EOTA®

TECHNICAL REPORT

Calculation Method for the Performance of Anchor Channels under Fatigue Cyclic Loading

TR 050

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EUROPEAN ORGANISATION FOR TECHNICAL ASSESSMENT

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Contents

1 SCOPE OF THE TECHNICAL REPORT

1.1 General

This Technical Report contains a design method for anchor channels under fatigue cyclic tension loading which have been awarded an ETA in accordance with EAD 330008 Anchor channels [3] and [8].

Note: This Technical Report is intended to provide a design method for anchor channels under fatigue cyclic tension loading and shall be used in conjunction with the static provisions of EN 1992-4 [2] and EOTA Technical Report 047 [4].

This document has been written to represent current best practice. However, users should verify that applying its provisions allows local regulatory requirements to be satisfied.

This Technical Report provides a design method for anchor channels under tension fatigue cyclic loading in combination with or without static or quasi-static loads in concrete members (connection between structural elements and attachment of non-structural elements to structural components). The anchor channel is used to transmit only tension loads into the concrete. No static or quasi-static shear or fatigue cyclic shear load may be applied in concomitance with a fatigue cyclic tension load.

This Technical Report provides a design method for anchor channels installed in members made of compacted normal weight concrete of strength classes in the range C20/25 to C90/105 all in accordance with EN 206-1 [5]. The anchor channel is intended to be used in cracked and non-cracked concrete.

This Technical Report is intended for safety related applications in which the failure of anchor channels may result in collapse or partial collapse of the structure, cause risk to human life or lead to significant economic loss. In this context it also covers non-structural elements.

The design rules in this Technical Report are only valid for anchor channels with a European Technical Assessment (ETA) with characteristic resistance under fatigue cyclic loading on basis of EAD 330008 [3] and [8].

The transfer of the loads applied to the anchor channel to the supports of the concrete member shall be shown according to EN 1992-1-1 [1].

This Technical Report does not cover the design of the fixture. The design of the fixture shall be carried out to comply with the appropriate Standards and fulfil the requirements on the fixture as given in this Technical Report.

This document relies on characteristic resistances and distances which are stated in an ETA and referred to in this Technical Report.

1.2 Type, dimensions and materials of anchor channels

This Technical Report applies to anchor channels with rigid connection (e.g. welded, forged, bolted) between anchor and channel. The anchor channels shall have an established suitability for the specified application in concrete, which is stated in the relevant ETA.

The effective embedment depth shall be $h_{ef} \geq 40$ mm.

This Technical Report covers anchor channels made of either carbon steel or stainless steel. The surface of the steel may be coated or uncoated. This Technical Report is valid for anchor channels with a nominal steel tensile strength $f_{uk} \leq 1000$ N/mm^2.

1.3 Anchor channel loading

In general, fatigue verification is required when more than or equal to 1000 load cycles are expected for pulsation tension loads on the anchor channel.

In general all types of actions occurring during the period of intended use of an anchor channel shall be taken into account for the design. Typically harmonic and/or periodic actions including different (peak-to-peak) amplitudes are considered in the context of fatigue cyclic loading. Harmonic and periodic actions can consist of:

- Oscillations touching zero,
- Oscillations with the same algebraic sign.

Cyclic loads may consist of a single constant or different amplitudes. When different amplitudes need to be taken into account, the sequence of loading may be converted into a collective action of one load level with an equivalent grade of damage by using the Miner's Rule [6]. An example of such a resulting collective action or a single constant amplitude load cycle is given in Figure 1.3.

For the overall fatigue design process, the knowledge of the relevant part of the characteristic S-N-curve is required and the design methods I and/or II as shown in Section 3 of this document can be used.

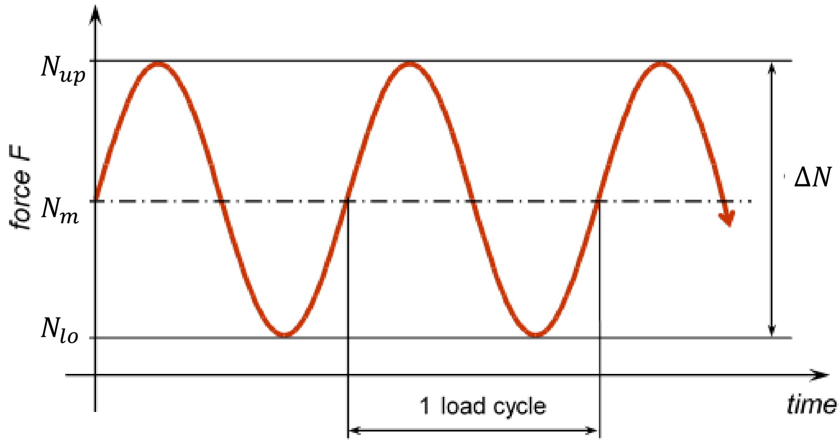


Figure 1.3 Definition of force of load cycle (N_{up} = maximum (upper) cyclic load; N_{lo} = minimum (lower) cyclic load, N_m = mean load, ΔN = cyclic (peak-to-peak range) load)

