EOTA®

TECHNICAL REPORT

Design method for fasteners in concrete under fatigue cyclic loading

TR 061

January 2018

EUROPEAN ORGANISATION FOR TECHNICAL ASSESSMENT

WWW.EOTA.EU

Content

1 SCOPE OF THE TECHNICAL REPORT

1.1 General

The construction of the fastener system is vitally important for the load-bearing capacity and serviceability. Constructive measures are recommended to minimize influences on the load-bearing behaviour by unexpected displacements for example as a result of the hole-clearance. This must be particularly pointed out for load transfer in fastener groups.

Uncontrolled displacements have to be limited to fulfil the increased serviceability requirements in particular at alternating cyclic loading. Slip has to be generally avoided.

The design rules in this Technical Report (TR) are only valid for fasteners with a European Technical Assessment (ETA) with characteristic resistance under fatigue cyclic loading on basis of EAD 330250-00-0601 [1].

This document relies on characteristic resistances and distances which are stated in the ETA and referred to in this TR.

The design method applies to the design of fasteners installed in members made of compacted normal weight concrete of strength classes in the range C20/25 to C50/60 all in accordance with EN 206:2013 [2]. The fastener is intended to be used in cracked and uncracked concrete.

This Technical Report is intended for safety related applications in which the failure of fasteners 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.

This Technical Report provides a design method for fasteners under tension, shear and combined tension and shear 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).

Note: The verification of the resistance under fatigue cyclic loading consists of both, the verification under static and cyclic loading. Under static loading the fasteners should be designed based on the design methods given in EN 1992-4 [6]. Additional to the verification according to EN 1992-4 [6] the determination of the fatigue resistance in relation to the lower cyclic load for a given number of load cycles is possible.

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.

The proof of local transmission of the fastener loads into the concrete member is delivered by using the design methods described in this document. Proof of transmission of fastener loads to the supports of the concrete members shall be done for both, ultimate limit state and serviceability limit state according to EN 1992-1-1 [5].

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.

Note: If only tension loads are involved in the application, the annular gap does not need to be filled.

1.2 Type, dimensions and materials of fasteners

The characteristic values of the fastener are given in the relevant ETA.

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

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

The design method is valid for single fasteners and fastener groups. In a fastener group only anchors of the same type, size and length shall be used.

1.3 Fastener loading

This Technical Report covers applications with fasteners subjected to pulsating tension load, pulsating or alternating shear load and combinations thereof.

In general, fatigue verification is required when:

- More than or equal to 1000 load cycles are expected for pulsation tension loads on the fastener.
- More than or equal to 100 load cycles of alternating or pulsating shear loads are expected on the fastener.
- Load cycles are imposed by climatic variations and the stress range caused by the restraint forces in the lowest stressed fastener is more than $\Delta\sigma_{Sk} = \sigma_{Sk,max} - \sigma_{Sk,min} > 100N/mm^2$or, in case of shear loading, the lowest stressed fastener is more than $\Delta\tau_{Sk} = \tau_{Sk,max} - \tau_{Sk,min} > 60N/mm^2$.

The shear load shall be applied without lever arm. A stand-off installation is not covered.

Torsion on the anchor plate with influence of edges shall be excluded.

The derivation of loads acting on fasteners under fatigue cyclic loading are based on the derivation of loads acting on fasteners under static and quasi-static loads (according to EN 1992-4 [6]).

All types of actions occurring during the period of intended use of a fastener shall be taken into account for the design. Typically harmonic and/or periodic actions (Figure 1.1 and Figure 1.2) 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.

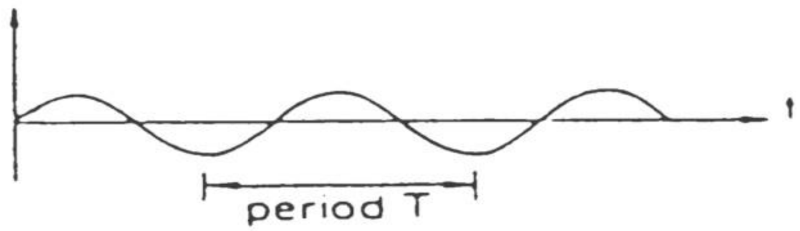


Figure 1.1 Oscillations with an alternating sign

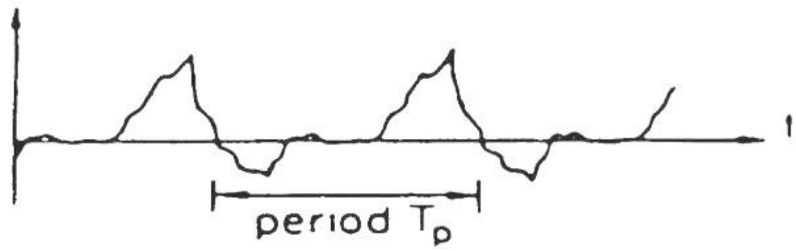


Figure 1.2 Periodic actions considered as harmonic load

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 [7]. 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 S-N-curve or, at a minimum, the fatigue limit resistance, is required and the design methods I and/or II as shown in Section 2 of this document can be used.

