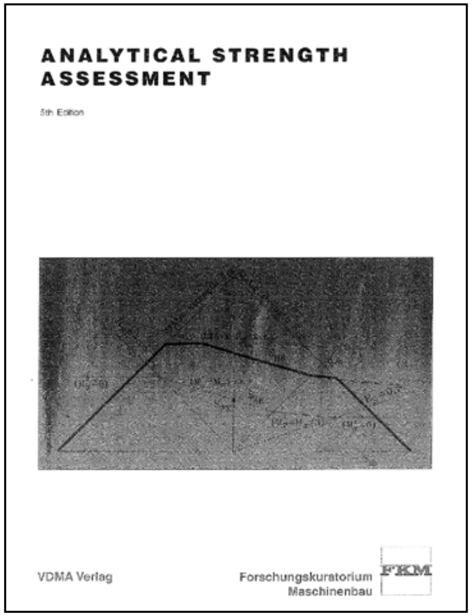
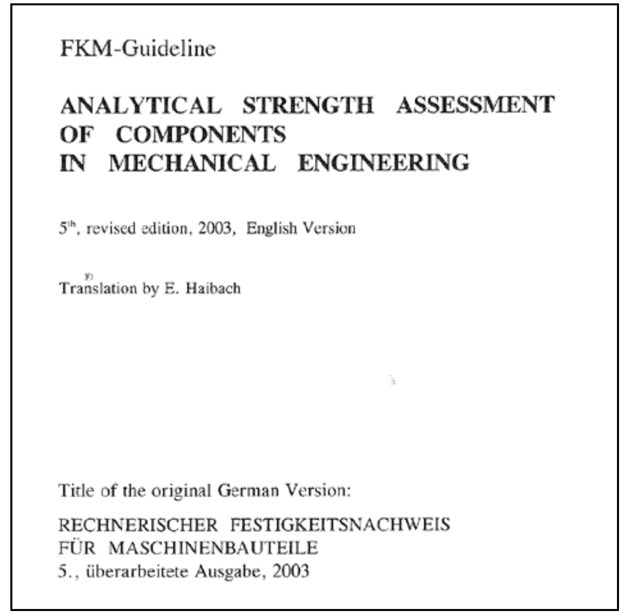



FKM-Guideline

ANALYTICAL STRENGTH ASSESSMENT
OF COMPONENTS
IN MECHANICAL ENGINEERING

5th, revised edition, 2003, English Version

Translation by E. Haibach

Title of the original German Version:

RECHNERISCHER FESTIGKEITSNACHWEIS
FÜR MASCHINENBAUTEILE
5., überarbeitete Ausgabe, 2003

EVALUACIÓN ANALÍTICA DE RESISTENCIA DE COMPONENTES EN INGENIERÍA MECÁNICA

Referencia: ANALYTICAL STRENGHT ASSESSMENT OF COMPONENTS IN MECHANICAL ENGINEERING

5th Edition

FKM

FORSCHUNGSKURATORIUM MASCHINENBAU

PANEL DE INVESTIGADORES DE CONSTRUCCIÓN DE MÁQUINAS

-PRESENTACIÓN INTRODUCCIÓN-

DISEÑO Y ANÁLISIS

Planteo de Problemas

Diseño: abarca la creación de formas y tamaños de un sistema, con cálculos preliminares, para alcanzar los requerimientos de performance.

Análisis: se refiere a la determinación del comportamiento de un sistema existente.

Sistema existente: implica la disponibilidad de la Ingeniería de Detalle.

