992-4. The design method given in the TR "Calculation Method for the Performance of Anchor Channels" complies with the final draft of EN 1992-4. Once EN 1992-4 has been published no ETA will be issued with reference to this Technical Report.

Note 2: The links between test and design methods acc. Technical Report "Calculation Method for the Performance of Anchor Channels under fatigue loads" [28] are shown in Table 2.4.

- (14) The design of the anchorage is performed under the responsibility of an engineer experienced in anchorage design and concrete work.

1.2.2 Working life/Durability

- (1) 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.
- (2) 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 works¹.
- (3) The indications given as to the working life of the construction product cannot be interpreted as a guarantee neither given by the product manufacturer or his representative nor by EOTA when drafting this EAD nor by the Technical Assessment Body issuing an ETA based on this EAD, but are regarded only as a means for expressing the expected economically reasonable working life of the product.

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

1.3 Specific terms used in this EAD (if necessary in addition to the definitions in CPR, Art 2)

The definitions and symbols used in this EAD are given in EN 1992-4 [3] and Technical Report "Calculation Method for the Performance of Anchor Channels" [4] and below.

$A_{chb,h}$	=	cross section of channel bolt head		[mm ²]
	=	$b_{chb,h} \cdot t_{chb,h}$		
$N_{Rk,s,ch}$	=	minimum characteristic resistance of anchor channel under tension load		[N]
	=	$\min(N_{Rk,s,l}; N_{Rk,s,c}; N_{Rk,s,a})$		
T_{crack}	=	torque moment, at which a hairline crack (crack with a width < 0,1 mm) is observed at least at one anchor.		[Nm]
$V_{Rk,s,ch}$	=	minimum characteristic resistance of anchor channel under shear load		[N]
	=	$\min(V_{Rk,s,l}; V_{Rk,s,c}; V_{Rk,s,a})$		
b_1	=	channel opening	Fig. 1.1	[mm]
b_{ch}	=	channel width	Fig. 1.1	[mm]
$b_{chb,h}$	=	width of head of channel bolt		[mm]
b_h	=	width of the head of the I-anchor	Fig. 1.1	[mm]
c_{nom}	=	concrete cover	Fig. 1.2	[mm]
c_1, c_2	=	edge distances of the anchor	Fig. 1.2	[mm]
c_1^l	=	net distance between edge of the concrete member and the anchor channel = $c_1 - 0,5b_{ch}$	Fig. 1.2	[mm]
d	=	diameter of channel bolt	Fig. 1.1	[mm]
d_a	=	diameter of round anchor	Fig. 1.1	[mm]
d_h	=	diameter of round anchor head	Fig. 1.1	[mm]
f	=	height of channel lips	Fig. 1.1	[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]
h	=	thickness of concrete member	Fig. 1.2	[mm]
h_{ch}	=	channel height	Fig. 1.1	[mm]
h_{ef}	=	effective embedment depth	Fig. 1.1	[mm]
$h_{ef,min}$	=	minimum effective embedment depth		[mm]
h_{nom}	=	distance between concrete surface and end of embedded anchor	Fig. 1.1	[mm]
l_a	=	anchor length	Fig. 1.1	[mm]
$l_{chb,h}$	=	length of channel bolt head	Fig. 2.4	[mm]
s	=	spacing of anchors	Fig. 1.2	[mm]
t_{ch}	=	thickness of channel back, web and lips	Fig. 1.1	[mm]
$t_{chb,h}$	=	height of channel bolt head	Fig. 1.1	[mm]

t_h	=	thickness of anchor head	Fig. 1.1	[mm]
t_w	=	web thickness of I-anchor	Fig. 1.1	[mm]
W_A	=	width (cutting length) of I-anchor		[mm]
x	=	end spacing (distance between end of channel and axis of nearest anchor)	Fig. 1.2	[mm]
α	=	angle of anchor head $\leq 45^\circ$	Fig. 1.1	[°]
$C_{cr,N}$	=	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 ($2 C_{cr,N}$)		[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 ($2C_{cr,sp}$)		[mm]
S_{max}	=	maximum spacing between anchors		[mm]
S_{min}	=	mimimum spacing between anchors		[mm]
$S_{min,cbo}$	=	mimimum spacing between channel bolts		[mm]
C_{min}	=	mimimum 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		[-]
$k_{h,p,1-\alpha}$	=	OWEN factor; h: total number of fatigue cyclic test results; p: 5%-quantile ($p = 0.05$); $1 - \alpha$: level of confidence of 90% ($1 - \alpha = 0.9$)		[-]

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

$k_{n,p,1-\alpha}$ = OWEN factor; n: number of static test results; p: 5%-quantile ($p = 0.05$); $1 - \alpha$: level of confidence of 90% ($1 - \alpha = 0.9$) [-]

$k_{r,p,1-\alpha}$ = OWEN factor; r: number of fatigue cyclic test results in finite life fatigue area; p: 5%-quantile ($p = 0.05$); $1 - \alpha$: level of confidence of 90% ($1 - \alpha = 0.9$) [-]

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)	[-]
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{s}_A	=	average standard deviation of area A	[N]
\hat{s}_B	=	average standard deviation of area B	[N]
\hat{s}_C	=	average standard deviation of area C	[N]
\hat{s}_j	=	average standard deviation for each three results	[N]
$\hat{\hat{s}}_j^2$	=	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]
\hat{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]
\bar{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]
$\hat{\sigma}_r$	=	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]
$\Delta \bar{S}$	=	load range of average regression line	[N]
$\Delta \hat{S}$	=	load range of the centroid of test result scatter	[N]
ΔS_a	=	load level of attempt a for quality control	[N]
$\Delta \bar{S}_A$	=	mean value of area A	[N]
$\Delta \hat{S}_{A,5\%}$	=	5%-quantile of area A	[N]
ΔS_b	=	load level of attempt b for quality control	[N]
$\Delta \bar{S}_B$	=	mean value of area B	[N]
$\Delta \hat{S}_{B,5\%}$	=	5%-quantile of area B	[N]
² logarithmic value			
ΔS_c	=	load level of attempt c for quality control	[N]
$\Delta \bar{S}_C$	=	mean value of area C	[N]
$\Delta \hat{S}_{C,5\%}$	=	5%-quantile of area C	[N]
$\Delta \bar{S}_I$	=	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]
$\bar{\Delta S}_j$	=	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]
$\Delta S_{II,95\%}$	=	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]
ΔS_D^{\approx}	=	estimated value of the fatigue limit resistance	[N]
ΔS_i	=	load level of the cross section for every step i	[N]
$\bar{\Delta S}_i$	=	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 product and methods and criteria for assessing the performance of the product in relation to those essential characteristics

No	Essential characteristic	Assessment method	Type of expression of product performance
Basic Works Requirement 1: Mechanical resistance and stability			
1	Characteristic resistance for tension under static and quasi-static loading	2.2.2	Description ($N_{RK,s,a}$, $N_{RK,s,c}$, $N_{RK,s,l}^0$, $M_{RK,s,flex}$, $N_{RK,s}$, $N_{RK,p}$, $S_{l,N}$, $K_{cr,N}$, $K_{ucr,N}$, $h_{ef,min}$, $C_{cr,sp}$, $S_{cr,sp}$)
2	Characteristic resistance for shear <i>and combined tension and shear</i> under static and quasi-static loading	2.2.3	Description ($V_{RK,s,a}$, $V_{RK,s,c}$, $V_{RK,s,l}^0$, $V_{RK,s}$, $S_{l,V}$, $K_{cr,V}$, $K_{ucr,V}$, k_8 , $M_{RK,s}^0$, k_{13} , k_{14})
3	Characteristic resistance for tension under fatigue loading	2.2.4 or 2.2.5	Description ($\Delta N_{RK,s;0;n}$, $\Delta N_{RK,c;0;n}$, $\Delta N_{RK,p;0;n}$, $\Delta N_{RK,s;0;\infty}$, $\Delta N_{RK,c;0;\infty}$)
4	Displacements	2.2.8	Description (δ_{N0} , $\delta_{N\infty}$, δ_{V0} , $\delta_{V\infty}$)
5	Durability	2.2.9	Description
Basic Works Requirement 2: Safety in case of fire			
6	Reaction to fire	2.2.10	Class
7	Resistance to fire	2.2.11	Description ($N_{RK,s,fi}$, $V_{RK,s,fi}$, $C_{cr,N,fi}$, $S_{cr,N,fi}$, $C_{min,fi}$, $S_{min,fi}$)

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

Characterisation of anchor channels to be assessed shall be done in accordance with available specifications, notably the anchor channel shall be characterised according to Table 2.2.

The subject of the references to the required content of the ETA concerning the performance of the product is the method of declaring the product performance. This just applies if the manufacturer wishes to declare such performance.

Table 2.2 Material and dimensions of the product

No	Product property	Testing procedure
(1)	(2)	(3)
1	Dimensions acc. Fig.1.1	Measuring
2	Tensile Load (N_p) or tensile strength (f_{uk})	Similar to ISO 898-1
3	Yield strength (f_{yk} or $N_{p0.2}$) of channel profile, anchor and channel bolt	Similar to EN 10025, EN ISO 6892 and EN ISO 898-1
4	Core hardness and Surface hardness (at specified functioning relevant points of the product)(where relevant)	Tests acc. to EN ISO 6507 or EN ISO 6508
5	Zinc plating (where relevant)	measurement
6	Fracture elongation	Similar to ISO 898-1

The method and criteria for assessment are only valid if the following conditions are met during design of the fastening and installation of the anchor channels (see also EN 1992-4:2015, Annex F [3] or Technical Report "Calculation Method for the Performance of Anchor Channels" [4]):

- (1) The following installation values have to be observed
 - minimum member thickness,
 - minimum edge distance of anchors,
 - minimum and maximum spacing of the anchors,
 - minimum spacing of the channel bolts,
 - minimum effective embedment depth,
 - minimum spacing between anchor channels.
- (2) The characteristic resistances are calculated with the minimum effective embedment depth.
- (3) Anchor channels to be installed ensuring not less than the specified minimum effective embedment depth. The edge distance and spacing of anchor and channel bolts have to be kept to the specified values.
- (4) Use of the anchor channel only as supplied by the manufacturer without exchanging the components.
- (5) The anchor channels shall 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.
- (6) The concrete shall be properly compacted especially in the region of the anchor channel and under the head of the anchors. The channels shall be protected from penetration of concrete into the internal space of the channels.
- (7) The product description shall be provided in the ETA including:

- a) Generic or trade name.
 - b) Height and width of anchor channel.
 - c) Dimensions and minimum and maximum spacing of anchors.
 - d) Method of connecting anchors to channel.
 - e) Geometry of channel bolts to be used in a certain channel size.
 - f) Constituent materials and appropriate physical properties of anchors, channel and channel bolts including yield and tensile strength, hardness (if applicable), and coatings (if applicable).
 - g) Protective coating of anchor channel or channel bolt (if applicable).
- (8) Installation by appropriately qualified personnel under the supervision of the person responsible for technical matters on site, in accordance with the manufacturer's installation instructions (MPII) given in the relevant ETA and information given in the design drawings
 - (9) If the channel bolt is torqued with a torque moment valid for steel-steel contact, a suitable steel part shall be placed between channel and fixture (see Fig. 1.3 b)) to ensure a sufficiently large gap between concrete and fixture.
 - (10) Size and spacing of channel bolts shall correspond to the design drawings.
 - (11) The channel bolt (marking according to relevant ETA) shall be oriented perpendicular to the longitudinal channel axis.
 - (12) The installation torque moment T_{inst} given in the relevant ETA shall not be exceeded.
 - (13) For all types of anchor channels the installation torque moment shall be applied using a calibrated torque wrench with a measuring error of $\pm 5\%$ of the maximum applied torque moment.
 - (14) The anchor channels shall be packed and stored such that corrosion of the product is avoided.
 - (15) Packages shall be labeled such that the product and manufacturing batch as well as the intended use is identifiable.
 - (16) The manufacturer's installation instruction which affects the characteristic data for the intended use shall be given on the package or package insert.
 - (17) The anchor channel may be cast in only once.

2.2.1 General

2.2.1.1 Characteristic resistances under static- and quasi-static load

- (1) The characteristic resistances are determined both by tests within the context of this EAD and/or following ETAG 001 [2] and by the calculating methods according to EN 1992-4 [3] or Technical Report "Calculation Method for the Performance of Anchor Channels" [4] taking into account the provisions according to this EAD.
- (2) Testing shall be done according to Table 2.3 and the following sections.
- (3) The concrete test member shall be manufactured in accordance with ETAG 001, Annex A [2] and [12]. The concrete strength shall be determined in accordance with [2]. Test members shall be at least 21 days at time of testing.
- (4) The anchor channels to be tested shall be representative of the production of the manufacturer as supplied to the market.
- (5) 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 tests to evaluate the compliance of anchor channels with manufacturer's specification. 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.
- (6) The relevant dimensions (e.g. thickness of the channel back) and material properties (e.g. channel, anchors or channel bolts) shall be measured. The test results shall be checked against the

manufacturer's product specifications. The results obtained shall be evaluated to make sure that the measured values are within the manufacturer's specification including tolerances.

- (7) Anchor channels shall be installed in the test member in accordance with the manufacturer's installation instructions in a formed face of the concrete or in concrete with a troweled finish. 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 behavior is not influenced by reinforcement, see ETAG 001, Annex A [2]. The concrete shall be properly compacted especially in the area of the channels and in the area of the head of the anchors.
- (8) The tests shall be performed according to ETAG 001, Appendix A [2] and this EAD. Where differences occur, this EAD shall take precedence over ETAG 001.
- (9) In tests with anchor channels embedded in concrete apply the installation torque moment T_{inst} specified in the manufacturer's installation instructions using a calibrated torque wrench having a measuring error within $\pm 5\%$ 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} , loosen the nut of the channel bolt and re-apply torque to a level of $0,5 T_{inst}$.
- (10) In tests with anchor channels not embedded in concrete, the channel bolts shall not be prestressed, if not noted otherwise for a specific test series.
- (11) The concrete strength is to be determined in accordance with ETAG 001, Annex A [2]. The tests are to be carried out at specimens under laboratory conditions.
- (12) For each individual test the peak load shall be determined, the failure mode shall be given and the load-displacement relationship shall be recorded continuously, if not noted otherwise with a specific test series.

Table 2.3 Required tests under static or quasi-static actions (tension and shear)

N°	Tests acc. to the following sections	Concrete	Δw [mm]	Number of tests	Channel	Anchor	Material	Channel bolt	
								Ø	quality
Steel failure under tension load									
1	2.2.2.1 Anchor	—	—	—	—	—	—	—	—
2	2.2.2.2 Channel / anchor	—	—	$\geq 5^1)$	all	all	all	see 2.2.2.2	
3	2.2.2.3 Failure of channel lips, pull-out channel bolt ^{2),12)}	— C20/25	— 0	$\geq 5^1)$	all	all	all	see 2.2.2.3	
4	2.2.2.4 Channel bolt head	—	—	≥ 5	see 2.2.2.4	—	all	see 2.2.2.4	
5	2.2.2.5 Bending strength of channel ³⁾	C20/25	0	≥ 5	all	see 2.2.2.5	all	see 2.2.2.5	
6	2.2.2.6 Torque tests ⁴⁾	—	—	≥ 5	all	max	all	all	all
Concrete failure under tension load									
7	0 Pull-out	—	—	—	—	—	—	—	—
8	2.2.2.8 Concrete cone failure	C20/25	—	≥ 5	small/ medium/ large	small	—	see 2.2.2.8	
9	2.2.2.9 Splitting failure due to installation ⁵⁾ C = C _{min} , S = S _{min} , h = h _{min}	C20/25	0	≥ 5	all	see 2.2.2.9			
10	2.2.2.10 Splitting failure under load ⁶⁾	—	—	—	—	—	—	—	—
11	2.2.2.11 Blow out	—	—	—	—	—	—	—	—
Steel failure under shear load and combined tension and shear loads									
12	2.2.3.1 Shear failure of the channel bolt	—	—	—	—	—	—	see 2.2.3.1	
13a	2.2.3.2 Bending or failure of channel lips, connection anchor/channel or anchor ⁷⁾	C20/25	0	$\geq 5^1),8)$	all	see 2.2.3.2	all	see 2.2.3.2	
13b				$\geq 5^1),9)$					
14	2.2.3.3 Bending of channel bolt	—	—	—	—	—	—	—	—
15	2.2.3.4 Interaction for combined tension and shear loads ^{10) 13)}	C20/25	0	$\geq 5^1)$	see 2.2.3.4				
Concrete failure under shear load									
16	2.2.3.5 Pry-out failure	—	—	—	—	—	—	—	—
17	2.2.3.6 Concrete edge failure ¹¹⁾ C = C _{min} ; S = S _{max}	C20/25	0	≥ 5	see section 2.2.3.6			see 2.2.3.6	

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

²⁾ The tests may also be performed in non-cracked concrete C20/25 (see 2.2.2.3).

³⁾ Tests are only necessary if restraint of channels embedded in concrete shall be taken into account ($\alpha_r > 4$, see 2.2.2.5).

⁴⁾ The test program may be reduced, if the conditions in 2.2.2.6 are fulfilled.

⁵⁾ The test program may be reduced, if the conditions in 2.2.2.9 are fulfilled.

⁶⁾ C_{cr,sp} is taken as $3,0 h_{ef}$

⁷⁾ Tests may be omitted if the conditions in 2.2.3.2 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 the conditions in 2.2.3.4 are fulfilled.

¹¹⁾ Tests may be omitted if the profile factors $k_{cr,v}=4,5 [N^{0,5}/mm^{0,33}]$ and $k_{ucr,v}=6,3 [N^{0,5}/mm^{0,33}]$ are accepted.

¹²⁾ Tests may be omitted if conditions in 2.2.2.3 (2) are observed.

¹³⁾ Currently, no tests are possible. As a test methods are not specified in this version of EAD.

- (13) 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.

$$F_{5\%} = F_m \cdot (1 - k_s \cdot V_{test}) \quad (2.1)$$

F_m = mean failure load of a test series

k_s = 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 statistical handbooks (e.g. [22]).

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

- (14) The test results shall be normalized to the nominal values (strength and dimensions). The normalization shall take into account the mode of failure.
- (15) The characteristic resistances N_{Rk} and V_{Rk} evaluated from the results of tests shall be rounded down in 0,1 kN steps.
- (16) The descriptions given in Table 2.1 shall be stated in the ETA.

2.2.1.2 Characteristic resistances under fatigue cyclic load

- (1) 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 ETAG 001 [2].
- (2) The concrete specimens for the tests are to be manufactured in accordance with ETAG 001, Annex A [2] and EN 206-1 [12]. The concrete strength is to be determined in accordance with ETAG 001, Annex A [2]. The tests are to be carried out under laboratory conditions.
- (3) For the determination of the characteristic fatigue resistances of anchor channels, one of the test methods outlined in Table 2.4 shall be chosen. Test method A1, which corresponds to the so-called Interactive Method ([29], [30], [31]) and is meant to provide a continuous function of the fatigue resistance, is described in Annex A1. Test method A2, which is meant to provide a tri-linear function of the fatigue resistance, is described in Annex A2. Test method B (simple), which only provides the value of the characteristic fatigue limit resistance is described in Annex B.

Table 2.4: Test methods for fatigue cyclic tension

		Test Method		
		A1 (Interactive)	A2 (Tri-linear)	B (Simple)
Design Method	Method I	X	X	N.A.
	Method II	X	X	X

- (4) The characteristic fatigue resistance functions (test methods A1 and A2) shall be determined by testing performed in accordance with Table 2.5.

Table 2.5: Test methods A1 and A2: Required tests under fatigue cyclic tension

N°	Tests according to the following sections	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												
1	2.2.4.1 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
2	2.2.4.1 any steel failure of the whole system (anchor, connection anchor/ channel, flexure channel lips, channel bolt, flexure channel)	C20/25	Pos. 2	3(+2) ²⁾	all	all	all	all	all	all ¹⁾	all ¹⁾	all
Pre-tests for steel failure												
3	2.2.4.2 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
4		C20/25	Pos. 2	6 ³⁾	all	all	all	all	all	all ¹⁾	all ¹⁾	all
Final tests for steel failure												
5	2.2.4.3 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⁾
Concrete failure												
6	2.2.4.4 any concrete failure (concrete cone, pull-out)	—	—	—	—	—	—	—	—	—	—	—

¹⁾ Only channel bolts with the smallest head size and providing the lowest characteristic static tension resistance as determined in Section 2.2.2.4 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 as per Section 2.2.4.3.

⁴⁾ Only channel bolts providing the lowest resistances as determined in Section 2.2.4.1 and 2.2.4.2 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 Section 2.2.4.1 and 2.2.4.2 may be tested if the resulting static and fatigue resistance are applied to all other anchor channel coatings specified by the manufacturer.

- (5) The value of the characteristic fatigue limit resistance shall be determined by testing in accordance with Table 2.6.

Table 2.6: Test method B: Required tests under fatigue cyclic tension

N°	Tests according to the following sections	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												
7	2.2.5.1 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
8		C20/25	Pos. 2	3	all	all	all	all	all	all ¹⁾	all ¹⁾	all
Reference tests for steel failure												
9	2.2.5.2 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
10		C20/25	Pos. 2	3	all	all	all	all	all	all ¹⁾	all ¹⁾	all
Concrete failure												
11	2.2.5.3 any concrete failure (concrete cone, pull-out)	—	—	—	—	—	—	—	—	—	—	—

⁶⁾ The same conditions as per Table 2.5, Footnote ¹⁾ shall be applied.

- (6) 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.
- (7) The tests shall be carried out on anchor channels with two anchors cast in non-cracked concrete acc. to Fig. 2.1.
- (8) The spacing between the anchors, s , must be equal to the maximum value, s_{max} , for which recognition is sought.
- (9) The overlap, x , must be equal to the minimum value, x_{min} , for which recognition is sought.
- (10) 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).

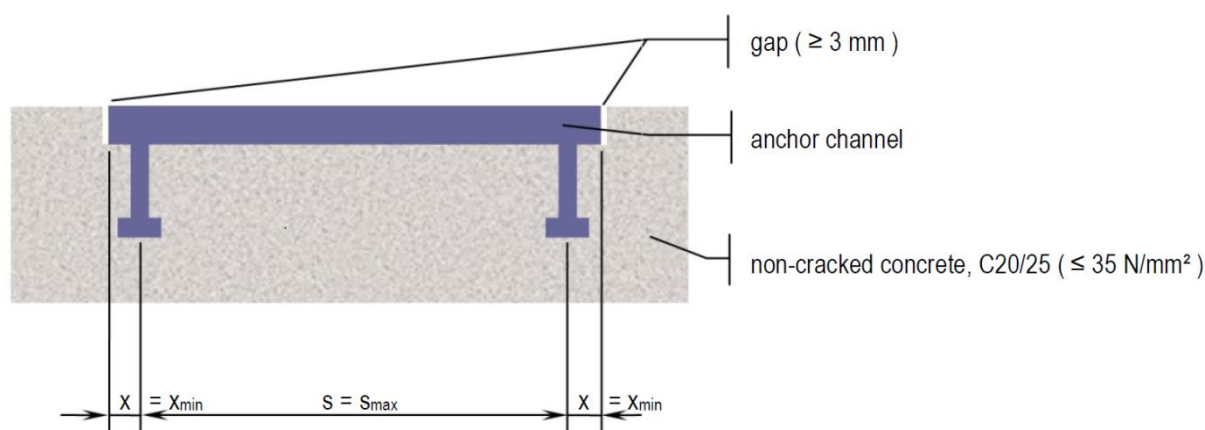


Fig. 2.1: Test specimen (sample)

- (11) 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.
- (12) 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.
- (13) 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 Fig. 1.3. For this purpose the provisions according to Section 1.2.1 shall be adhered to.
- (14) In all tests, apply the required (e.g., depending on the contact condition) installation torque moment, T_{inst} , specified in the manufacturer's published installation instructions using a calibrated torque wrench having a measuring error within $\pm 5\%$ of the specified torque.

For steel-steel contact: After a minimum of ten minutes after the initial application of T_{inst} , loosen the nut of the channel bolt and re-apply torque to a maximum level of $0.5 T_{inst}$. 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} , loosen the nut of the channel bolt and install the channel bolt with a finger-tight condition. If $0.2 T_{inst}$ is lower than or equal to 5 Nm, the finger-tight installation torque shall be equal to 5 Nm. If $0.2 T_{inst}$ is larger than or equal to 10 Nm, the finger-tight installation torque shall be equal to 10 Nm. If $0.2 T_{inst}$ is between 5 Nm and 10 Nm, the finger-tight installation torque shall be equal to $0.2 T_{inst}$. This testing procedure allows qualification 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.

- (15) 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.
- (16) 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 Fig. 2.2. 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 0.6m. The maximum and minimum dimensions of the tension rod and loading fixture are shown in Fig. 2.2 and shall be adhered to.