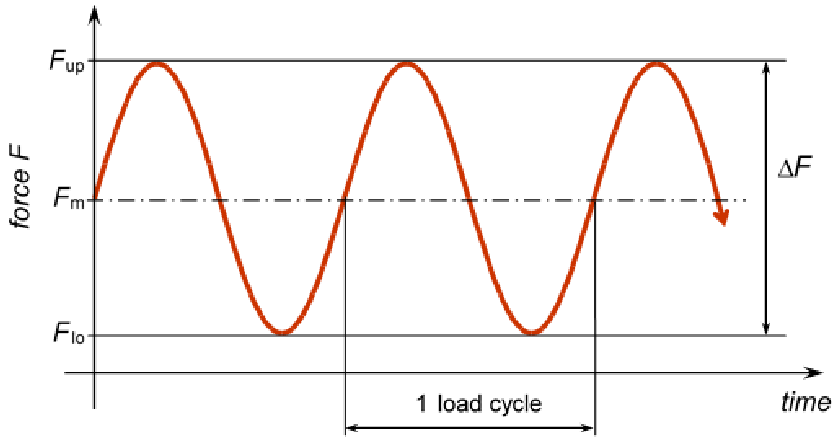


Figure 1.3 Definition of force of load cycle (F_{up} = maximum (upper) cyclic load; F_{lo} = minimum (lower) cyclic load, F_m = mean load, ΔF = cyclic (peak-to-peak range) load)

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	
		A Continuous function of fatigue resistance depending on number of load cycles	B Fatigue limit resistance
Design Method	Method I	X	not applicable
	Method II	X	X

1.4 Specific terms used in this TR

Indices

E	action effects
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/edge
cp	concrete pry-out
p	concrete pull-out
sp	concrete splitting
cb	concrete blow-out
up	upper
lo	lower

Actions

F_{Ed}	design static or quasi-static action
F_{Elod}	design lower cyclic action
ΔF_{Ed}	design cyclic action
F_{Eupd}	= $F_{Elod} + \Delta F_{Ed}$, design upper cyclic action

Resistances (general)

F_{Rk}	characteristic static resistance
F_{Rd}	design static resistance
ΔF_{Rk}	characteristic fatigue resistance
ΔF_{Rd}	design fatigue resistance
$\Delta F_{Rk,0,n}$	characteristic fatigue resistance with origin load ($F_{Elod} = 0$) and n load cycles
$\Delta F_{Rk,E,n}$	characteristic fatigue resistance for pulsating or alternating load ($F_{Elod} \neq 0$) and n load cycles
$\Delta F_{Rk,0,\infty}$	characteristic fatigue limit resistance with origin load ($F_{Elod} = 0$)
$\Delta F_{Rk,E,\infty}$	characteristic fatigue limit resistance for pulsating or alternating load ($F_{Elod} \neq 0$)
$\Delta F_{Rd,0,n}$	design fatigue resistance with origin load ($F_{Elod} = 0$) and n load cycles
$\Delta F_{Rd,E,n}$	design fatigue resistance for pulsating or alternating load ($F_{Elod} \neq 0$) and n load cycles
$\Delta F_{Rd,0,\infty}$	design fatigue limit resistance with origin load ($F_{Elod} = 0$)
$\Delta F_{Rd,E,\infty}$	design fatigue limit resistance for pulsating or alternating load ($F_{Elod} \neq 0$)

Resistances in axial and transverse direction regarding the relevant failure modes

$\Delta N_{Rk,s,0,n}$ ($\Delta V_{Rk,s,0,n}$)	Characteristic steel fatigue resistance with origin load ($F_{Elod} = 0$) in axial direction (transverse direction) and n load cycles taken from the European Technical Product Specification
$\Delta N_{Rk,s,E,n}$ ($\Delta V_{Rk,s,E,n}$)	Characteristic steel fatigue resistance for pulsating or alternating load ($F_{Elod} \neq 0$) in axial direction (transverse direction) and n load cycles
$\Delta N_{Rk,s,0,\infty}$ ($\Delta V_{Rk,s,0,\infty}$)	Characteristic steel fatigue limit resistance with origin load ($F_{Elod} = 0$) in axial direction (transverse direction) taken from the European Technical Product Specification
$\Delta N_{Rk,s,E,\infty}$ ($\Delta V_{Rk,s,E,\infty}$)	Characteristic steel fatigue limit resistance for pulsating or alternating load ($F_{Elod} \neq 0$) in axial direction (transverse direction)
$\Delta N_{Rk,c(p,sp,cb),0,n}$ ($\Delta V_{Rk,c(cp),0,n}$)	Characteristic concrete fatigue resistance with origin load ($F_{Elod} = 0$) in axial direction (transverse direction) and n load cycles taken from the European Technical Product Specification
$\Delta N_{Rk,c(p,sp,cb),E,n}$ ($\Delta V_{Rk,c(cp),E,n}$)	Characteristic concrete fatigue resistance for pulsating or alternating load ($F_{Elod} \neq 0$) in axial direction (transverse direction) and n load cycles
$\Delta N_{Rk,c(p,sp,cb),0,\infty}$ ($\Delta V_{Rk,c(cp),0,\infty}$)	Characteristic concrete fatigue limit resistance with origin load ($F_{Elod} = 0$) in axial direction (transverse direction) taken from the European Technical Product Specification
$\Delta N_{Rk,c(p,sp,cb),E,\infty}$ ($\Delta V_{Rk,c(cp),E,\infty}$)	Characteristic concrete fatigue limit resistance for pulsating or alternating load ($F_{Elod} \neq 0$) in axial direction (transverse direction)
$\Delta N_{Rd,s,0,n}$ ($\Delta V_{Rd,s,0,n}$)	Design steel fatigue resistance with origin load ($F_{Elod} = 0$) in axial direction (transverse direction) and n load cycles
$\Delta N_{Rd,s,E,n}$ ($\Delta V_{Rd,s,E,n}$)	Design steel fatigue resistance for pulsating or alternating load ($F_{Elod} \neq 0$) in axial direction (transverse direction) and n load cycles
$\Delta N_{Rd,s,0,\infty}$ ($\Delta V_{Rd,s,0,\infty}$)	Design steel fatigue limit resistance with origin load ($F_{Elod} = 0$) in axial direction (transverse direction)
$\Delta N_{Rd,s,E,\infty}$ ($\Delta V_{Rd,s,E,\infty}$)	Design steel fatigue limit resistance for pulsating or alternating load ($F_{Elod} \neq 0$) in axial direction (transverse direction)
$\Delta N_{Rd,c(p,sp,cb),0,n}$ ($\Delta V_{Rd,c(cp),0,n}$)	Design concrete fatigue resistance with origin load ($F_{Elod} = 0$) in axial direction (transverse direction) and n load cycles
$\Delta N_{Rd,c(p,sp,cb),E,n}$ ($\Delta V_{Rd,c(cp),E,n}$)	Design concrete fatigue resistance for pulsating or alternating load ($F_{Elod} \neq 0$) in axial direction (transverse direction) and n load cycles
$\Delta N_{Rd,c(p,sp,cb),0,\infty}$ ($\Delta V_{Rd,c(cp),0,\infty}$)	Design concrete fatigue limit resistance with origin load ($F_{Elod} = 0$) in axial direction (transverse direction)
$\Delta N_{Rd,c(p,sp,cb),E,\infty}$ ($\Delta V_{Rd,c(cp),E,\infty}$)	Design concrete fatigue limit resistance for pulsating or alternating load ($F_{Elod} \neq 0$) in axial direction (transverse direction)