The assignment between design method and test method is shown in Table 1.1. The test method is stated in the European Technical Assessment (ETA).

Table 1.1: Test methods and related design methods for fatigue cyclic loading

		Test Method			
		A1 Continuous function of fatigue resistance depending on number of load cycles	A2 Tri-linear function of fatigue resistance depending on number of load cycles	B Fatigue limit resistance	C Bi-linear function of fatigue resistance depending on number of load cycles
Design Method	Method I	X	X	not applicable	X
	Method II	X	X	X	X

1.4 Specific terms used in this TR

Indices

E	static action / quasi-static action
N	normal force
R	resistance
M	material
n	number of load cycles or oscillations
k	characteristic value
d	design values
s	steel
c	concrete cone
p	concrete pull-out
up	upper
lo	lower

Actions

N_{Ed}	design static or quasi-static load
N_{Elok}	characteristic lower cyclic load
N_{Elod}	design lower cyclic load
ΔN_{Ek}	characteristic fatigue cyclic load
ΔN_{Ed}	design fatigue cyclic load
N_{Eupd}	= $N_{Elod} + \Delta N_{Ed}$, design upper cyclic load
ΔN_{Ed}^{a}	design fatigue cyclic load acting on the anchor
ΔN_{Ed}^{loc}	design fatigue cyclic load acting at the local point, where the load is introduced

Resistances

N_{Rk}	characteristic static resistance
N_{Rd}	design static resistance
ΔN_{Rk}	characteristic fatigue resistance
ΔN_{Rd}	design fatigue resistance
$N_{lok,s,n}$	Characteristic lower cyclic load relevant for steel resistance with n load cycles taken from the ETA
$N_{lod,s,n}$	Design lower cyclic load relevant for steel resistance with n load cycles
$\Delta N_{Rk,0,n}$	Characteristic fatigue resistance with origin load ($N_{Elod} = 0$) and n load cycles taken from the ETA
$\Delta N_{Rk,lo,n}$	Characteristic fatigue resistance with lower cyclic load $N_{lok,n}$ and n load cycles taken from the ETA
$\Delta N_{Rk,s,0,n}$	Characteristic steel tensile fatigue resistance with origin load ($N_{Elod} = 0$) and n load cycles taken from the ETA
$\Delta N_{Rk,s,lo,n}$	Characteristic steel tensile fatigue resistance with lower cyclic load $N_{lok,s,n}$ and n load cycles taken from the ETA
$\Delta N_{Rk,p,0,n}$	Characteristic concrete pull-out fatigue resistance with origin load ($N_{Elod} = 0$) and n load cycles taken from the ETA
$\Delta N_{Rk,p,E,n}$	Characteristic concrete pull-out fatigue resistance with ($N_{Elod} \geq 0$) and n load cycles taken from the ETA
$\Delta N_{Rk,c,0,n}$	Characteristic concrete cone fatigue resistance with origin load ($N_{Elod} = 0$) and n load cycles taken from the ETA
$\Delta N_{Rk,c,E,n}$	Characteristic concrete cone fatigue resistance with ($N_{Elod} \geq 0$) and n load cycles taken from the ETA
$\Delta N_{Rk,0,\infty}$	Characteristic fatigue limit resistance with origin load ($N_{Elod} = 0$) taken from the ETA
$\Delta N_{Rk,s,0,\infty}$	Characteristic steel tensile fatigue limit resistance with origin load ($N_{Elod} = 0$) taken from the ETA
$\Delta N_{Rk,p,0,\infty}$	Characteristic concrete pull-out fatigue limit resistance with origin load ($N_{Elod} = 0$) taken from the ETA
$\Delta N_{Rk,c,0,\infty}$	Characteristic concrete cone fatigue limit resistance with origin load ($N_{Elod} = 0$) taken from the ETA
$\Delta N_{Rd,0,n}$	Design steel tensile fatigue resistance with origin load ($N_{Elod} = 0$) and n load cycles
$\Delta N_{Rd,lo,n}$	Design steel tensile fatigue resistance with lower cyclic load $N_{lod,n}$ and n load cycles