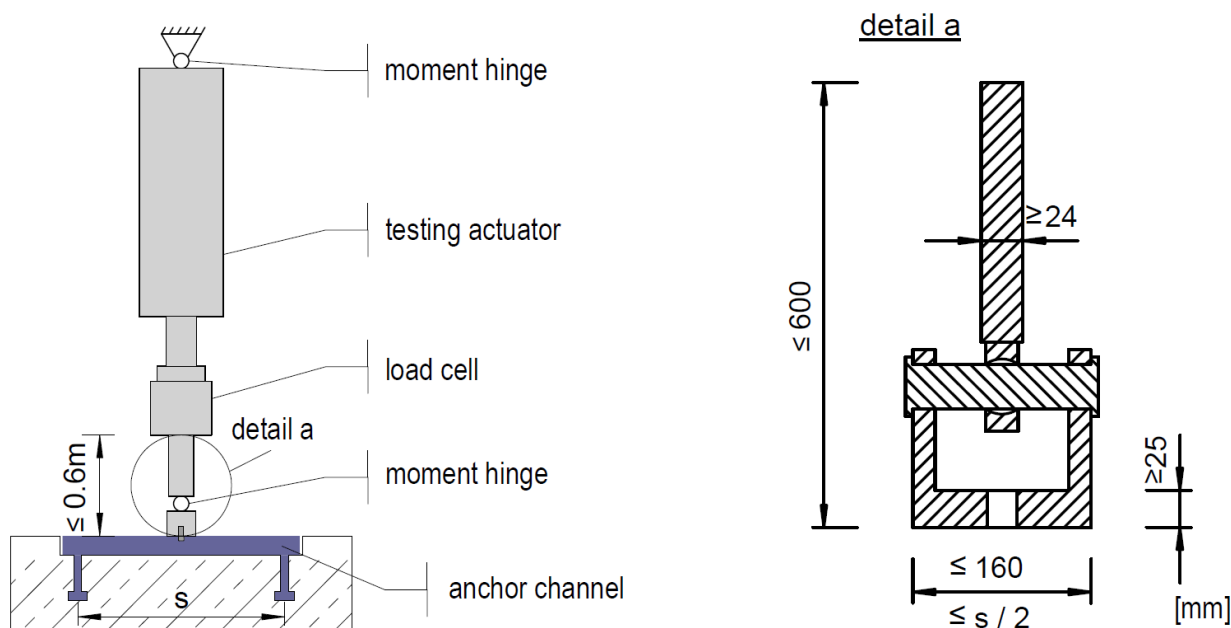


Fig. 2.2: Example of test setup including two moment hinges and dimensions of tension rod and loading fixture

- (17) The tests shall be conducted as unconfined tension tests in accordance with ETAG 001 [2]. 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.
- (18) Testing shall be performed according to Table 2.5 or Table 2.6 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 occur (See Annexes A1, A2 and B for additional details).
- (19) The anchor channel shall be loaded with a sinusoidal load process according Fig. 2.12.
- (20) 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 2.5 Footnote ¹⁾.
- (21) The load has to be controlled in accordance with Fig. 2.12, 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.
- (22) 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.
- (23) The fatigue cyclic force range shall be varied according to the selected method of testing and evaluation (see Table 2.4).
- (24) An example for the load application and displacement measurement without influence of deformation of the test rig is given in Fig. 2.3.

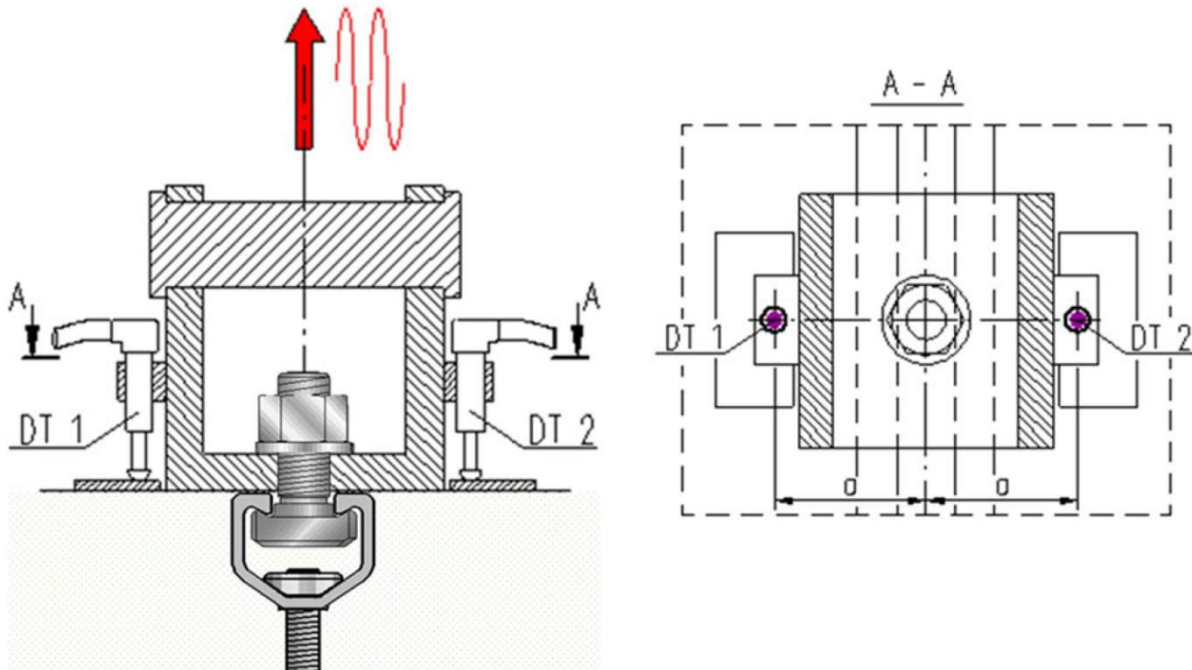


Fig. 2.3: Example of test setup with displacement transducer (DT)

- (25) In the static tests, the load displacement functions shall be continuously recorded and the failure mode shall be given.
 In the fatigue cyclic tests, the number of cycles at failure and the failure mode shall be given. In addition, the following values shall be continuously recorded:
- Displacements corresponding to the maximum load as a function of the number of cycles, n
 - Elapsed time and number of cycles
 - N_u and s_u (minimum force and corresponding displacement)
 - N_o and s_o (maximum force and corresponding displacement)
- (26) In the test reports, all information described in Section 2.2.1.2 (25), in addition to all other relevant installation parameters (e.g., T_{inst} , contact condition, etc.), shall be provided.

2.2.2 Characteristic resistance for tension under static and quasi-static loading

2.2.2.1 Steel failure of anchors under tension load (Table 2.3, line 1)

- (1) **Purpose:** Determination the characteristic resistance of the anchor.
- (2) **Required tests:** No tests are required.
- (3) The characteristic resistance $N_{Rk,s,a}$ of an anchor shall be determined according to Equation (2.2).

$$N_{Rk,s,a} = A_s \cdot f_{uk} \quad (2.2)$$

$$A_s = \text{stressed cross section of anchor}$$

$$f_{uk} = \text{nominal characteristic steel strength of anchor}$$

- (4) The characteristic resistance of the anchor, $N_{Rk,s,a}$, shall be given in the ETA.

2.2.2.2 Steel failure of connection channel/anchor under tension load (Table 2.3, line 2)

- (1) **Purpose:** Determination of the characteristic resistance of the connection between anchor and channel.
- (2) **Required tests:** If the calculation value is determined according to EN 1993-1 no tests are necessary. Test No. 2 according to Table 2.3 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.
- (3) **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 Fig. 2.. No fixture shall be used.

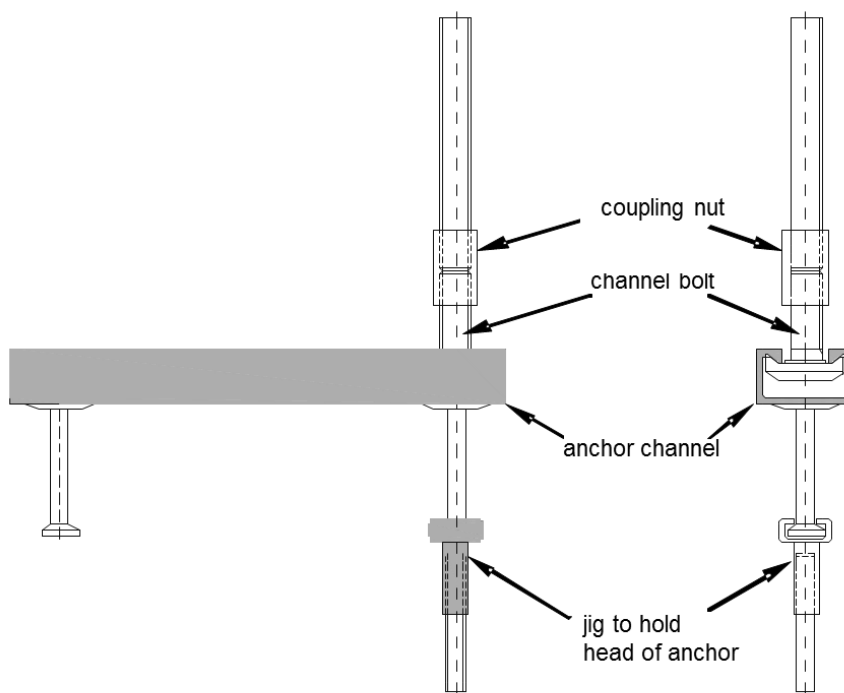


Fig. 2.4: Tension test setup for testing anchor channels in a universal testing machine.

- (4) The characteristic resistance can be calculated according to EN 1993-1.
- (5) When evaluating test results the characteristic resistance, $N_{Rk,s,c}$ shall be determined according to Equation (2.3) taking into account the actual dimensions and actual steel strengths.

$$N_{Rk,s,c} = N_{Rk,s,c,test} \cdot \frac{f_{uk}}{f_{u,test}} \cdot \frac{t_{ch,nom}}{t_{ch,test}} \quad [N] \quad (2.3)$$

$$N_{Rk,s,c,test} = \text{5\%-fractile of the ultimate loads measured in test series 2 according to Table 2.3} \quad [N]$$

$$f_{uk} = \text{nominal characteristic tensile strength of channel} \quad [N/mm^2]$$

$$f_{u,test} = \text{actual tensile strength of channel back} \quad [N/mm^2]$$

$t_{ch,nom}$	=	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]

- (6) The characteristic resistances of the connection anchor/channel, $N_{Rk,s,c}$, shall be given in the ETA.

2.2.2.3 Steel failure of the channel lips and subsequent pull-out of channel bolt under tension load (Table 2.3, line 3)

- (1) Purpose: Determination of the characteristic resistance of the channel against bending and local rupture of the channel lips.

(2) Required tests:

- a) No tests are required if the following conditions are fulfilled:

- In test series 2 according to Table 2.3, 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 2 is used as $N_{Rk,s,l,test}^0$ to calculate the characteristic resistance of the channel lips $N_{Rk,s,l}^0$ acc. (2.4).

- b) Tests according to Table 2.3, line 3 shall be performed if 2.2.2.3 (2) a) is not fulfilled. 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 still results in bolt failure, the bolt failure load shall be taken as load corresponding to lip failure.

(3) 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 2.2.2.2 (3) 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) It shall also be permitted to perform test no. 3 according to Table 2.3 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. 1.2) shall be x_{min} specified by the manufacturer. The anchor spacing shall be $s \geq s_{min}$ where s_{min} is specified by the manufacturer and given in the ETA but is not less than 100 mm. Insert the channel bolt over one anchor.

The channel bolt shall not be prestressed and the tension load shall be applied to the channel bolt shaft without a fixture or washer.

The test shall be conducted with a test rig as shown in Fig. 4.1 of ETAG 001, Annex A [2]; however the support spacing may be reduced to $\geq h_{ef}$. Direct contact between the test rig and the channel is not allowed. Report load-displacement curve, failure load and failure mode of each test.

- (4) If test series 3 of Table 2.3 has not been performed, the characteristic resistance of the channel lips shall be taken as $N_{Rk,s,c}$ (see 2.2.2.2).

- (5) If test series 3 of Table 2.3 has been performed, the characteristic resistance $N_{Rk,s,l}^0$ shall be determined according to Equation (2.4) taking into account the actual dimensions and actual steel strength.

$$N_{Rk,s,l}^0 = N_{Rk,s,l,test}^0 \cdot \frac{f_{uk}}{f_{u,test}} \cdot \frac{t_{ch,nom}}{t_{ch,test}} \quad [N] \quad (2.4)$$

$N_{Rk,s,l,test}^0$	= 5%-fractile of the ultimate loads measured in test series 3 according to Table 2.3	[N]
f_{uk}	= nominal characteristic tensile strength of channel	[N/mm ²]
$f_{u,test}$	= actual tensile strength of channel back	[N/mm ²]
$t_{ch,nom}$	= nominal thickness of channel back or channel lips depending on the failure mode	[mm]
$t_{ch,test}$	= actual thickness of channel back or channel lips depending on the failure mode	[mm]

- (6) 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 (2.4) instead of the thickness of the channel lips.
- (7) Currently, no tests are available to determine $s_{I,N}$. $s_{I,N}$ shall be taken as $2 b_{ch}$.

2.2.2.4 Steel failure of the channel bolt under tension load (Table 2.3, line 4)

- (1) Purpose: Determination of the characteristic resistance of the channel bolt.
- (2) Required tests: Perform the tests according to Table 2.3, line 4. 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 unfavorable, all channel bolt sizes shall be tested.
- (3) 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 Fig. 2. a)). Alternatively, channel bolts may be tested in a steel template (see Fig. 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 Fig. 2. a)) or template (see Fig. 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.

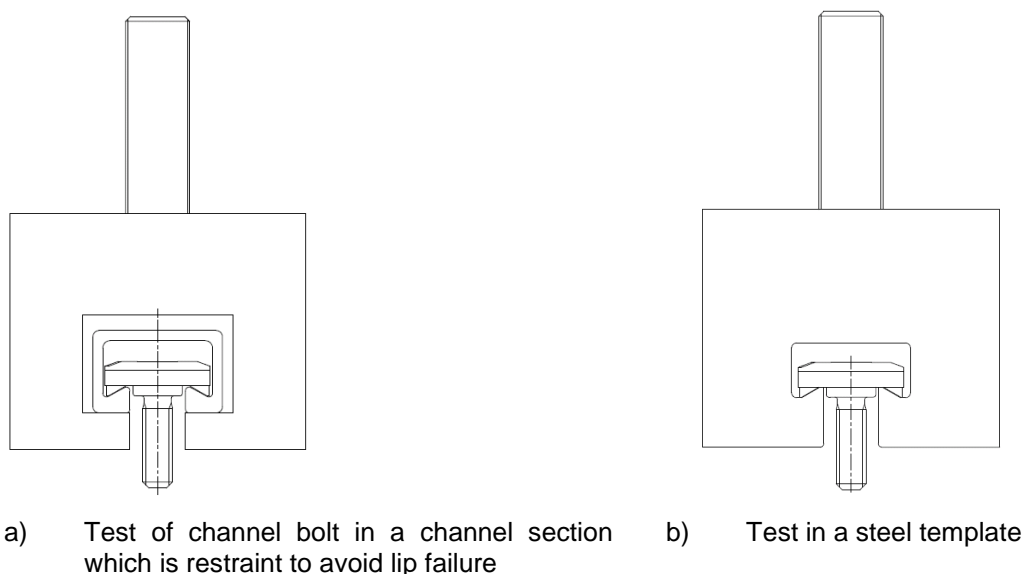


Fig. 2.5: Tests on channel bolts

- (4) In case of failure of the shaft of the channel bolt the value $N_{Rk,s}$ shall be calculated according to Equation (2.5). The 5%-fractile of the measured failure loads for bolt failure (not normalized) shall be larger than $N_{Rk,s}$.

$$N_{Rk,s} = A_s \cdot f_{uk} \leq N_{Rk,s,test} \quad [N] \quad (2.5)$$

A_s = 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 4 according to Table 2.3, not normalized [N]

- (5) In case of failure of the channel bolt head the characteristic resistance $N_{Rk,s}$ shall be calculated according to Equation (2.6) taking into account the actual steel strength.

$$N_{Rk,s} = N_{Rk,s,test} \cdot \frac{f_{uk}}{f_{u,test}} \quad [N] \quad (2.6)$$

$N_{Rk,s,test}$ = see Equ. (2.5) [N]
 f_{uk} = nominal characteristic tensile strength of channel bolt shaft [N/mm²]
 $f_{u,test}$ = actual tensile strength of channel bolt shaft [N/mm²]

- (6) The smaller of the values calculated according to Equation (2.5) and (2.6) shall be reported as $N_{Rk,s}$ in the ETA.

2.2.2.5 Steel failure by exceeding the bending strength of the channel under tension load (Table 2.3, line 5)

- (1) Purpose: 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.

(2) Required tests:

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

- b) Perform tests according to Table 2.3, line 5, 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 strength for the tested channel size.
- c) If for an anchor channel size the characteristic resistance for bending failure of the channel, $N_{Rk,s,flex}$, computed in accordance with Equation (2.7) is smaller than the characteristic resistance $N_{Rk,s,l}$ for lip failure evaluated in accordance with 2.2.2.3, 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.

$$N_{Rk,s,flex} = \alpha_r \cdot W_{pl,y,nom} \cdot f_{yk} / s_{min} \quad [N] \quad (2.7)$$

α_r = degree of constraint evaluated according to 2.2.2.5 (5) [-]
from the failure loads measured in test series no. 5 according to Table 2.3 with anchor channels with $s = s_{max}$

$W_{pl,y,nom}$ = plastic section modulus around y-axis (see Fig. 1.1) [mm³]
computed with nominal channel dimensions.

f_{yk} = nominal characteristic yield strength of the channel. [N/mm²]

s_{min} = minimum anchor spacing specified by the manufacturer. [mm]

- (3) 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. No fixture shall be used. 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.
- (4) If no tests have been performed the restraint factor shall be taken as $\alpha_r = 4.0$.
- (5) The degree of constraint shall be calculated from the 5%-fractile of the measured ultimate loads according to Equation (2.8), taking account of the actual steel strength and the actual dimensions.

$$\alpha_r = \frac{N_{Rk,s,test} \cdot s_{test}}{W_{pl,y,act} \cdot f_{y,test}} \quad [-] \quad (2.8)$$

$N_{Rk,s,test}$ = 5%-fractile of the ultimate loads measured in test series 5 of Table 2.3 [N]

s_{test} = spacing of anchors in tests [mm]

$W_{pl,y,act}$ = plastic section modulus of the tested channel around the y-axis (see Fig. 1.1) computed with actual channel dimensions [mm³]

$f_{y,test}$ = actual mean yield strength of the channel back [N/mm²]

- (6) The value of α_r calculated according to Equation (2.8) 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).
- (7) The reference characteristic bending moment $M_{Rk,s,flex}$ of the channel shall be determined according to Equation (2.9).

$$M_{Rk,s,flex} = \frac{\alpha_r}{4} \cdot M_{pl} \quad [Nm] \quad (2.9)$$

α_r = value computed in according to Equation 2.8 [-]

M_{pl} = $W_{pl,y,nom} \cdot f_{yk}$ [Nm] (2.10)

$W_{pl,y,nom}$ = plastic section modulus of the channel around the y-axis (see Fig. 1.1) computed with nominal channel dimensions [mm³]

$$f_{yk} = \text{nominal characteristic yield strength of channel} \quad [\text{N/mm}^2]$$

- (8) The reference characteristic bending moment $M_{Rk,s,flex}$ of the channel shall be stated in the ETA.

2.2.2.6 Assessment of maximum installation torque moment (Table 2.3, line 6)

- (1) Purpose: Determination of the maximum installation torque moment that can be applied without inducing damage to the channel bolt and/or channel and/or concrete.
- (2) Required tests: Perform 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. Exceptions see below:
- If the results of torque tests with the most unfavorable combination material and coating are accepted for all variants only the most unfavorable variant need to be tested. If the most unfavorable combination cannot be established channel bolts with all materials and coatings shall be tested.
 - 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 prestressing force $N_{95\%}$ is calculated according to Equation (2.11) with a value $k = \min(0,2; k_{test})$ where k_{test} is determined according to Equation (2.12).
 - No torque tests are required with channel bolts without lubricants or friction-reducing coatings if the prestressing force $N_{95\%}$ is calculated according to Equation (2.11) with $k = 0,15$.

$$N_{95\%} = \frac{\alpha \cdot T_{inst}}{k \cdot d} \quad [\text{N}] \quad (2.11)$$

$$N_{95\%} = \text{95\%-fractile of the prestressing force at } T = \alpha \cdot T_{inst} \quad [\text{N}]$$

$$\alpha = 1,0 \text{ for verifications in accordance with 2.2.2.6 (7)}$$

$$= 1,3 \text{ for verifications in accordance with 2.2.2.6 (8)}$$

$$T_{inst} = \text{installation torque moment specified by the manufacturer and given in the ETA} \quad [\text{Nmm}]$$

$$k = \text{friction factor to be taken as lower bound value (5\%-fractile)} \quad [-]$$

$$d = \text{diameter of the channel bolt shaft} \quad [\text{mm}]$$

$$k_{test} = k_{test,m} \cdot (1 - k_s \cdot v_{test}) \quad [\text{N}] \quad (2.12)$$

$$k_{test,m} = \text{mean of the values } k_{test,i} \text{ calculated according to Equation (2.13)} \quad [\text{N}]$$

$$k_{test,i} = \frac{\alpha \cdot T_{inst}}{N_{test,i} \cdot d} \quad (2.13)$$

$$N_{test,i} = \text{prestressing force at } T = \alpha \cdot T_{inst} \text{ measured in test } i \quad [\text{N}]$$

$$\alpha, T_{inst}, d \text{ see Equation (2.11)}$$

$$k_s, v_{test} \text{ see Equation (2.1)}$$

- (3) Test conditions: The torque tests shall be carried out on anchor channels not cast into concrete. A test set-up similar to the one shown in ETAG 001, Annex A [2], Fig. 4.4 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 ETAG 001, Annex A [2], Table 4.1. Apply torque up to a torque moment $T \geq 1,3 T_{inst}$ (T_{inst} acc. to Fig. 1.3 a))

- (4) If torque tests have been performed according to 2.2.2.6 calculate the 95%-fractile of the measured prestressing forces, $N_{95\%,test}$, according to Equation (2.14)

$$N_{95\%,test} = N_{m,test} \cdot (1 + k_s \cdot v_{test}) \quad [N] \quad (2.14)$$

$$N_{m,test} = \text{mean prestressing force at } T = \alpha \cdot T_{inst} \quad [N]$$

$$k_s, v_{test} = \text{see Equation (2.1)}$$

$$\alpha, T_{inst} = \text{see Equation (2.11)}$$

- (5) If torque tests have been performed according to 2.2.2.6 (2) b) calculate the 95%-fractile of the prestressing force, $N_{95\%}$, according to Equation (2.11) with $k = \min(0,2; k_{test})$ with k_{test} according to Equation (2.12).
- (6) If no torque tests have been performed (compare 2.2.2.6 (2) c)) calculate the 95%-fractile of the prestressing force, $N_{95\%}$, according to Equation (2.11) with $k = 0,15$.
- (7) The 95%-fractile of the prestressing force ($N_{95\%,test}$ or $N_{95\%}$ respectively) at $T = 1,0 \cdot T_{inst}$ ($\alpha = 1,0$) (T_{inst} acc. to Fig. 1.3 a)) shall not exceed the characteristic resistance $N_{Rk,s,a}$ according to 2.2.2.1, $N_{Rk,s,c}$ according to 2.2.2.2, $N_{Rk,s,l}$ according to 2.2.2.3 and $N_{Rk,p}$ according to 2.2.2.7. Exception: For anchor channels with an embedment depth $h_{ef} \geq 90$ mm, verification of the prestressing force with respect to the pullout strength is not required.
- (8) The 95%-fractile of the prestressing force ($N_{95\%,test}$ or $N_{95\%}$, respectively) at $T = 1,3 \cdot T_{inst}$ ($\alpha = 1,3$) (T_{inst} acc. to Fig. 1.3 a)) shall not exceed the characteristic resistance of the channel bolt evaluated in accordance with 2.2.2.4 multiplied by the ratio f_{yk}/f_{uk} where f_{yk} (f_{uk}) are the nominal yield strength (ultimate strength) of the channel bolt.
- (9) For applications with anchor channels where the fixture is not in contact with the concrete (steel-steel contact) (see Fig. 1.3 b) and 1.2.1 (5)) the verifications according to 2.2.2.6 (7) are not required because no force on the anchor is generated and the channel lips cannot bent up. For anchor channels where the fixture is not in contact with the concrete verification according to 2.2.2.6 (7) is to be done with T_{inst} acc. to Fig. 1.3 b).
- (10) If the conditions according to 2.2.2.6 (7) to (8) are not fulfilled, then the installation torque moment shall be reduced until the conditions are fulfilled.
- (11) The installation torque moment T_{inst} for general application and steel-steel contact, that fulfills 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.

2.2.2.7 Concrete pull-out failure under tension load (Table 2.3, line 7)

- (1) Purpose: Determination of the characteristic resistance of the anchor for pull-out failure.
- (2) Required tests: No tests are required.
- (3) The characteristic resistance $N_{Rk,p}$ for pull-out failure shall be calculated according to Equation (2.15).

$$N_{Rk,p} = k_2 \cdot A_h \cdot f_{ck} \quad [N] \quad (2.15)$$

k_2	=	7,5 in cracked concrete 10,5 in non-cracked concrete
f_{ck}	=	nominal characteristic compressive cylinder strength [N/mm ²] (150 mm diameter by 300 mm cylinder)
A_h	=	projected load bearing area of the head of the fastener [mm ²]

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

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

For the calculation of the bearing area of the anchor head A_h , d_h should not be taken larger than $6 t_h + d_a$ in equation (2.15) (compare Fig. 1.1 b)).

- (4) 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.

2.2.2.8 Concrete cone failure under tension load (Table 2.3, line 8)

- (1) Purpose: Determination of characteristic resistance for concrete cone failure.

- (2) Required tests:

a) No tests are required if $h_{ch}/h_{ef} \leq 0.4$ and $b_{ch}/h_{ef} \leq 0.7$.

b) If channels are used with $h_{ch}/h_{ef} > 0.4$ and / or $b_{ch}/h_{ef} > 0.7$, then the embedment depth shall be taken as $h_{ef}^* = (h_{ef} - h_{ch})$. Currently, no tests are available to determine $\alpha_{ch,N}$ and $s_{cr,N}$ in such cases.

- (3) The values $k_{cr,N}$ and $k_{ucr,N}$ are calculated according to Equation (2.16) and Equation (2.17)

$$k_{cr,N} = \alpha_{ch,N} \cdot 8,9 \quad \text{for cracked concrete} \quad \left[\frac{N^{0,5}}{mm^{0,5}} \right] \quad (2.16)$$

$$k_{ucr,N} = \alpha_{ch,N} \cdot 12,7 \quad \text{for uncracked concrete} \quad \left[\frac{N^{0,5}}{mm^{0,5}} \right] \quad (2.17)$$

with:

$$\alpha_{ch,N} = \left(\frac{h_{ef}}{180} \right)^{0,15} \leq 1,0 \quad \text{if } \frac{h_{ch}}{h_{ef}} \leq 0,4 \text{ and } \frac{b_{ch}}{h_{ef}} \leq 0,7 \quad [-] \quad (2.18)$$

$$\alpha_{ch,N} = 1,0 \quad \text{if } \frac{h_{ch}}{h_{ef}} > 0,4 \text{ and/ or } \frac{b_{ch}}{h_{ef}} > 0,7 \quad [-] \quad (2.19)$$

- (4) The values $k_{cr,N}$ and $k_{ucr,N}$ shall be stated in the ETA.