2 FATIGUE DESIGN OF FASTENERS

2.1 Design concept

For the design of fasteners under fatigue cyclic action the concept of partial safety factors in accordance with the general rules given in EN 1990:2002 + A1:2005 / AC:2010 [3] shall be applied. It shall be shown that the design actions, ΔE_d, do not exceed the design resistance, ΔR_d:

$$\Delta E_d \leq \Delta R_d \tag{1}$$

where: ΔE_d design action

ΔR_d design resistance

Actions to be used in design may be obtained from national regulations or in the absence of them from the relevant parts of EN 1991:2002 + AC 2009 [4].

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

$$\Delta E_d = \gamma_{F,fat} \cdot \Delta E_k \tag{2}$$

where: ΔE_k characteristic action

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

The following partial safety factors for 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, ΔE_{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 [7] 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 following partial safety factors for resistances are recommended for fasteners under fatigue cyclic loading.

The values of the partial factors for fasteners under fatigue cyclic loading for use in a Country may be found in its National Annex of EN 1992-4 [6]. For the determination of the design fatigue limit resistance it is recommended to take the partial factor for material as $\gamma_{Ms,fat}$ = 1,35 (steel failure) and $\gamma_{Mc,fat}$ = 1,5 (failure modes other than steel failure).

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

$$\gamma_{M,fat,n} = \gamma_{M,fat} + (\gamma_M - \gamma_{M,fat}) \cdot (\Delta F_{Rk,n} - \Delta F_{Rk,\infty}) / (F_{Rk} - \Delta F_{Rk,\infty}) \tag{3}$$

For the determination of the design fatigue limit resistance, the characteristic value determined by tests shall be divided with the partial safety factor $\gamma_{M,fat}$ (e.g., $\Delta F_{Rd,\infty} = \Delta F_{Rk,\infty} / \gamma_{M,fat}$).

For the transition zone from the static bearing capacity up to the fatigue limit resistance, the characteristic value determined by tests shall be divided with the partial safety factor $\gamma_{M,fat,n}$ (e.g., $\Delta F_{Rd,n} = \Delta F_{Rk,n} / \gamma_{M,fat,n}$).

The effective embedment depth h_{ef} of bonded fasteners with bonding elements (e.g. thread, reinforcement) in the range of Δh_{ef} below the concrete surface shall be reduced for design regarding combined pull-out/concrete failure (see Figure 2.1) as follows:

$$h_{ef,fat} = h_{ef} - \Delta h_{ef} \tag{4}$$

$$\Delta h_{ef,cal} = max\{1{,}25 \cdot d;\ 25\ mm\} \tag{5}$$

where: $h_{ef,fat}$ effective embedment depth for fatigue design

h_{ef} effective embedment depth for static design

Δh_{ef} effective reduction of embedment depth for static design

d diameter of the fastener

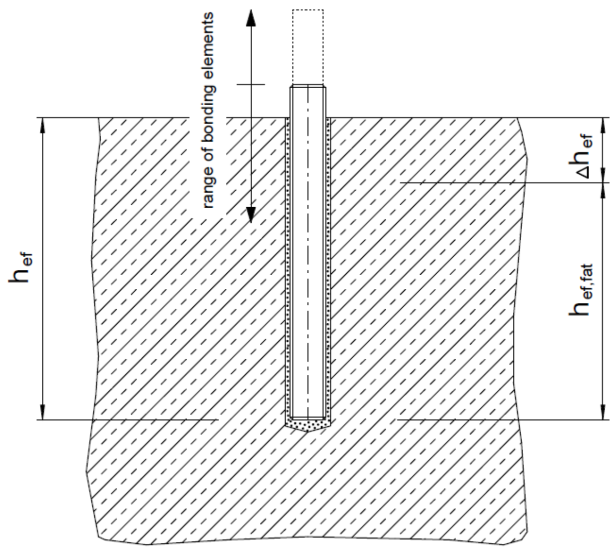


Figure 2.1 Effective embedment depth $h_{ef,fat}$ of bonded fasteners

Each failure mode (steel failure, concrete cone failure, pull-out failure, combined pull-out and concrete failure, splitting failure, blow-out failure, concrete edge failure and pry-out failure) shall be verified separately.