EVALUACIÓN ANALÍTICA DE RESISTENCIA DE COMPONENTES EN INGENIERÍA MECÁNICA - FKM

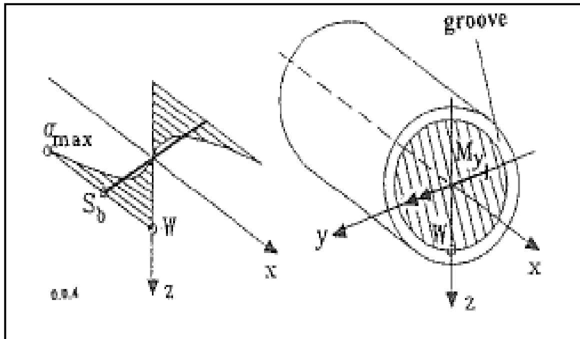
ASPECTOS GENERALES

• Es aplicable en Ingeniería Mecánica y en campos afines de la industria. Su aplicación debe acordarse entre las partes del contrato.

• Plantea un algoritmo, sobre la base de documentos, fórmulas y tablas. Hay software con aplicaciones de la guía.

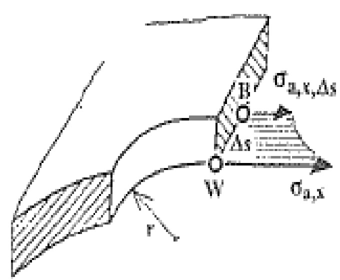
• Permite la evaluación analítica de resistencias para componentes de tipo:

1D – Barras – Ejes – Vigas



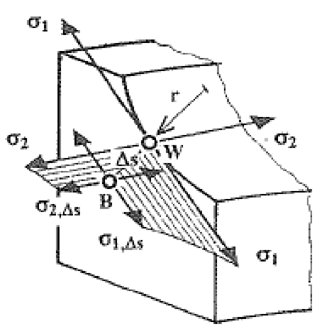
Rod-shaped (1D) component (round specimen with groove) in bending. Nominal stress S_b and maximum local stress σ_{max} at the reference point W.

2 D – Cáscaras – Discos - Placas



Shell-shaped (2D) component (shell with cutout detail). Local stresses $\sigma_{a,x}$ at the reference point W (peak value) and $\sigma_{a,x,\Delta s}$ at the neighbouring point B.

3 D – Bloques σ1– σ2 – σ3



Block-shaped (3D) component (flange). Local longitudinal stress σ_1 and circumferential stress σ_2 at the reference point W (peak values), stresses $\sigma_{1,\Delta s}$ and $\sigma_{2,\Delta s}$ at neighboring point B.

• Permite una evaluación de resistencia considerando tensiones:
a) **Nominales** - b) **Elásticas locales**, derivadas por ejemplo, de un análisis por elementos finitos.

• Las tensiones pueden ser determinadas de acuerdo a principios y técnicas conocidas:
- Analíticas elementales.
- Analíticas con métodos avanzados.
- Métodos numéricos.
- Mediciones experimentales.

• Permite una evaluación de resistencia para las siguientes condiciones:
a) **Estática** b) **Fatiga**. La evaluación de la resistencia estática es requerida previo a la evaluación de la resistencia a la fatiga.

• Aplicable a componentes producidos con o sin mecanizado, o por soldadura.

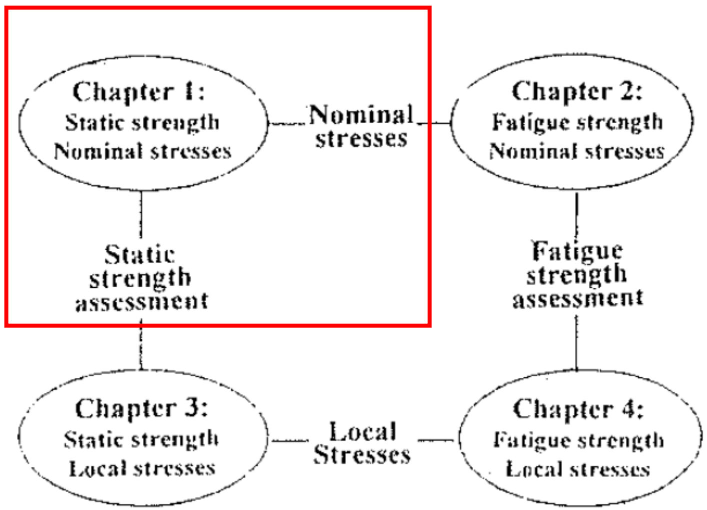
• Válida para componentes de:
- Acero, fundición de acero y fundición de hierro para temperaturas de -40 a 500 ºC.
- Aleaciones de aluminio y fundiciones de aluminio para temperaturas de -40 a 200 ºC.