$\Delta N_{Rd,s,0,n}$	Design steel tensile fatigue resistance with origin load ($N_{Elod} = 0$) and n load cycles
$\Delta N_{Rd,s,lo,n}$	Design steel tensile fatigue resistance with lower cyclic load $N_{lod,s,n}$ and n load cycles
$\Delta N_{Rd,p,0,n}$	Design concrete pull-out fatigue resistance with origin load ($N_{Elod} = 0$) and n load cycles
$\Delta N_{Rd,c,0,n}$	Design concrete cone fatigue resistance with origin load ($N_{Elod} = 0$) and n load cycles
$\Delta N_{Rd,0,\infty}$	Design limit resistance with origin load ($N_{Elod} = 0$)
$\Delta N_{Rd,s,0,\infty}$	Design steel tensile fatigue limit resistance with origin load ($N_{Elod} = 0$)
$\Delta N_{Rd,p,0,\infty}$	Design concrete pull-out fatigue limit resistance with origin load ($N_{Elod} = 0$)
$\Delta N_{Rd,c,0,\infty}$	Design concrete cone fatigue limit resistance with origin load ($N_{Elod} = 0$)
$\Delta N_{Rd,E,n}$	Design fatigue resistance with N_{Elod} and n load cycles
$\Delta N_{Rd,s,E,n}$	Design tensile steel fatigue resistance with N_{Elod} and n load cycles
$\Delta N_{Rd,p,E,n}$	Design concrete pull-out fatigue resistance with N_{Elod} and n load cycles
$\Delta N_{Rd,c,E,n}$	Design concrete cone fatigue resistance with N_{Elod} and n load cycles
$\Delta N_{Rd,E,\infty}$	Design fatigue limit resistance with N_{Elod}
$\Delta N_{Rd,s,E,\infty}$	Design steel tensile fatigue limit resistance with N_{Elod}
$\Delta N_{Rd,p,E,\infty}$	Design concrete pull-out fatigue limit resistance with N_{Elod}
$\Delta N_{Rd,c,E,\infty}$	Design concrete cone fatigue limit resistance with N_{Elod}

2 COMBINATION OF STATIC AND CYCLIC LOADS AND INFLUENCE RANGES

This Technical Report covers only combinations of static and cyclic tension loads perpendicular to the concrete surface. Load combinations including static and cyclic shear loads acting alone or in combination with any type of tension load are not covered in this Technical Report.

In the design for fatigue loading the distribution of cyclic as well as static loads on the anchors shall be done by considering the anchor channel as a chain of simply supported single span beams between the anchors.

Note: The approach to use a chain of single span beams is due to the fact that the method according to EN 1992-4 [2] is only valid for static loads considering redistribution of loads close to failure. Those loads redistribution is not to be expected under cyclic actions relevant to fatigue, where elastic behaviour shall be assumed.

In case of multiple loads acting simultaneously on the anchor channel, a linear superposition of the anchor forces shall be assumed separately for all static loads and for all fatigue loads.

If the exact position of the load is not known, the most unfavourable loading position shall be assumed for each failure mode.

3 FATIGUE DESIGN OF ANCHOR CHANNELS

3.1 Design concept

For the design of anchor channels under fatigue cyclic action the concept of partial factors shall be applied. It shall be shown that the design actions, ΔN_{Ed}, do not exceed the design resistance, ΔN_{Rd}:

$$\Delta N_{Ed} \leq \Delta N_{Rd} \quad (3.1)$$

where: ΔN_{Ed} design action

ΔN_{Rd} design resistance

The general form of the ultimate limit state verification with fatigue influence is as follows:

$$(\Delta N_{Ed} / \Delta N_{Rd}) \leq 1{,}0 \quad (3.2)$$

Each failure mode shall be verified separately.

The design of anchor channels with fatigue influence shall be conducted in accordance with the concept provided in Table 3.1 (test method A1, A2 and B) and Table 3.2 (test method C), respectively. The equations in Section 3.2.3 – design method I - and Section 3.3.2 – design method II – shall be used.

3.1.1 Actions

For the determination of the design actions, the following procedure shall be applied.