2.2.2.9 Concrete splitting failure due to installation (Table 2.3, line 9)

- (1) Purpose: Determination of minimum edge distance and minimum spacing for a specified minimum member thickness to avoid splitting of concrete during installation (prestressing of anchors).

(2) Required tests:

Tests shall be performed with anchor channels embedded in uncracked concrete according to Table 2.3, line 9 with each channel size. The most unfavorable combination of material, kind of manufacturing, coating, and diameter of channel bolt shall be tested that result in the highest prestressing 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:

- The value γ_{inst} to be applied in Equation (2.23) is increased by 30%; and
- The ratio of the prestressing 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 (2.11) with $T = T_{inst}$ and k as determined in accordance with 2.2.2.6. For calculating $N_{95\%}$ of the tested channel sizes the value T_{inst} to be inserted in Equation (2.11) may be replaced by $T_{inst,adm}$ according to Equation (2.20).

$$T_{inst,adm} = T_{inst} \cdot \gamma / \gamma_{req} \quad [Nm] \quad (2.20)$$

$$\gamma = T_{crack,5\%} \cdot (f_{ck}/f_{c,test})^{0.5} / T_{inst} \quad [-] \quad (2.21)$$

$$T_{crack,5\%} = 5\text{-fractile of the torque moments } T_{crack} \text{ calculated according to Equation (2.1).} \quad [Nm]$$

$$T_{crack} = \text{torque moment at which a hairline crack (crack with a width } < 0,1 \text{ mm) is observed.} \quad [Nm]$$

$$f_{ck} = 20 \text{ N/mm}^2$$

$$f_{c,test} = \text{concrete compression strengths at time of testing measured on cylinder} \quad [N/mm^2]$$

$$T_{inst} = \text{Installation torque moment specified by the manufacturer and given in the ETA for applications according to Fig. 1.3 a) (fixture in contact with the concrete)} \quad [Nm]$$

$$\gamma_{req} = 1,3 \cdot \gamma_{inst} \quad [-] \quad (2.22)$$

$$\gamma_{inst} = \text{see Equation (2.23)}$$

(3) Test conditions:

- Anchor channels with two anchors at minimum spacing specified by the manufacturer shall be cast into concrete members with the minimum specified member depth at the minimum edge distance specified by the manufacturer. 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 $\sim 1.1d$
- 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 Fig. 2.6). 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 $0,2 T_{inst}$ until the torque cannot be increased further. 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} acc. to Fig. 1.3 a)).

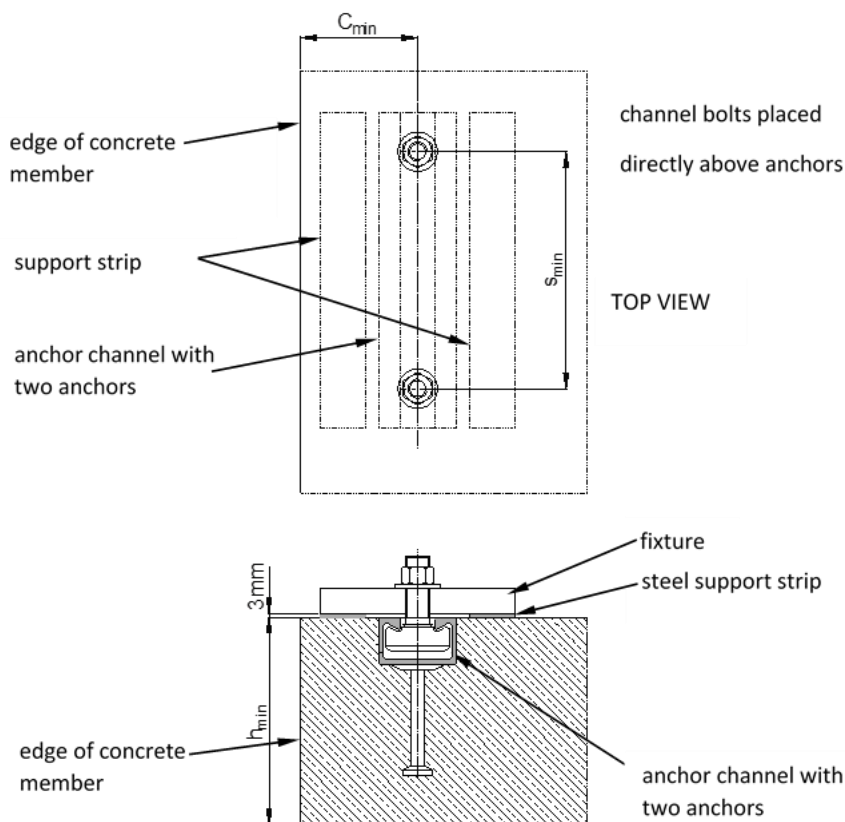


Fig. 2.6: Test setup for tests in accordance with Table 2.3, line 9

- (4) 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 (2.1) shall fulfill Equation (2.23).

$$T_{crack,5\%} \geq \gamma_{inst} \cdot T_{inst} \cdot \left(f_{c,test} / f_{ck} \right)^{0,5} \quad [\text{Nm}] \quad (2.23)$$

$$\gamma_{inst} = 1,3 \quad \text{anchorages in cracked concrete} \quad [-]$$

$$= 1,7 \quad \text{anchorages in uncracked concrete} \quad [-]$$

$$T_{crack,5\%}, T_{inst}, f_{c,test}, f_{ck}: \text{ see Equation (2.21)}$$

- (5) If tests with the smallest, medium and largest channel size have been performed only, the value γ_{inst} for the verification according to Equation (2.23) shall be increased by 30 % and the conditions given in 2.2.2.9 (2) b) shall be fulfilled for the untested channel sizes.
- (6) If Equation (2.23) is not fulfilled, either T_{inst} 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 (2.23) is fulfilled.
- (7) 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} shall be stated in the ETA for each channel size and channel bolt.

2.2.2.10 Concrete splitting failure due to tension loading (Table 2.3, line 10)

- (1) **Purpose:** Determination of the characteristic edge distance $c_{cr,sp}$ and characteristic spacing $s_{cr,sp} = 2c_{cr,sp}$ in case of splitting failure.
- (2) **Required tests:** No tests are required.
- (3) The values $s_{cr,sp}$ and $c_{cr,sp}$ are calculated according to Equation (2.24) and Equation (2.25).

$$s_{cr,sp} = 2 \cdot c_{cr,sp} \quad [\text{mm}] \quad (2.24)$$

$$c_{cr,sp} = 3,0 \cdot h_{ef} \quad [\text{mm}] \quad (2.25)$$

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

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

2.2.2.11 Concrete blow out failure under tension load (Table 2.3, line 11)

- (1) **Purpose:** Determination of the characteristic resistance for blowout failure.
- (2) **Required tests:** No tests are required.
- (3) The bearing area of the anchor head, A_h , shall be stated in the ETA for each anchor type and size.

2.2.3 Characteristic resistance for shear under static and quasi-static loading

2.2.3.1 Steel failure of the channel bolt under shear load without lever arm (Table 2.3, line 12)

- (1) **Purpose:** Determination of the characteristic resistance $V_{Rk,s}$ for steel failure of the channel bolt under shear loading without lever arm.
- (2) **Required tests:** No tests are required
- (3) The characteristic resistance for steel failure of the channel bolt under shear loading without lever arm, $V_{Rk,s}$, shall be calculated according to Equation (2.26).

$$V_{Rk,s} = \alpha_s \cdot N_{Rk,s} \quad [\text{N}] \quad (2.26)$$

$$\alpha_s = 0,6 \quad (\text{for carbon steel, strength class} < 8.8 \text{ and stainless steel, } 50 \leq \text{strength class} \leq 70) \quad [-]$$

$$= 0,5 \quad (\text{for carbon steel, strength class} = 8.8) \quad [-]$$

$$A_s, f_{uk} \quad \text{see Equation (2.5)}$$

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

2.2.3.2 Local steel failure of channel lips, steel failure of connection between anchor and channel or steel failure of anchor under shear load (Table 2.3, line 13)

- (1) **Purpose:** 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.
- (2) **Required tests:**
 - a) If $V_{Rk,s,l}^0 \leq N_{Rk,s,l}^0$ and $V_{Rk,s,c} \leq N_{Rk,s,c}$ and $V_{Rk,s,a} \leq N_{Rk,s,a}$ is accepted, no tests are required.

- b) Tests according to Table 2.3, line 13 are required, if $V_{Rk,s,l}^0 > N_{Rk,s,l}^0$ and/or $V_{Rk,s,c} > N_{Rk,s,c}$ and/or $V_{Rk,s,a} > N_{Rk,s,a}$ 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.
- (3) **Test conditions:** The tests shall be performed according to Fig. 2.11 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 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 13a), the channel bolt shall be inserted in the channel over one anchor and shall be pre-tensioned in accordance with 2.2.1.1 (9). In a second test series (test series 13b), the channel bolt shall be positioned midway between the two anchors and pre-tensioned in accordance with 2.2.1.1 (9). 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.
- (4) The characteristic resistance of the channel lips, $V_{Rk,s,l}^0$ shall be determined according to Equation (2.27) taking into account the actual steel strength and the actual dimensions.

$$V_{Rk,s,l}^0 = V_{Rk,s,l,test}^0 \cdot \frac{f_{uk}}{f_{u,test}} \cdot \frac{t_{ch,nom}}{t_{ch,test}} \quad [\text{N}] \quad (2.27)$$

$$V_{Rk,s,l,test}^0 = \text{5\%-fractile of the ultimate loads measured in test series 13} \quad [\text{N}]$$

$$f_{uk} = \text{nominal characteristic tensile strength of channel} \quad [\text{N/mm}^2]$$

$$f_{u,test} = \text{actual mean tensile strength of channel back} \quad [\text{N/mm}^2]$$

$$t_{ch,nom} = \text{nominal dimension of channel lips or channel back depending on the failure mode} \quad [\text{mm}]$$

$$t_{ch,test} = \text{actual dimension of channel lips or channel back depending on the failure mode} \quad [\text{mm}]$$

- (5) The characteristic resistances for failure of the connection between anchor and channel and for failure of the anchor may be taken as $V_{Rk,s,c} = V_{Rk,s,a} = V_{Rk,s,l}^0$ and shall be stated in the ETA.
- (6) Currently, no tests are available to determine $s_{l,v}$. $s_{l,v}$ shall be taken as $2 b_{ch}$.

2.2.3.3 Steel failure by bending of the channel bolt under shear load with lever arm (Table 2.3, line 14)

- (1) **Purpose:** Determination of the characteristic bending resistance of the channel bolt subjected to shear load with lever arm.
- (2) **Required tests:** No tests are required.
- (3) The characteristic bending resistance $M_{Rk,s}^0$ of the channel bolt shall be determined according to Equation (2.28).

$$M_{Rk,s}^0 = \begin{aligned} & 1,2 \cdot W_{el} \cdot f_{uk} \leq 0,5 \cdot N_{Rk,s,l} \cdot a \\ & \leq 0,5 \cdot N_{Rk,s} \cdot a \end{aligned} \quad [\text{Nmm}] \quad (2.28)$$

$$W_{el} = \text{elastic section modulus of channel bolt calculated with}$$

	the equivalent diameter of the stressed cross section	[mm ³]	
f_{uk}	nominal characteristic tensile strength of channel bolt shaft	[N/mm ²]	
$N_{Rk,s,l}$	= characteristic resistance of channel lips, see 2.2.2.3	[N]	
a	= Distance between tension and compression force acting on the channel lips generated by the bending moment (see Fig. 2.)		
	= $\frac{1}{3}(b_{cbo,2} + d_{w,2} + d_{ch})$	[mm]	(2.29)
$b_{cbo,2}$	= length of channel bolt head	[mm]	
d_{ch}	= width of channel opening	[mm]	
$d_{w,2}$	= diameter of washer	[mm]	

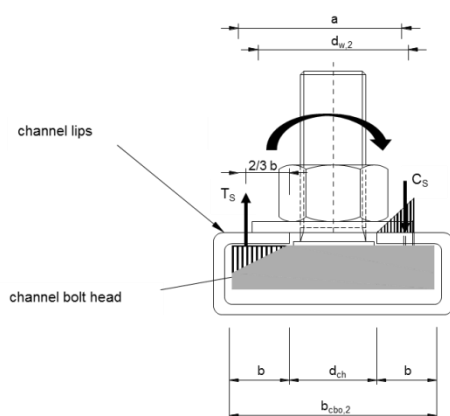


Fig. 2.7: Statical system for calculating the forces on the channel lips generated by a bending moment on the channel bolt

2.2.3.4 Steel failure of anchor channel due to combined tension and shear loads on anchor channels embedded in concrete (Table 2.3, line 15)

- (1) **Purpose:** Determination of the exponent k_{13} and k_{14} in the interaction equations for channel steel failure according to EN 1992-4 [3] or Technical Report "Calculation Method for the Performance of Anchor Channels" [4].
- (2) **Required tests:**
 - a) No tests are required if $V_{Rk,s,l}^0 \leq N_{Rk,s,l}^0$, $V_{Rk,s,c} \leq N_{Rk,s,c}$ and $V_{Rk,s,a} \leq N_{Rk,s}$ or $k_{13} = k_{14} = 1$ are accepted.
 - b) Currently, no tests are possible. A test method is not specified in this version of the EAD.
- (3) The values k_{13} and k_{14} shall be given in the ETA for each channel size.

2.2.3.5 Concrete pry-out failure under shear load (Table 2.3, line 16)

- (1) **Purpose:** Determination of the factor k_8 according to EN 1992-4 [3] or Technical Report "Calculation Method for the Performance of Anchor Channels" [4]
- (2) **Required tests:** No tests are required.

- (3) The characteristic resistance $V_{Rk,cp}$ shall be determined according to EN 1992-4 [3] or Technical Report "Calculation Method for the Performance of Anchor Channels" [4]. The value k_8 shall be taken as:

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

$$k_8 = 2,0 \text{ for anchor channels with } h_{ef} \geq 60 \text{ mm}$$

- (4) The value k_8 shall be given in the ETA for each channel size.

2.2.3.6 Concrete edge failure under shear load (Table 2.3 line 17)

- (1) Purpose: Determination of the channel factors $k_{cr,V}$ and $k_{ucr,V}$ in EN 1992-4 [3] or Technical Report "Calculation Method for the Performance of Anchor Channels" [4] for the calculation of the characteristic concrete edge resistance under shear load.

- (2) Required tests:

- a) No tests are required, if the factors $k_{cr,V} = 4,5 [N^{0,5}/mm^{0,33}]$ and $k_{ucr,V} = 6,3 [N^{0,5}/mm^{0,33}]$ are accepted for all types and sizes of anchor channels applied for and if channels are used with $h_{ch}/h_{ef} \leq 0,4$ and $b_{ch}/h_{ef} \leq 0,7$.
- b) If channels are used with $h_{ch}/h_{ef} > 0,4$ and / or $b_{ch}/h_{ef} > 0,7$, tests are required to determine $s_{cr,V}$ and $h_{cr,V}$. Currently, no tests are available to determine $s_{cr,V}$ and $h_{cr,V}$ in this version of the EAD.
- c) If $k_{cr,V} > 4,5 [N^{0,5}/mm^{0,33}]$ is applied for, the tests according to Table 2.3, line 17 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 Fig. 2. for typical anchor channel profiles.
2. The anchor type (round, I-profile, other) and orientation is constant (see Fig. 2.).
3. The connection type and manufacturing method is constant (see Fig. 2.).
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 center 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 Fig. 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 Fig. 1.2).
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.

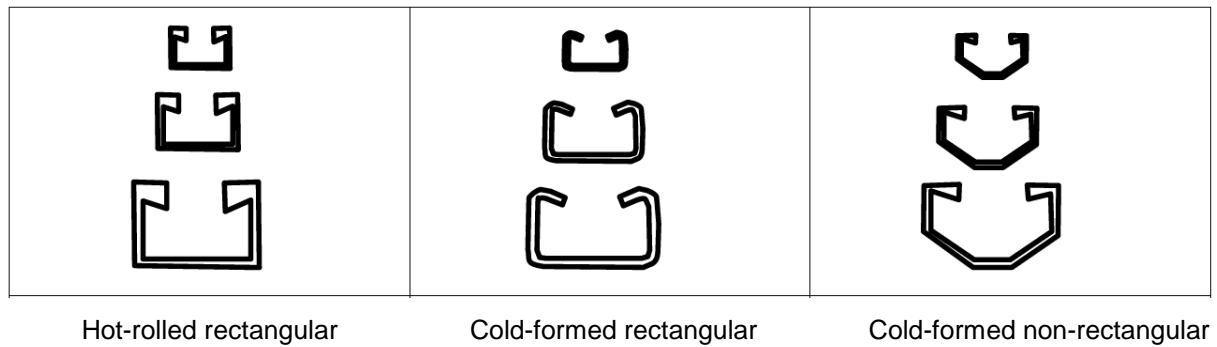


Fig. 2.8: Anchor channel grouping by profile

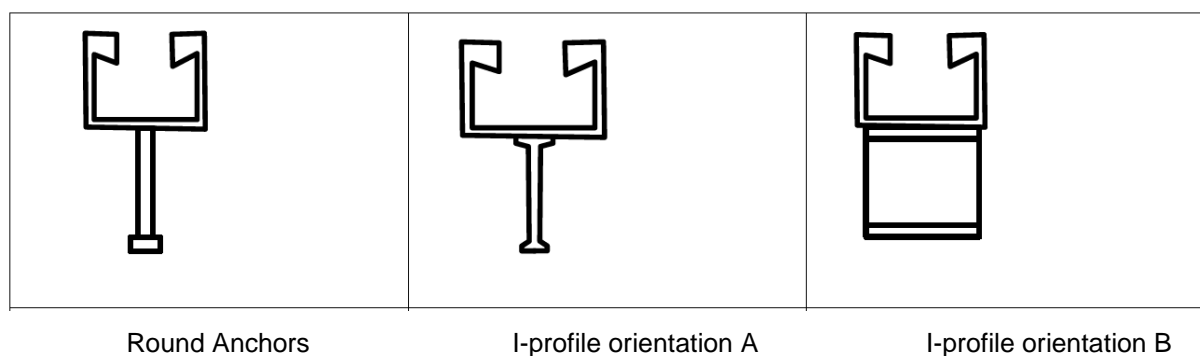


Fig. 2.9: Anchor channel grouping by anchor type

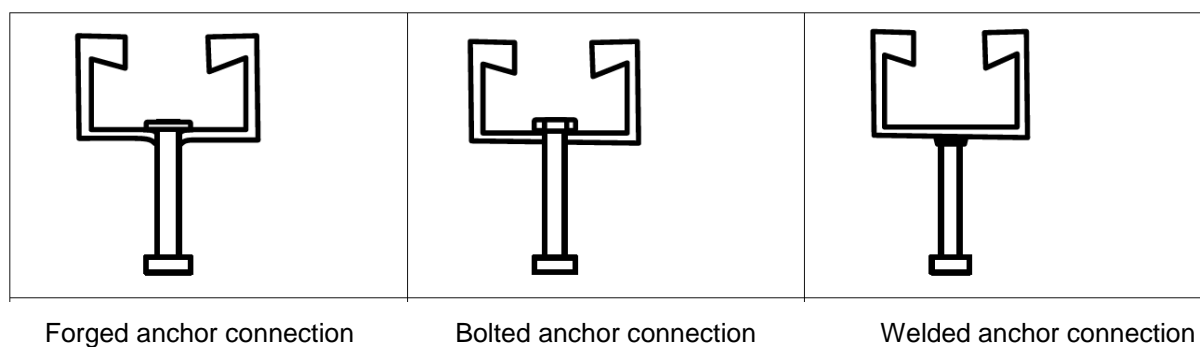


Fig. 2.10: Anchor channel grouping by connection type

- (3) **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. The diameter of the clearance hole in the fixture shall agree with ETAG 001, Annex A [2], Table 4.1. Two channel bolts shall be inserted in the channel directly over the anchors and shall be prestressed in accordance with 2.2.1.1 (9). 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 center of the fixture (distance between applied shear force and concrete surface $0,5 \cdot t_{fix}$) (see Fig. 2.). 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 ETAG 001, Annex, Table 4.1. A typical test setup is shown in Fig. 2..

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.

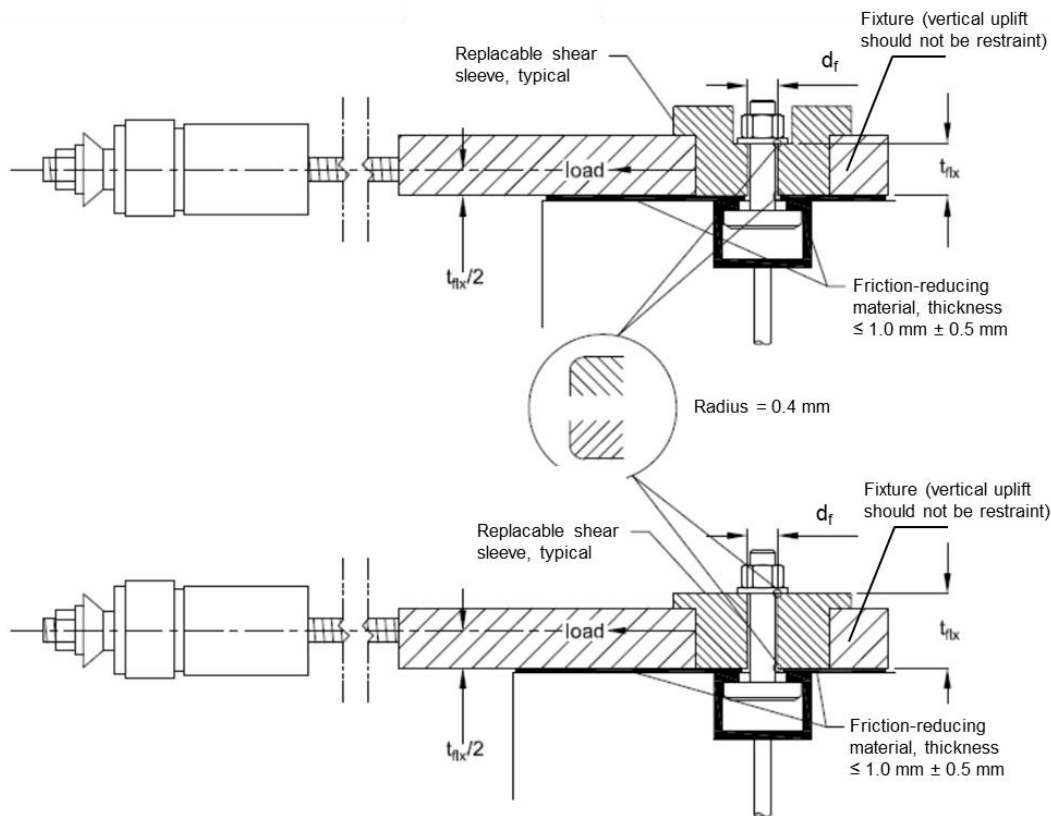


Fig. 2.11: Example of shear plate with sleeves and required location of the applied shear-load for test series no. 17 of Table 2.3

- (4) If no tests according to Table 2.3, test no 17 have been performed, the factors $k_{cr,V} = 4,5 [N^{0,5}/mm^{0,33}]$ and $k_{ucr,V} = 6,3 [N^{0,5}/mm^{0,33}]$ shall be assumed for all types and sizes of anchor channels.
- (5) If tests according to Table 2.3, test no 17 have been performed, the factor $k_{cr,V}$ shall be computed according to Equation (2.30). The minimum value according to Equation (2.30) is decisive.

$$k_{cr,V} = \frac{\min(0,75 \cdot V_{u,m,test}, V_{Rk,test})}{(f_{c,test})^{0,5} \cdot c_1^{4/3} \cdot \psi_{ch,s,V}} \cdot \frac{1}{1,4} \leq 7,5 \quad [N^{0,5}/mm^{0,33}] \quad (2.30)$$

(cracked concrete without reinforcement)

$$V_{Rk,test} = 5 \% \text{ fractile of the failure loads applied to one anchor measured in test series 17 of Table 2.3} \quad [N]$$

$V_{u,m,test}$	=	mean value of the failure loads applied to one anchor measured in test series 17 of Table 2.3	[N]
$f_{c,test}$	=	actual concrete compressive strength of the test member at time of testing measured on cylinders	[N/mm ²]
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 neighboring anchors on the concrete edge failure load calculated according to Equation (2.31)	[-]
$\psi_{ch,s,V}$	=	$\frac{1}{1 + \left(1 - \frac{s}{s_{cr,V}}\right)^{1,5}}$	[-] (2.31)
s	=	actual anchor spacing in the tests	[mm]
$s_{cr,V}$	=	$4c_1 + 2b_{ch}$	[mm]

- (6) The factor $k_{cr,V}$ according to Equation (2.30) shall be stated in steps of 0,1 and shall be rounded down to the nearest 0,1.
- (7) The factor $k_{ucr,V}$ shall be computed according to Equation (2.32).
- $$k_{ucr,V} = k_{cr,V} \text{ (rounded value acc. to Eq. (2.30))} \cdot 1,4 \quad [-] \quad (2.32)$$
- (8) The factors $k_{cr,V}$ and $k_{ucr,V}$ determined as described above shall be stated in the ETA for each channel size.

2.2.4 Characteristic resistance for tension under static and fatigue cyclic loading – test methods A1, A2

2.2.4.1 Reference tests for steel failure under tension (Table 2.5, lines 1 and 2)

- (1) **Purpose:** Determination of the characteristic resistance for any steel failure of the whole system (anchor, connection anchor/channel, flexure channel lips, channel bolt, flexure channel).
- (2) **Required tests:** For the determination of the characteristic static (or, equivalently, fatigue) resistance for n=1 cycles, testing in accordance with Table 2.5, lines 1 and 2 shall be performed. All channel bolts, channels, connection types, and anchor sizes with all materials and coatings specified by the manufacturer shall be tested. The same conditions as per Section 2.2.1.2 (20) shall be applied.
- (3) **Test conditions:** The tests shall be performed according to Section 2.2.1.2, Fig. 2.1, and Fig. 2.2. The anchor channels shall be loaded in position 1 (test series 1) and position 2 (test series 2) 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 (Section 2.2.4.3).
- (4) 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 up to three test results. 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.
- (5) 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 as per Section 2.2.4.3 (8).

