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 loading which have been awarded a European Technical Assessment (ETA) in accordance with EAD 330008 Anchor channels [3].

Note: This Technical Report is intended to provide a design method for anchor channels under fatigue cyclic 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 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 may be used to transmit tension loads, shear loads acting perpendicular to the longitudinal axis of the channel, shear loads acting in direction of the longitudinal axis of the channel and combinations thereof into the concrete.

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 without fibres all in accordance with EN 206 [5]. The anchor channel is intended to be used in cracked and uncracked 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].

The design provisions can also be used for anchor channels subjected to fatigue shear loads which have been assessed according to assessment method C (see Table 1.1.1). Furthermore, the design method for fatigue shear loads is limited to the following anchor channels and applications:

- Anchor channels with 2 or 3 anchors.
- Anchor channels where the annular gap between channel bolt and fixture as well as the gap between the channel bolt and the channel lips is filled with suitable material, e.g., mortar in order to avoid uncontrolled displacements.
- Anchor channels where the shear load in the longitudinal axis of the channel is transferred via mechanical interlock by means of serrated channel lips with matching serrated channel bolt.
- Anchor channels located far from the edge of the concrete member to avoid concrete edge failure. This may be assumed if the edge distance in all directions is $c \geq max(10\ h_{ef}\ or\ 60\ d_a)$.

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.

The assignment between design method and assessment method is shown in Table 1.1.1 The accompanying clause in this TR is also given. The assessment method is stated in the ETA.

Table 1.1.1: Assessment methods, and related design methods, load direction, type of loading and accompanying clause in this TR for fatigue cyclic loading

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="4">Assessment method</th></tr>
<tr><td>A1
Continuous function of fatigue resistance depending on number of load cycles</td><td>A2
Tri-linear function of fatigue resistance depending on number of load cycles</td><td>B
Fatigue limit resistance</td><td>C
Bi-linear function of fatigue resistance depending on number of load cycles</td></tr>
<tr><td colspan="2">Load direction</td><td colspan="3">Tension</td><td>Tension and/or shear</td></tr>
<tr><td colspan="2">Type of loading</td><td colspan="3">Pulsating load</td><td>Pulsating and/ or alternating load</td></tr>
<tr><td rowspan="2">Design Method</td><td>Method I</td><td>Clause 3</td><td>Clause 3</td><td>not applicable</td><td>Clause 4</td></tr>
<tr><td>Method II</td><td>Clause 3</td><td>Clause 3</td><td>Clause 3</td><td>Clause 4</td></tr>
</table>

Note: The design provisions are valid for anchor channels under fatigue tension loading with an ETA according to assessment *method A1, A2, B or C. The design methods are applicable for fatigue tension and shear loads acting on anchor channels which have been assessed according to* assessment *method C.*

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

This Technical report covers applications with anchor channels subjected to pulsating tension loads, pulsating or alternating shear loads acting perpendicular to the longitudinal axis of the channel, pulsating or alternating shear loads acting in direction of the longitudinal channel axis in accordance with Figure 1.3.1 and Figure 1.3.2. The loads may occur in any combination.

Note: Any compression forces acting on the fixture are assumed to be transmitted directly to the concrete surface without influencing the load transfer mechanism of the anchor channel.

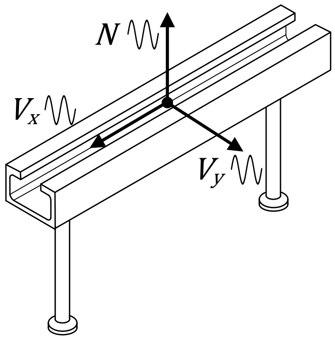


Figure 1.3.1 Load directions covered by this Technical Report

In general, fatigue verification is required in the following cases:

- More than or equal to 1000 load cycles are expected for pulsating tension loads on the anchor channel.
- More than or equal to 100 load cycles of pulsating or alternating shear loads are expected on the anchor channel.

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 and algebraic signs are considered in the context of fatigue cyclic loading. Harmonic and periodic actions can consist of:

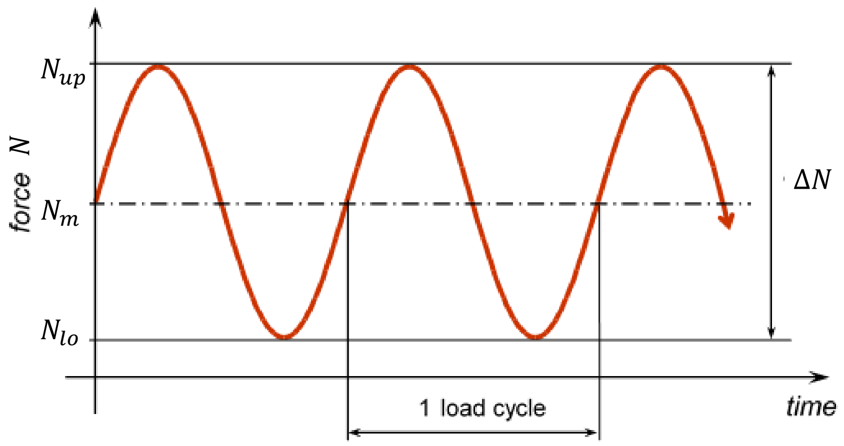
- Oscillations touching zero,
- Oscillations with the same algebraic sign.
- Oscillations with a changing algebraic sign - alternating sign (only for shear loading).

The shear load shall be applied without lever arm according to EN 1992-4:2018, clause 6.2.2.3 (1) a) and b) 1). Neither a levelling mortar according to EN 1992-4:2018, clause 6.2.2.3 (1) b) 2) nor a stand-off installation according to EN 1992-4:2018, Figure 6.6 are covered for shear loads.

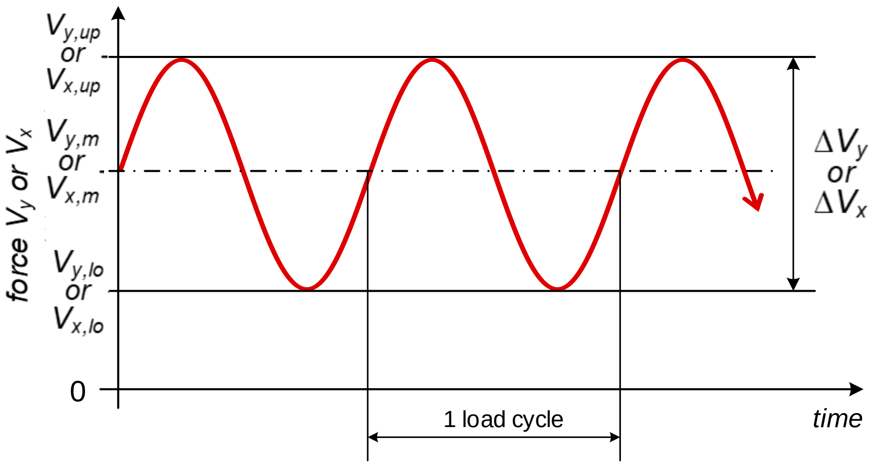
Shear loads on the anchor channel with influence of an edge of the concrete member shall be excluded.

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 1.3.2.