The design fatigue cyclic load shall be calculated as follows.

$$\Delta N_{Ed} = \gamma_{F,fat} \cdot \Delta N_{Ek} \quad (3.3)$$

where: ΔN_{Ek} characteristic action

$\gamma_{F,fat}$ partial factor for fatigue actions

The following partial factors for fatigue actions are recommended in absence of other national regulations.

$\gamma_{F,fat}$ = 1,0 If there is a collective load with different levels of actions and the maximum value of actions, ΔN_{max}, is assumed for the design.

$\gamma_{F,fat}$ = 1,2 If the effective (actual) collective action is converted by using the Miner's Rule [6] to a collective of one level with an equivalent level of damage or

if the effective (actual) collective action is a collective of one load level.

The design lower cyclic load shall be calculated as follows.

$$N_{Elod} = \gamma_{F,stat} \cdot N_{Elok} \quad (3.4)$$

where: N_{Elok} characteristic lower cyclic load

$\gamma_{F,stat}$ partial factor for static actions

Partial factors for static actions shall be applied in accordance with EN 1990 [7].

3.1.2 Resistances

For the determination of the design resistances, the following procedure shall be applied:

The design fatigue resistance shall be calculated as follows.

$$\Delta N_{Rd} = \Delta N_{Rk} / \gamma_{M,fat} \quad (3.5)$$

where: ΔN_{Rk} characteristic fatigue resistance

$\gamma_{M,fat}$ partial ~~safety~~ factor for material

The following partial ~~safety~~ factors for resistances are recommended for anchor channels under fatigue cyclic loading.

The values of the partial factors for anchor channels under fatigue cyclic loading for use in a Country may be found in its National Annex of EN 1992-4 [2].

For the determination of the design fatigue limit resistance according to test method A1, A2 and B, it is recommended to take the partial factor for material as $\gamma_{M,fat}$ = 1,35 for all modes of failure.

For the transition zone from the static bearing capacity (γ_M) up to the fatigue limit resistance ($\gamma_{M,fat}$), the partial factors are calculated as follows:

$$\gamma_{M,fat,n} = \gamma_{M,fat} + (\gamma_M - \gamma_{M,fat}) \cdot (\Delta N_{Rk,n} - \Delta N_{Rk,\infty}) \; / \; (N_{Rk} - \Delta N_{Rk,\infty}) \qquad (3.6)$$

For the determination of the design fatigue resistance according to test method C, it is recommended to take the constant partial factor for material as $\gamma_{Ms,fat}$ = 1,35 for steel failure and $\gamma_{Mc,fat}$ = $\gamma_{Mp,fat}$ = 1,5 for concrete related failure modes in accordance with the recommended values given in EN 1992-4 [2].

The design lower load of the steel tensile fatigue resistance shall be calculated as follows.

$$N_{lod,s,n} = N_{lok,s,n} \; / \; \gamma_{Ms} \qquad (3.7)$$

where: $N_{lok,s,n}$ characteristic value of lower load

γ_{Ms} partial factor for static resistance

In absence of national regulations, the recommended partial safety factors for static resistances are given in EN 1992-4 [2].

Table 3.1 Concept for design of anchor channels with fatigue influence (Test method A1, A2 and B)