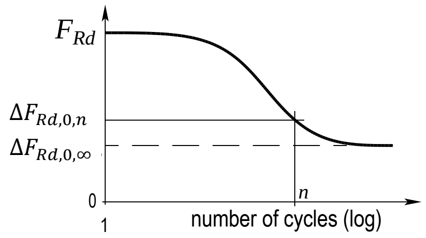
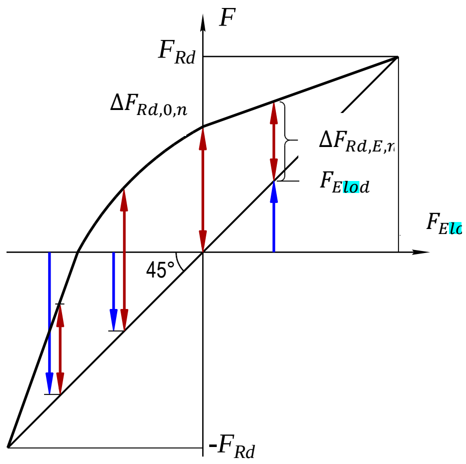
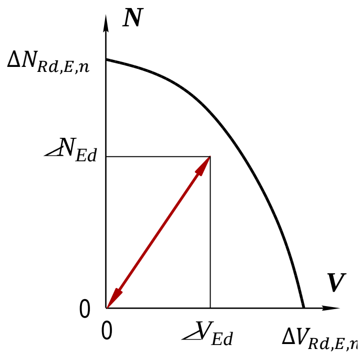
The general form of the ultimate limit state verification for combined tension and shear with fatigue influence is as follows:

$$(\Delta N_{Ed}/\,\Delta N_{Rd})^{\alpha} + (\Delta V_{Ed}/\,\Delta V_{Rd})^{\alpha} \leq 1{,}0 \qquad (6)$$

For combined tension and shear loading Equation (6) shall be satisfied for steel failure and concrete failure separately.

The design of fasteners with fatigue influence shall be conducted in accordance with the concept provided in Table 2.1. The Equations in Section 2.2.3 – design method I - and Section 2.3.2 – design method II – shall be used.

Table 2.1 Concept for design of fasteners with fatigue influence$\Delta F_{Rd,0,n}$

Step		Result	Note
1	S-N-curve for design fatigue resistance with a lower cyclic load $F_{Elod} = 0$ and n load cycles ($\Delta F_{Rd,0,n}$)		S-N-curves can be determined for each failure mode. At a minimum, the value of the fatigue limit resistance, ($\Delta F_{Rd,0,\infty}$), shall be given
2	Fatigue resistance with an arbitrary lower cyclic load F_{Elod} and n load cycles ($\Delta F_{Rd,E,n}$)		The Goodman diagram allows the determination of the fatigue resistance, ($\Delta F_{Rd,E,n}$), in relation to the lower cyclic load, F_{Elod}, for a given number of load cycles, n
3	Verification for the ultimate limit state of fatigue resistance with consideration of the interaction [1)]		The interaction diagrams are adapted in consideration of the lower cyclic load F_{Elod}

[1)] e.g. for steel and concrete failure, respectively: $(\Delta N_{Ed}/\Delta N_{Rd,s(c),E,n})^{\alpha_{s(c)}} + (\Delta V_{Ed}/\Delta V_{Rd,s(c),E,n})^{\alpha_{s(c)}} \leq 1{,}0$

2.2 Design method I – Complete method

2.2.1 Conditions of applicability

(a) a precise allocation of the design lower cyclic load, F_{Elod}, for pulsating load ② or alternating load ④, respectively, or a precise allocation of the design upper negative cyclic load, F_{Eupd}, ③ 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:

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

The fatigue resistance corresponds to the design fatigue limit resistance ($n = \infty$) for pulsating or alternating load, respectively, with consideration of the lower cyclic load F_{Elod}.

Design fatigue cyclic load:

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

Only the design fatigue relevant load is taken into account.

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

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

The fatigue resistance corresponds to the design fatigue resistance with an origin load ($F_{Elod} = 0$) and n load cycles ①.

Design fatigue cyclic load:

$\Delta F_{Ed} = F_{Eupd}$ for $F_{Elod} > 0$, but the positive amount of F_{Elod} is not known ②

$\Delta F_{Ed} = -F_{Elod}$ for $F_{Eupd} < 0$, but the negative amount of F_{Eupd} is not known ③

ΔF_{Ed} must be known, for $F_{Elod} < 0$ and $F_{Eupd} > 0$, but the amounts of F_{Elod} and F_{Eupd} are not known ④

Note: Load cases ①, ②, ③ and ④ are illustrated in Figure 2.3.

All acting loads are assumed to be fatigue-relevant.

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

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

The fatigue resistance corresponds to the design fatigue resistance for pulsating or alternating load, respectively, with consideration of the lower cyclic load F_{Eud} and n load cycles.

Design fatigue cyclic load:

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

Only the design fatigue relevant load is taken into account.

2.2.2 Calculation of fatigue resistance, $\Delta F_{Rd,E,n}$, in relation to the lower cyclic load, F_{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, $\Delta F_{Rk,0,n}$, for a given number of load cycles, n, and for each failure mode.

In cases where actions consist of a combination of a non-negligible lower cyclic load and a fatigue (cyclic) relevant part, 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.

Note: The definition of the lower cyclic load, F_{Elod}, depends on the following cases (see also Figure 2.2):

a) the static load, F_{Ed}, corresponds to F_{Elod};

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

c) the static load, F_{Ed}, corresponds to $F_{Eupd} = F_{Ed} = F_{Elod} + \Delta F_{Ed}$.