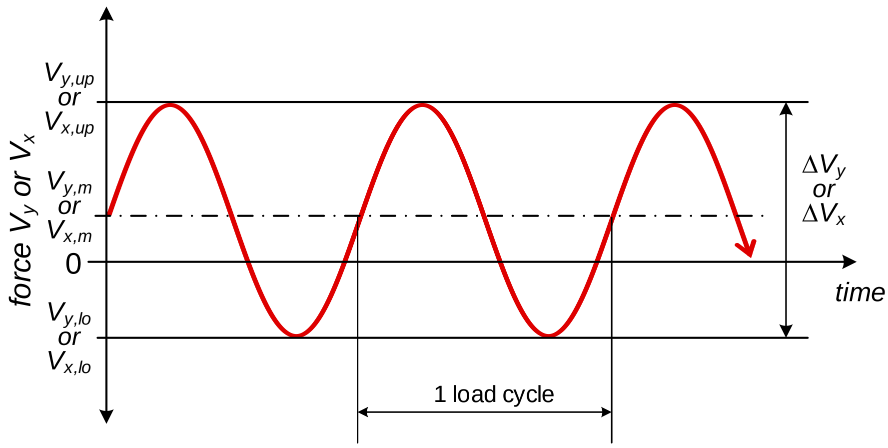
For the overall fatigue design process, the knowledge of the relevant part of the characteristic S-N-curve is required and the design methods I and/or II as shown in clause 3 of this document can be used.



a) For method A1, A2, B and C: Pulsating tension loads
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)



b) For method C: Pulsating shear loads
($V_{y,up}$ or $V_{x,up}$ = maximum (upper) cyclic shear; $V_{y,lo}$ or $V_{x,lo}$ = minimum (lower) cyclic shear, $V_{y,m}$ or $V_{x,m}$ = mean shear, ΔV_y or ΔV_x = cyclic (peak-to-peak range) shear)



c) For method C: Alternating shear loads
($V_{y,up}$ or $V_{x,up}$ = maximum (upper) cyclic shear; $V_{y,lo}$ or $V_{x,lo}$ = minimum (lower) cyclic shear, $V_{y,m}$ or $V_{x,m}$ = mean shear, ΔV_y or ΔV_x = cyclic (peak-to-peak range) shear)

Figure 1.3.2 Definition of force of load cycle

1.4 Specific terms used in this TR

Indices

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

Actions

N	tension
V_y	perpendicular shear
V_x	longitudinal shear
N_{up}	maximum upper cyclic tension
$V_{y,up}$	maximum upper cyclic perpendicular shear
$V_{x,up}$	maximum upper cyclic longitudinal shear
N_m	mean tension
$V_{y,m}$	mean perpendicular shear
$V_{x,m}$	mean longitudinal shear
N_{lo}	minimum lower cyclic tension
$V_{y,lo}$	minimum lower cyclic perpendicular shear
$V_{x,lo}$	minimum lower cyclic longitudinal shear
ΔN	cyclic (peak-to-peak range) tension
ΔV_y	cyclic (peak-to-peak range) perpendicular shear
ΔV_x	cyclic (peak-to-peak range) longitudinal shear
N_{Ed}	design static or quasi-static tension
$V_{Ed,y}$	design static or quasi-static perpendicular shear
$V_{Ed,x}$	design static or quasi-static longitudinal shear
F_{Ed}	design static or quasi-static load ($N_{Ed}, V_{Ed,y}, V_{Ed,x}$)

N_{Elod}	design lower cyclic tension
$V_{y,Elod}$	design lower cyclic perpendicular shear
$V_{x,Elod}$	design lower cyclic longitudinal shear
F_{Elod}	design lower cyclic load (N_{Elod}, $V_{y,Elod}$, $V_{x,Elod}$)
N_{Elok}	characteristic lower cyclic tension
$V_{y,Elok}$	characteristic lower cyclic perpendicular shear
$V_{x,Elok}$	characteristic lower cyclic longitudinal shear
F_{Elok}	characteristic lower cyclic load (N_{Elok}, $V_{y,Elok}$, $V_{x,Elok}$)
N_{Eupd}	= $N_{Elod} + \Delta N_{Ed}$, design upper cyclic tension
$V_{y,Eupd}$	= $V_{y,Elod} + \Delta V_{Ed,y}$, design upper cyclic perpendicular shear
$V_{x,Eupd}$	= $V_{x,Elod} + \Delta V_{Ed,x}$, design upper cyclic longitudinal shear
F_{Eupd}	= $F_{Elod} + \Delta F_{Ed}$, design upper cyclic load (N_{Eupd}, $V_{y,Eupd}$, $V_{x,Eupd}$)
ΔN_{Ek}	characteristic fatigue cyclic tension
$\Delta V_{Ek,y}$	characteristic fatigue cyclic perpendicular shear
$\Delta V_{Ek,x}$	characteristic fatigue cyclic longitudinal shear
ΔF_{Ek}	characteristic fatigue cyclic action (ΔN_{Ek}, $\Delta V_{Ek,y}$, $\Delta V_{Ek,x}$)
ΔN_{Ed}	design fatigue cyclic tension
$\Delta V_{Ed,y}$	design fatigue cyclic perpendicular shear
$\Delta V_{Ed,x}$	design fatigue cyclic longitudinal shear
ΔF_{Ed}	design fatigue cyclic load (ΔN_{Ed}, $\Delta V_{Ed,y}$, $\Delta V_{Ed,x}$)
ΔN_{Ed}^{a}	design fatigue cyclic tension acting on the anchor
$\Delta V_{Ed,y}^{a}$	design fatigue perpendicular shear load acting on the anchor
$\Delta V_{Ed,x}^{a}$	design fatigue longitudinal shear load acting on the anchor
ΔN_{Ed}^{loc}	design fatigue cyclic tension acting at the local point, where the load is introduced
$\Delta V_{Ed,y}^{loc}$	design fatigue perpendicular shear acting at the local point, where the load is introduced
$\Delta V_{Ed,x}^{loc}$	design fatigue longitudinal shear acting at the local point, where the load is introduced

Resistances

N_{Rk}	characteristic static tension resistance for all failure modes
$V_{Rk,s,y}$	characteristic static perpendicular shear resistance for steel failure
$V_{Rk,s,x}$	characteristic static longitudinal shear resistance for steel failure
$F_{Rk,s}$	characteristic static resistance for steel failure ($N_{Rk,s}$, $V_{Rk,s,y}$, $V_{Rk,s,x}$)
N_{Rd}	design static tension resistance for all failure modes
$V_{Rd,s,y}$	design static perpendicular shear resistance for steel failure
$V_{Rd,s,y}$	design static longitudinal shear resistance for steel failure
$F_{Rd,s}$	design static resistance for steel failure ($N_{Rd,s}$, $V_{Rd,s,y}$, $V_{Rd,s,x}$)
ΔN_{Rk}	characteristic fatigue tension resistance
$\Delta V_{Rk,y}$	characteristic fatigue perpendicular shear resistance
$\Delta V_{Rk,x}$	characteristic fatigue longitudinal shear resistance
ΔF_{Rk}	characteristic fatigue resistance (ΔN_{Rk}, $\Delta V_{Rk,y}$, $\Delta V_{Rk,x}$)