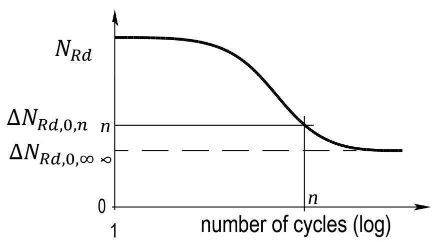
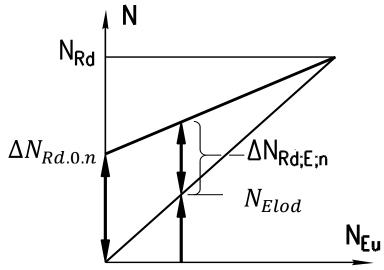
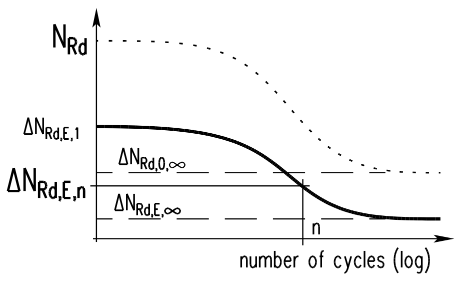
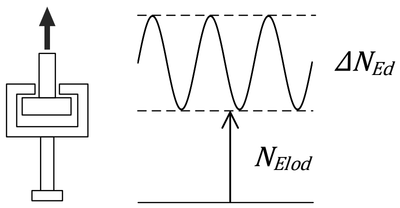
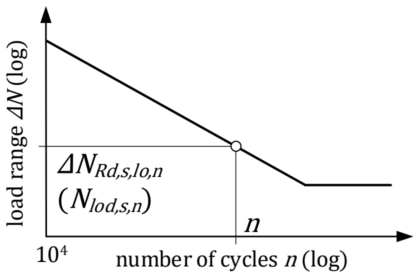
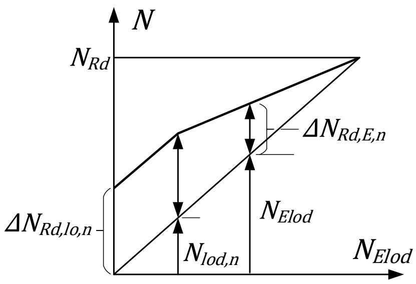
Step		Result	Note
1	S-N-curve for design fatigue resistance with a lower cyclic load $N_{Elod} = 0$ and n load cycles ($\Delta N_{Rd,0,n}$)		S-N-curves can be determined for each failure mode. At a minimum, the value of the fatigue limit resistance, ($\Delta N_{Rd,0,\infty}$), shall be given
2	Goodman Diagram developed for a selected number of load cycles, *n*		The Goodman Diagram allows to establish the fatigue resistance, $\Delta N_{Rd,E,n}$, in relation to the lower cyclic load, N_{Elod}, for a given number of load cycles, n
3	Converted S-N-curves under pulsating load $N_{Elod} > 0$		The conversion of the S-N-curves developed with zero or low minimum (lower) cyclic load (see step 1) into S-N-curves including different ($N_{Elod} >$ 0) lower cyclic loads is achieved by means of the Goodman Diagram (see step 2) for given number(s) of load cycles, n
4	Design verifications: Steel failure Pull-out failure Concrete cone failure	 $\Delta N_{Ed} / \Delta N_{Rd,s,E,n} \leq 1{,}0$ $\Delta N_{Ed} / \Delta N_{Rd,p,E,n} \leq 1{,}0$ $\Delta N_{Ed} / \Delta N_{Rd,c,E,n} \leq 1{,}0$	ΔN_{Ed} – design value of the applied load range

Table 3.2 Concept for design of anchor channels with fatigue influence (Test method C)

Step		**Result**	**Note**
1	Actions		The design actions, ΔN_{Ed} and N_{Elod}, are obtained by the characteristic values of loads acting on the anchor channel multiplied by the factors according to Section 3.1.1.
2	Resistances		The characteristic fatigue resistance, $\Delta N_{Rk,s,lo,n}$, with lower cyclic load, $N_{lok,s,n}$ for steel failure and $\Delta N_{Rk,p,E,n}$ or $\Delta N_{Rk,c,E,n}$ for concrete related failure, for a given number of load cycles, *n*, can be taken from the ETA. The design values, $\Delta N_{Rd,s,lo,n}$ with $N_{lod,s,n}$, $\Delta N_{Rd,p,E,n}$ and $\Delta N_{Rd,c,E,n}$ are calculated by applying the partial factors in accordance with Section 3.1.2.
3	Goodman diagram		Determination of the design resistance $\Delta N_{Rd,s,E,n}$ for steel failure by means of the Goodman diagram (see Figure 3.3) according to Section 3.2.2, Equations 3.10 and 3.11 if necessary.
4	Design verifications: Steel failure Pull-out failure Concrete cone failure	 $\Delta N_{Ed} / \Delta N_{Rd,s,E,n} \leq 1{,}0$ $\Delta N_{Ed} / \Delta N_{Rd,p,E,n} \leq 1{,}0$ $\Delta N_{Ed} / \Delta N_{Rd,c,E,n} \leq 1{,}0$	The verification is performed by comparing the design actions with the design resistances. Each failure mode shall be verified separately as given in Table 3.3.

3.2 Design method I – Complete method

3.2.1 Conditions of applicability

(a) a precise allocation of the design lower cyclic load, N_{Elod}, is possible

and/or

(b) an upper limit of load cycles, n, during working life is known.