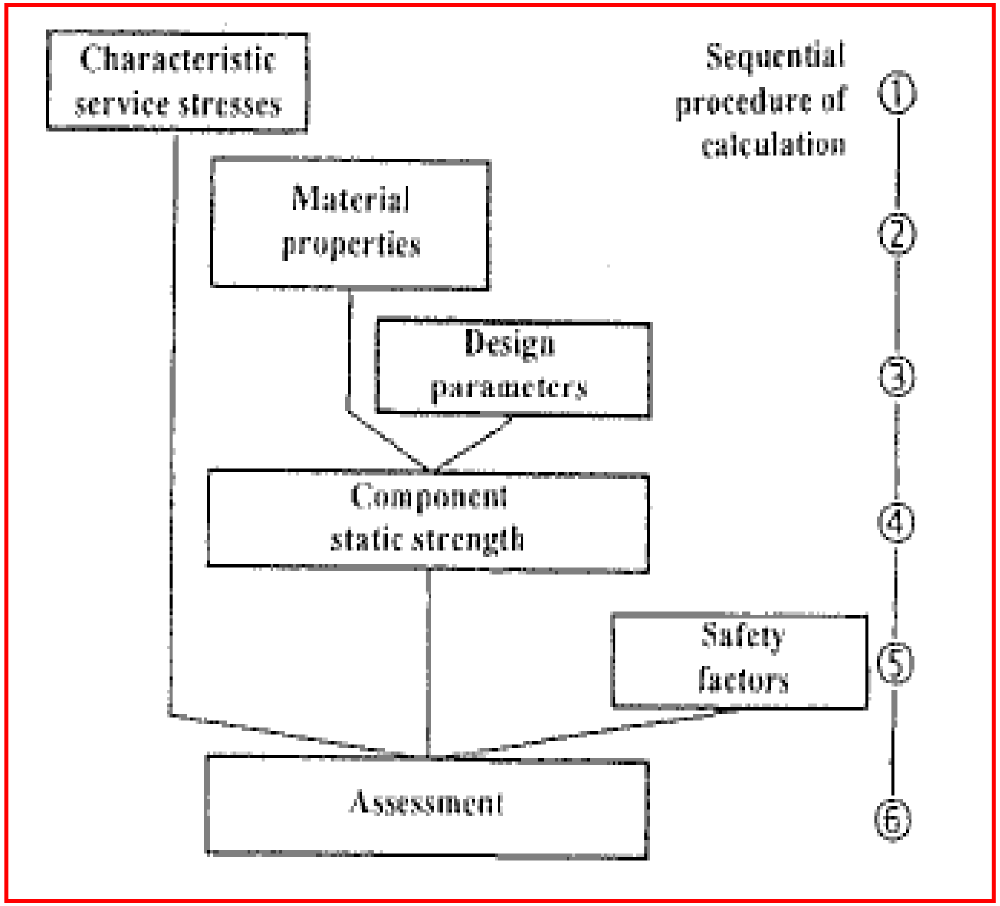
• Previo a la aplicación de la guía se debe decidir:
  - Que sección transversal o detalle estructural va a ser evaluado.
  - Que cargas de servicio serán consideradas.