ΔN_{Rd}	design fatigue tension resistance
$\Delta V_{Rd,y}$	design fatigue perpendicular shear resistance
$\Delta V_{Rd,x}$	design fatigue longitudinal shear resistance
ΔF_{Rd}	design fatigue resistance (ΔN_{Rd}, $\Delta V_{Rd,y}$, $\Delta V_{Rd,x}$)
$N_{lok,s,n}$	characteristic lower cyclic tension relevant for steel resistance with n load cycles taken from the ETA (assessment method C)
$V_{lok,s,y,n}$	characteristic lower cyclic perpendicular shear relevant for steel resistance with n load cycles taken from the ETA (assessment method C)
$V_{lok,s,x,n}$	characteristic lower cyclic longitudinal shear relevant for steel resistance with n load cycles taken from the ETA (assessment method C)
$F_{lok,s,n}$	characteristic lower cyclic load relevant for steel resistance with n load cycles taken from the ETA ($N_{lok,s,n}$, $V_{lok,s,y,n}$, $V_{lok,s,x,n}$)
$N_{lod,s,n}$	design lower cyclic tension ~~load~~ relevant for steel resistance with n load cycles
$V_{lod,s,y,n}$	design lower cyclic perpendicular shear relevant for steel resistance with n load cycles
$V_{lod,s,x,n}$	design lower cyclic longitudinal shear relevant for steel resistance with n load cycles
$F_{lod,s,n}$	design lower cyclic load relevant for steel resistance with n load cycles ($N_{lod,s,n}$, $V_{lod,s,y,n}$, $V_{lod,s,x,n}$)
$\Delta N_{Rk,s,lo,n}$	characteristic steel fatigue tension resistance with lower cyclic load $N_{lok,s,n}$ and n load cycles taken from the ETA (assessment method C)
$\Delta V_{Rk,s,y,lo,n}$	characteristic steel fatigue perpendicular shear resistance with lower cyclic load $V_{lok,y,s,n}$ and n load cycles taken from the ETA (assessment method C)
$\Delta V_{Rk,s,x,lo,n}$	characteristic steel fatigue longitudinal shear resistance with lower cyclic load $V_{lok,x,s,n}$ and n load cycles taken from the ETA (assessment method C)
$\Delta F_{Rk,s,lo,n}$	characteristic steel fatigue resistance with lower cyclic load $F_{lok,s,n}$ and n load taken from the ETA ($\Delta N_{Rk,s,lo,n}$, $\Delta V_{Rk,s,y,lo,n}$, $\Delta V_{Rk,s,x,lo,n}$)
$\Delta N_{Rd,s,lo,n}$	design steel fatigue tension resistance with lower cyclic load $N_{lod,sn}$ and n load cycles
$\Delta V_{Rd,s,y,lo,n}$	design steel fatigue perpendicular shear resistance with lower cyclic load $V_{lod,y,s,n}$ and n load cycles
$\Delta V_{Rd,s,x,lo,n}$	design steel fatigue longitudinal shear resistance with lower cyclic load $V_{lod,x,s,n}$ and n load cycles
$\Delta F_{Rd,s,lo,n}$	design steel fatigue resistance with lower cyclic load $F_{lod,s,n}$ and n load cycles ($\Delta N_{Rd,s,lo,n}$, $\Delta V_{Rk,s,y,lo,n}$, $\Delta V_{Rk,s,x,lo,n}$)
$\Delta N_{Rk,s,0,n}$	characteristic steel fatigue tension resistance with origin load ($N_{Elod} = 0$) and n load cycles taken from the ETA (assessment method A1 and A2)
$\Delta N_{Rk,p,0,n}$	characteristic concrete pull-out fatigue tension resistance with origin load ($N_{Elod} = 0$) and n load cycles taken from the ETA (assessment method A1and A2)
$\Delta N_{Rk,c,0,n}$	characteristic concrete cone fatigue tension resistance with origin load ($N_{Elod} = 0$) and n load cycles taken from the ETA (assessment method A1 and A2)
$\Delta N_{Rk,0,n}$	characteristic fatigue tension resistance with origin load ($N_{Elod} = 0$) and n load cycles for steel and concrete failure taken from the ETA ($\Delta N_{Rk,s,0,n}$, $\Delta N_{Rk,p,0,n}$, $\Delta N_{Rk,c,0,n}$)
$\Delta N_{Rd,s,0,n}$	design steel fatigue tension resistance with origin load ($N_{Elod} = 0$) and n load cycles
$\Delta N_{Rd,p,0,n}$	design concrete pull-out fatigue tension resistance with origin load ($N_{Elod} = 0$) and n load cycles (assessment method A1, A2 and B)
$\Delta N_{Rd,c,0,n}$	design concrete cone fatigue tension resistance with origin load ($N_{Elod} = 0$) and n load cycles (assessment method A1, A2 and B)
$\Delta N_{Rd,0,n}$	design fatigue tension resistance with origin load ($N_{Elod} = 0$) and n load cycles for steel and concrete failure ($\Delta N_{Rd,s,0,n}$, $\Delta N_{Rd,p,0,n}$, $\Delta N_{Rd,c,0,n}$)

$\Delta N_{Rk,s,0,\infty}$	characteristic steel fatigue limit tension resistance with origin load ($N_{Elod} = 0$) taken from the ETA (assessment method B)
$\Delta N_{Rk,p,0,\infty}$	characteristic concrete pull-out fatigue limit tension resistance with origin load ($N_{Elod} = 0$) taken from the ETA (assessment method B)
$\Delta N_{Rk,c,0,\infty}$	characteristic concrete cone fatigue limit tension resistance with origin load ($N_{Elod} = 0$) taken from the ETA (assessment method B)
$\Delta N_{Rk,0,\infty}$	characteristic fatigue limit tension resistance with origin load ($N_{Elod} = 0$) for steel and concrete failure taken from the ETA ($\Delta N_{Rk,s,0,\infty}$, $\Delta N_{Rk,p,0,\infty}$, $\Delta N_{Rk,c,0,\infty}$)
$\Delta N_{Rd,s,0,\infty}$	design steel fatigue limit tension resistance with origin load ($N_{Elod} = 0$
$\Delta N_{Rd,p,0,\infty}$	design concrete pull-out fatigue limit resistance with origin load ($N_{Elod} = 0$) (assessment method A1, A2 and B)
$\Delta N_{Rd,c,0,\infty}$	design concrete cone fatigue limit resistance with origin load ($N_{Elod} = 0$) (assessment method A1, A2 and B)
$\Delta N_{Rd,0,\infty}$	design fatigue limit tension resistance with origin load ($N_{Elod} = 0$) for steel and concrete failure ($\Delta N_{Rd,s,0,\infty}$, $\Delta N_{Rd,p,0,\infty}$, $\Delta N_{Rd,c,0,\infty}$)
$\Delta N_{Rk,p,E,n}$	characteristic concrete pull-out fatigue tension resistance for N_{Elod} and n load taken from the ETA (assessment method C)
$\Delta N_{Rk,c,E,n}$	characteristic concrete cone fatigue tension resistance for N_{Elod} and n load taken from the ETA (assessment method C)
$\Delta V_{Rk,cp,y,E,n}$	Characteristic concrete pry-out shear fatigue resistance perpendicular to the longitudinal channel axis for $V_{y,Elok}$ and n load cycles taken from the ETA (assessment method C)
$\Delta V_{Rk,cp,x,E,n}$	Characteristic concrete pry-out shear fatigue resistance in the direction of the longitudinal channel axis for $V_{x,Elok}$ and n load cycles taken from the ETA (assessment method C)
$\Delta N_{Rd,s,E,n}$	design steel fatigue tension resistance for N_{Elod} and n load cycles
$\Delta N_{Rd,p,E,n}$	design concrete pull-out fatigue tension resistance for N_{Elod} and n load cycles
$\Delta N_{Rd,c,E,n}$	design concrete cone fatigue tension resistance for N_{Elod} and n load cycles
$\Delta N_{Rd,E,n}$	design fatigue tension resistance for N_{Elod} and n load cycles for steel and concrete failure ($\Delta N_{Rd,s,E,n}$, $\Delta N_{Rd,p,E,n}$, $\Delta N_{Rd,c,E,n}$)
$\Delta V_{Rd,s,y,E,n}$	design steel fatigue perpendicular shear resistance with lower cyclic load $V_{y,Elod}$ and n load cycles
$\Delta V_{Rd,s,x,E,n}$	design steel fatigue longitudinal shear resistance with lower cyclic load $V_{x,Elod}$ and n load cycles
$\Delta V_{Rd,cp,y,E,n}$	design concrete pry-out shear fatigue resistance perpendicular to the longitudinal channel axis for $V_{y,Elok}$ and n load cycles
$\Delta V_{Rd,cp,x,E,n}$	design concrete pry-out shear fatigue resistance in the direction of the longitudinal channel axis for $V_{x,Elok}$ and n load cycles
$\Delta F_{Rd,s,E,n}$	Design steel fatigue resistance for lower cyclic load F_{Elod} and n load cycles ($\Delta N_{Rd,s,E,n}$, $\Delta V_{Rd,s,y,E,n}$, $\Delta V_{Rd,s,x,E,n}$)
$\Delta N_{Rd,E,1}$	design fatigue tension resistance for N_{Elod} and n = 1 load cycle (assessment method A1, A2 and B)
$\Delta N_{Rd,s,E,\infty}$	Design steel fatigue limit tension resistance with N_{Elod}
$\Delta N_{Rd,p,E,\infty}$	Design concrete pull-out fatigue limit tension resistance with N_{Elod}
$\Delta N_{Rd,c,E,\infty}$	Design concrete cone fatigue limit tension resistance with N_{Elod}
$\Delta N_{Rd,E,\infty}$	Design fatigue limit tension resistance for N_{Elod} ($\Delta N_{Rd,s,E,\infty}$, $\Delta N_{Rd,p,E,\infty}$, $\Delta N_{Rd,c,E,\infty}$)
$\Delta V_{Rd,s,y,E,\infty}$	design steel fatigue perpendicular shear limit resistance with lower cyclic load $V_{y,Elod}$
$\Delta V_{Rd,s,x,E,\infty}$	design steel fatigue longitudinal shear limit resistance with lower cyclic load $V_{x,Elod}$