2.2.4.2 Pre-tests for steel failure under fatigue cyclic tension (Table 2.5, lines 3 and 4)

- (1) **Purpose:** 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.
- (2) **Required tests:** For the determination of the unfavourable loading position for fatigue loading, pre-tests according to Table 2.5, lines 3 and 4 shall be performed. All channel bolts, channels, connection types, and anchor sizes with all materials and coatings specified by the manufacturer shall be tested.

The same conditions as per Section 2.2.1.2 (20) shall be applied.

- (3) **Test conditions:** The same conditions as per Section 2.2.4.1 (3) shall be applied.

The anchor channel shall be loaded in position 1 (test series 3) and position 2 (test series 4) with a sinusoidal load process according to Fig. 2.12. In position 1, the channel bolt shall be inserted in the channel midway between the two anchors and, in position 2, over one anchor.

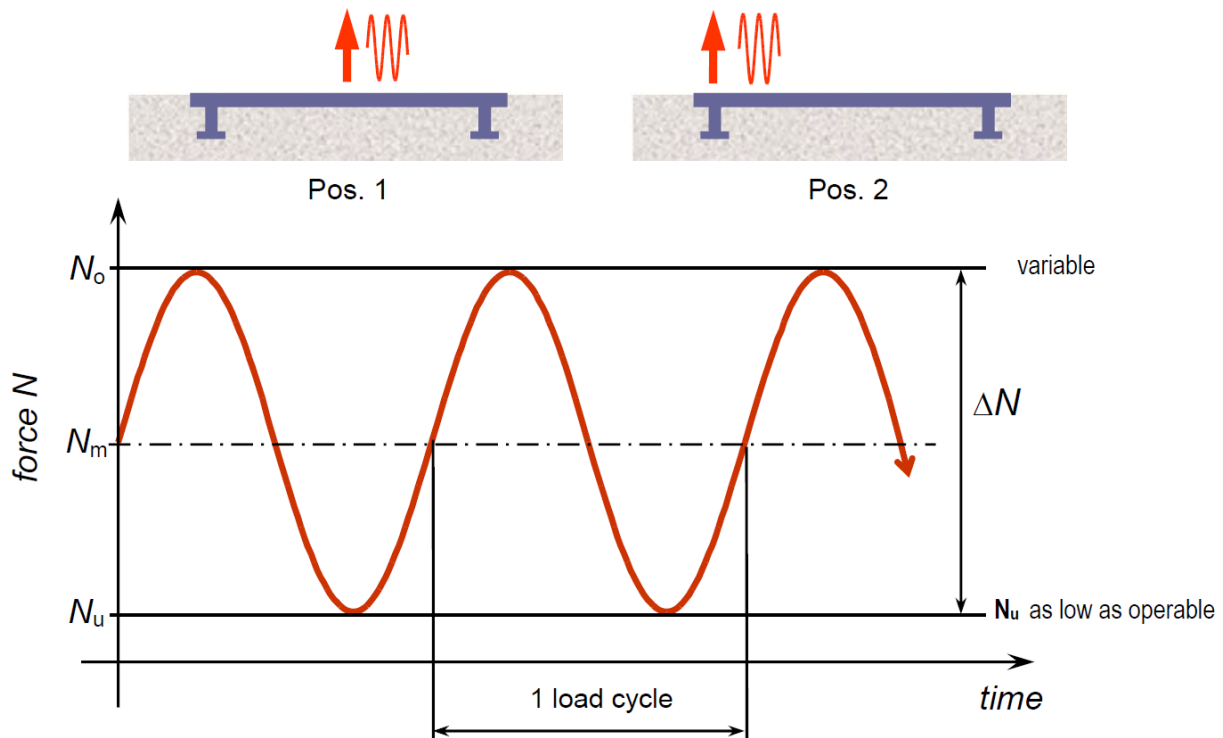


Fig. 2.12: Load positions and example of fatigue cyclic loading protocol

- (4) **For Method A1:** 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 according to Section 2.2.4.3.

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 Fig. 2.14 and Fig. 2.15).

If the preliminary fatigue resistance functions do not show any crossing point between testing in Position 1 and Position 2 (see Fig. 2.14), final tests according to Section 2.2.4.3 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 Fig. 2.15), final tests according to Section 2.2.4.3 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 according to Section 2.2.4.3 shall only take into account those test and pre-test results performed in the unfavourable loading position(s) (see Fig. 2.13).

Additional information on the determination of the preliminary and final fatigue resistance functions is included in Annex A1.

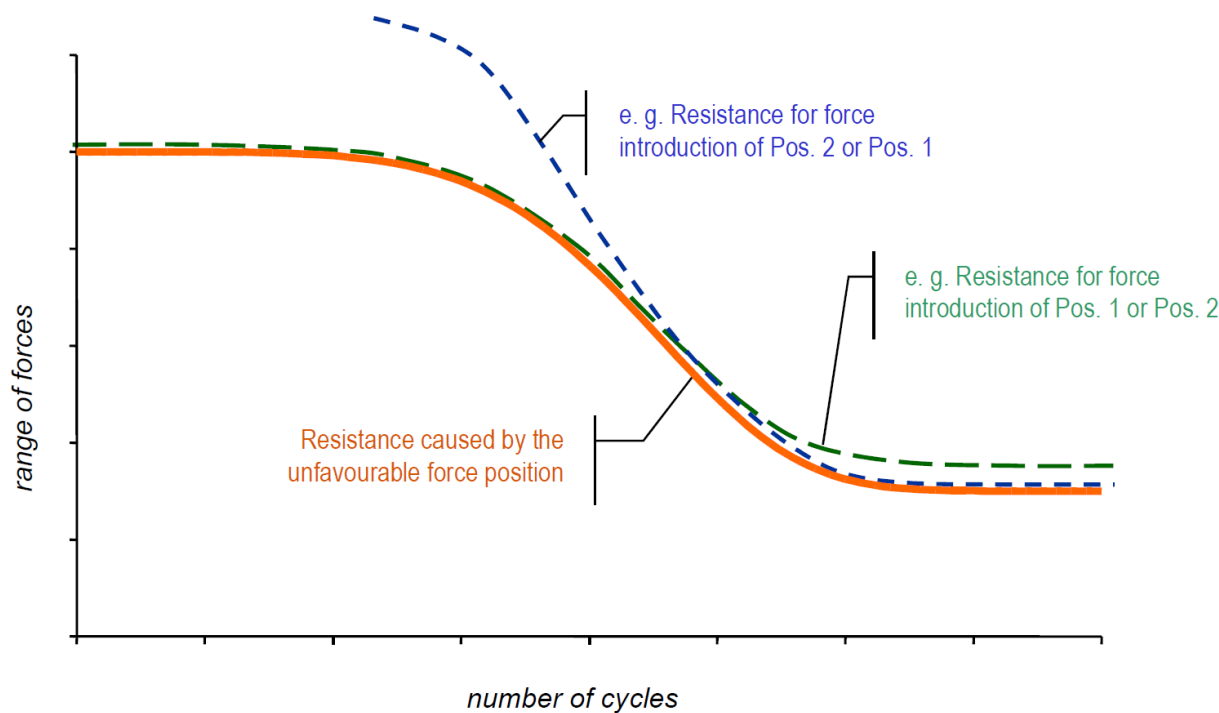


Fig. 2.13: Example for the determination of the fatigue failure function depending on the unfavourable load position (test method A1)

- (5) For Method A2: 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 according to Section 2.2.4.3.

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 Fig. 2.14 and Fig. 2.15).

If the pre-test results do not show any crossing point between testing in Position 1 and Position 2 (see Fig. 2.14), final tests according to Section 2.2.2.3 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 Fig. 2.15), final tests according to Section 2.2.4.3 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 according to Section 2.2.4.3 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 A2.

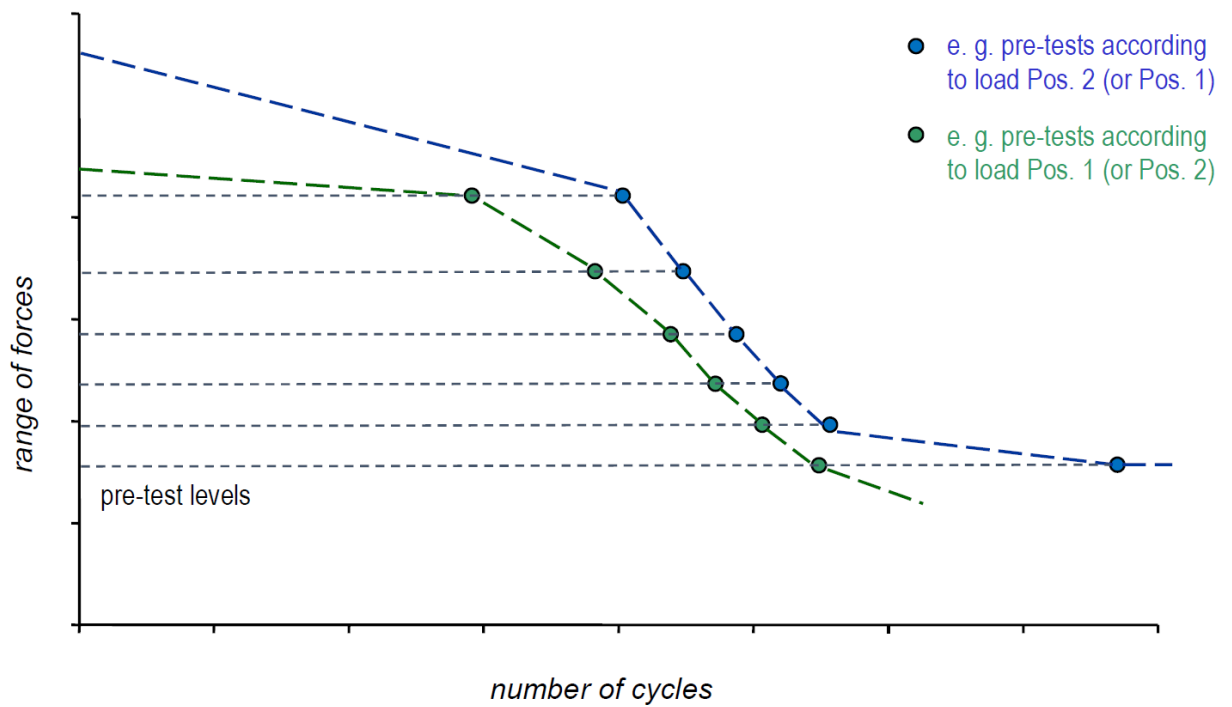


Fig. 2.14: Example for the determination of the unfavourable load position - no crossing observed during pre-testing in Position 1 and Position 2

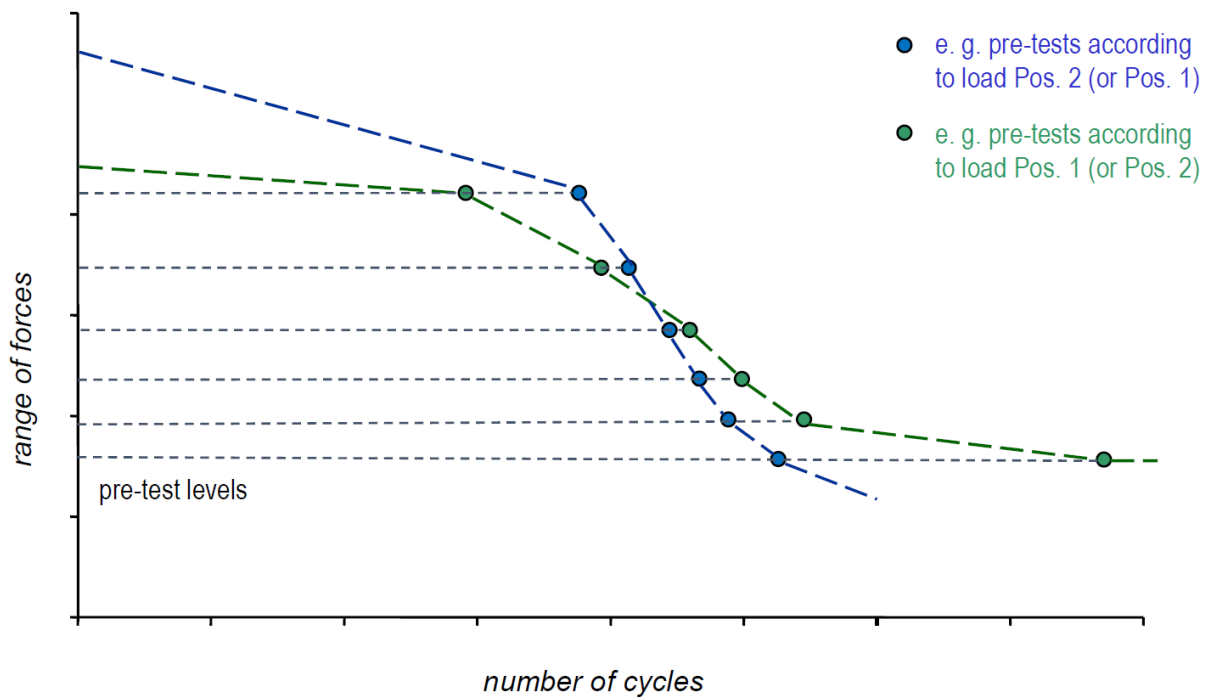


Fig. 2.15: Example for the determination of the unfavourable load position - crossing observed during pre-testing in Position 1 and Position 2

2.2.4.3 Final tests for steel failure under fatigue cyclic tension (Table 2.5, line 5)

- (1) **Purpose:** 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 .
- (2) **Required tests:** For the determination of the final characteristic fatigue resistance functions, testing in accordance with Table 2.5 (test method A1 or A2, test series 5) shall be performed. All channel bolts, channels, connection types, and anchor sizes with all materials and coatings specified by the manufacturer shall be tested.

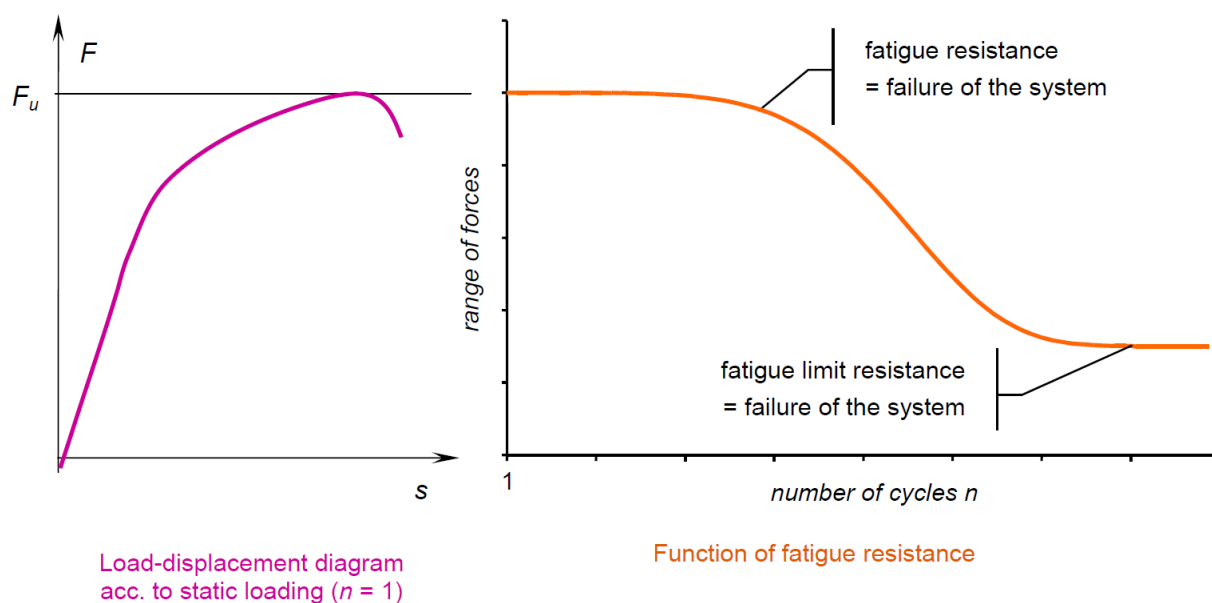
The same conditions as per Section 2.2.1.2 (20) shall be applied.

- (3) **Test conditions:** The same conditions as per Section 2.2.4.1 (3) and Section 2.2.4.2 shall be applied.

The anchor channels shall be loaded in the unfavourable load position, as determined in Section 2.2.4.2, with a sinusoidal load process. Additional information on the testing and loading requirements is included in Annexes A1 and A2.

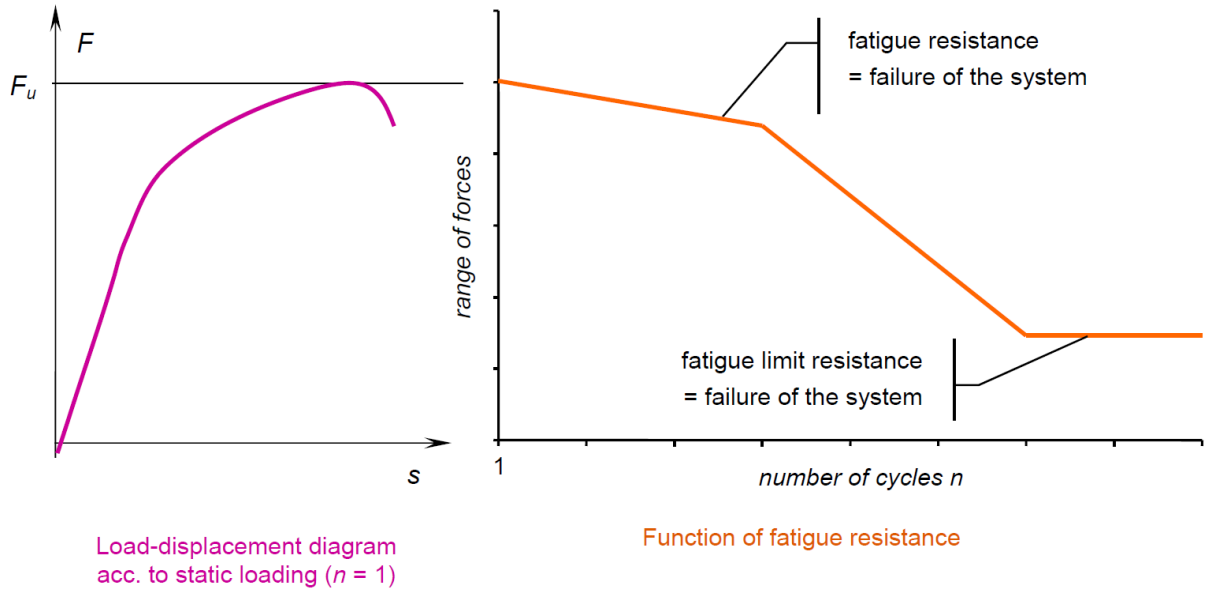
- (4) The verification method shall follow the methods outlined in Technical Report "Calculation Method for the Performance of Anchor Channels under fatigue loads" [28] and shall be given in the relevant ETA. The verification method applies to anchorage in normal weight concrete of C20/25 to C90/105 according to EN 206 1 [12].
- (5) 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 Fig. 2.16 (Method A1) and Fig. 2.17 (Method A2)).



F_u static load resistance

Fig. 2.16: Example of a fatigue resistance function based on failure of the system (test method A1)



F_u static load resistance

Fig. 2.17: Example of a fatigue resistance function based on failure of the system (test method A2)

- (6) Tests which are stopped without failure and started again with a higher stress range may be included in the final evaluation (Reference Annexes A1 and A2 for additional information).
- (7) All tests according to Table 2.5, series 1 to 5 which belong to the unfavourable decisive load position in accordance with Sections 2.2.4.1 to 2.2.4.3 shall be used for the evaluation of the final fatigue resistance functions.
- (8) The characteristic fatigue resistance functions are determined by statistical evaluation (Fig. 2.18 (Method A1) or Fig. 2.19 (Method A2)) based on the 5%-quantile (5%-fractile) with a confidence level of 90%.

The minimum of (a) the characteristic resistance $N_{Rk,s}$ of the anchor channel for $n=1$ cycles as determined from test series 1 and 2 acc. Table 2.5 the characteristic resistances $N_{Rk,s,a}$, $N_{Rk,s,c}$, $N_{Rk,s,l}$, $N_{Rk,s}$, 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 1 and 2 acc. Table 2.5 is larger than the characteristic resistances $N_{Rk,s,a}$, $N_{Rk,s,c}$, $N_{Rk,s,l}$, $N_{Rk,s}$, 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

$$\eta_{k,red,n} = \eta_{k,red,\infty} + (\eta_{k,red} - \eta_{k,red,\infty}) \cdot (\Delta N_{Rk,n} - \Delta N_{Rk,\infty}) / (N_{Rk,s} - \Delta N_{Rk,\infty}) \tag{2.33}$$

where:

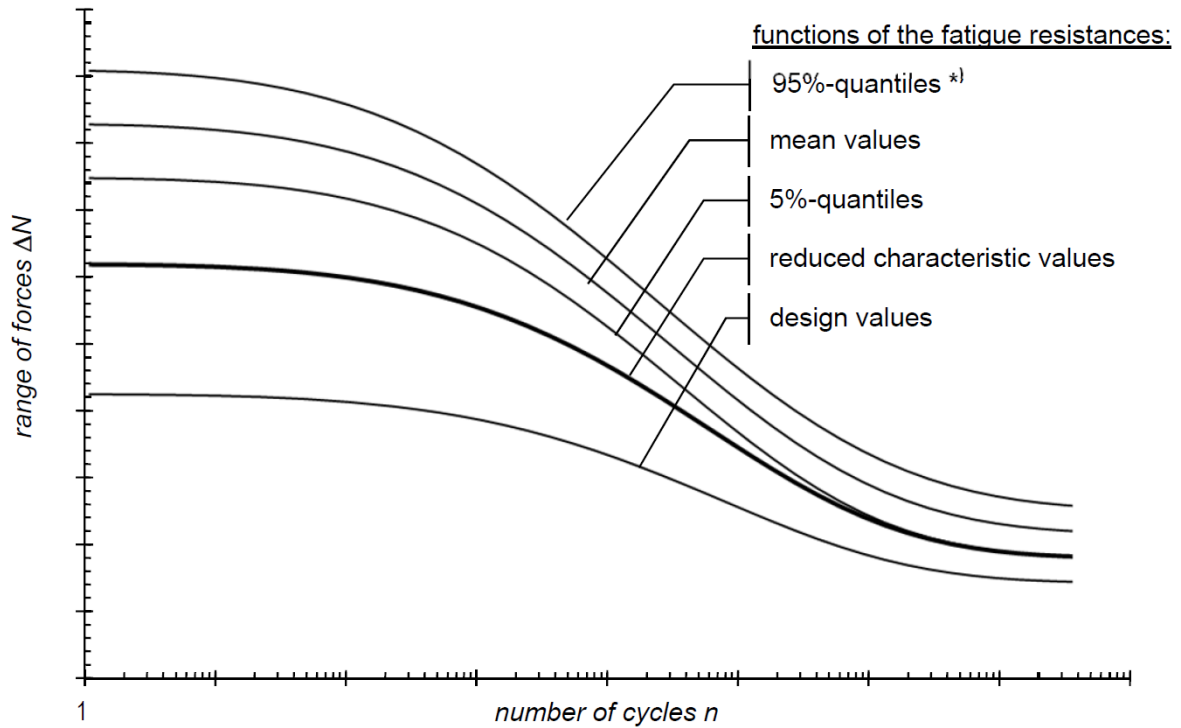
- $N_{Rk,s}$ characteristic value of static resistance as determined from tests series 1 and 2
- $\Delta N_{Rk,n}$ characteristic value of fatigue resistance under fatigue cyclic loading after n load cycles
- $\Delta N_{Rk,\infty}$ characteristic value of fatigue limit resistance under fatigue cyclic loading

$$\eta_{k,red} = N_{Rk,s} / \min(N_{Rk,s,a}, N_{Rk,s,c}, N_{Rk,s,l}, N_{Rk,s}, N_{Rk,s,flex}) \tag{2.34}$$

Note that the fatigue resistance corresponds to the failure of the system and not to its yield strength (see Fig. 2.16 and 2.17).

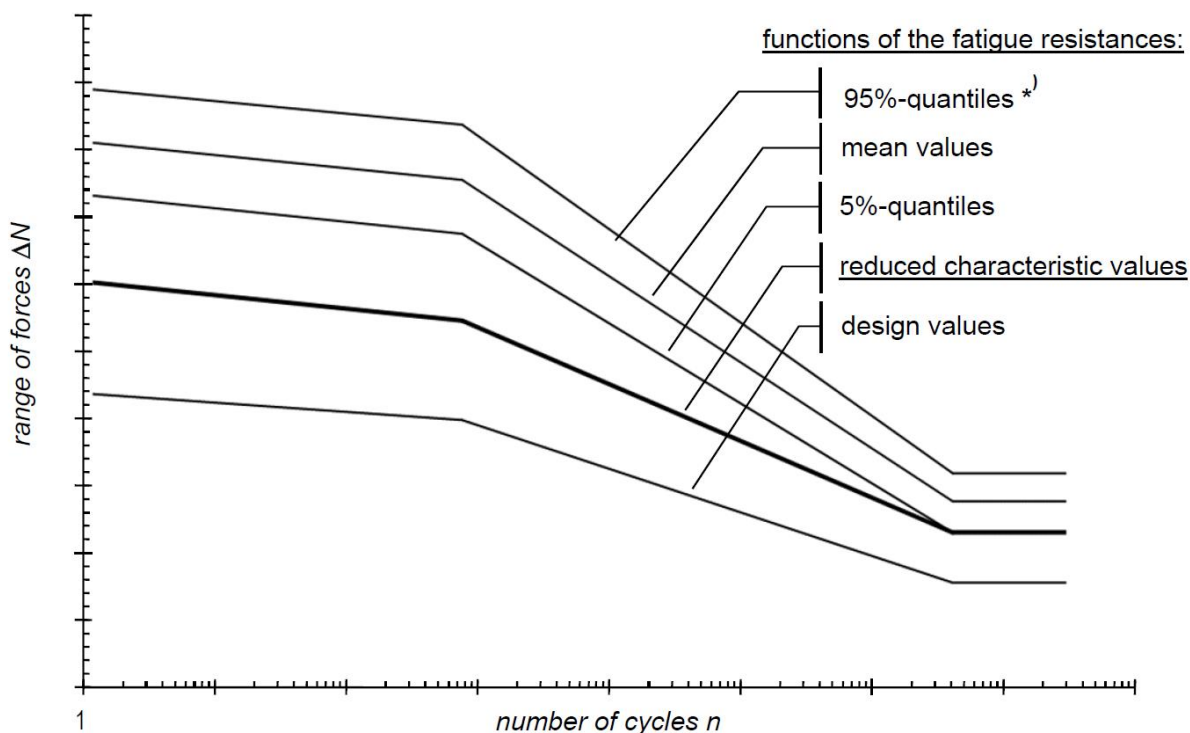
The design failure functions are determined applying the appropriate safety factors to the characteristic resistance functions.