Based on (a) and (b), the following values shall be used for design:

Design Case 1: Only condition (a) is met:

$\Delta N_{Rd} = \Delta N_{Rd,E,n} = \Delta N_{Rd,E,\infty}$

The fatigue resistance used in the design verification is determined using the Goodman Diagram assuming an infinite number of cycles, $n = \infty$, and the appropriate value of the lower cyclic load, N_{Elod}, in accordance with Section 3.2.2 Equation (3.9) or Equations (3.10) and (3.11)

and

$\Delta N_{Ed} = N_{Eupd} - N_{Elod}$

Only the design fatigue relevant load is taken into account.

Design Case 2: Only condition (b) is met:

$\Delta N_{Rd} = \Delta N_{Rd,E,n} = \Delta N_{Rd,lo,n} = \Delta N_{Rd,0,n}$

The fatigue resistance used in the design verification is taken from the S-N curve for the given number of load cycles n.

and

$\Delta N_{Ed} = N_{Eupd}$

All acting loads are assumed to be fatigue-relevant.

Design Case 3: Conditions (a) and (b) are both met:

$\Delta N_{Rd} = \Delta N_{Rd,E,n}$

The fatigue resistance used in the design verification is determined using the Goodman Diagram for the given number of load cycles, n, and the appropriate value of the lower cyclic load, N_{Elod}, in accordance with Section 3.2.2 Equation (3.8) or Equations (3.10) and (3.11)

and

$\Delta N_{Ed} = N_{Eupd} - N_{Elod}$

Only the design fatigue relevant load is taken into account.

3.2.2 Calculation of fatigue resistance, $\Delta N_{Rd,E,n}$, in relation to the lower cyclic load, N_{Elod}

The fatigue resistance diagram (also known as S-N curve) is determined experimentally with cyclic load tests where a constant minimum lower load as low as possible is used (i.e., the contribution or influence of the lower cyclic load to the total applied load is minimized). This procedure allows the determination of the characteristic fatigue resistance, $\Delta N_{Rk,0,n}$, for a given number of load cycles, n, and for each failure mode (test method A1, A2 and B).

If the fatigue resistance diagram is determined by tests with a higher level of constant lower load or with constant upper load, the influence of the lower cyclic load to the fatigue resistance is considered. This procedure allows the determination of the characteristic fatigue resistance, $\Delta N_{Rk,s,lo,n}$, with the characteristic lower load, $N_{lok,s,n}$, for steel failure. The characteristic concrete pull-out fatigue resistance $\Delta N_{Rk,p,E,n}$ and the characteristic concrete cone fatigue resistance $\Delta N_{Rk,c,E,n}$ for *n* load cycles are given in the ETA depending on $N_{Elod} \geq 0$.The design resistances $\Delta N_{Rd,p,E,n}$ and $\Delta N_{Rd,c,E,n}$ can therefore be directly calculated by applying the appropriate partial factors for resistance to the characteristic values according to Equation 3.5 (test method C).

In cases where fatigue relevant actions consist of a lower cyclic load $N_{Elod} > 0$ (test method A1, A2 and B) or $N_{Elod} > N_{lod,n}$ (test method C), it is necessary to determine the influence of the lower cyclic load on the fatigue resistance. This is achieved by using the Goodman Diagram, which allows the determination of the fatigue resistance as a function of the magnitude of the applied lower cyclic load. The fundamental principles of the Goodman Diagram are valid for every type of failure mode (test method A1, A2 and B) or for steel failure (test method C).

Note: The definition of the lower cyclic load, N_{Elod}, depends on the following cases (see also Figure 3.1):

a) the static load, N_{Ed}, is amplified by the cyclic load ΔN_{Ed}, meaning that N_{Elod} corresponds to N_{Ed};

b) the static load, N_{Ed}, is superimposed with the cyclic load resulting in N_{Elod} being smaller than N_{Ed};

c) the static load, N_{Ed}, is reduced by the cyclic load, meaning that N_{Elod} corresponds to $N_{Ed} - \Delta N_{Ed}$.