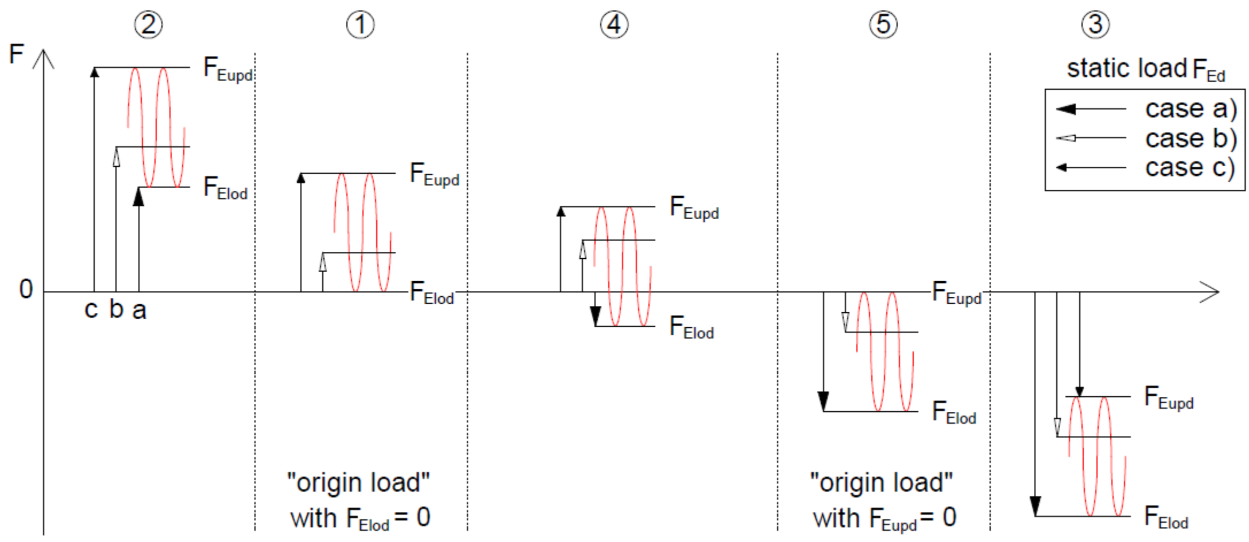


Figure 2.2 Superimposition of static and fatigue cyclic loads

Figure 2.3 shows the Goodman-diagram for a selected number of oscillation cycles n. F_{Elod} is the lower cyclic load and $\Delta F_{Rd,E,n}$ is the corresponding fatigue resistance. The design fatigue resistance, $\Delta F_{Rd,0,n}$, with lower cyclic load, F_{Elod}, equal to zero for n load cycles and the static resistance, F_{Rd}, can be derived by applying the appropriate material partial safety factors to the characteristic values.

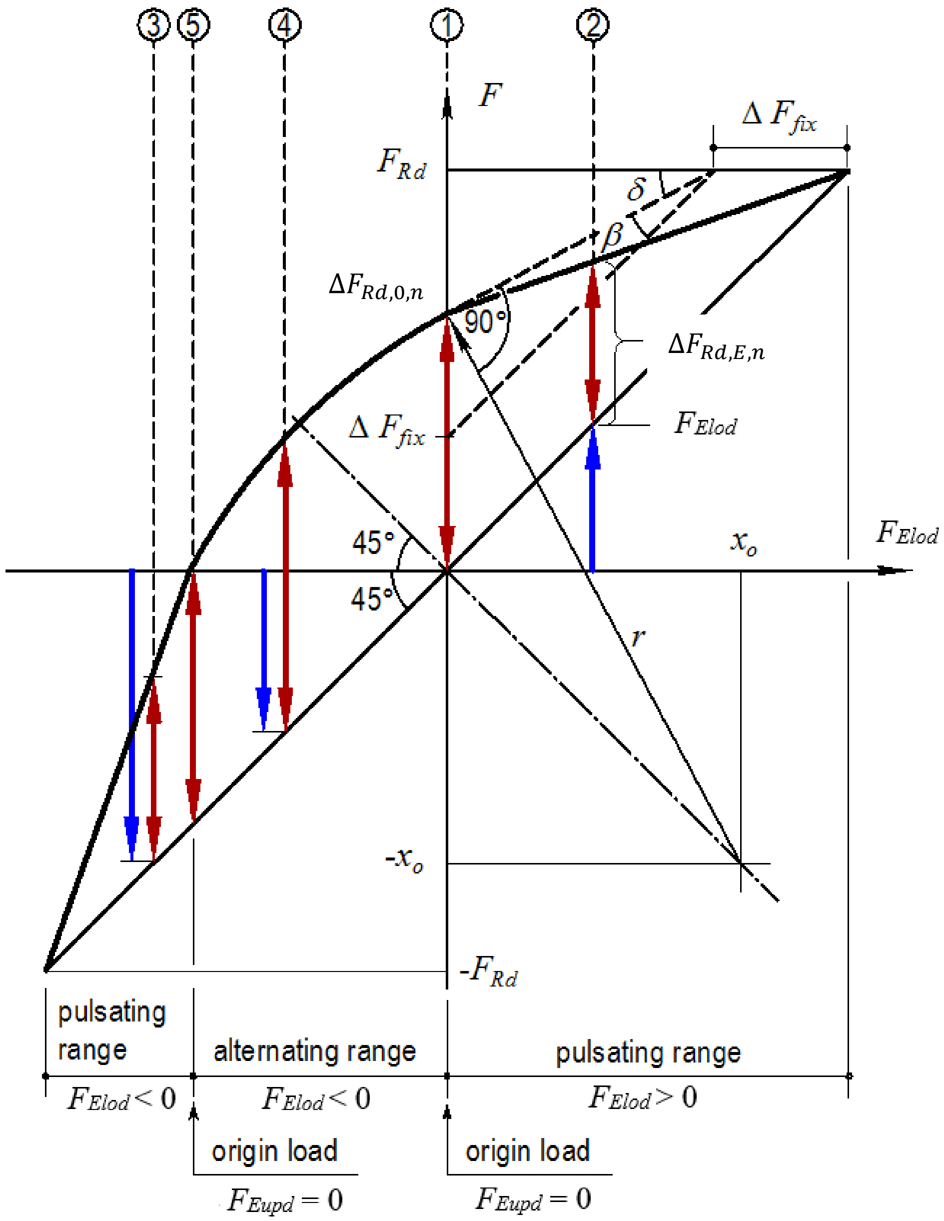


Figure 2.3 Goodman diagram. Fatigue resistance depending on the lower cyclic load F_{Elod}.
Note: $\Delta F_{fix} = 0{,}9 \cdot \Delta F_{Rd,0,\infty}$