- (9) 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

Fig. 2.18: Example of characteristic and design fatigue resistance functions (test method A1)



*) optional

Fig. 2.19: Example of characteristic and design fatigue resistance functions (test method A2)

2.2.4.4 Concrete related failure under fatigue cyclic tension (Table 2.5, line 6)

- (1) Purpose: Determination of the characteristic resistance for any concrete related failure mode (concrete cone, pull-out)
- (2) Required tests: No tests are required.
- (3) 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:

$$\Delta N_{Rk,c,0,n} = \eta_{k,c,fat} \cdot N_{Rk,c} \quad (2.35)$$

Where the reduction factor $\eta_{c,fat}$ is defined as:

$$1,0 \geq \eta_{k,c,fat} = 1,108 \cdot n^{-0,0444} \geq 0,5 \quad (2.36)$$

The characteristic pullout fatigue resistance, $\Delta N_{Rk,p,0,n}$, can be calculated following the same rule. The static characteristic value will be reduced with the factor $\eta_{p,fat} = \eta_{c,fat}$:

$$\Delta N_{Rk,p,0,n} = \eta_{k,p,fat} \cdot N_{Rk,p} \quad (2.37)$$

2.2.5 Characteristic resistance for tension under fatigue cyclic loading – test method B

2.2.5.1 Final tests for steel failure under fatigue cyclic tension (Table 2.6, lines 7 and 8)

- (1) Purpose: 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} .
- (2) Required tests: For the determination of the characteristic fatigue limit resistance final tests according to Table 2.6 (test method B, test series 7 and 8) shall be performed. All channel bolts, channels, connection types, and anchor sizes with all materials and coatings specified by the manufacturer shall be tested.

The same conditions as per Section 2.2.1.2 (20) shall be applied.

- (3) Test conditions: The same conditions as per Section 2.2.4.1 (3) shall be applied.
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.
- (4) The verification method shall be the methods outlined in Technical Report "Calculation Method for the Performance of Anchor Channels under fatigue loads" [28] and shall be given in the relevant ETA. The verification method applies to anchorage in normal weight concrete of C20/25 to C90/105 according to EN 206 1 [12].
- (5) 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.
- (6) 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 B.
 - run-out test is passed.
- (7) In the case that one or multiple failures are observed, the test program shall be repeated using a lower fatigue cyclic load. It shall not be permitted to combine results from tests performed at different load levels.
- (8) The characteristic fatigue limit resistance is calculated in accordance with the Annex B.

2.2.5.2 Reference tests for steel failure under fatigue cyclic tension (Table 2.6, lines 9 and 10)

- (1) Purpose: 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).
- (2) Required tests: For the determination of the minimum number of load cycles for run-out tests reference tests according to Table 2.6 (test method B, test series 9 and 10) shall be performed. All channels, connection types, and anchor sizes with all materials and coatings specified by the manufacturer shall be tested.

The same conditions as per Section 2.2.1.2 (20) shall be applied.

- (3) Test conditions: The same conditions as per Section 2.2.4.1(3) shall be applied.
The anchor channels shall be loaded in Position 1 and Position 2 with a sinusoidal load process.
- (4) During the fatigue cyclic tests with constant load amplitude, the increase of deformation into the direction of the acting force shall be measured.
- (5) All tests according to Table 2.6, series 9 and 10, 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.
- (6) The minimum number of load cycles for run-out tests shall be determined in accordance with Annex B.

2.2.5.3 Concrete related failure under fatigue cyclic tension (Table 2.6, line 11)

- (1) Purpose: Determination of the characteristic resistance for any concrete related failure (concrete cone, pull-out)
- (2) Required tests: No tests are required.
- (3) The characteristic concrete cone fatigue and pullout fatigue resistances under fatigue cyclic tension can be calculated as follows:

$$\Delta N_{Rk,c,0,\infty} = 0.5 \cdot N_{Rk,c} \quad (2.38)$$

$$\Delta N_{Rk,p,0,\infty} = 0.5 \cdot N_{Rk,p} \quad (2.39)$$

2.2.6 Installation parameters

The parameters c_{min} , h_{min} , s_{min} , s_{max} and T_{inst} are specified by the manufacturer. These parameters shall be used and assessed in the test series according to Table 2.3.

The parameter $s_{min,cbo} = 5$ d.

2.2.7 Geometric parameters

The parameters h_{ch} , b_{ch} , d , A_h are specified by the manufacturer. The parameter l_y shall be determined by calculation.

2.2.8 Displacements

- (1) 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 equation:

$$N = N_{Rk} / (\gamma_F \cdot \gamma_M)$$

with: N_{Rk} = characteristic resistance

γ_F = partial safety factor for actions = 1,4

γ_M = partial safety factor for material according EN 1992-4 [3] or Technical Report "Calculation Method for the Performance of Anchor Channels" [4]

$$V = V_{Rk} / (\gamma_F \cdot \gamma_M)$$

with: V_{Rk} = characteristic resistance

γ_F = partial safety factor for actions = 1,4

γ_M = partial safety factor for material according EN 1992-4 [3] or Technical Report "Calculation Method for the Performance of Anchor Channels" [4]

- (2) The displacements δ_{N0} and δ_{V0} under short-term loading are evaluated from test series Table 2.3, line 5 and line 13. 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.
- (3) 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 $\delta_{V\infty}$ under long-term shear loading are assumed to be approximately equal to 1,5-times the value δ_{V0} . Under shear loading, the displacements might increase due to a gap between fixture and anchor channel. The influence of this gap is taken into account in design.

2.2.9 Durability

Supporting evidence that corrosion will not occur is not required if the steel parts of the anchor channel 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 steel parts as coatings provided for preventing corrosion during storage prior to use and for ensuring proper functioning zinc coating with a minimum thickness of 5 microns) is considered sufficient.
- (2) 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):
Metal parts of the anchor made of steel material 1.0038 or 1.0044 acc. EN 10025-2 [6], 1.0976 or 1.0979 acc. EN 10149-1 and -2 [18], 1.0213, 1.0214, 1.1132, 1.5525 or 1.5535 acc. to EN 10263-2,

-3, and -4 [15], 1.5523 acc. EN 10269 [19] or 1.0401 acc. EN 10277-2 [25] hot dip galvanized according EN ISO 1461 [23] or EN ISO 10684 [24] with at least 50 µm thickness can be used.

- (3) Anchor channels for use in structures subject to external atmospheric exposure (including industrial and marine environments), or exposure in permanently damp internal condition, if no particular aggressive conditions according to (4) exists:

Metal parts of the anchor made of stainless steel material 1.4401, 1.4404, 1.4571, 1.4578, 1.4362, 1.4062, 1.4162, 1.4662, 1.4439, 1.4462 or 1.4539 according to EN 10088-4 and 5 [7] can be used.

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

Metal parts of the anchor made of stainless

2.2.10 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.

2.2.11 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 Technical Report 020 [5] subjected to the following conditions:

- (1) The fire resistance to steel failure may only be determined by testing. For determining the stress acc. TR 020 the cross section of the channel bolt shall be used.
- (2) For fire resistance to concrete failure no tests have to be performed if the simplified design method of TR 020 [5] is used.
- (3) Anchor channels with two or more anchors may be used.
- (4) The anchor channels shall be used with the minimum end spacing x_{min} and the maximum spacing s_{max} of the anchors.
- (5) The anchor channel shall be basically loaded in midspan.
- (6) Fire resistance performance cannot be claimed for individual products only, since it is a characteristic of a complete system.

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: Decision 2000/273. 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 (control plan).

Table 3.1 is an example only; the control plan depends on the individual manufacturing process and has to be established between notified body and manufacturer for each product.

The manufacturer of the anchor channel shall demonstrate that the manufacturing plant is capable of performing the selected welding process in accordance with the applicable standards.

Table 3.1 Control plan for the manufacturer; cornerstones

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
Factory production control (FPC) [including testing of samples taken at the factory in accordance with a prescribed test plan]*					
Raw material					
1	Material and material properties of channel	Inspection certificate 3.1 according to EN 10204	control plan	1	Each manufacturing batch
2	Material and material properties of anchor	Test report 2.2 according to EN 10204			
3	Dimensions and material properties of channel bolts	Inspection certificate 3.1 according to EN 10204 ¹⁾			
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 acc. line 7 are carried out					
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 2.2.1.1 resp. 2.2.1.3		3 ²⁾	

No	Subject/type of control	Test or control method	Criteria, if any	Minimum number of samples	Minimum frequency of control
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 2.2.1.1 resp. 2.2.1.3		3	
8	Determination of the thickness of the corrosion protection	Visual, measurement		3 ²⁾	
9	Fatigue tests related to the adopted assessment procedure and in accordance with Annex A1, A2, and B	Fatigue cyclic tension test		3 ²⁾	
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 acc. to EN ISO 898-1 and EN ISO 3506-1					

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 factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the anchor channel.	-	Laid down in control plan	-	1
Continuous surveillance, assessment and evaluation of factory production control					
2	Verifying that the system of factory production control and the specified automated manufacturing process are maintained taking account of the control plan.	-	Laid down in control plan	-	1/year

4 REFERENCE DOCUMENTS

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

- | | | |
|------|----------------------|--|
| [1] | CPR | REGULATION (EU) No 305/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 March 2011 laying down harmonized conditions for the marketing of construction products and repealing Council Directive 89/106/EEC; |
| [2] | ETAG 001 used as EAD | Guideline for European technical approval of metal anchors for use in concrete current version of European Assessment Document (EAD); |
| [3] | EN 1992-4:201X | Eurocode 2: Design of concrete structures; Part 4: Design of fastenings for use in concrete; |
| [4] | EOTA TR 047 | Technical Report 047, "Calculation Method for the Performance of Anchor Channels", XX 2015; |
| [5] | EOTA TR 020 | Technical Report 020, Evaluation of Anchorages in Concrete concerning Resistance to Fire, May 2004; |
| [6] | EN 10025-1+2 | 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 | 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 | Welding and allied processes – Nomenclature of processes and reference numbers; |
| [9] | EN ISO 4018 | Hexagon head screws – Product grade C; |
| [10] | EN ISO 898-1 | 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 | Mechanical properties of corrosion-resistant stainless steel fasteners. Part 1: Bolts, channel bolts and studs, Part 2: Nuts; |
| [12] | EN 206-1+A1+A2 | Concrete. Part 1: Specification, performance, production and conformity; |
| [13] | EN 10204 | Metallic products - Types of inspection documents; |
| [14] | DIN 17111 | Low carbon unalloyed steels for bolts, nuts and rivets; technical conditions of delivery; |
| [15] | EN 10263-2, -3 + 4 | 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 | Hexagon regular nuts (style 1) – Product grades A and B; |
| [17] | EN ISO 4034 | Hexagon regular nuts (style 1) - Product grade C; |

- [18] EN 10149-1+2 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 10269:1999+A1 Steels and nickel alloys for fasteners with specified elevated and/or low temperature properties, including corrigendum;
- [20] EN ISO 7089 Plain washers – Normal series – Product grade A;
- [21] EN 1993-1-1:2005+AC Eurocode 3: Design of steel structures. Part 1-1: General rules and rules for buildings, including corrigendum;
- [22] Owen, D. Handbook of Statistical Tables, Addison/Wesley Publishing Company Inc., 1962;
- [23] EN ISO 1461 Hot dip galvanized coatings on fabricated iron and steel articles- Specifications and test methods;
- [24] EN ISO 10684+Cor. 1 Fasteners – Hot dip galvanized coatings;
- [25] EN 10277-2 Bright steel products – Technical delivery conditions
Part 2: Steels for general engineering purposes;
- [26] EN ISO 7090 Plain washers, chamfered – Normal series – Product grade A;
- [27] EN ISO 7091 Plain washers – Normal series – Product grade C;
- [28] EOTA TR 050 Technical Report 050, "Calculation Method for the Performance of Anchor Channels under fatigue loads", XX 201X;
- [29] Block, K.; Dreier, F. Die Ermüdungsfestigkeit zuverlässig und kostengünstig ermitteln - Das Interaktive Verfahren. Materialprüfung 40 (1998) 3;
- [30] Block, K.; Dreier, F. Das Ermüdungsverhalten von Dübelbefestigungen. Deutscher Ausschuss für Stahlbeton, Heft 541. Beuth Verlag, Berlin 2003,
- [31] Maurer, R.; Block, K.; Dreier, F. Ermüdungstragfähigkeit von Betonstahl – Bestimmung mit dem Interaktiven Verfahren.

Annex A1 The Interactive Method to determine the characteristic fatigue resistance

1 Basics

- (1) The force-controlled periodic loading with sinusoidal course should be used for the most disadvantageous case (practical application) of the test specimen.
- (2) 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.
- (3) Test specimen reaching the limit number of cycles without failure, are to be tested again at a higher stress level (verification of non-damaged specimen). This run-out test is applied to identify a potential damage of the test specimen despite reaching the limit number of cycles.
- (4) 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 ($n \Rightarrow \infty$).
- (5) The used capital letter S in this Annex shall be replaced by the letter N for tension loads.

2 Procedure steps

2.1 Determination of the characteristic static resistance

- (1) 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 Fig. 2.12). 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.
- (2) For the determination of the static and fatigue resistances testing shall be done on the identical product regarding batch, geometry, material etc.
- (3) The characteristic value S_k is equivalent to the 5%-quantile ($p = 0.05$), 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:

$$S_k = \bar{S} - k_{n,p,1-\alpha} \cdot \hat{s} \quad (\text{A1.1})$$

where

$$\hat{s} = \sqrt{\frac{\sum_{i=1}^n (\bar{S} - S_i)^2}{n-1}}, \text{ standard deviation} \quad (\text{A1.2})$$

2.2 Determination of the unfavourable loading position for fatigue loading

- (1) 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 Fig. 2.12).
- (2) The fatigue cyclic load levels correspond to the first six load levels of Section 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 2.3.

2.3 Planning of the fatigue cyclic load levels

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

$$\Delta S_i = S_{oi} - S_u \quad (\text{A1.3})$$
- (2) The lower level of the sinusoidal course, S_u , is equal for all fatigue cyclic load levels and should be kept to a minimum.
- (3) Results from testing with only one cycle, i.e. under quasi-static loading, already exist (See Section 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.
- (4) After the first attempt, the expected fatigue limit resistance ΔS_D shall be estimated by existing experiences. The estimated value, ΔS_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 \bar{S} .

$$\text{Hot-rolled:} \quad \Delta S_D^{\approx} \approx (0.10, \dots, 0.30) \cdot \bar{S}$$

$$\text{Cold-formed:} \quad \Delta S_D^{\approx} \approx (0.05, \dots, 0.20) \cdot \bar{S}$$

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

- (5) 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 2.5 and 2.6).

- (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.

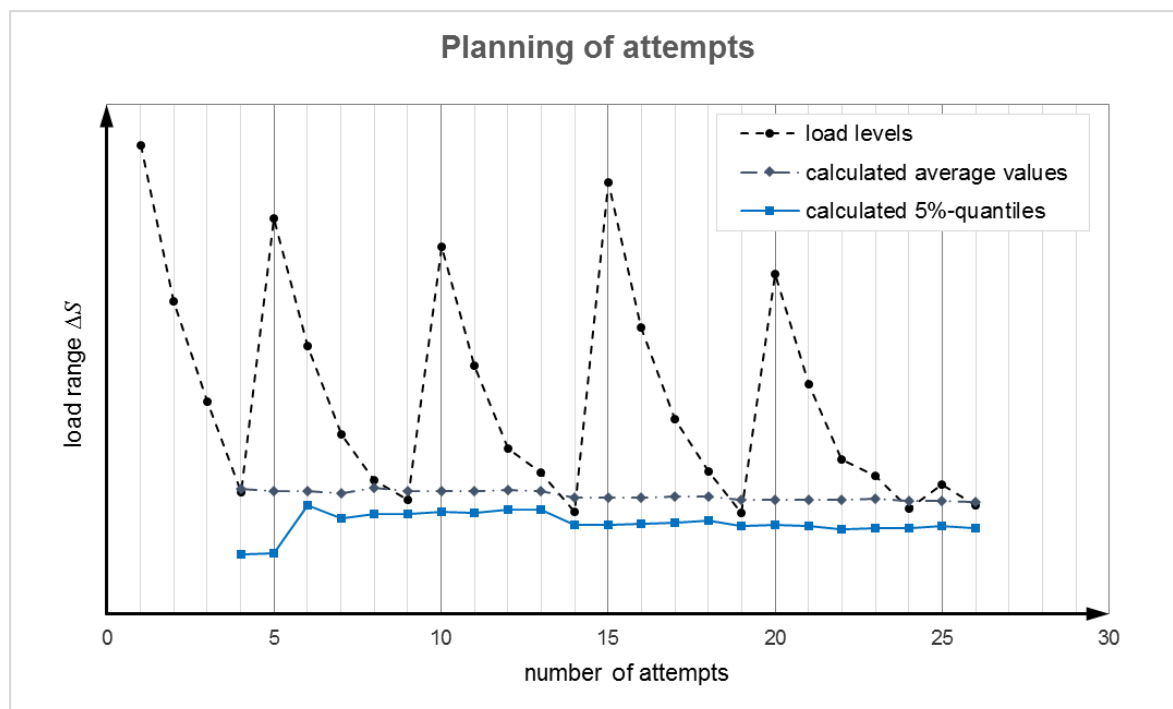


Fig. A1.1: Planning of attempts – average values and 5%-quantiles apply to the fatigue limit resistance

- (7) The further course of experimental design is detailed shown in Fig. A1.1. 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 Fig. A1.1.
- (8) During the testing at least three „real“ run-out specimens shall be identified. Failure of specimens between run-outs is permitted.

2.4 Determination of the limit number of cycles and load level for run-out test

- (1) 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).
- (2) 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 verification 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 Fig. A1.2). 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 (see Section 2.4(1)) 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 (see Section 2.4(3)).

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

Centroid of test result scatter for one area:

$$\dot{s}_o = \frac{1}{m} \sum_{i=1}^m s_{o,i} \quad (A1.4)$$

$$\dot{n} = \frac{1}{m} \sum_{i=1}^m n_i \quad (A1.5)$$

where $s_{o,i}$ = Displacement of the cross section, regarding the upper limit $S_{o,i}$ 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:

$$s_o = a_s + b_s n \quad (A1.6)$$

where

$$a_s = \dot{s}_o - b_s \dot{n} \quad (A1.7)$$

$$b_s = \frac{\sum_{i=1}^m (n_i - \dot{n})(s_{o,i} - \dot{s}_o)}{\sum_{i=1}^m (n_i - \dot{n})^2} \quad (A1.8)$$

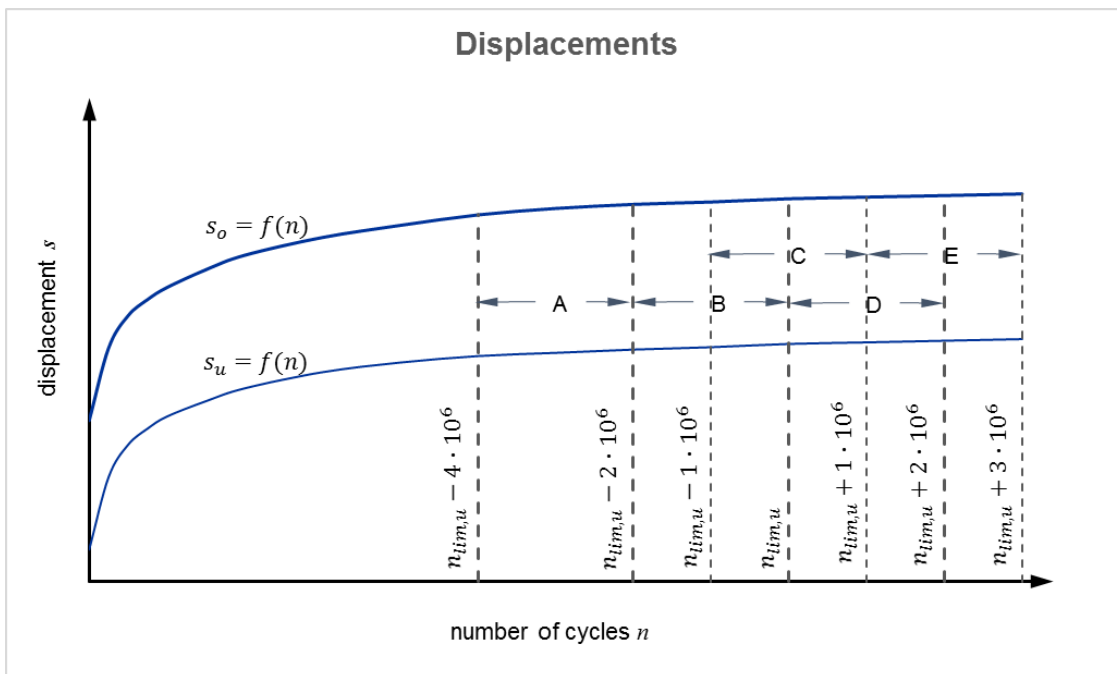


Fig. A1.2: Stabilization of deformations of a run-out

- (3) 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 2.5) and characteristic resistance functions (Section 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 Fig. A1.3) and is calculated as follows:

$$\Delta S_{RT} \approx \bar{S} - (\bar{S} - \Delta \bar{S}_D) / 3 \quad (\text{A1.9})$$

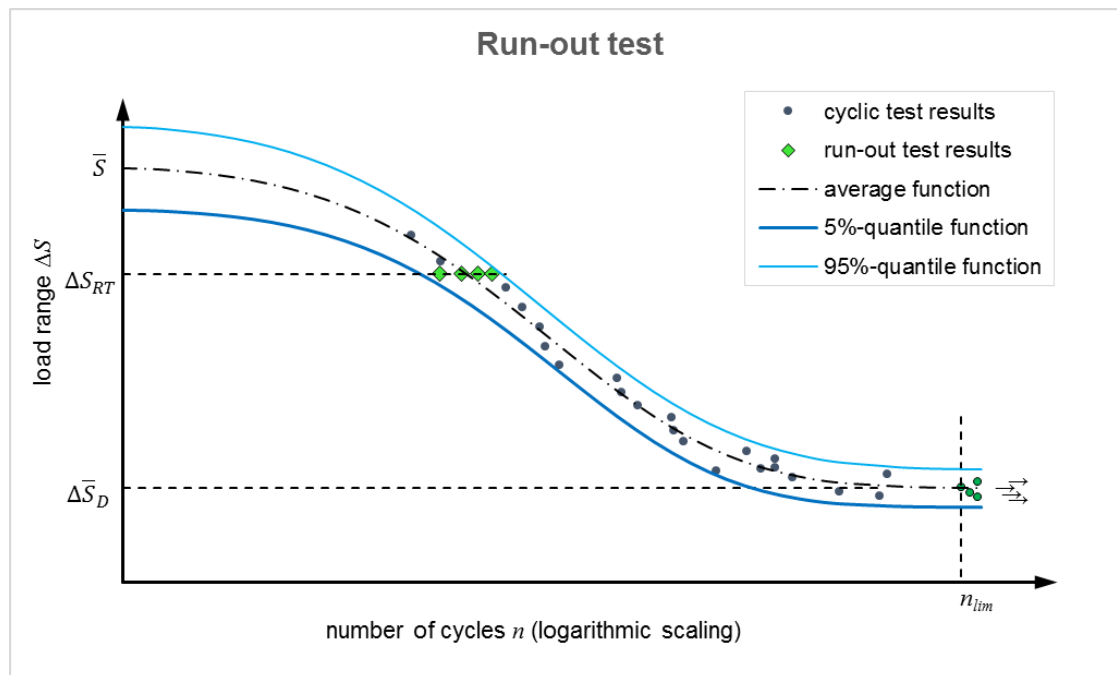


Fig. A1.3: Load level for run-out test (general)

- (4) If the pre-test results show a crossing point between testing in Position 1 and Position 2 (see Fig. 2.5) 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 Fig. A1.4. Once the scatter band is transferred, then the same conditions as per Section 2.4 (3) shall be applied for the run-out test verification.