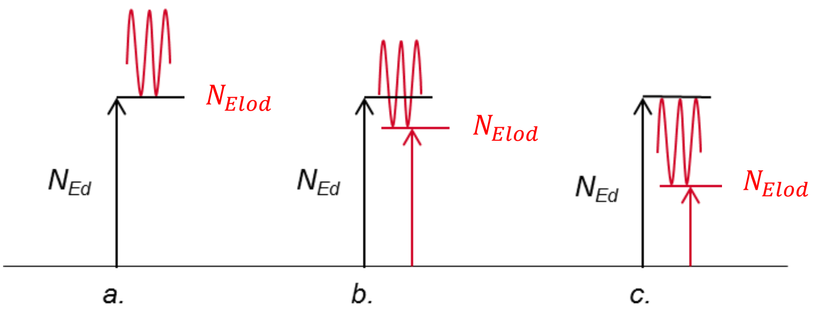


Figure 3.1 Superimposition of static and fatigue cyclic loads

Figure 3.2 shows the Goodman Diagram according to test method A1, A2 and B for a selected number of cycles n. N_{Elod} is the lower cyclic load and $\Delta N_{Rd,E,n}$ is the corresponding fatigue resistance. The design fatigue resistance, $\Delta N_{Rd,0,n}$, with lower cyclic load, N_{Elod}, equal to zero for n load cycles and the static resistance, N_{Rd}, can be derived by applying the appropriate material partial factors to the characteristic values.

Figure 3.3 shows the Goodman Diagram according to test method C for a selected number of cycles n. N_{Elod} is the lower cyclic load and $\Delta N_{Rd,s,E,n}$ is the corresponding fatigue resistance for steel failure. The design steel tensile fatigue resistance, $\Delta N_{Rd,s,lo,n}$, with lower cyclic load, $N_{lod,s,n}$, for *n* load cycles and the static steel tensile resistance, $N_{Rd,s}$, can be derived by applying the appropriate material partial factors to the characteristic values.

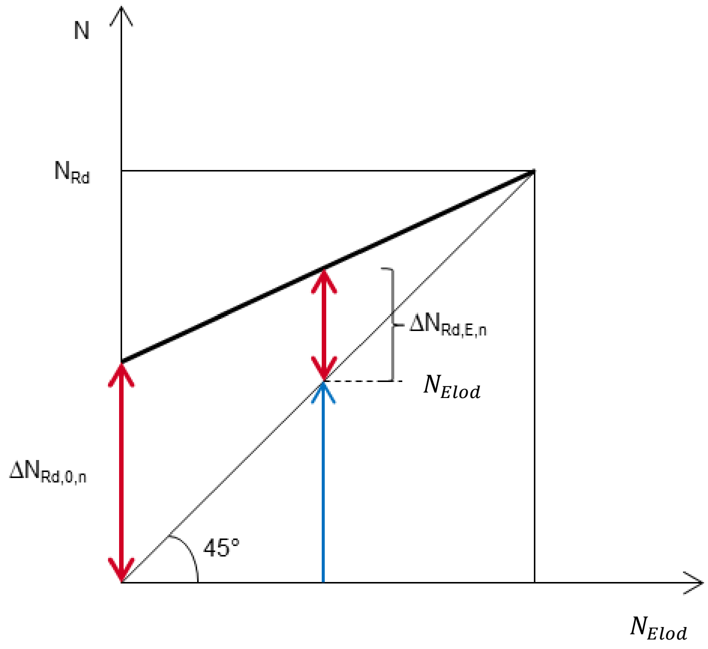


Figure 3.2 Goodman Diagram according to test method A1, A2 and B. Example for the determination of the fatigue resistance as a function of the lower cyclic load ($\boldsymbol{N_{Elod}} \geq \mathbf{0}$)

Note: For oscillations with the same algebraic sign the design value of the fatigue resistance for n cycles, $\Delta N_{Rk,E,n}$, and the fatigue limit resistance, $\Delta N_{Rk,E,\infty}$, is calculated according to Equations (3.8) and (3.9), respectively.

$$\Delta N_{Rd,E,n} = \Delta N_{Rd,0,n} \cdot \left(1 - \frac{N_{Elod}}{N_{Rd}}\right) \tag{3.8}$$

$$\Delta N_{Rd,E,\infty} = \Delta N_{Rd,0,\infty} \cdot \left(1 - \frac{N_{Elod}}{N_{Rd}}\right) \tag{3.9}$$