Procedimientos de Cálculo

- Evaluación de la Resistencia Estática

Organización de la Guía





Ejemplo de aplicación

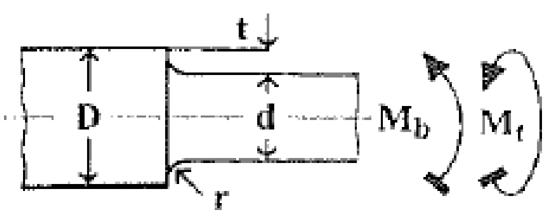
Shaft with shoulder

Key words: Shaft with shoulder, milled steel, assessment of static strength, assessment of fatigue limit, fatigue notch factor by calculation, type of overloading F2, multiaxial stresses, rotating bending and torsion. Supplemented: improved calculation of the fatigue limit, calculation using a class of utilization.

Given:

Stresses: constant amplitude loading in bending and torsion, where the nominal stresses are, Figure 6.1.1,

$S_b = \pm S_{a,b} = \pm 150$ MPa,
$T_t = T_{m,t} \pm T_{a,t} = 50$ MPa ± 100 MPa.



Material: 41 Cr 4 after DIN EN 10 083.

Dimensions:
D = 50 mm, d = 42 mm, r = 5 mm, t = 4 mm,
d / D = 0,84, r / d = 0,119, r / t = 1,25.

Surface: average roughness R_z = 10 µm.

Type of overloading: When overloaded in service the stress ratios remain constant (Type of overloading F2).

Safety requirement: according to the statements "with moderate consequences of failure; regular inspections".

Task: Assessment of the component static strength and of the component fatigue limit.

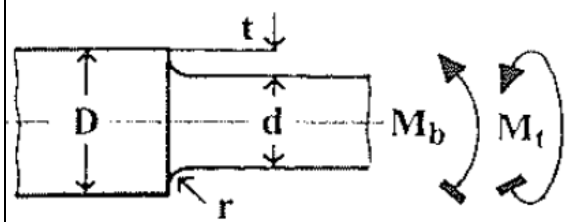
Method of calculation: Rod-shaped (1D) component. Assessment with nominal stresses, Chapter 1 and 2.

ASSESSMENT OF THE COMPONENT STATIC STRENGTH

1 CHARACTERISTIC STRESSES

$S_b = \pm S_{a,b} = \pm 150$ MPa,

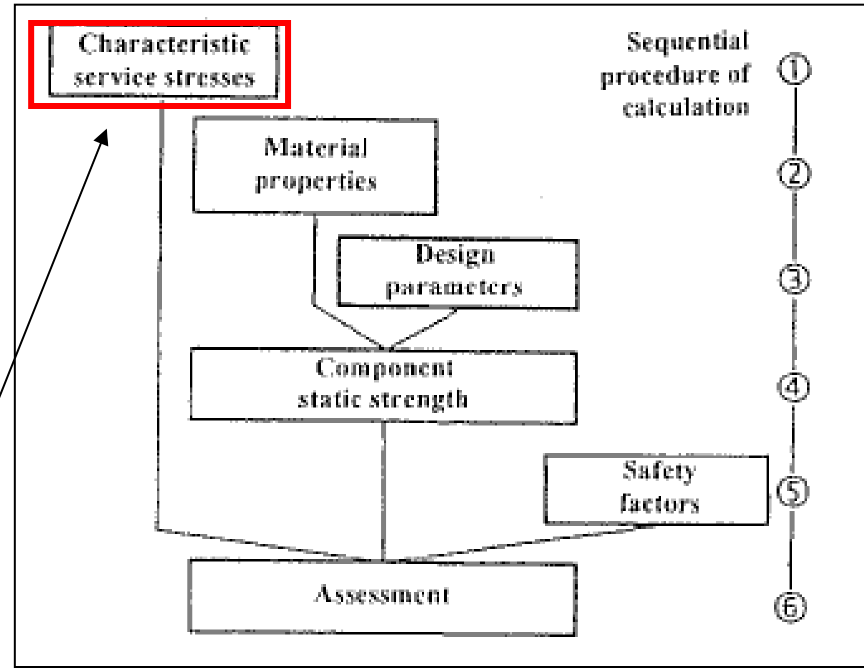
$T_t = T_{m,t} \pm T_{a,t} = 50$ MPa ± 100 MPa.