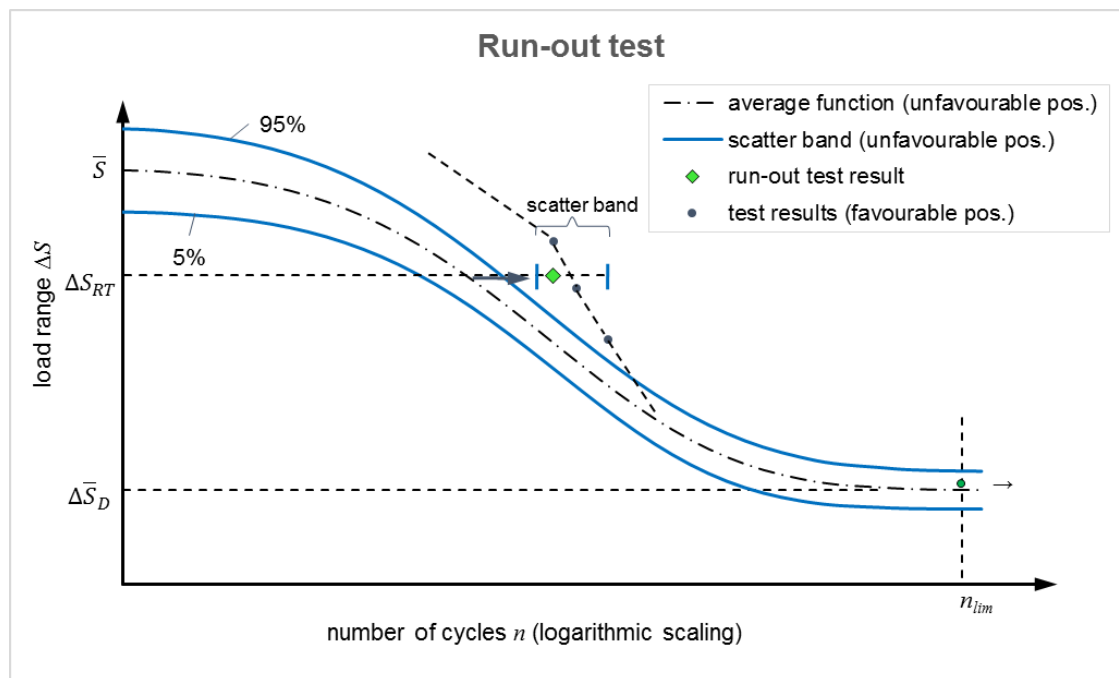


Fig. A1.4: Transfer of the scatter band (unfavourable position) to the favourable position

2.5 Determination of the average function

- (1) If test results with different load ranges and number of cycles are available, then the results are described by the equation (A1.10) 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 Fig. A1.5).

$$\Delta\bar{S} = \Delta\bar{S}_D + (\bar{S} - S_u - \Delta\bar{S}_D) \cdot a^{(\lg n)^b} \quad (\text{A1.10})$$

where

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 acc. Table 2.5, line 1 and 2

S_u = lower limit of fatigue cyclic loads

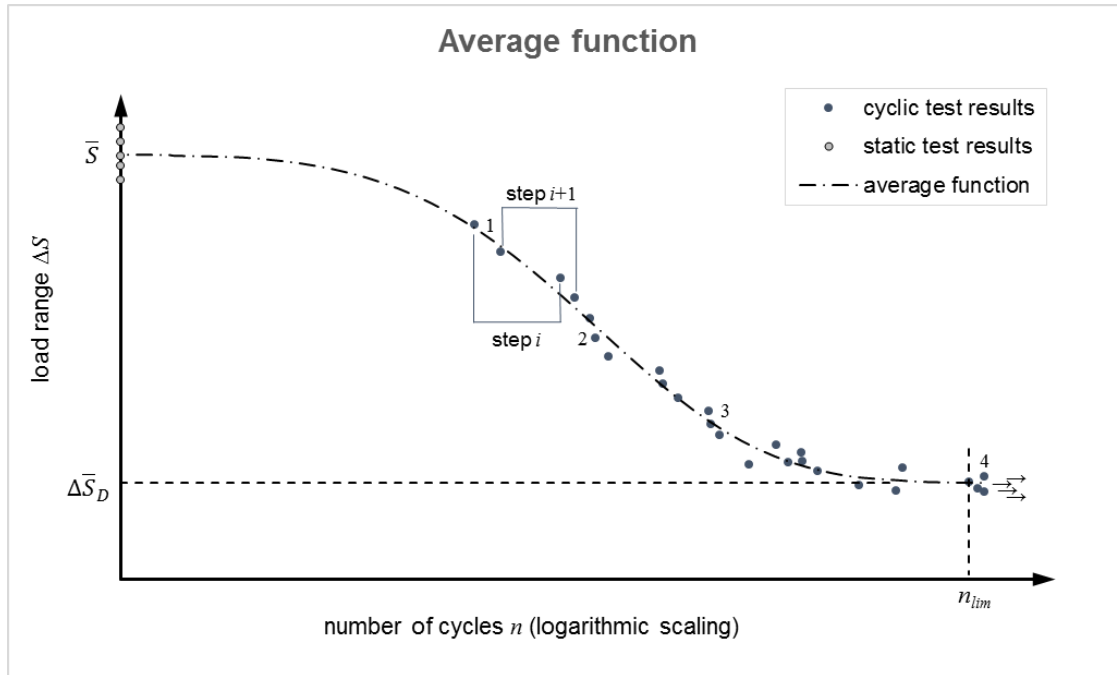


Fig. A1.5: Tests results and average function of fatigue resistance

2.6 Determination of the characteristic fatigue resistance

- (1) For the statistical evaluation three juxtaposed results are considered.
- (2) 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 Fig. A1.5). 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.
- (3) The 5%-quantiles are determined according to the following sequence:

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

$$\Delta \bar{S}_i = \text{mean value of the cross section for every step } i \text{ according to equation (A1.9)}$$

where

$$n_i = \text{number of cycles of the cross section for every step } i$$

$$\Delta \Delta S_i = \Delta S_i - \Delta \bar{S}_i, i = 1, \dots, h \tag{A1.11}$$

where

$$h = \text{total number of available fatigue cyclic test results}$$

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

$$\hat{\sigma}_j^2 = \frac{((\Delta \Delta S_i)^2 + (\Delta \Delta S_{i+1})^2 + (\Delta \Delta S_{i+2})^2) \cdot h}{3 \cdot (h - 1)}, j = 1, \dots, h - 2 \tag{A1.12}$$

$$\hat{\sigma}_j = \sqrt{\hat{\sigma}_j^2} \tag{A1.13}$$

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

$$\Delta \bar{S}_j = \text{mean value of the cross section for every step } j \text{ according to equation (A1.9)}$$

where

$$\hat{n}_j = 10^{((\lg n_i + \lg n_{i+1} + \lg n_{i+2})/3)} \tag{A1.14}$$

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

$$\Delta \hat{S}_{j,5\%} = \Delta \bar{S}_j - k_{h,p,1-\alpha} \cdot \hat{S}_j, j = 1, \dots, h - 2 \tag{A1.15}$$

where

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

- (4) The course of the 5%-quantiles is calculated using equation (A1.16) according to the principles of the least squares method (ref. Eq. (A1.10)). An example of the 5%-quantile function is shown in Fig. A1.6.

$$\Delta S_k = \Delta S_{D,k} + (S_k - S_u - \Delta S_{D,k}) \cdot a^{(\lg n)^b} \tag{A1.16}$$

where

- 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 acc. Table 2.5, line 1 and 2
- S_u = lower limit of fatigue cyclic loads

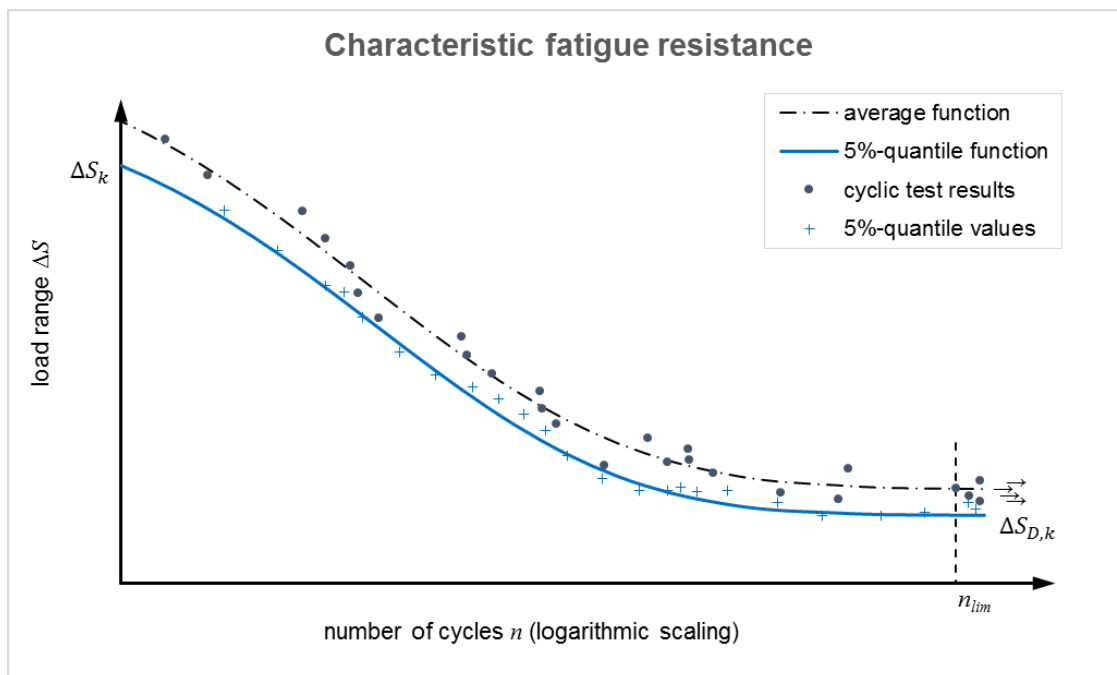


Fig. A1.6: Tests results, average function and 5%-quantile after regression analysis

2.7 Control of the characteristic fatigue resistance

- (1) On one hand, to check the characteristic fatigue resistance 5%-quantiles are determined at three cross sections along the number of cycles-axis (see Fig. A1.7):

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

$$\Delta\hat{S}_{A,5\%} = \Delta\bar{S}_A - k_{h,p,1-\alpha} \cdot \hat{S}_A \quad (\text{A1.17})$$

where

$$\Delta\bar{S}_A = \text{mean value of area A according to equation (A1.10)}$$

$$\text{where } \dot{n}_A = 10^{((\sum_{i=1}^h \lg n_i)/h)} \quad (\text{A1.18})$$

$$\hat{S}_A = \sqrt{\frac{\sum_{i=1}^h (\Delta\Delta S_i)^2}{h-1}} \quad (\text{A1.19})$$

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

$$\Delta\hat{S}_{B,5\%} = \Delta\bar{S}_B - k_{h,p,1-\alpha} \cdot \hat{S}_B \quad (\text{A1.20})$$

where

$$\Delta\bar{S}_B = \text{mean value of area B according to equation (A1.10)}$$

$$\text{where } \dot{n}_B = 10^{((\sum_{i=1}^{0.5h} \lg n_i)/0.5h)} \quad (\text{A1.21})$$

$$\hat{S}_B = \sqrt{\frac{(\sum_{i=1}^{0.5h} (\Delta\Delta S_i)^2) \cdot h}{0.5h \cdot (h-1)}} \quad (\text{A1.22})$$

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):

$$\Delta\hat{S}_{C,5\%} = \Delta\bar{S}_C - k_{h,p,1-\alpha} \cdot \hat{S}_C \quad (\text{A1.23})$$

where

$$\Delta\bar{S}_C = \text{mean value of area C according to equation (A1.10)}$$

$$\text{where } \dot{n}_C = 10^{((\sum_{i=1}^{0.5h} \lg n_i)/0.5h)} \quad (\text{A1.24})$$

$$\hat{S}_C = \sqrt{\frac{(\sum_{i=1}^{0.5h} (\Delta\Delta S_i)^2) \cdot h}{0.5h \cdot (h-1)}} \quad (\text{A1.25})$$

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 :

$$\eta_A = \Delta\hat{S}_{A,5\%}/\Delta\bar{S}_A \quad (\text{A1.26})$$

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

$$\eta_A \cdot \Delta\bar{S}_D \quad (\text{A1.27})$$

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.

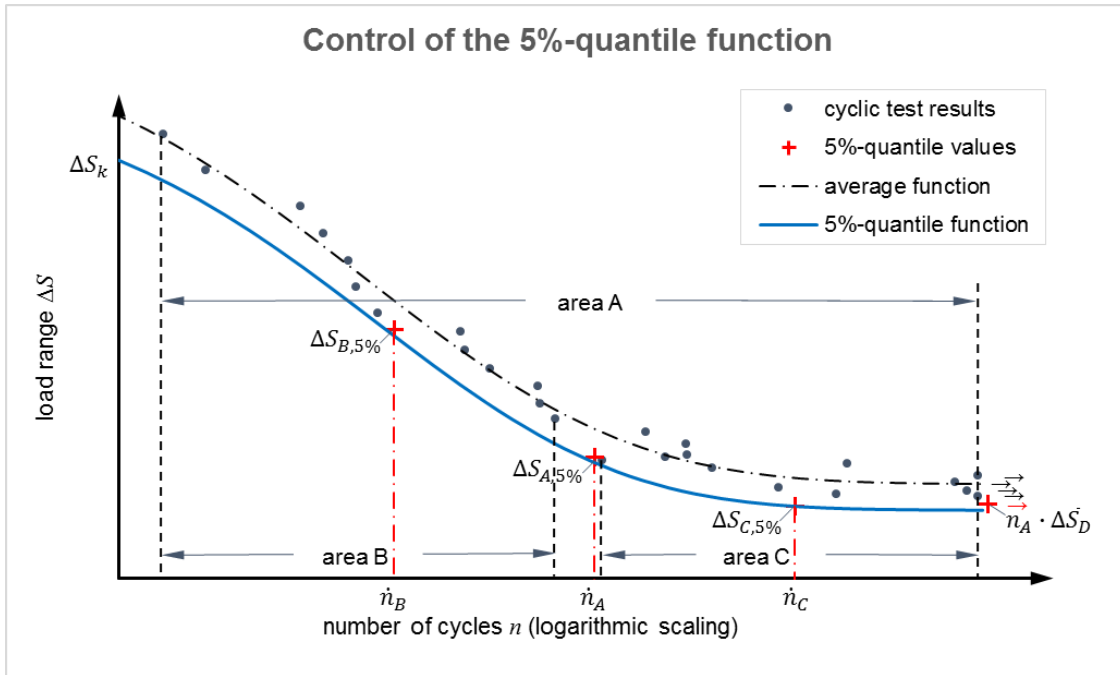


Fig. A1.7: Control of the characteristic fatigue resistance

2.8 Determination of the design value of fatigue resistance

- (1) The design values are calculated by reducing the characteristic values using the material safety factors γ_M , $\gamma_{M,fat,n}$ and $\gamma_{M,fat}$ in accordance with Technical Report "Calculation Method for the Performance of Anchor Channels under fatigue loads" [28]:

$$S_d = S_k / \gamma_M \tag{A1.28}$$

$$\Delta S_{D,d} = \Delta S_{D,k} / \gamma_{M,fat} \tag{A1.29}$$

The reduction of the characteristic values in the transition area from the static resistance to the fatigue limit resistance is carried out using the following reduction factor:

$$\gamma_{M,fat,n} = \gamma_{M,fat} + (\gamma_M - \gamma_{M,fat}) \cdot (\Delta S_{k,n} - \Delta S_{D,k}) / (S_k - \Delta S_{D,k}) \tag{A1.30}$$

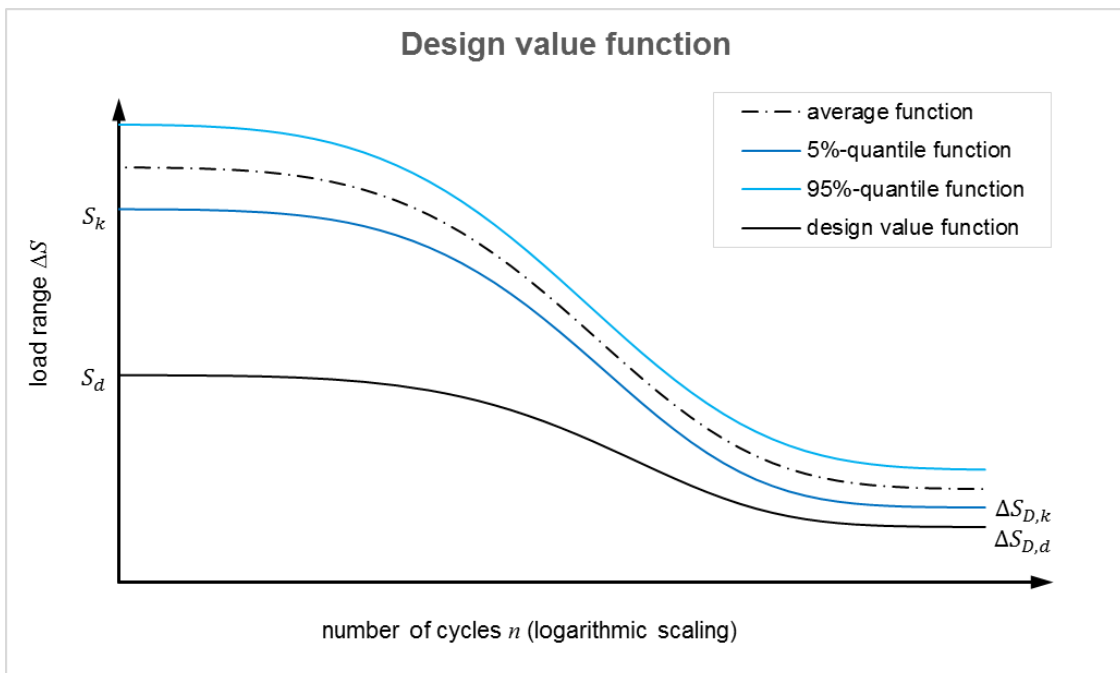


Fig. A1.8: Determination of the design value of fatigue resistance

2.9 System of assessment and verification of constancy of performance

- (1) Three tests under different fatigue cyclic loading shall be done to meet quality requirements of the characteristic fatigue resistance. The load levels are determined as follows:

$$\text{Attempt a:} \quad \Delta S_a = S_k - \frac{1}{3}(S_k - \Delta S_{D,k}) \quad (\text{A1.31})$$

$$\text{Attempt b:} \quad \Delta S_b = S_k - \frac{2}{3}(S_k - \Delta S_{D,k}) \quad (\text{A1.32})$$

$$\text{Attempt c:} \quad \Delta S_c = \Delta S_{D,k} \quad (\text{A1.33})$$

Quality requirements are fulfilled if the number of cycles of the first two specimen exceed 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 first attempt level.

Annex A2 Method to determine the characteristic fatigue resistance as a trilinear function

1 Basics

- (1) 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.
- (2) 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
- (3) 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 (verification of non-damaged specimen). This run-out test is applied to identify a potential damage of the test specimen despite reaching the limit number of cycles.
- (4) The used capital letter S in this Annex shall be replaced by the letter N for tension loads.

2 Procedure steps

2.1 Determination of the characteristic static resistance

- (1) 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 Fig. 2.12). 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.
- (2) 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.
- (3) The characteristic value S_k is equivalent to the 5%-quantile ($p = 0.05$), 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:

$$S_k = \bar{S} - k_{n,p,1-\alpha} \cdot \hat{s} \quad (\text{A2.1})$$

where

$$\hat{s} = \sqrt{\frac{\sum_{i=1}^n (\bar{S} - S_i)^2}{n-1}}, \text{ standard deviation} \quad (\text{A2.2})$$

2.2 Determination of the unfavourable loading position for fatigue loading

- (1) 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 Fig. 2.12).
- (2) 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 2.3). The load levels are calculated as follows (for the determination of ΔS_1 and ΔS_5 , see Section 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	$\lg \Delta S_{19} = \lg \Delta S_1 - 18\Delta_S$

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

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

$$\Delta S_i = S_{oi} - S_u \quad (\text{A2.3})$$
- (2) The lower level of the sinusoidal course S_u is equal for all fatigue cyclic load levels and should be kept to a minimum.
- (3) For further planning of the load levels the expected fatigue limit resistance ΔS_D is to be estimated by existing experiences. The estimated value ΔS_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 \bar{S} .

$$\text{Hot-rolled:} \quad \Delta S_D^{\approx} \approx (0.10, \dots, 0.30) \cdot \bar{S}$$

$$\text{Cold-formed:} \quad \Delta S_D^{\approx} \approx (0.05, \dots, 0.20) \cdot \bar{S}$$

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.

$$\Delta_S = 0.05 \cdot (\lg \Delta S_1 - \lg \Delta S_D^{\approx}) \tag{A2.4}$$

where

$$\Delta S_1 = S_k - S_u \rightarrow \lg \Delta S_1 \tag{A2.5}$$

$$\Delta S_D^{\approx} \rightarrow \lg \Delta S_D^{\approx}$$

(4) 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 $\lg \Delta S_h = \lg \Delta S_1 - (h - 1)\Delta_S$ (A2.6)

(5) 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 2.4 and 2.5. Afterward the limit number of cycles n_{lim} for attempt h shall be determined by step 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 2.6).

2.4 Linear regression analysis

(1) 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 A2.1 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 A2.1: 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:			$\dot{y} = \frac{1}{r} \sum_{i=l}^m y_i$ (A2.7)	$\dot{x} = \frac{1}{r} \sum_{i=l}^m x_i$ (A2.8)

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

$$y_i = a + bx_i + e_i \tag{A2.9}$$

(3) 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.

(4) Account should be taken of the random variables X and Y. These are to be determined with two mutually independent regression lines (see Fig. A2.1). The first for the assumed linear dependency

$y = a_y + b_y x$ for line 1 according to (A2.10) and (A2.11), the second for the assumed dependency $x = a_x + b_x y$ for line 2 according to (A2.12) and (A2.13). 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:

$$a_y = \bar{y} - b_y \bar{x} \quad (A2.10) \quad b_y = \frac{\sum_{i=1}^m (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^m (x_i - \bar{x})^2} \quad (A2.11)$$

Regression line 2:

$$a_x = \bar{x} - b_x \bar{y} \quad (A2.12) \quad b_x = \frac{\sum_{i=1}^m (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^m (y_i - \bar{y})^2} \quad (A2.13)$$

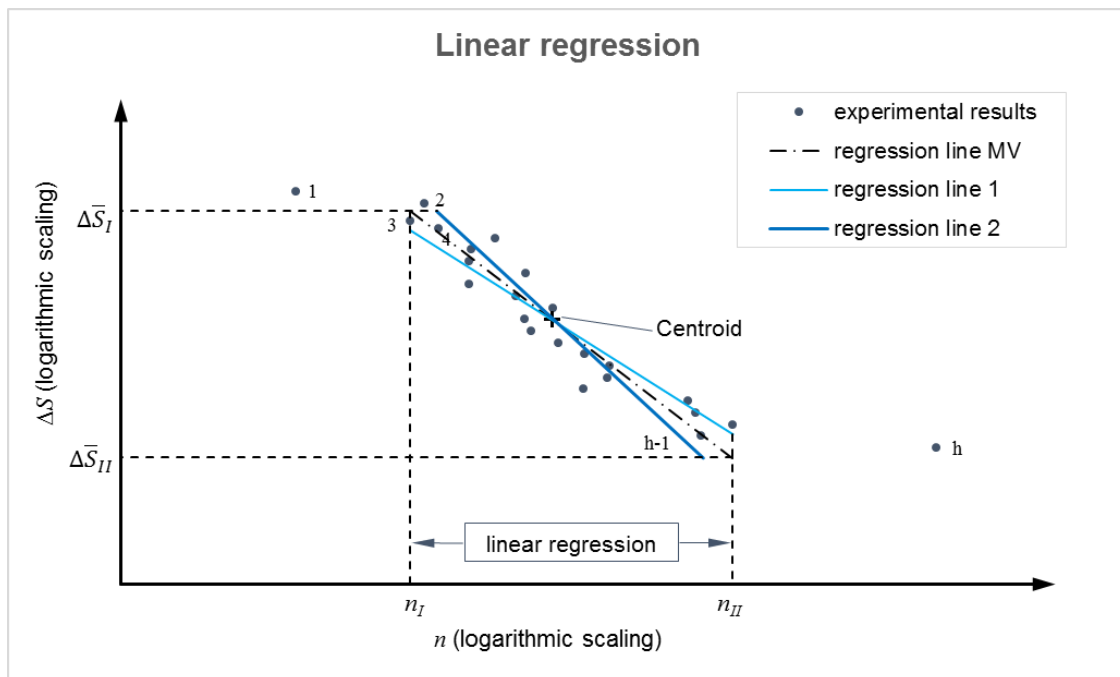


Fig. A2.1: Regression analysis with two mutually independent regression lines

- (5) 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 Fig. A2.1) 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):

$$a = \bar{y} - b \bar{x} \quad (A2.14) \quad b = \left(b_y + \frac{1}{b_x} \right) / 2 \quad (A2.15)$$

- (6) If a specimen fails on the first load level during the determination of the characteristic fatigue limit resistance $\Delta S_{D,k}$ (see Section 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 A2.1).
- (7) 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 2.5) are determined (see

example in Fig. A2.2). These ten results correspond to the fifth to fourteenth load level (ΔS_5 to ΔS_{14}).

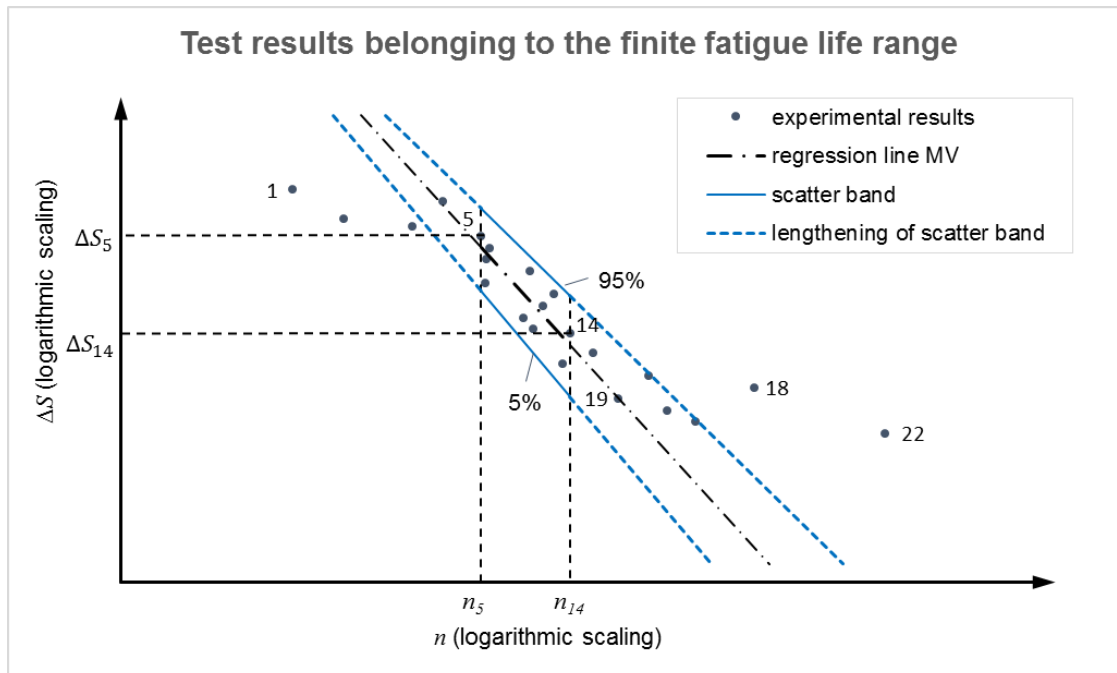


Fig. A2.2: Result after first evaluation including ten test results (example)

- (8) 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.
- (9) 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 Fig. A2.2. 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 A2.3 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.