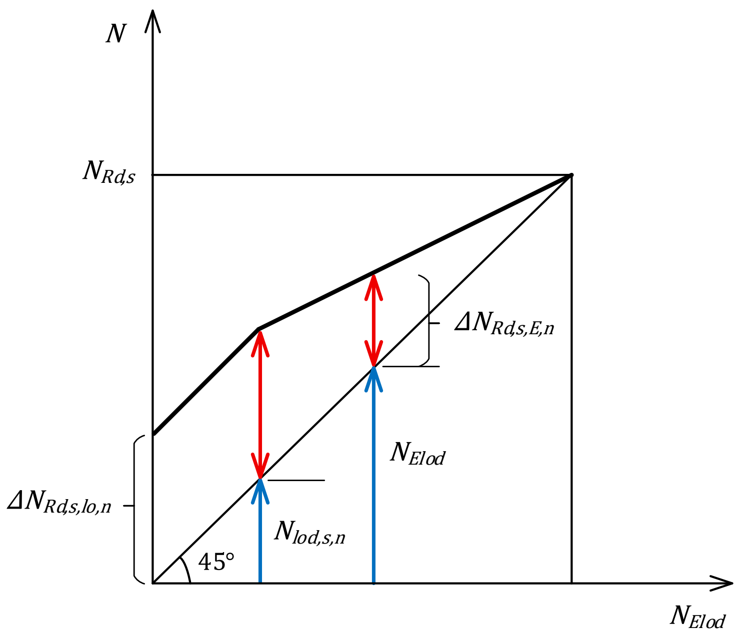


Figure 3.3 Goodman Diagram according to test method C. Example for the determination of the steel tensile fatigue resistance as a function of the lower cyclic load ($\boldsymbol{N_{Elod}} \geq \boldsymbol{N_{lod,s,n}}$)

Note: For oscillations with the same algebraic sign and lower cyclic load $N_{Elod} > N_{lod,s,n}$ *the design value of the steel tensile fatigue resistance for n cycles,* $\Delta N_{Rk,s,E,n}$*, is calculated according to Equations (3.10). In case of lower cyclic loads* $0 \le N_{Elod} \le N_{lod,s,n}$ *the fatigue resistance is assumed to be constant on the safe side, see Equation (3.11).*

$$\Delta N_{Rd,s,E,n} = \Delta N_{Rd,s,lo,n} \cdot \left(1 - \frac{N_{Elod} - N_{lod,s,n}}{N_{Rd,s} - N_{lod,s,n}}\right) \quad \text{for } N_{Elod} > N_{lod,s,n} \tag{3.10}$$

$$\Delta N_{Rd,s,E,n} = \Delta N_{Rd,s,lo,n} \quad \text{for } 0 \le N_{Elod} \le N_{lod,s,n} \tag{3.11}$$

3.2.3 Required verifications for design

The required verifications are summarized in Table 3.3.

Table 3.3 Required verifications for anchor channels under tension loading

Failure mode				Channel / channel bolt	most loaded anchor
1	Steel failure	anchor related failure	anchor		$\frac{\Delta N^{a}_{Ed}}{\Delta N_{Rd,s,E,n}} \le 1.0$
			connection between anchor and channel		
2		local failure of load introduction	failure of channel lips [1)]	$\frac{\Delta N^{loc}_{Ed}}{\Delta N_{Rd,s,E,n}} \le 1.0$	
			channel bolt		
			flexure of channel [1)]		
3	Pull-out failure				$\frac{\Delta N^{a}_{Ed}}{\Delta N_{Rd,p,E,n}} \le 1.0$
4	Concrete cone failure				$\frac{\Delta N^{a}_{Ed}}{\Delta N_{Rd,c,E,n}} \le 1.0$
1) If multiple channel bolts are applied between two anchors, it shall be assumed that the tension forces are acting at the same location: $\Delta N^{loc}_{Ed} = \sum \Delta N_{Ed}$.					

3.3 Design method II – Simplified method

3.3.1 Conditions of applicability

A precise allocation of the design lower cyclic load, N_{Elod}, is not possible and an upper limit to the number of load cycles, n, over the working life of the fastener cannot be predicted.

Therefore, the following values shall be used for design:

$$\Delta N_{Rd} = \Delta N_{Rd,E,n} = \Delta N_{Rd,lo,n} = \Delta N_{Rd,0,\infty}$$

The fatigue resistance used in the design verifications is the design value of fatigue limit resistance with an origin load ($N_{Elod} = 0$).

and

$$\Delta N_{Ed} = N_{Eupd}$$

All acting loads are assumed to be fatigue-relevant.

3.3.2 Required verifications for design

The required verifications correspond to the verifications of design method I as per Section 3.2.3, Table 3.3, with the fatigue resistance $\Delta N_{Rd,E,n} = \Delta N_{Rd,lo,n} = \Delta N_{Rd,0,\infty}$ for steel and concrete failure.

4 REFERENCE DOCUMENTS

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