$\Delta V_{Rd,cp,y,E,\infty}$ design concrete pry-out shear fatigue limit resistance perpendicular to the longitudinal channel axis for $V_{y,Elok}$

$\Delta V_{Rd,cp,x,E,\infty}$ design concrete pry-out shear fatigue limit resistance in the direction of the longitudinal channel axis for $V_{x,Elok}$

2 COMBINATION OF STATIC AND CYCLIC LOADS AND INFLUENCE RANGES

This Technical Report covers combinations of static and cyclic loads including tension loads perpendicular to the concrete surface, shear loads perpendicular to the longitudinal axis of the channel and shear loads in direction of the longitudinal axis of the channel.

In the design for fatigue loading the distribution of static and cyclic loads to the anchors of an anchor channel depends on the load direction:

- For tension loads and shear loads acting perpendicular to the longitudinal axis of the channel the loads on the anchors shall be distributed by considering the anchor channel as a chain of simply supported single span beams between the anchors with a span length equal to the anchor spacing.
- For shear loads acting in direction of the longitudinal axis of the channel it is assumed that all shear loads are transferred by the most unfavourable anchor.

Note: The approach to use a chain of single span beams under tension load and perpendicular shear load is due to the fact that the design method according to EN 1992-4 [2] and EOTA TR 047 [4] is only valid for static loads considering redistribution of loads close to failure. This load redistribution cannot expected under cyclic actions relevant to fatigue, where elastic behaviour shall be assumed. The same applies for fatigue shear loads acting longitudinal to the channel axis.

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 in each load direction.

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

3 FATIGUE DESIGN OF ANCHOR CHANNELS UNDER TENSION FOR METHOD A1, A2 AND B

3.1 Design concept

For the design of anchor channels under fatigue cyclic tension 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}:

$$\Delta N_{Ed} \leq \Delta N_{Rd} \qquad (3.1.1)$$

where: ΔN_{Ed} design fatigue tension action

ΔN_{Rd} design fatigue tension resistance

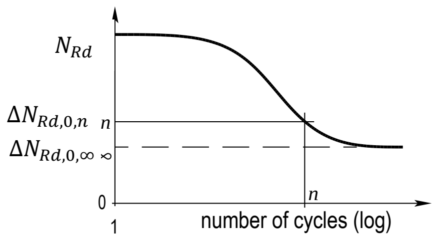
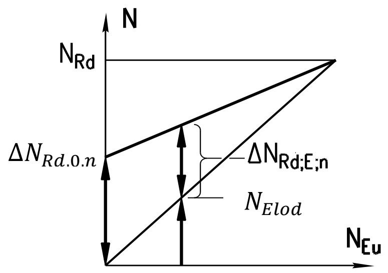
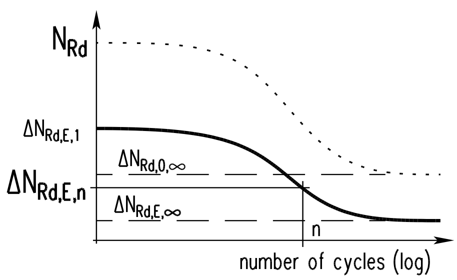
The general form of the ultimate limit state verification with fatigue influence is as follows:

$$(\Delta N_{Ed} / \Delta N_{Rd}) \leq 1{,}0 \qquad (3.1.2)$$

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 3.1.1 (assessment method A1, A2 and B). The Equations in Clause 3.2.3 – design method I - and Clause 3.3.2 – design method II – shall be used.

Table 3.1.1 Concept for design of anchor channels under fatigue tension (assessment method A1, A2 and B)

Step		Result	Note
1	S-N-curve for design fatigue tension resistance with origin 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 design fatigue limit tension 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 tension 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 fatigue cyclic tension

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.

$$\Delta N_{Ed} = \gamma_{F,fat} \cdot \Delta N_{Ek} \qquad (3..1.1.1)$$

where: ΔN_{Ek} characteristic fatigue cyclic 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.

$$N_{Elod} = \gamma_{F,stat} \cdot N_{Elok} \qquad (3.1.1.2)$$

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.

$$\Delta N_{Rd} = \Delta N_{Rk} \,/\, \gamma_{M,fat} \qquad (3.1.2.1)$$

where: ΔN_{Rk} characteristic fatigue resistance

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

The following partial 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 assessment 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:

$$\gamma_{M,fat,n} = \gamma_{M,fat} + (\gamma_M - \gamma_{M,fat}) \cdot (\Delta N_{Rk,0,n} - \Delta N_{Rk,0,\infty}) \,/\, (N_{Rk} - \Delta N_{Rk,0,\infty}) \qquad (3.1.2.2)$$

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

3.2 Design method I – Complete method

3.2.1 Conditions of applicability

For the use of the design method at least one of the following conditions must be fulfilled:

(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 Clause 3.2.2 Equation (3.2.2.2)

and

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

Only the design fatigue relevant load is taken into account.

Note: In cases where no fatigue limit resistance ($n = \infty$) is given in the ETA, e.g., for concrete failure, the fatigue resistance may be defined alternatively for a maximum number of load cycles, e.g., $n = 10^8$, which shall not be exceeded during the design working life.

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 Clause 3.2.2 Equation (3.2.2.1)

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 (assessment method A1, A2 and B).

In cases where fatigue relevant actions consist of a lower cyclic load $N_{Elod} > 0$ (assessment method A1, A2 and B) 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 (assessment method A1, A2 and B).