Maximum stresses

$$S_{max,ex,b} = + S_{a,b} = 150 \text{ MPa},$$

$$T_{max,ex,t} = T_{m,t} + T_{a,t} = 150 \text{ MPa}.$$



2 *MATERIAL PROPERTIES*

Tensile strength and yield strength for the standard dimension

$$R_{m,N} = 1000\ \text{MPa},\quad R_{p,N} = 800\ \text{MPa}. \quad \text{Tab. 5.1.4}$$

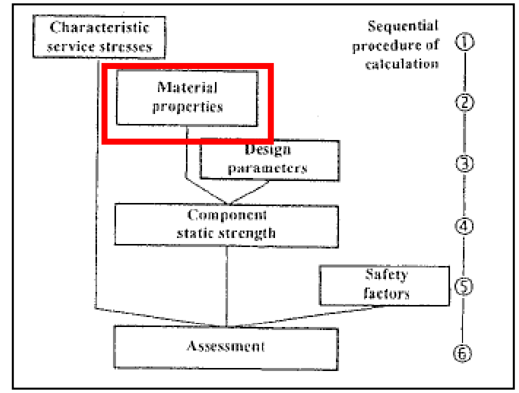
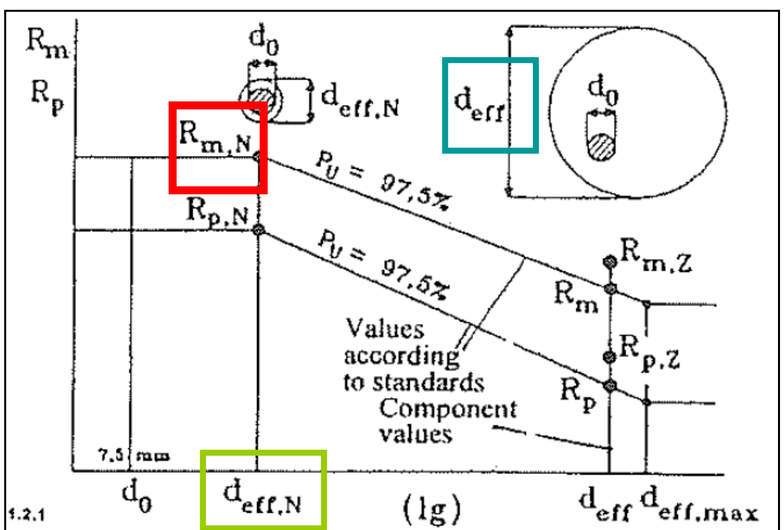


Table 5.1.4 Mechanical properties in MPa for quenched and tempered steels in the quenched and tempered condition, after DIN EN 10 083-1 (1996-10-00) ◊1. Notes ◊1 to ◊4 see next page.

Type of material, after DIN EN 10 027-1	Type of material, after DIN 17 200	Material No.	$R_{m,N}$	$R_{e,N}$ ◊2	$\sigma_{W,zd,N}$ ◊3	$\sigma_{Sch,zd,N}$ ◊3	$\sigma_{W,b,N}$ ◊3	$\tau_{W,s,N}$ ◊3	$\tau_{W,t,N}$ ◊3	$a_{d,m}$ ◊4	$a_{d,p}$ ◊4
41Cr4 41CrS4	41 Cr 4 41 CrS 4	1.7035 1.7039	1000	800	450	360	480	260	285	0,30	0,44

◊1 Effective diameter $d_{eff,N}$ = 40 mm for 30 CrNiMo 8 and 36 NiCrMo 16, $d_{eff,N}$ = 16 mm for all other types of material listed.



$$R_m = K_{d,m} \cdot K_A \cdot R_{m,N}\,, \qquad (1.2.1)$$
$$R_p = K_{d,p} \cdot K_A \cdot R_{p,N}\,,$$