Pulsating load: For oscillations with the same algebraic sign the design fatigue resistance for n cycles, $\Delta F_{Rd,E,n}$, is calculated according to Equations (7) and (8), respectively.

② $$\Delta F_{Rd,E,n} = \Delta F_{Rd,0,n} \cdot \left(1 - \frac{F_{Elod}}{F_{Rd}}\right) \quad \text{for } F_{Elod} \geq 0 \qquad (7)$$

③ $$\Delta F_{Rd,E,n} = \Delta F_{Rd,0,n} \cdot \left(1 + \frac{F_{Elod}+\Delta F_{Rd,0,n}}{F_{Rd}-\Delta F_{Rd,0,n}}\right) \quad \text{for } F_{Elod} \leq -\Delta F_{Rd,0,n} \qquad (8)$$

Alternating load: For oscillations with alternating algebraic sign the design fatigue resistance for n cycles, $\Delta F_{Rd;E;n}$, is calculated according to Equation (9).

④ $$\Delta F_{Rd,E,n} = \sqrt{r^2 - (F_{Elod} - x_0)^2} - x_0 - F_{Elod} \quad \text{for } -\Delta F_{Rd,0,n} < F_{Elod} < 0 \qquad (9)$$

where

$x_0 = r \cdot \sin\delta$ $\qquad r = \sqrt{0{,}5} \cdot \Delta F_{Rd,0,n} / \sin\beta_0$

$\beta = \frac{\pi}{4} - \delta\ [Rad]$ $\qquad \delta = arctan\left(\frac{F_{Rd} - \Delta F_{Rd,0,n}}{F_{Rd} - \Delta F_{fix}}\right)$

$\Delta F_{fix} = 0{,}9 \cdot \Delta F_{Rd,0,\infty}$

2.2.3 Required verifications for design

The required verifications for tension load are summarised in Table 2.2.

Table 2.2 Required verifications for tension loading

		Single fastener	Fastener group	
			most loaded fastener	fastener group
1	Steel failure	$\frac{\Delta N_{Ed}}{\Delta N_{Rd,s,E,n}} \leq 1{,}0$	$\frac{\Delta N_{Ed}}{\psi_{FN} \cdot \Delta N_{Rd,s,E,n}} \leq 1{,}0$	
2	Pull-out failure	$\frac{\Delta N_{Ed}}{\Delta N_{Rd,p,E,n}} \leq 1{,}0$	$\frac{\Delta N_{Ed}}{\psi_{FN} \cdot \Delta N_{Rd,p,E,n}} \leq 1{,}0$	
3	Combined pull-out and concrete failure 1)	$\frac{\Delta N_{Ed}}{\Delta N_{Rd,p,E,n}} \leq 1{,}0$		$\frac{\Delta N_{Ed}}{\Delta N_{Rd,p,E,n}} \leq 1{,}0$
4	Concrete cone failure	$\frac{\Delta N_{Ed}}{\Delta N_{Rd,c,E,n}} \leq 1{,}0$		$\frac{\Delta N_{Ed}}{\Delta N_{Rd,c,E,n}} \leq 1{,}0$
5	Concrete splitting failure	$\frac{\Delta N_{Ed}}{\Delta N_{Rd,sp,E,n}} \leq 1{,}0$		$\frac{\Delta N_{Ed}}{\Delta N_{Rd,sp,E,n}} \leq 1{,}0$
6	Concrete blow-out failure 2)	$\frac{\Delta N_{Ed}}{\Delta N_{Rd,cb,E,n}} \leq 1{,}0$		$\frac{\Delta N_{Ed}}{\Delta N_{Rd,cb,E,n}} \leq 1{,}0$

1) not required for post-installed mechanical fasteners

2) not required for post-installed bonded fasteners

ψ_{FN} $< 1{,}0$ for fastener groups, taken from the European Technical Product Specification

$\Delta N_{Rd,x,E,n}$ $= \Delta F_{Rd,E,n}$, according to Equation (7), (8) or (9) for the relevant failure mode

ΔN_{Ed} design fatigue relevant action (tension)