Note: The definition of the lower cyclic load, N_{Elod}, depends on the following cases (see also Figure 3.2.2.1):

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 $N_{Ed} - \Delta N_{Ed}$.*

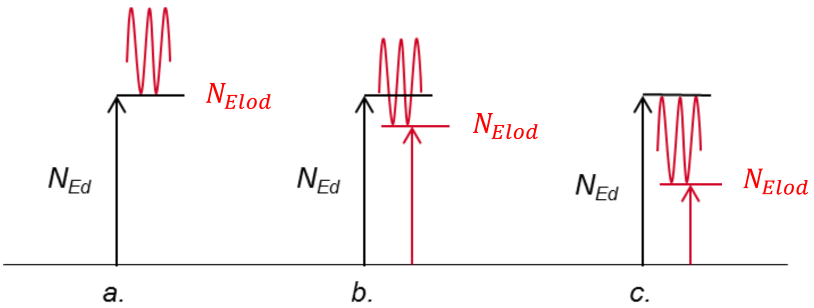


Figure 3.2.2.1 Superimposition of static and fatigue cyclic loads

Figure 3.2.2.2 shows the Goodman Diagram according to assessment 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.

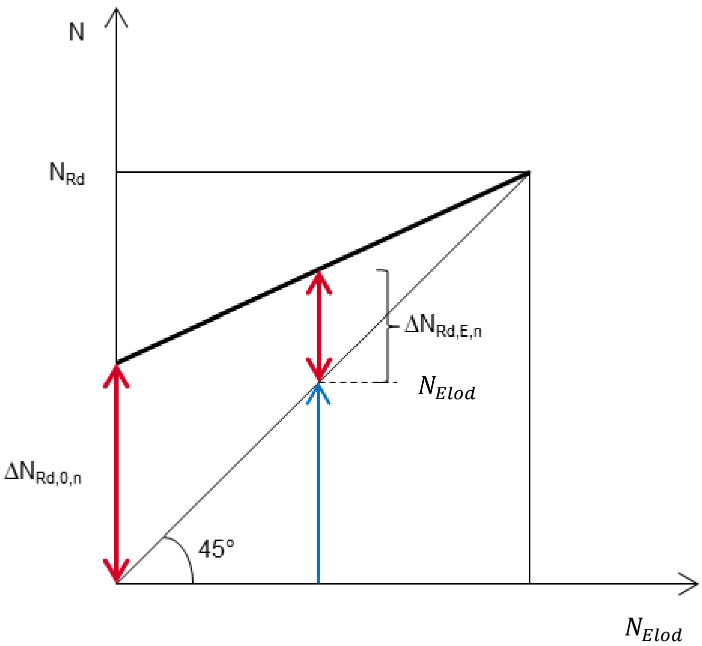


Figure 3.2.2.2 Goodman Diagram according to assessment method A1, A2 and B. Example for the determination of the fatigue resistance as a function of the lower cyclic load ($N_{Elod} \geq 0$)

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 (3.2.2.1) and (3.2.2.2), respectively.

$$\Delta N_{Rd,E,n} = \Delta N_{Rd,0,n} \cdot \left(1 - \frac{N_{Elod}}{N_{Rd}}\right) \tag{3.2.2.1}$$

$$\Delta N_{Rd,E,\infty} = \Delta N_{Rd,0,\infty} \cdot \left(1 - \frac{N_{Elod}}{N_{Rd}}\right) \tag{3.2.2.2}$$

3.2.3 Required verifications for design

The required verifications for tension load are summarized in Table 3.2.3.1.

Table 3.2.3.1 Required verifications for anchor channels under tension loading

Failure mode				Channel / channel bolt	most unfavourable [2)] anchor
1	Steel failure	anchor related failure	anchor		$\frac{\Delta N_{Ed}^{a}}{\Delta N_{Rd,s,E,n}} \leq 1,0$
			connection between anchor and channel		
2		local failure of load introduction	failure of channel lips [1)]	$\frac{\Delta N_{Ed}^{loc}}{\Delta N_{Rd,s,E,n}} \leq 1,0$	
			channel bolt		
			flexure of channel [1)]		
3	Pull-out failure				$\frac{\Delta N_{Ed}^{a}}{\Delta N_{Rd,p,E,n}} \leq 1,0$
4	Concrete cone failure				$\frac{\Delta N_{Ed}^{a}}{\Delta N_{Rd,c,E,n}} \leq 1,0$

1) If multiple channel bolts are applied between two anchors, it shall be assumed that the tension forces are acting at the same location: $\Delta N_{Ed}^{loc} = \sum \Delta N_{Ed}$.

2) The load on the anchor in conjunction with the edge distance and spacing shall be considered in determining the most unfavourable anchor.

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 Clause 3.2.3, Table 3.2.3.1, 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 FATIGUE DESIGN OF ANCHOR CHANNELS UNDER TENSION AND SHEAR FOR METHOD C

4.1 Design concept

The variable F may be used as N, Vx or Vy with every further index (see clause 1.4 for detail).

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, ΔF_{Ed}, do not exceed the design resistance, ΔF_{Rd}:

$$\Delta F_{Ed} \leq \Delta F_{Rd} \tag{4.1.1}$$

where: ΔF_{Ed} design fatigue cyclic action

ΔF_{Rd} design fatigue resistance

Each failure mode shall be verified separately for all load directions (tension, perpendicular shear, longitudinal shear) and possible load combinations.

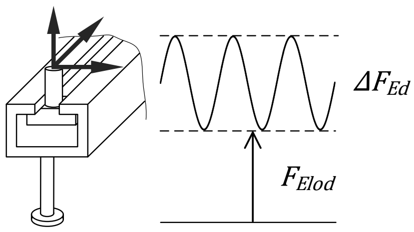
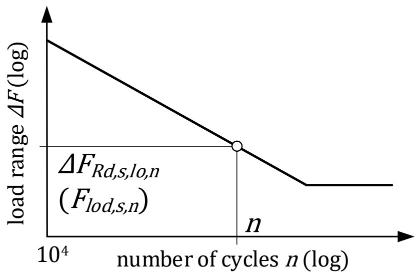
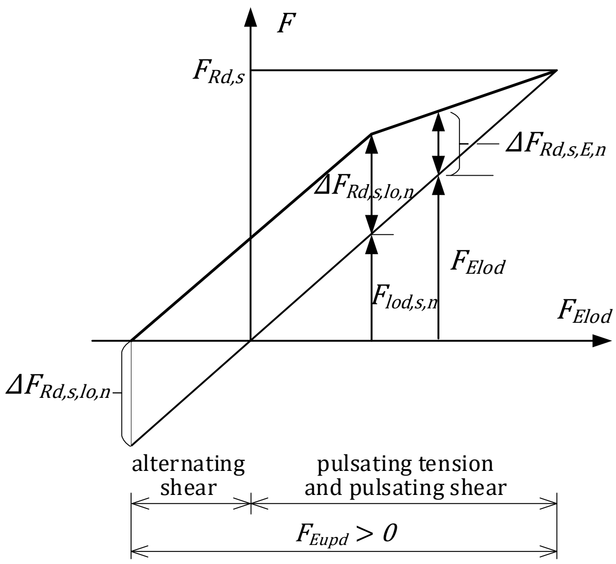
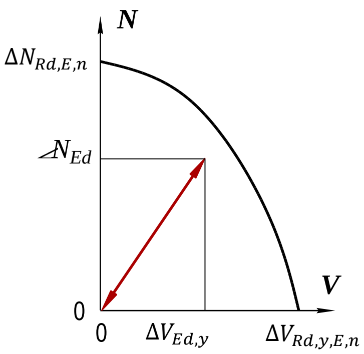
The general form of the ultimate limit state verification for combined tension and shear loads with fatigue influence is as follows:

$$(\Delta N_{Ed} / \Delta N_{Rd})^k + (\Delta V_{Ed,y} / \Delta V_{Rd,y})^k + (\Delta V_{Ed,x} / \Delta V_{Rd,x})^k \leq 1{,}0 \tag{4.1.2}$$

For any combinations of tension and shear loads Equation (4.1.2) shall be satisfied for steel failure and all concrete failure modes separately.