$K_{d,m}$, $K_{d,p}$ technological size factors, Chapter 1.2.2,
K_A anisotropy factor, Chapter 1.2.3,
$R_{m,N}$, $R_{p,N}$ values of the semi-finished product or of a test piece defined by standards,

$$K_{d,m} = \frac{1 - 0,7686 \cdot a_{d,m} \cdot \lg(d_{eff} / 7,5\text{mm})}{1 - 0,7686 \cdot a_{d,m} \cdot \lg(d_{eff,N,m} / 7,5\text{mm})}\,,$$

$$K_{d,m} = \frac{1 - 0{,}7686 \cdot a_{d,m} \cdot \lg(d_{eff} / 7{,}5\mathrm{mm})}{1 - 0{,}7686 \cdot a_{d,m} \cdot \lg(d_{eff,N,m} / 7{,}5\mathrm{mm})} ,$$

Case 1

Components (also forgings) made of heat treatable steel, of case hardening steel, of nitriding steel, both nitrided or quenched and tempered, of heat treatable cast steel, of GGG, GT or GG.

Case 2

Components (also forgings) made of non-alloyed structural steel, of fine grained structural steel, of normalized quenched and tempered steel, of cast steel, or of aluminum materials.

2 *MATERIAL PROPERTIES*

Tensile strength and yield strength for the standard dimension

$R_{m,N} = 1000$ MPa, $R_{p,N} = 800$ MPa.

Technological size factor

$a_{d,m} = 0{,}30$, $a_{d,p} = 0{,}44$,
$d_{eff,N} = 16$ mm,
$d_{eff} = d = 42$ mm,
$K_{d,m} = 0{,}895$, $K_{d,p} = 0{,}841$.

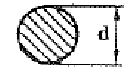
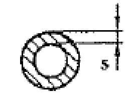
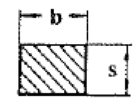
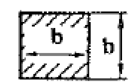
Anisotropy factor

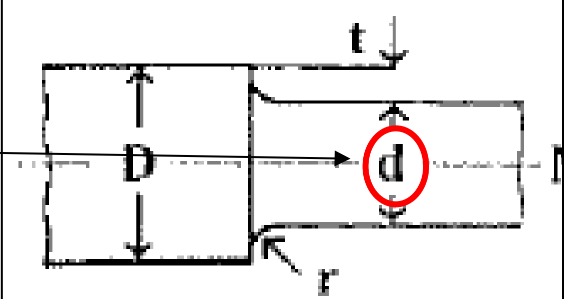
$K_A = 1$.

Tensile strength and yield strength of the component

$R_m = 0{,}895 \cdot 1 \cdot 1000$ MPa $=$ **895** MPa ,
$R_p = 0{,}841 \cdot 1 \cdot 800$ MPa $=$ **672** MPa . (1.2.1)