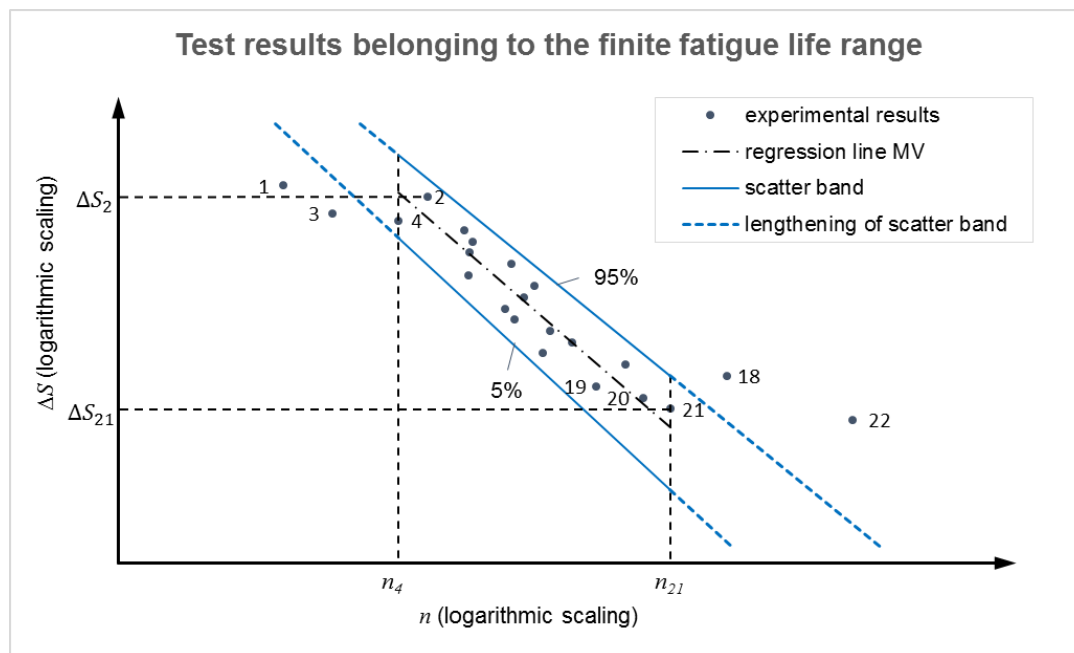


Fig. A2.3: End result with defined specimen belonging to the finite fatigue life area (example)

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

(1) The determination of the characteristic fatigue resistance is carried out on the finite fatigue life area limits, i.e. in the cross sections n_l and n_{ll} (see Fig. A2.4). 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:

$$\Delta \bar{S} = 10^y = 10^{(a+bx)} \tag{A2.16}$$

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

$$\Delta \bar{S}_i = 10^{(a+bx_i)}, i = 1, \dots, r \tag{A2.17}$$

$$\Delta \Delta S_i = \Delta S_i - \Delta \bar{S}_i, i = 1, \dots, r \tag{A2.18}$$

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

$$\hat{\sigma}^2 = \frac{\sum_{i=1}^r (\Delta \Delta S_i)^2}{r - 1} \tag{A2.19}$$

$$\hat{\sigma} = \sqrt{\hat{\sigma}^2} \tag{A2.20}$$

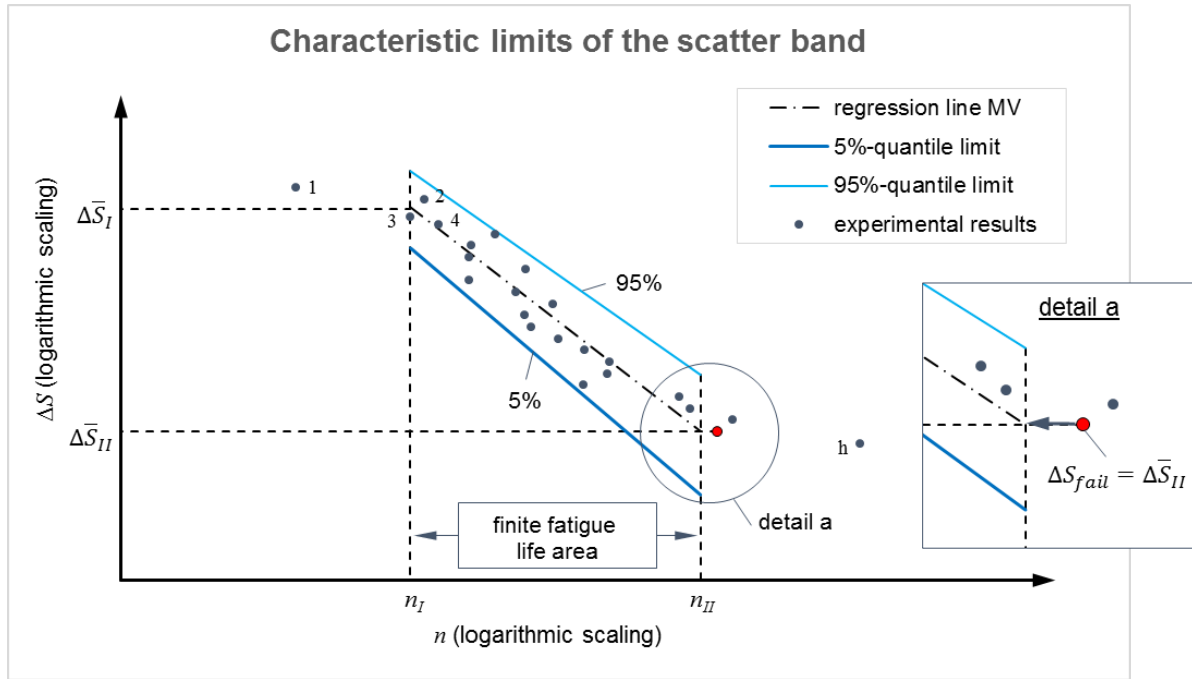


Fig. A2.4: Scatter band including lower 5%- and upper 95%-quantile limit

(2) 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 \hat{v} may be determined by means of the average standard deviation \hat{s} in cross section \hat{x} (centroid):

$$\hat{v} = \hat{s} / \Delta \hat{S} \tag{A2.21}$$

where

$$\Delta \hat{S} = 10^{\hat{v}} \tag{A2.22}$$

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

Section n_I :

$$\Delta \bar{S}_I = 10^{(a+bx_I)} \tag{A2.23}$$

where

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

Section n_{II} :

$$\Delta \bar{S}_{II} = \Delta S_{fail} = 10^{(a+bx_{II})} \tag{A2.24}$$

where

$$x_{II} = (y_{fail} - a) / b \tag{A2.25}$$

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 :

$$\hat{s}_I = v_I \cdot \Delta \bar{S}_I \tag{A2.26}$$

where

$$v_I = \eta_I \cdot \hat{v} \tag{A2.27}$$

$$\text{where } \eta_I = \eta_{I,b} \cdot \eta_{I,\hat{v}} \Leftarrow \eta_{I,b} = 0.05 \cdot b + 0.11 \Leftarrow \eta_{I,\hat{v}} = -14 \cdot \hat{v} + 10 \tag{A2.28}$$

Section n_{II} :

$$\hat{s}_{II} = v_{II} \cdot \Delta \bar{S}_{II} \quad (\text{A2.29})$$

where

$$v_{II} = \eta_{II} \cdot \hat{v} \quad (\text{A2.30})$$

$$\text{where } \eta_{II} = \eta_{II,b} \cdot \eta_{II,v} \Leftarrow \eta_{II,b} = 1.32 \cdot b + 1.66 \Leftarrow \eta_{II,v} = 0.22 + 1.18 \cdot 0.26^{(3.6 \cdot \hat{v})^{1.3}} \quad (\text{A2.31})$$

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:

$$\Delta S_{I,k} = \Delta S_{I,5\%} = \Delta \bar{S}_I - k_{r,p,1-\alpha} \cdot \hat{s}_I \quad (\text{A2.32})$$

$$\Delta S_{II,k} = \Delta S_{II,5\%} = \Delta \bar{S}_{II} - k_{r,p,1-\alpha} \cdot \hat{s}_{II} \quad (\text{A2.33})$$

Parameters of 5%-quantile limit:

$$a_k = y_{I,k} - b_k \cdot x_I \quad (\text{A2.34})$$

where

$$b_k = (y_{I,k} - y_{II,k}) / (x_I - x_{II}) \quad (\text{A2.35})$$

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

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

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

$$\Delta S_{I,95\%} = \Delta \bar{S}_I + k_{r,p,1-\alpha} \cdot \hat{s}_I \quad (\text{A2.36})$$

$$\Delta S_{II,95\%} = \Delta \bar{S}_{II} + k_{r,p,1-\alpha} \cdot \hat{s}_{II} \quad (\text{A2.37})$$

Parameters of 95%-quantile limit:

$$a_{95\%} = y_{I,95\%} - b_{95\%} \cdot x_I \quad (\text{A2.38})$$

where

$$b_{95\%} = (y_{I,95\%} - y_{II,95\%}) / (x_I - x_{II}) \quad (\text{A2.39})$$

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

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

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

- (1) 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 Fig. A2.5). If the calculated value is outside the interval $5 \cdot 10^6 \leq n_{lim,a} \leq 8 \cdot 10^6$ (carbon steel) respectively $7 \cdot 10^6 \leq n_{lim,a} \leq 10^7$ (stainless steel) the limit number of cycles is allocated to the lower or upper limit of the respective interval.

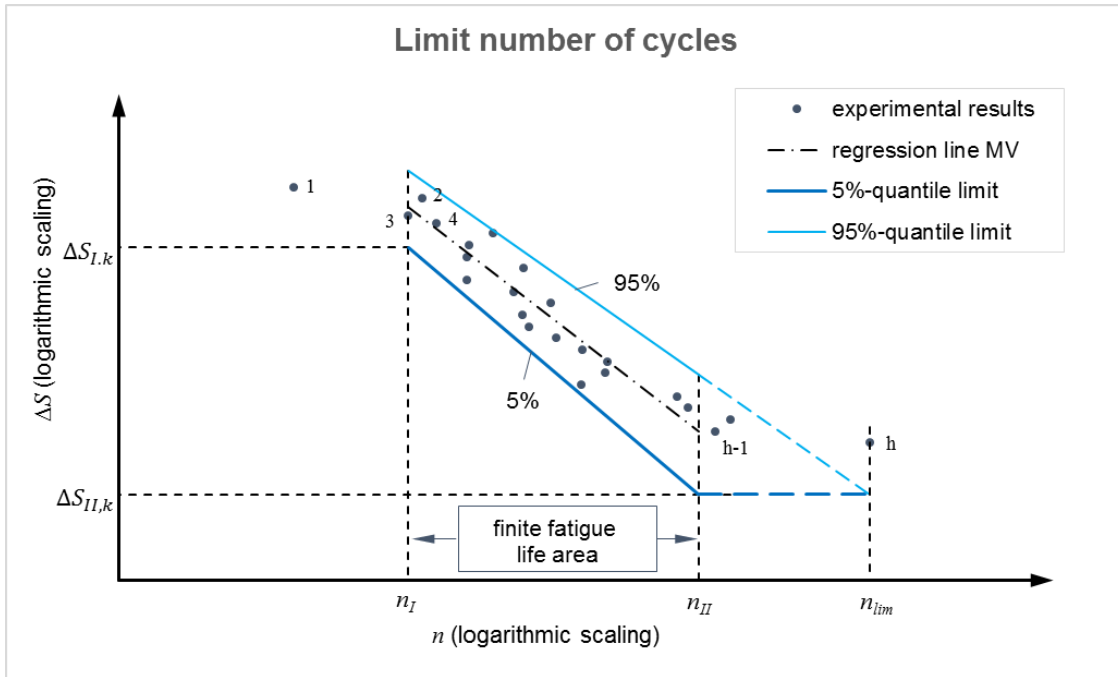


Fig. A2.5: Determination of the limit number of cycles n_{lim}

- (2) The verification 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 verification 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 Fig. A2.6). 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 (see Section 2.6(1)) 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 (see Section 2.6(3)).

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

Centroid of test result scatter for one area:

$$\hat{s}_o = \frac{1}{m} \sum_{i=1}^m s_{o,i} \quad (A2.40)$$

$$\hat{n} = \frac{1}{m} \sum_{i=1}^m n_i \quad (A2.41)$$

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:

$$s_o = a_s + b_s n \quad (A2.42)$$

where

$$a_s = \dot{s}_o - b_s \dot{n} \quad (A2.43)$$

$$b_s = \frac{\sum_{i=1}^m (n_i - \dot{n})(s_{o,i} - \dot{s}_o)}{\sum_{i=1}^m (n_i - \dot{n})^2} \quad (A2.44)$$

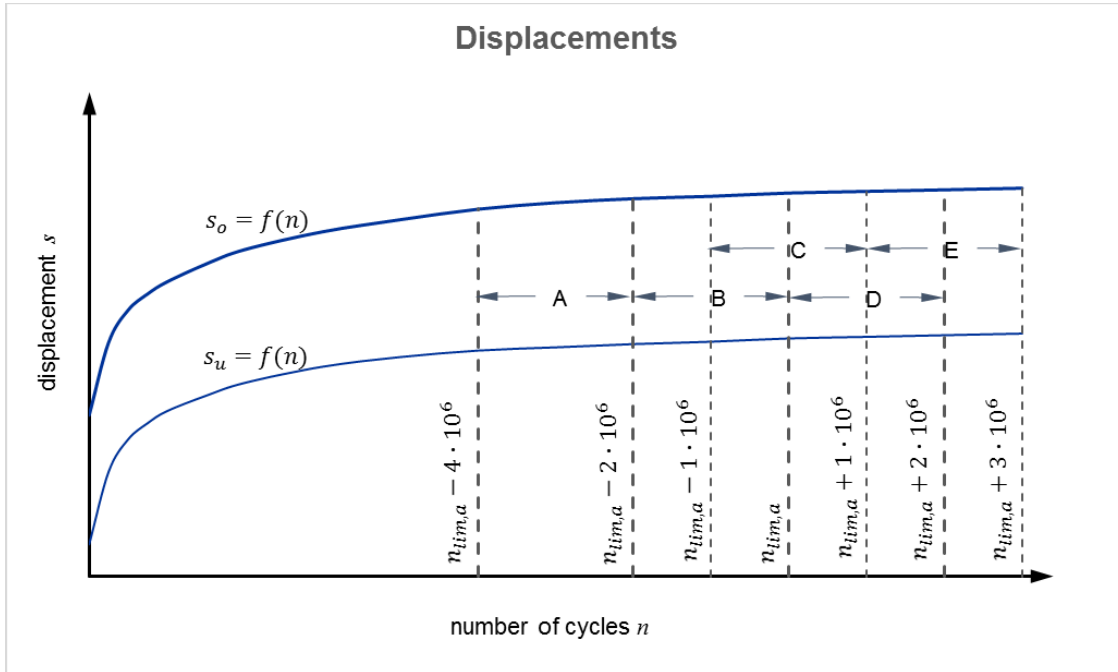


Fig. A2.6: Stabilization of deformations of a run-out

- (3) 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 Fig. A2.7) and is calculated as follows:

$$\Delta S_{RT} \approx \Delta \bar{S}_I - (\Delta \bar{S}_I - \Delta \bar{S}_{II}) / 3 \quad (A2.45)$$

- (4) If the pre-test results show a crossing point between testing in Position 1 and Position 2 (see Fig. 2.5) 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 Fig. A1.4. Once the scatter band is transferred, then the same conditions as per Section 2.6 (3) shall be applied for the run-out test verification.

2.7 Determination of the characteristic fatigue limit resistance

- (1) The determination of the characteristic fatigue limit resistance $\Delta S_{D,k}$ starts with the first run-out ΔS_h (see Fig. A2.7 – 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.

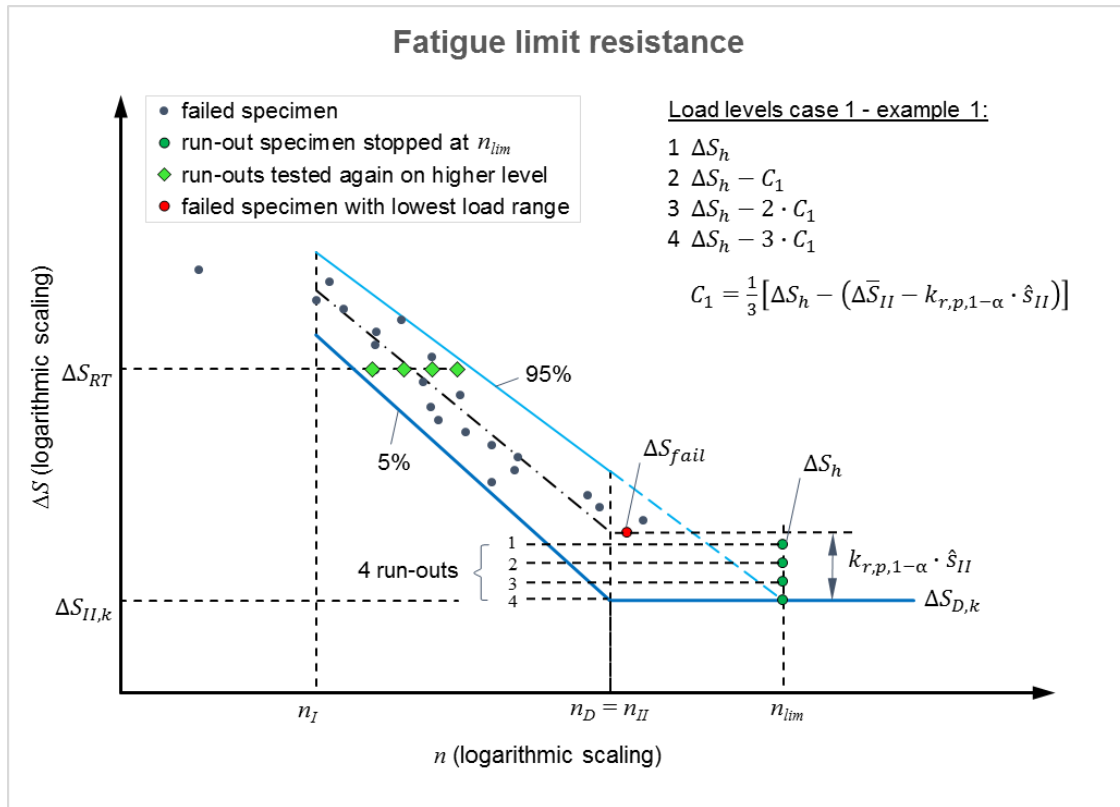


Fig. A2.7: Determination of the characteristic fatigue limit resistance (case 1: example 1)

- (2) In case two a specimen below the first run-out ΔS_h has failed ($\cong \Delta S_{fail}$ case 2 - example 1) or do not passes the run-out test. The parameters of cross section n_{II} (see Section 2.5) and the limit number of cycles (see Section 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 Fig. A2.8). 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.

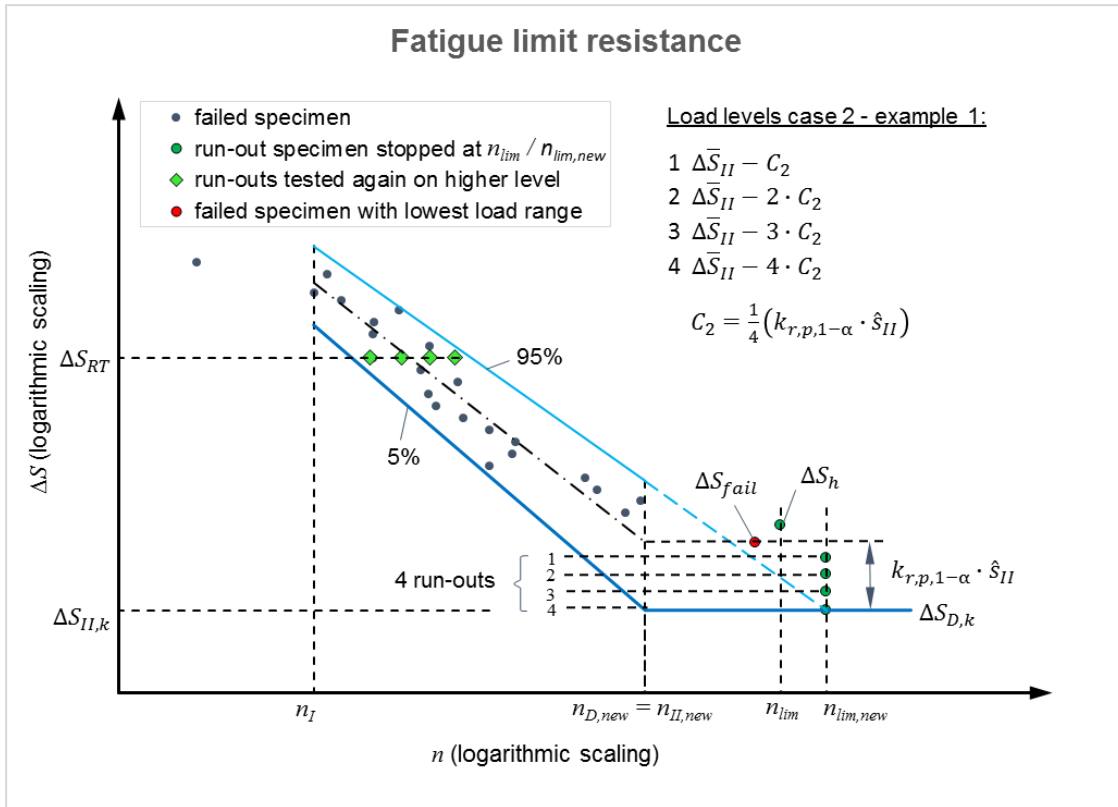


Fig. A2.8: Determination of the characteristic fatigue limit resistance (case 2: example 1)

(3) In example two of case two a specimen below the first run-out ΔS_h has failed ($\cong \Delta S_{fail}$ case 2 example 2) and falls into the finite fatigue life area (see Fig. A2.9). The parameters of finite fatigue life area (see Section 2.4 and 2.5) and the limit number of cycles (see Section 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.

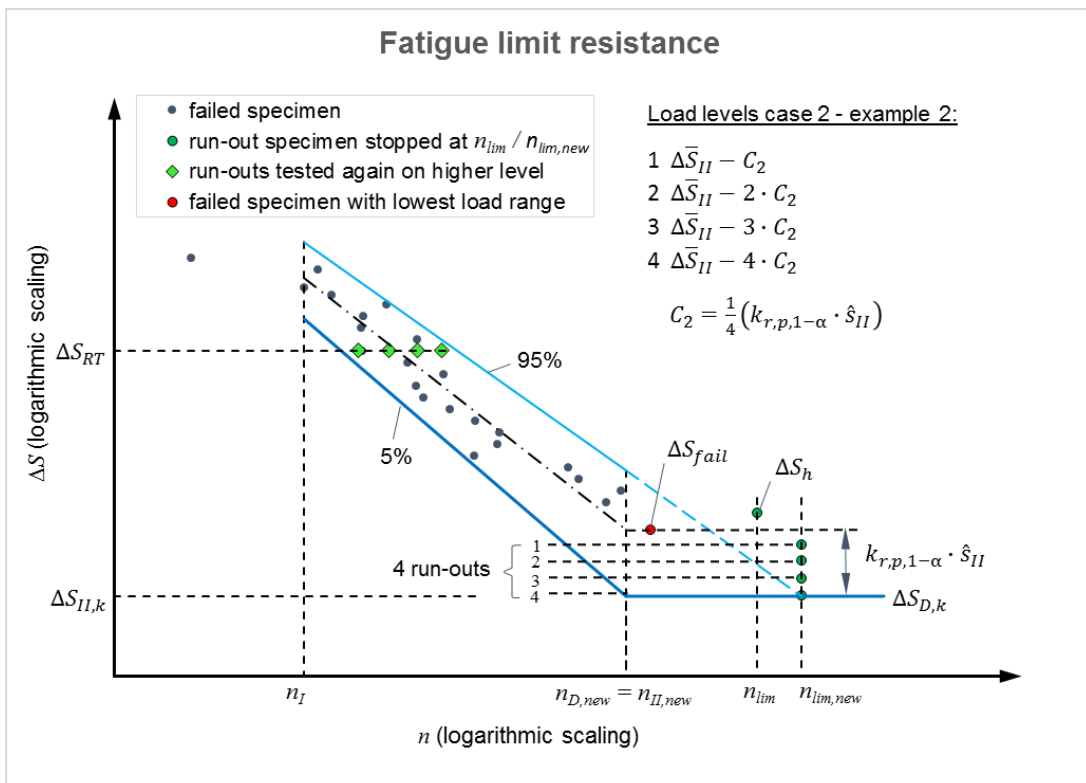


Fig. A2.9: Determination of the characteristic fatigue limit resistance (case 2: example 2)

2.8 Reduction of the finite fatigue life resistance

- (1) 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:

$$\Delta S_{I,k,red} = 10^{y_{I,k,red}} \quad (A2.46)$$

where

$$y_{I,k,red} = \eta_{I,red} \cdot y_{I,k} \quad (A2.47)$$

$$\text{where } \eta_{I,red} = 1 - 0,03 \cdot \Delta \dot{S} / \Delta \bar{S}_I \quad (A2.48)$$

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

- (2) This leads to the following parameters of the characteristic limit in the finite fatigue life area:

$$a_{k,red} = y_{I,k,red} - b_k \cdot x_I \quad (A2.49)$$

- (3) The number of cycles $n_{D,red}$, i.e. the transition from finite fatigue life to fatigue limit resistance is calculated as follows:

$$n_{D,red} = 10^{x_{D,red}} \quad (A2.50)$$

where

$$x_{D,red} = \frac{y_D - a_{k,red}}{b_k} \quad (A2.51)$$

$$\text{where } y_D = \lg \Delta S_{D,k}$$

- (4) The characteristic limit in the finite fatigue life area is shifted by the amount of reduction in parallel downwards (see Fig. A2.10).