The design of anchor channels with fatigue influence shall be conducted in accordance with the concept provided in Table 4.1.1 (assessment method C), respectively. The Equations in clause 4.2.3 – design method I - and clause 4.3.2 – design method II – shall be used.

Table 4.1.1 Concept for design of anchor channels under fatigue tension and shear (assessment method C)

Step		Result	Note
1	Actions		The design actions, ΔF_{Ed} and F_{Elod}, are obtained by the characteristic values of loads acting on the anchor channel multiplied by the factors according to clause 4.1.1.
2	Resistances		The characteristic fatigue resistance, $\Delta F_{Rk,s,lo,n}$ with lower cyclic load $F_{lok,s,n}$ for steel failure and $\Delta N_{Rk,p,E,n}$, $\Delta N_{Rk,c,E,n}$ or $\Delta V_{Rk,cp,y,E,n}$ or $\Delta V_{Rk,cp,x,E,n}$ for concrete related failure, for a given number of load cycles, *n*, can be taken from the ETA. The design values, $\Delta F_{Rd,s,lo,n}$ with $F_{lod,s,n}$ and $\Delta N_{Rd,p,E,n}$, $\Delta N_{Rd,c,E,n}$ or $\Delta V_{Rd,cp,y,E,n}$ or $\Delta V_{Rd,cp,x,E,n}$ are calculated by applying the factors in accordance with clause 4.1.2.
3	Goodman diagram For tension is $N_{Elod} \geq 0$		Determination of the design resistance $\Delta F_{Rd,s,E,n}$ for steel failure by means of the Goodman diagram (see Figure 4.2.2.2) according to clause 4.2.2, Equations (4.2.2.1) and (4.2.2.2) in the pulsating range and Equation (4.2.2.3) and (4.2.2.4) for alternating shear loads.
4	Design verifica-tions with considera-tion of interaction [1]		The verification is performed by comparing the design actions with the design resistances. Each failure mode and each load direction including load combinations shall be verified separately as given in Table 4.2.3.1, Table 4.2.3.2, Table 4.2.3.3 and Table 4.2.3.4

[1] e.g., for combined tension and perpendicular shear loading

4.1.1 Actions

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

The design fatigue cyclic load shall be calculated as follows.

$$\Delta F_{Ed} = \gamma_{F,fat} \cdot \Delta F_{Ek} \quad (4.1.1.1)$$

where: ΔF_{Ek} characteristic fatigue cyclic 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, ΔF_{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.

$$F_{Elod} = \gamma_{F,stat} \cdot F_{Elok} \quad (4.1.1.2)$$

where: F_{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].

4.1.2 Resistances

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

The design fatigue resistance shall be calculated as follows.

$$\Delta F_{Rd} = \Delta F_{Rk} / \gamma_{M,fat} \quad (4.1.2.1)$$

where: ΔF_{Rk} characteristic fatigue resistance

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

The following partial 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 resistance according to assessment 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 cyclic load relevant for steel resistance with n load cycles shall be calculated as follows.

$$F_{lod,s,n} = F_{lok,s,n} / \gamma_{Ms} \quad (4.1.2.2)$$

where: $F_{lok,s,n}$ characteristic lower cyclic load relevant for steel resistance with n load cycles tested according EAD

γ_{Ms} partial factor for static resistance

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

4.2 Design method I – Complete method

4.2.1 Conditions of applicability

For the use of the design method at least one of the following conditions must be fulfilled:

(a) a precise allocation of the design lower cyclic load, F_{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:

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

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, F_{Elod}, in accordance with clause 4.2.2 Equations (4.2.2.1) and (4.2.2.2)

and

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

Only the design fatigue relevant load is taken into account.

Note: In cases where no fatigue limit resistance ($n = \infty$) is given in the ETA, e.g., for concrete failure, the fatigue resistance may be defined alternatively for a maximum number of load cycles, e.g., $n = 10^8$, which shall not be exceeded during the design working life.

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

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

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

and

In case of pulsating load:

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

All acting loads are assumed to be fatigue-relevant.

In case of alternating load:

The cyclic load must be known.

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

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

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, F_{Elod}, in accordance with clause 4.2.2 Equations (4.2.2.1) and (4.2.2.2)

and

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

Only the design fatigue relevant load is taken into account.

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

If the fatigue resistance diagram is determined by tests with a higher level of constant lower load or with constant upper load (assessment method C), the influence of the lower cyclic load to the fatigue resistance is considered. This procedure allows the determination of the characteristic fatigue resistance, $\Delta F_{Rk,s,lo,n}$, with the characteristic lower load, $F_{lok,s,n}$, for steel failure. The characteristic concrete pull-out fatigue resistance $\Delta N_{Rk,p,E,n}$, ~~and~~ the characteristic concrete cone fatigue resistance $\Delta N_{Rk,c,E,n}$ and the characteristic pry-out fatigue resistance perpendicular to the longitudinal channel axis $\Delta V_{Rk,cp,y,E,n}$ or in the direction of the longitudinal channel axis $\Delta V_{Rk,cp,x,E,n}$ for *n* load cycles are given in the ETA depending on F_{Elok}. The design resistances $\Delta N_{Rd,p,E,n}$, $\Delta N_{Rd,c,E,n}$, $\Delta V_{Rd,cp,y,E,n}$ and $\Delta V_{Rd,cp,x,E,n}$ can therefore be directly calculated by applying the appropriate partial factors for resistance to the characteristic values according to Equation (4.1.2.1) (assessment method C).

In cases where fatigue relevant actions in the pulsating range consist of a lower cyclic load $F_{Elod} > F_{lod,s,n}$ (assessment 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 steel failure (assessment method C).

In case of fatigue relevant shear actions with a lower cyclic load $F_{Elod} < 0$ (alternating shear load), the fatigue resistance corresponds to the fatigue resistance with an origin load ($F_{Elod} = 0$) for assessment method C. The fatigue resistance value is constant within the alternating range.

Note: The definition of the lower cyclic load, F_{Elod}, depends on the following cases (see also Figure 4.2.2.1):

d) the static load, F_{Ed}, is amplified by the cyclic load ΔF_{Ed}, meaning that F_{Elod} corresponds to F_{Ed};

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

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

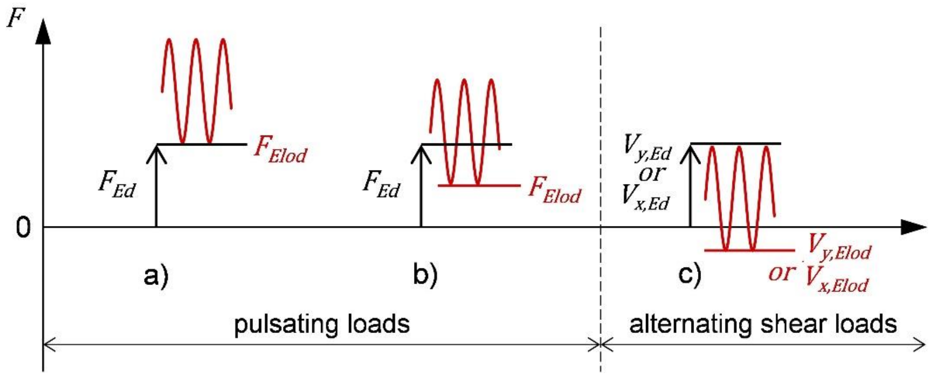


Figure 4.2.2.1 Superimposition of static and fatigue cyclic loads

Figure 4.2.2.2 shows the Goodman Diagram according to assessment method C in the pulsating range for a selected number of cycles n. F_{Elod} is the lower cyclic load and $\Delta F_{Rd,s,E,n}$ is the corresponding fatigue resistance for steel failure. The design steel fatigue resistance, $\Delta F_{Rd,s,lo,n}$, with lower cyclic load, $F_{lod,s,n}$, for *n* load cycles and the static steel resistance, $F_{Rd,s}$, can be derived by applying the appropriate material partial factors to the characteristic values.