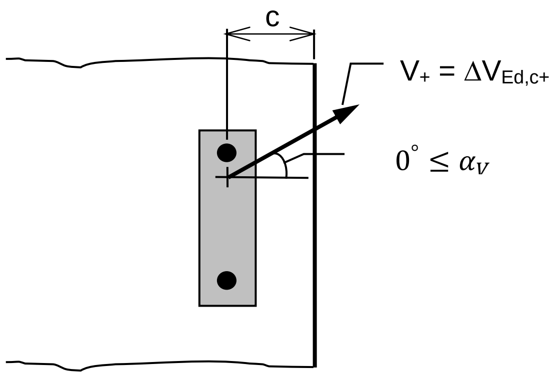
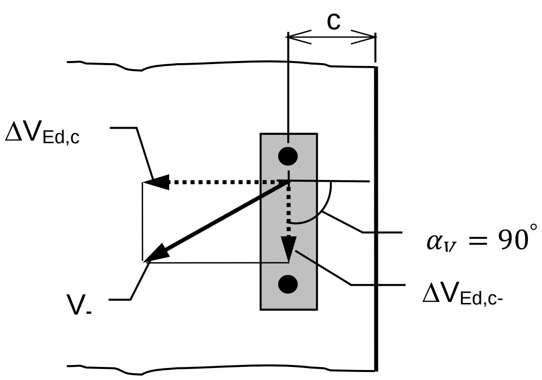
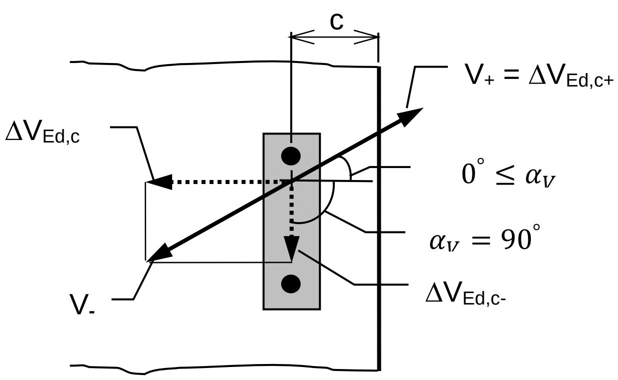
The required verifications for shear load are summarised in Table 2.3 and the distribution of the shear load ΔV_{Ed} acting on fasteners is given in Table 2.4.

Table 2.3 Required verifications for shear loading

		Single fastener	Fastener group	
			most loaded fastener	fastener group
1	Steel failure without lever arm	$\frac{\Delta V_{Ed}}{\Delta V_{Rd,s,E,n}} \leq 1{,}0$	$\frac{\Delta V_{Ed}}{\psi_{FV} \cdot \Delta V_{Rd,s,E,n}} \leq 1{,}0$	
2	Concrete Pry-out failure	$\frac{\Delta V_{Ed}}{\Delta V_{Rd,cp,E,n}} \leq 1{,}0$		$\frac{\Delta V_{Ed}}{\Delta V_{Rd,cp,E,n}} \leq 1{,}0$
3	Concrete edge failure (load acting towards the edge)	$\frac{\Delta V_{Ed,c+}}{\Delta V_{Rd,c+,E,n}} \leq 1{,}0$		$\frac{\Delta V_{Ed,c+}}{\Delta V_{Rd,c+,E,n}} \leq 1{,}0$
4	Concrete edge failure (load acting away from the edge)	$\frac{\Delta V_{Ed,c-}}{\Delta V_{Rd,c-,E,n}} \leq 1{,}0$		$\frac{\Delta V_{Ed,c-}}{\Delta V_{Rd,c-,E,n}} \leq 1{,}0$
5	Concrete failure (complete)	$\frac{\Delta V_{Ed,c+}}{\Delta V_{Rd,c+,E,n}} + \frac{\Delta V_{Ed,c-}}{\Delta V_{Rd,c-,E,n}} + \frac{\Delta V_{Ed}}{\Delta V_{Rd,cp,E,n}} \leq 1{,}0$		$\frac{\Delta V_{Ed,c+}}{\Delta V_{Rd,c+,E,n}} + \frac{\Delta V_{Ed,c-}}{\Delta V_{Rd,c-,E,n}} + \frac{\Delta V_{Ed}}{\Delta V_{Rd,cp,E,n}} \leq 1{,}0$

ψ_{FV}	$< 1{,}0$ for fastener groups, taken from the European Technical Product Specification
$\Delta V_{Rd,x,E,n}$	$= \Delta F_{Rd,E,n}$, according to Equation (7), (8) or (9) for the relevant failure mode
ΔV_{Ed}	design fatigue relevant action (shear)

Table 2.4 Distribution of the shear load ΔV_{Ed} acting on fasteners

1) Pulsating shear load $\Delta \boldsymbol{V_{Ed}} = \boldsymbol{V_+}$ acting to the edge of concrete member ($\mathbf{0}^\circ \leq \boldsymbol{\alpha_V} \leq \mathbf{90}^\circ$) Verification in accordance with Table 2.5 (series 3) only with $\Delta \boldsymbol{V_{Ed,c+}}$ (a)	
2) Pulsating shear load $\Delta \boldsymbol{V_{Ed}} = \boldsymbol{V_-}$ acting away from the edge of concrete member $\boldsymbol{V_-}$ is divided into the force components $\Delta \boldsymbol{V_{Ed,c-}}$ ($\boldsymbol{\alpha_V} = \mathbf{90}^\circ$) and $\Delta \boldsymbol{V_{Ed,cp}}$ Verification in accordance with Table 2.5 (series 3) with $\Delta \boldsymbol{V_{Ed,c-}}$ (b) and $\Delta \boldsymbol{V_{Ed,cp}}$ (c)	
3) Alternating shear load $\Delta \boldsymbol{V_{Ed}} = \boldsymbol{V_+} + \boldsymbol{V_-}$ acting to and away from the edge of concrete member $\boldsymbol{V_-}$ is divided into the force components $\Delta \boldsymbol{V_{Ed,c-}}$ ($\boldsymbol{\alpha_V} = \mathbf{90}^\circ$) and $\Delta \boldsymbol{V_{Ed,cp}}$ Verification with all possible combinations and/or orientations of $\Delta \boldsymbol{V_{Ed,c+}}$ (a), $\Delta \boldsymbol{V_{Ed,c-}}$ (b) and $\Delta \boldsymbol{V_{Ed,cp}}$ (c) in accordance with Table 2.5 (series 3)	

The required verifications for combined tension and shear load are summarised in Table 2.5. In case of concrete failure only verification number 2 or 3 is required. That depends on whether the fastener is positioned at the edge of concrete member or not.