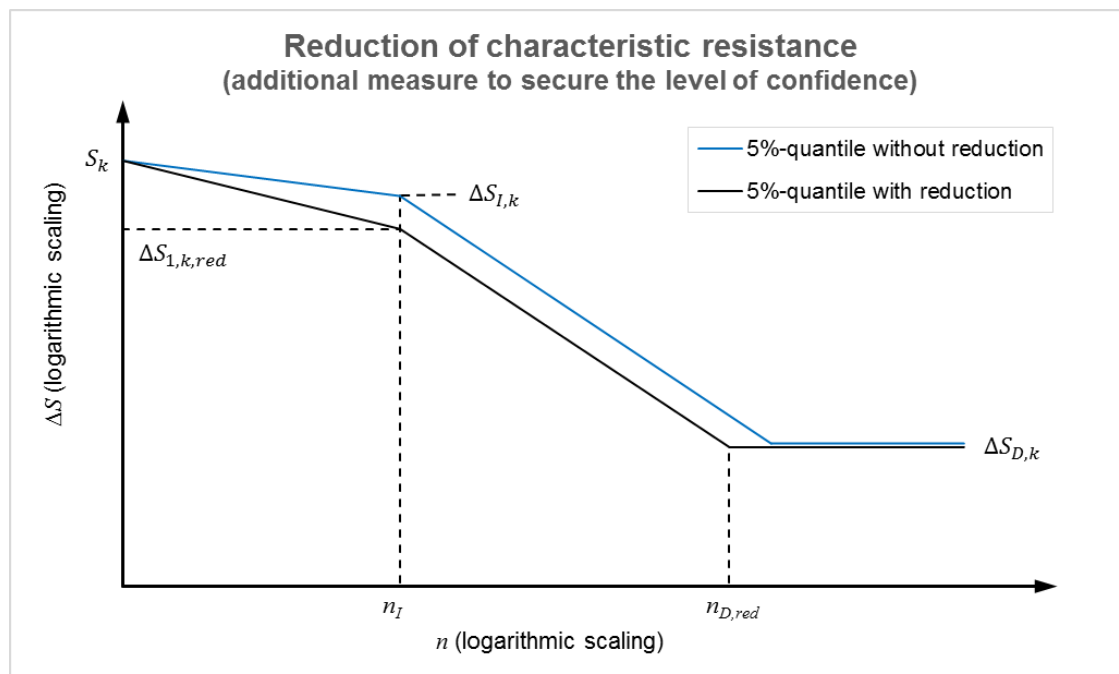


Fig. A2.10: Reduction of characteristic fatigue resistance

2.9 Course of the functions of characteristic fatigue resistance and derivation of the design value of fatigue resistance

- (1) The fatigue resistance is presented as a trilinear function when using logarithmic scaling of abscissa and ordinate (see Fig. A2.11). Here, the fatigue resistance in the low cycle area should

take a maximum horizontal course. The design values are calculated by reducing the characteristic values using the material safety factors γ_M , $\gamma_{M,fat,n}$ and $\gamma_{M,fat}$ in accordance with Technical Report "Calculation Method for the Performance of Anchor Channels under fatigue loads" [28]:

$$S_d = S_k / \gamma_M \quad (A2.52)$$

$$\Delta S_{I,d} = \Delta S_{I,k,red} / \gamma_{M,fat,n} \quad (A2.53)$$

$$\Delta S_{D,d} = \Delta S_{D,k} / \gamma_{M,fat} \quad (A2.54)$$

The reduction of the characteristic values in the transition area from the static resistance to the fatigue limit resistance is carried out using the following reduction factor:

$$\gamma_{M,fat,n} = \gamma_{M,fat} + (\gamma_M - \gamma_{M,fat}) \cdot (\Delta S_{k,n} - \Delta S_{D,k}) / (S_k - \Delta S_{D,k}) \quad (A2.55)$$

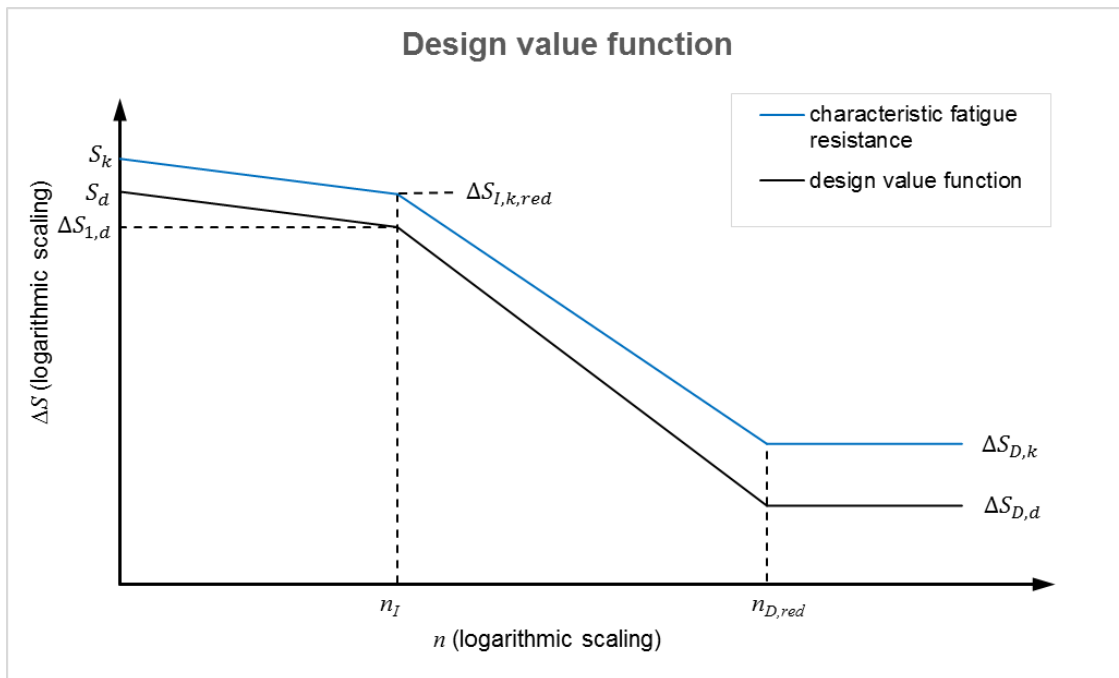


Fig. A2.11: Deriving the design values of the characteristic function

2.10 System of assessment and verification of constancy of performance

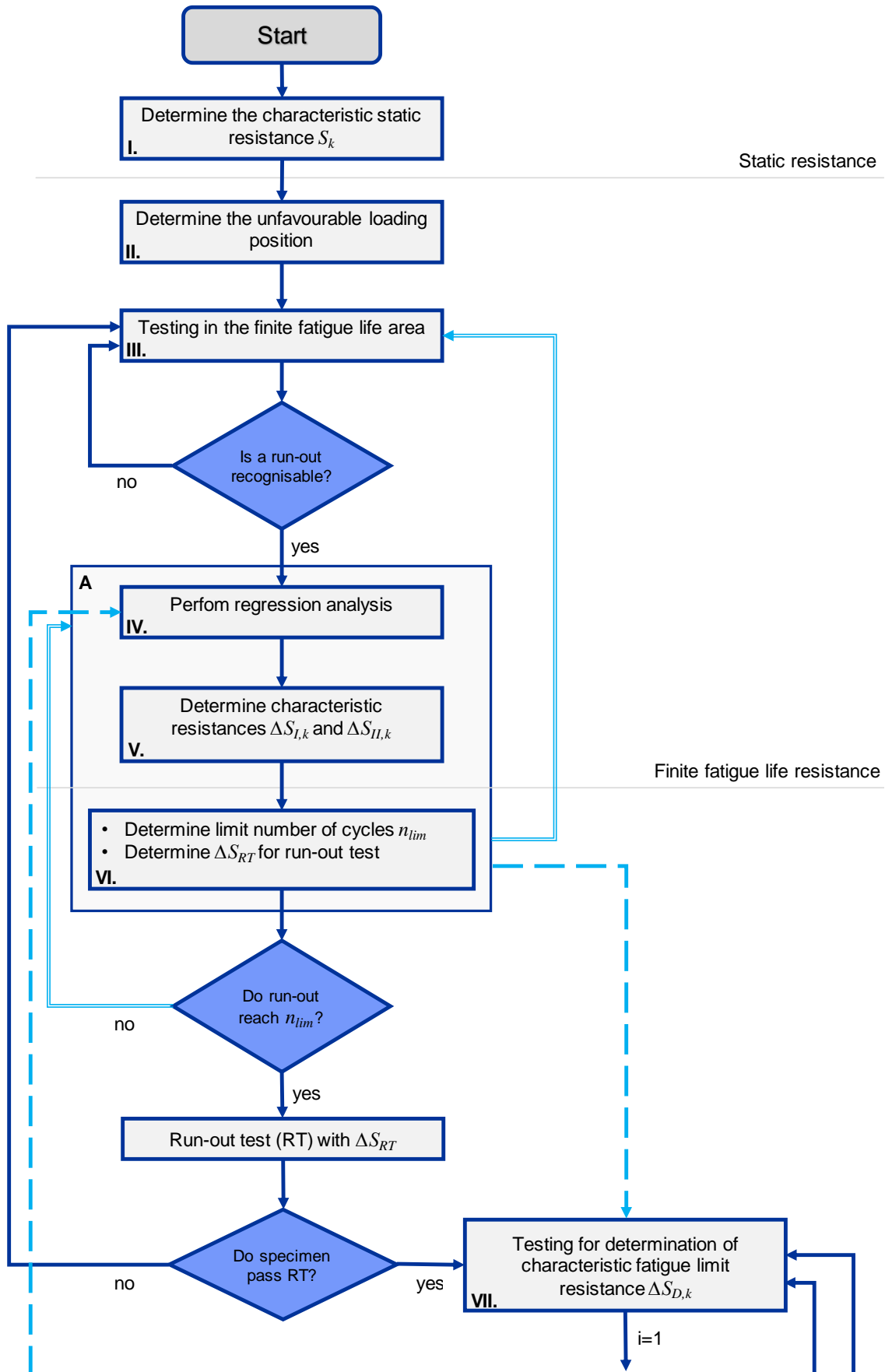
- (1) Three tests under different fatigue cyclic loading shall be done to meet quality requirements of the characteristic fatigue resistance. The load levels are determined as follows:

$$\text{Attempt a:} \quad \Delta S_a = S_k - \frac{1}{3}(S_k - \Delta S_{D,k}) \quad (A2.56)$$

$$\text{Attempt b:} \quad \Delta S_b = S_k - \frac{2}{3}(S_k - \Delta S_{D,k}) \quad (A2.57)$$

$$\text{Attempt c:} \quad \Delta S_c = \Delta S_{D,k} \quad (A2.58)$$

Quality requirements are fulfilled if the number of cycles of the first two specimen exceed 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 first attempt level.



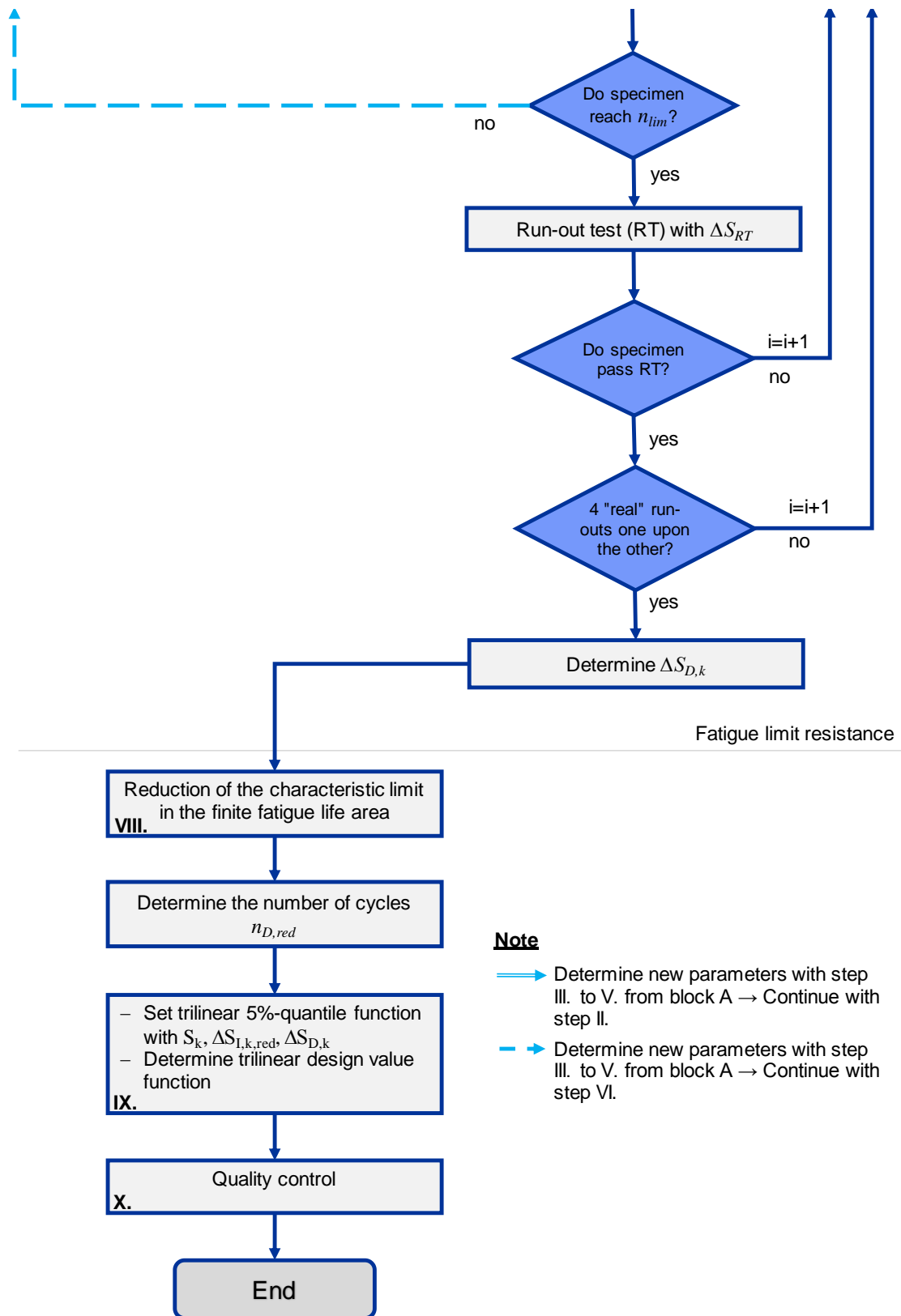


Fig. A2.12: Flow chart for trilinear method

Annex B Method to determine the characteristic fatigue limit resistance

1 Basics

- (1) The force-controlled periodic loading with sinusoidal course should be used for the most disadvantageous case (practical application) of the test specimen.
- (2) 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.
- (3) Test specimen reaching the limit number of cycles without failure, are to be tested again at a higher stress level (verification of non-damaged specimen). This run-out test is applied to identify a potential damage of the test specimen despite reaching the limit number of cycles.
- (4) This method provides the characteristic fatigue limit resistance for infinite number of cycles ($n \Rightarrow \infty$).
- (5) The used capital letter *S* in this Annex shall be replaced by the letter *N* for tension loads.

2 Procedure steps

2.1 Planning of the fatigue cyclic load levels

- (1) The expected fatigue limit resistance ΔS_D is to be estimated by existing experiences. The estimated value ΔS_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 \bar{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.

$$\text{Hot-rolled:} \quad \Delta S_D^{\approx} \approx (0.10, \dots, 0.30) \cdot \bar{S}$$

$$\text{Cold-formed:} \quad \Delta S_D^{\approx} \approx (0.05, \dots, 0.20) \cdot \bar{S}$$

- (2) The load level for reference attempts corresponds to the load level ΔS_{RT} (see Section 2.2 (3)).

2.2 Determination of the limit number of cycles and load level for run-out test

- (1) 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).
- (2) 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 verification 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 Fig. B.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 (see Section 2.2(1)) 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 (see Section 2.2(3)).

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

Centroid of test result scatter for one area:

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

$$\dot{n} = \frac{1}{m} \sum_{i=1}^m n_i \quad (\text{B.2})$$

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:

$$s_o = a_s + b_s n \quad (\text{B.3})$$

where

$$a_s = \dot{s}_o - b_s \dot{n} \quad (B.4)$$

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

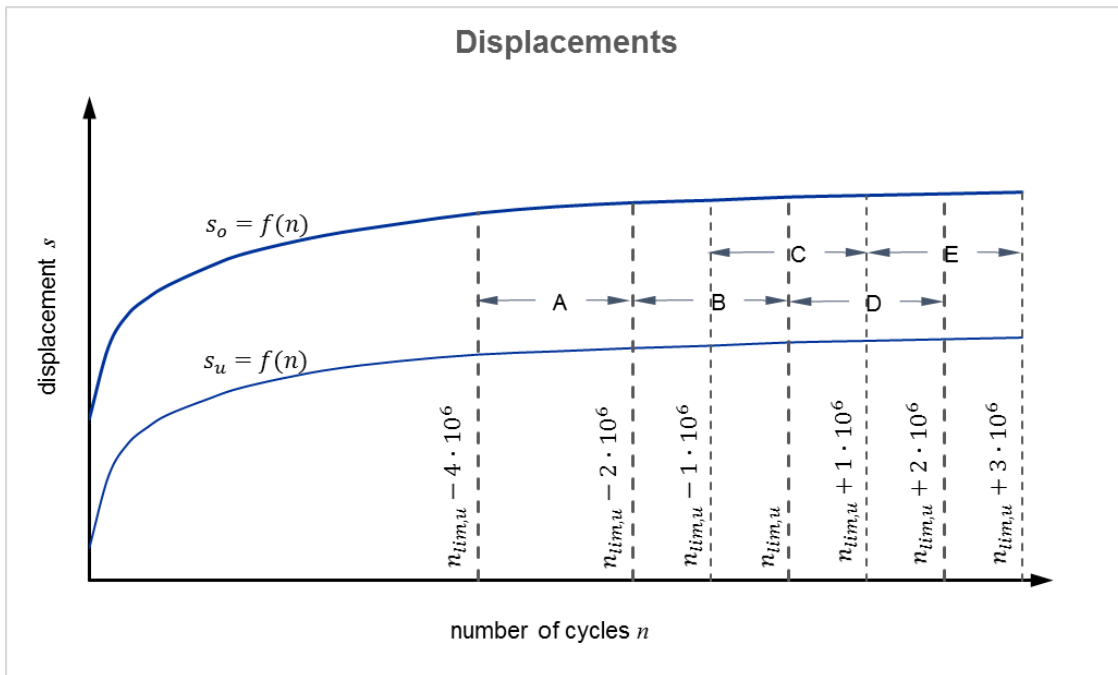


Fig. B.1: Stabilization of deformations of a run-out

- (3) 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 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 Fig. B.2) and is calculated as follows:

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

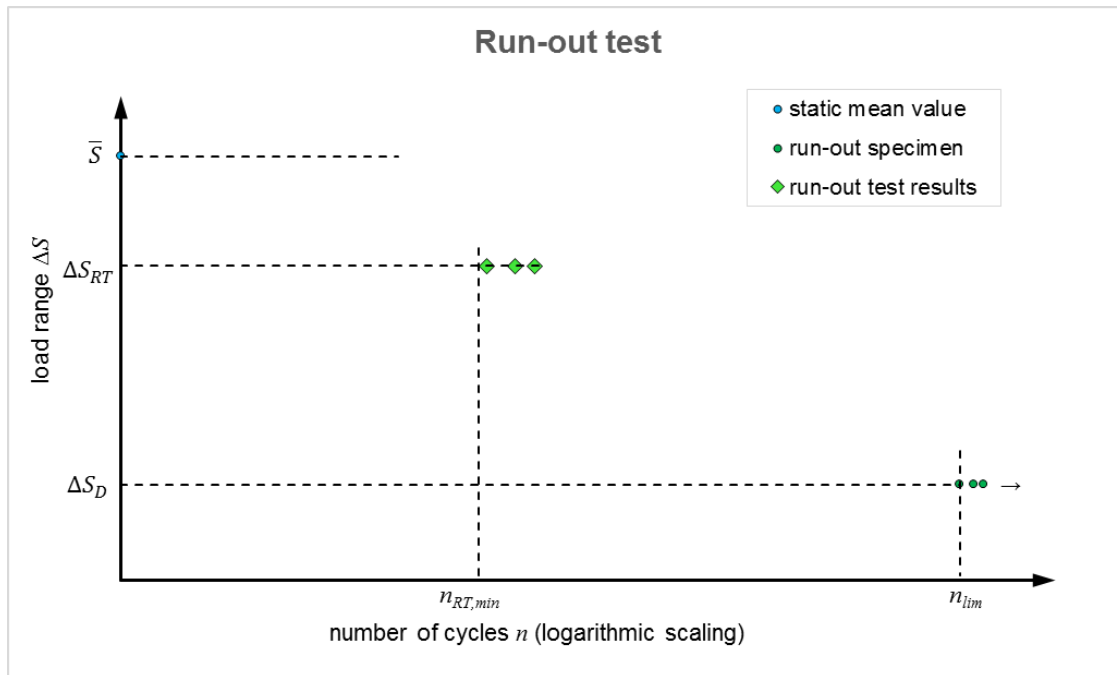


Fig. B.2: Load level for run-out test

2.3 Reference attempts for determination of the minimum number of cycles for run-out test

- (1) 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:

$$n_{RT,min} = \bar{n}_r - 2 \cdot \hat{s}_r \quad (B.7)$$

where

$$\bar{n}_r = 10^{((\lg n_1 + \lg n_2 + \lg n_3)/3)} \quad (B.8)$$

$$\hat{s}_r = \sqrt{\frac{\sum_{i=1}^3 (\bar{n}_r - \lg n_i)^2}{2}} \quad (B.9)$$

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

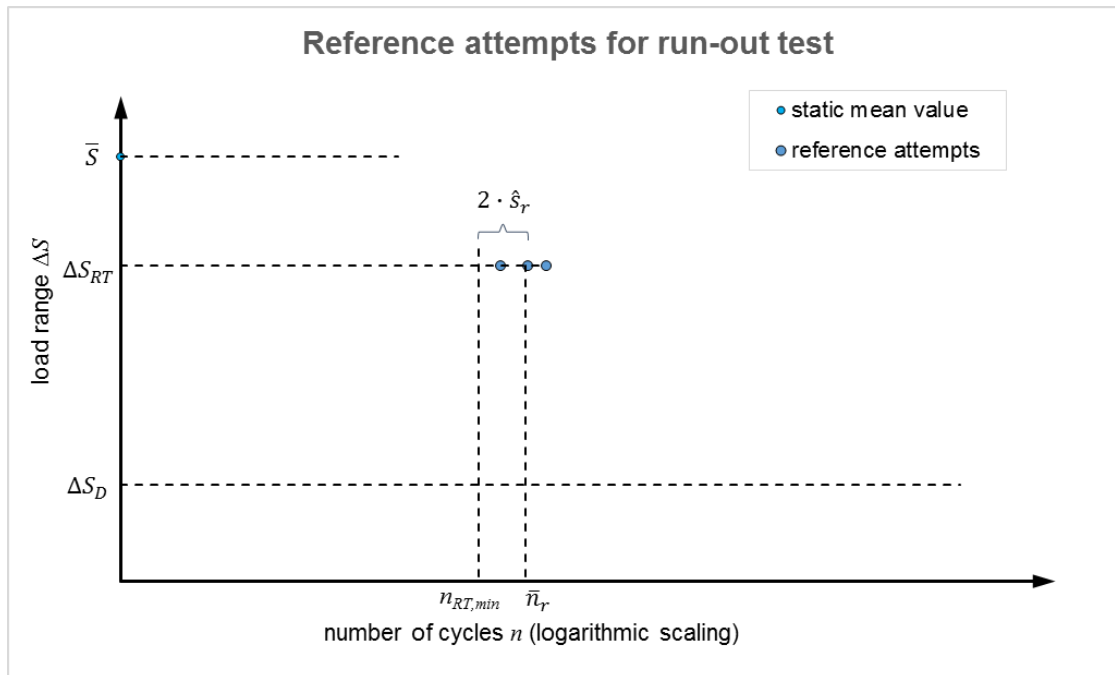


Fig. B.3: Minimum number of cycles for run-out test

2.4 Determination of the characteristic fatigue limit resistance

- (1) 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:

$$\Delta S_{D,k} = 0.6 \cdot \Delta S_D \quad (\text{B.10})$$

2.5 Determination of the design value of the characteristic fatigue limit resistance

- (1) The design value is calculated by reducing the characteristic value using material safety factor $\gamma_{M,fat}$ in accordance with Technical Report "Calculation Method for the Performance of Anchor Channels under fatigue loads" [28]:

$$\Delta S_{D,d} = \Delta S_{D,k} / \gamma_{M,fat} \quad (\text{B.11})$$

2.6 System of assessment and verification of constancy of performance

- (1) Three tests on load level ΔS_D shall be done to meet quality requirements of the characteristic fatigue limit resistance.

Quality requirements are fulfilled if the number of cycles of tested specimen reach the limit number of cycles n_{lim} and pass the run-out test on the load level ΔS_{RT} .