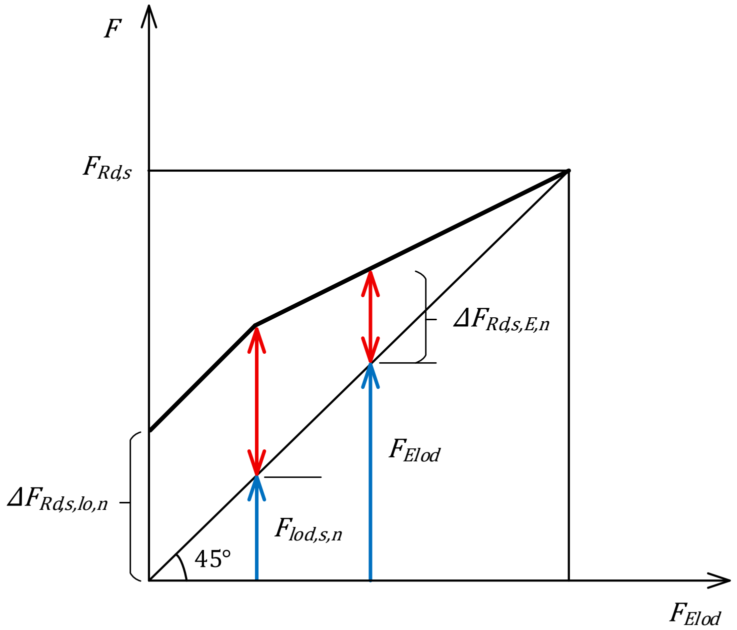


Figure 4.2.2.2 Goodman Diagram according to assessment method C. Example for the determination of the steel fatigue resistance as a function of the lower cyclic load in the pulsating range ($\boldsymbol{F_{Elod} \geq F_{lod,s,n}}$)

Pulsating load: For oscillations with the same algebraic sign and lower cyclic load $F_{Elod} > F_{lod,s,n}$ the design value of the steel fatigue resistance for *n* cycles, $\Delta F_{Rd,s,E,n}$, is calculated according to Equation (4.2.2.1). In case of lower cyclic loads $0 \leq F_{Elod} \leq F_{lod,s,n}$ the fatigue resistance is assumed to be constant on the safe side, see Equation (4.2.2.2).

$$\Delta F_{Rd,s,E,n} = \Delta F_{Rd,s,lo,n} \cdot \left(1 - \frac{F_{Elod} - F_{lod,s,n}}{F_{Rd,s} - F_{lod,s,n}}\right) \quad \text{for } F_{Elod} > F_{lod,s,n} \qquad (4.2.2.1)$$

$$\Delta F_{Rd,s,E,n} = \Delta F_{Rd,s,lo,n} \quad \text{for } 0 \leq F_{Elod} \leq F_{lod,s,n} \qquad (4.2.2.2)$$

Figure 4.2.2.3 shows the Goodman Diagram for shear loads according to assessment method C in the alternating and pulsating range for a selected number of cycles n. $V_{y,Elod}$ or $V_{x,Elod}$ is the lower cyclic load and $\Delta V_{Rd,s,y,E,n}$ or $\Delta V_{Rd,s,x,E,n}$ is the corresponding fatigue resistance for steel failure. The design steel shear fatigue resistance $\Delta V_{Rd,s,y,lo,n}$ or $\Delta V_{Rd,s,x,lo,n}$ with lower cyclic load $V_{lod,s,y,n}$ or $V_{lod,s,x,n}$ for *n* load cycles and the static steel shear resistance $V_{Rd,s,y}$ or $V_{Rd,s,x}$ can be derived by applying the appropriate material partial factors to the characteristic values.

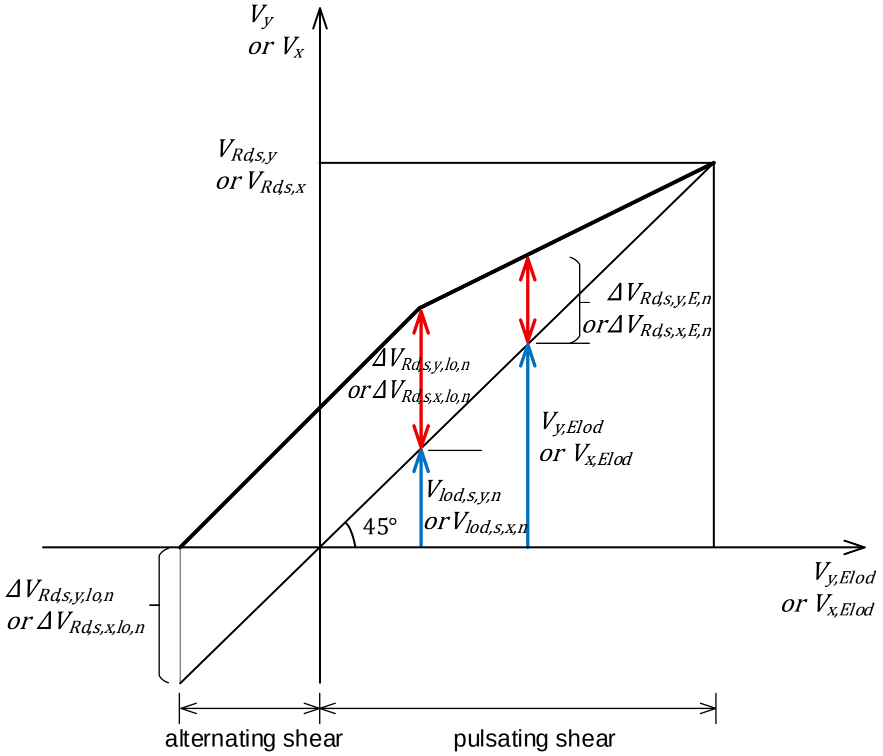


Figure 4.2.2.3 Goodman Diagram according to assessment method C. Example for the determination of the steel shear fatigue resistance as a function of the lower cyclic load in the alternating and pulsating range

Alternating shear load: For oscillations with alternating algebraic sign of Figure 4.2.2.3 the design value of the steel fatigue resistance for *n* cycles, $\Delta V_{Rd,s,y,E,n}$ and $\Delta V_{Rd,s,x,E,n}$, is calculated according to Equation (4.2.2.3) and (4.2.2.4).

$$\Delta V_{Rd,s,y,E,n} = \Delta V_{Rd,s,y,lo,n} \quad \text{for} -\Delta V_{Rd,s,y,E,n} < V_{y,Elod} < 0 \qquad (4.2.2.3)$$

$$\Delta V_{Rd,s,x,E,n} = \Delta V_{Rd,s,x,lo,n} \quad \text{for} -\Delta V_{Rd,s,x,E,n} < V_{x,Elod} < 0 \qquad (4.2.2.4)$$

4.2.3 Required verifications for design

The required verifications for tension load are summarized in Table 4.2.3.1.