Table 2.5 Required verifications for combined tension and shear loading

		Single fastener / Fastener group
1	Steel failure [1)]	$\left(\frac{\Delta N_{Ed}}{\psi_{FN} \cdot \Delta N_{Rd,s,E,n}}\right)^{\alpha_{sn}} + \left(\frac{\Delta V_{Ed}}{\psi_{FV} \cdot \Delta V_{Rd,s,E,n}}\right)^{\alpha_{sn}} \leq 1{,}0$
2	Concrete failure without influence of an edge of concrete member	$\left(\frac{\Delta N_{Ed}}{\Delta N_{Rd,c(p,sp,cb),E,n}}\right)^{\alpha_c} + \left(\frac{\Delta V_{Ed}{}^{2)}}{\Delta V_{Rd,cp,E,n}}\right)^{\alpha_c} \leq 1{,}0$
3	Concrete failure [3)] at the edge of concrete member	$\left(\frac{\Delta N_{Ed}}{\Delta N_{Rd,c(p,sp,cb),E,n}}\right)^{\alpha_c} + \left(\frac{\Delta V_{Ed,c+}{}^{(a)}}{\Delta V_{Rd,c+,E,n}} + \frac{\Delta V_{Ed,c-}{}^{(b)}}{\Delta V_{Rd,c-,E,n}} + \frac{\Delta V_{Ed,cp}{}^{(c)}}{\Delta V_{Rd,cp,E,n}}\right)^{\alpha_c} \leq 1{,}0$

1)	verification for most loaded fastener in a fastener group
2)	in case of alternating load ($\Delta V_{Ed} = \Delta V_{Ed,cp}$) only the direction of force with the higher amount is taken into account
3)	in case of pull-out of the most loaded anchor, the factor ψ_{FN} must be considered in the term for tension utilization
(a), (b), (c)	decisive acting shear loads ($\Delta V_{Ed,c+}\ (a)$, $\Delta V_{Ed,c-}\ (b)$, $\Delta V_{Ed,cp}\ (c)$) for verification see Table 2.4
$\psi_{FN} = \psi_{FV}$	$= 1{,}0$ for single fastener
ψ_{FN}	$< 1{,}0$ for fastener groups, taken from the European Technical Product Specification
ψ_{FV}	$< 1{,}0$ for fastener groups, taken from the European Technical Product Specification
α_{sn}	$\leq 2{,}0$ taken from the European Technical Product Specification
α_c	$= 1{,}5$ or taken from the European Technical Product Specification
$\Delta N_{Rd,c(p,sp,cb),E,n}$	$= min\ (\Delta N_{Rd,c;E,n};\ \Delta N_{Rd,p,E,n};\ \Delta N_{Rd,sp,E,n};\ \Delta N_{Rd,cb,E,n})$
$\Delta V_{Rd,c+,E,n}$	determination with $V_{Rk,c}$ according to EN 1992-4 [6], Equation (7.40), using an angle of $0^\circ \leq \alpha_V \leq 90^\circ$
$\Delta V_{Rd,c-,E,n}$	determination with $V_{Rk,c}$ according to EN 1992-4 [6], Equation (7.40), using an angle of $\alpha_V = 90^\circ$
$\Delta V_{Rd,cp,E,n}$	determination with $V_{Rk,cp}$ according to EN 1992-4 [6], Equations (7.39a), (7.39b), (7.39c) respectively (7.39d)

Note: If multiple fatigue relevant shear loads are acting simultaneously on the anchorage then the following assumption can be used:

For every shear load direction (static and fatigue load) the coefficient for the utilization β_{Vi} is calculated for its one (with $\beta_{Vi} = \Delta V_{Ed,i} / \Delta V_{Rd,i}$).

For design purpose the decisive direction is the direction of max β_V.

Therefore it is assumed that all shear forces act in the direction of max β_V.

Finally the interaction with tension forces, when present, can be considered.

2.3 Design method II – Simplified method

2.3.1 Conditions of applicability

A precise allocation of the design lower cyclic load, F_{Elod}, for pulsating load ② or alternating load ④, respectively, or a precise allocation of the design upper negative cyclic load, F_{Eupd}, ③ 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:

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

The fatigue resistance corresponds to the design fatigue limit resistance with an origin load ($F_{Elod} = 0$) ①.

Design fatigue cyclic load:

$\Delta F_{Ed} = F_{Eupd}$ for $F_{Elod} > 0$, but the positive amount of F_{Elod} is not known ②

$\Delta F_{Ed} = -F_{Elod}$ for $F_{Eupd} < 0$, but the negative amount of F_{Eupd} is not known ③

ΔF_{Ed} must be known, for $F_{Elod} < 0$ and $F_{Eupd} > 0$, but the amounts of F_{Elod} and F_{Eupd} are not known ④

Note: Load cases ①, ②, ③ and ④ are illustrated in Figure 2.3.

All acting loads are assumed to be fatigue-relevant.

2.3.2 Required verifications for design

The required verifications corresponds to the verifications of design method I as per Section 2.2.3, Table 2.2, Table 2.3 and Table 2.5, with the fatigue resistance $\Delta F_{Rd,E,n} = \Delta F_{Rd,0,\infty}$ for steel and concrete failure for the axial direction ($F = N$) and the transverse direction ($F = V$).

3 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] EAD 330250-00-0601: Post installed fasteners in concrete under fatigue cyclic loading

[2] EN 206:2013: Concrete - Specification, performance, production and conformity, 2013

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

[4] EN 1991:2002 + AC 2009: Actions on structures

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

[6] FprEN 1992-4:2016: Design of concrete structures; Part 4: Design of fastenings for use in concrete, in Formal Vote process

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