Table 4.2.3.1 Required verifications for anchor channels under tension loading

Failure mode				Channel / channel bolt	Most unfavourable [2)] anchor
1	Steel failure	anchor related failure	anchor		$\frac{\Delta N_{Ed}^{a}}{\Delta N_{Rd,s,E,n}} \leq 1{,}0$
			connection between anchor and channel		
2		local failure of load introduction	failure of channel lips [1)]	$\frac{\Delta N_{Ed}^{loc}}{\Delta N_{Rd,s,E,n}} \leq 1{,}0$	
			channel bolt		
			flexure of channel [1)]		
3	Pull-out failure				$\frac{\Delta N_{Ed}^{a}}{\Delta N_{Rd,p,E,n}} \leq 1{,}0$
4	Concrete cone failure				$\frac{\Delta N_{Ed}^{a}}{\Delta N_{Rd,c,E,n}} \leq 1{,}0$

1) If multiple channel bolts are applied between two anchors, it shall be assumed that the tension forces are acting at the same location: $\Delta N_{Ed}^{loc} = \sum \Delta N_{Ed}$.

2) The load on the anchor in conjunction with the edge distance and spacing shall be considered in determining the most unfavourable anchor.

The required verifications for anchor channels located far from edges under shear load perpendicular to the longitudinal axis of the channel are summarized in Table 4.2.3.2.

Table 4.2.3.2 Required verifications for shear loading perpendicular to the channel axis

Failure mode				Channel / channel bolt	Most unfavourable [2)] anchor
1	Steel failure	anchor related failure	anchor		$\frac{\Delta V_{Ed,y}^{a}}{\Delta V_{Rd,s,y,E,n}} \leq 1{,}0$
			connection between anchor and channel		
2		local failure of load introduction	failure of channel lips [1)]	$\frac{\Delta V_{Ed,y}^{loc}}{\Delta V_{Rd,s,y,E,n}} \leq 1{,}0$	
			channel bolt		
3	Pry-out failure				$\frac{\Delta V_{Ed,y}^{a}}{\Delta V_{Rd,cp;y,E,n}} \leq 1{,}0$

1) If multiple channel bolts are applied between two anchors, it shall be assumed that the shear forces are acting at the same location: $\Delta V_{Ed,y}^{loc} = \sum \Delta V_{Ed,y}$.

2) The load on the anchor in conjunction with the edge distance and spacing shall be considered in determining the most unfavourable anchor.

The required verifications for anchor channels located far from edges under shear load in direction to the longitudinal axis of the channel are summarized in Table 4.2.3.3.

Table 4.2.3.3 Required verifications for shear loading longitudinal to the channel axis

Failure mode				Channel / channel bolt	Most unfavourable [1)] anchor
1	Steel failure	anchor related failure	anchor		$\frac{\Delta V_{Ed,x}^{a}}{\Delta V_{Rd,s,x,E,n}} \leq 1{,}0$
			connection between anchor and channel		
2		local failure of load introduction	connection between channel bolt and channel lip	$\frac{\Delta V_{Ed,x}^{loc}}{\Delta V_{Rd,s,x,E,n}} \leq 1{,}0$	
			channel bolt		
3	Pry-out failure				$\frac{\Delta V_{Ed,x}^{a}}{\Delta V_{Rd,cp,x,E,n}} \leq 1{,}0$

1) The load on the anchor in conjunction with the edge distance and spacing shall be considered in determining the most unfavourable anchor.

Note: Verification for concrete edge failure under shear loading is not required for anchor channels located far from the edge of the concrete member.

The required verifications under combined tension and shear loads are summarized in Table 4.2.3.4. The verification for steel failure shall be fulfilled for the most unfavourable anchor and for the most unfavourable position of load introduction. In case of concrete failure verification for the most unfavourable anchor is required. If the most unfavourable anchor or load position cannot be determined all anchors / positions shall be verified.

Table 4.2.3.4 Required verifications for combined tension and shear loading

Failure mode			Most unfavourable anchor / load position
1	Steel failure	anchor related failure [1)]	$\left(\frac{\Delta N_{Ed}^{a}}{\Delta N_{Rd,s,E,n}}\right)^{k_{sn}} + \left(\frac{\Delta V_{Ed,y}^{a}}{\Delta V_{Rd,s,y,E,n}}\right)^{k_{sn}} + \left(\frac{\Delta V_{Ed,x}^{a}}{\Delta V_{Rd,s,x,E,n}}\right)^{k_{sn}} \leq 1{,}0$
2		local failure of load introduction	$\left(\frac{\Delta N_{Ed}^{loc}}{\Delta N_{Rd,s,E,n}}\right)^{k_{sn}} + \left(\frac{\Delta V_{Ed,y}^{loc}}{\Delta V_{Rd,s,y,E,n}}\right)^{k_{sn}} + \left(\frac{\Delta V_{Ed,x}^{loc}}{\Delta V_{Rd,s,x,E,n}}\right)^{k_{sn}} \leq 1{,}0$
3	Concrete failure without influence of a concrete edge [1)]		$max\left(\frac{\Delta N_{Ed}^{a}}{\Delta N_{Rd,p,E,n}}; \frac{\Delta N_{Ed}^{a}}{\Delta N_{Rd,c,E,n}}\right)^{1,5} + \left(\frac{\Delta V_{Ed,y}^{a}}{\Delta V_{Rd,cp,y,E,n}}\right)^{1,5} + \left(\frac{\Delta V_{Ed,x}^{a}}{\Delta V_{Rd,cp,x,E,n}}\right)^{1,5} \leq 1{,}0$

k_{sn} taken from the European Technical Assessment

1) The load on the anchor in conjunction with the edge distance and spacing shall be considered in determining the most unfavourable anchor.

4.3 Design method II – Simplified method

4.3.1 Conditions of applicability

This design method may be used if a precise allocation of the design lower cyclic load, F_{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:

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

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

Note: In cases where no fatigue limit resistance ($n = \infty$) is given in the ETA, e.g., for concrete failure, the fatigue resistance may be defined alternatively for a maximum number of load cycles, e.g., $n = 10^8$, which shall not be exceeded during the design working life.

and

In case of pulsating load:

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

All acting loads are assumed to be fatigue-relevant.

In case of alternating load:

The cyclic load must be known.

4.3.2 Required verifications for design

The required verifications correspond to the verifications of design method I as per clause 4.2.3, Table 4.2.3.1, Table 4.2.3.2, Table 4.2.3.3 and Table 4.2.3.4 with the fatigue resistance $\Delta F_{Rd,E,n} = \Delta F_{Rd,lo,n} = \Delta F_{Rd,0,\infty}$ for steel and concrete failure under tension load ($F = N$), shear load perpendicular to the channel axis ($F = V_y$) and shear load in direction of the longitudinal axis of the channel ($F = V_x$).

5 REFERENCE DOCUMENTS

[1] EN 1992-1-1:2004+AC:2010: Design of concrete structures. Part 1-1: General rules and rules for buildings

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[4] EOTA TR 047:2020: Calculation method for the performance of anchor channels

[5] EN 206:2013+A2:2021: Concrete - Specification, performance, production and conformity

[6] Miner, M., A.: Cumulative Damage in Fatigue, Journal of Applied Mechanics, 12 (1945), 159-164

[7] EN 1990: 2002 + A1:2005 + A1:2005/AC:2010: Basis of structural design