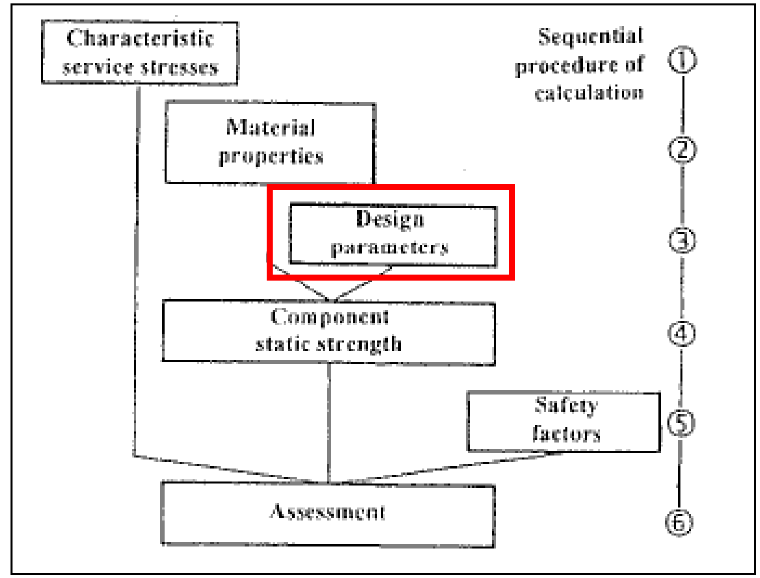
Table 1.2.3 Effective diameter d_{eff}

No.	Cross section	d_{eff} Case 1	d_{eff} Case 2
1		d	d
2		2s	s
3		2s	s
4		$\frac{2b \cdot s}{b+s}$	s
5		b	b



Nota: La resistencia se corrige también por tipo de solicitación, compresión o corte, y temperatura.

3 DESIGN PARAMETERS



The nominal values of the component static strength of rod-shaped (1D) components for axial (tension or compression), for bending, for shear, and for torsional stress are *1 *2 *3

$$
\begin{aligned}
S_{SK,zd} &= f_\sigma \cdot R_m / K_{SK,zd} , \\
S_{SK,b} &= f_\sigma \cdot R_m / K_{SK,b} , \\
T_{SK,s} &= f_\tau \cdot R_m / K_{SK,s} , \\
T_{SK,t} &= f_\tau \cdot R_m / K_{SK,t} .
\end{aligned}
\qquad (1.4.1)
$$

Referencia

Compression strength factor f_σ and shear strength factor f_τ

Kinds of material	f_σ for tension	f_σ for compress.	f_τ *1
Case harden'g steel	1	1	0,577
Stainless steel	1	1	0,577
Forging steel	1	1	0,577
Other kinds of steel	1	1	0,577
GS	1	1	0,577
GGG	1	1,3	0,65
Aluminum alloys	1	1	0,577

*1 $0{,}577 = 1/\sqrt{3}$, according to v. Mises criterion.

The design factors of rod-shaped (1D) non-welded components for axial (tension or compression), for bending, for shear, and for torsional stress are

$$
\begin{aligned}
K_{SK,zd} &= 1, \\
K_{SK,b} &= 1 / n_{pl,b} , \\
K_{SK,s} &= 1, \\
K_{SK,t} &= 1 / n_{pl,t} .
\end{aligned}
\qquad (1.3.1)
$$

$n_{pl,b}$ ... section factor *1,

Section factors

The section factors $n_{pl,b}$ and $n_{pl,t}$ allow for the influence of the stress gradient in bending and/or torsion in connection with the shape of the cross section on the static strength of components, Figure 1.3.1. They serve to make best use of the load carrying capacity of a component by accepting some yielding as the outside fiber stress exceeds the yield strength.

Bending moment M_b, yield strength R_p, static component strength for bending $S_{SK,b}$, section factor $n_{pl,b} = S_{SK,b} / R_p$.

For other types of steel, GS and GGG [*4] the section factors for tension or compression, for bending, for shear, and for torsion are [*5] [*6]

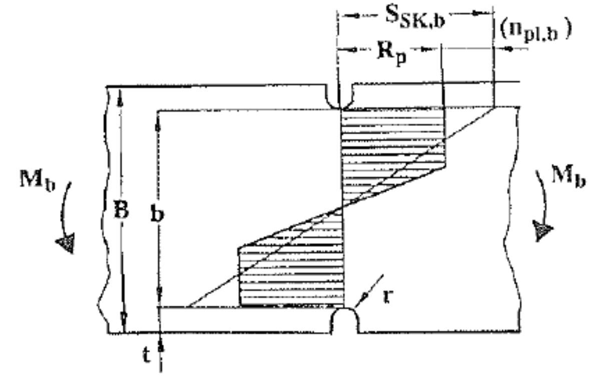
$n_{pl,zd} = 1,$

$n_{pl,b} = MIN\left(\sqrt{R_{p,max} / R_p}\ ;\ K_{p,b}\right),$

$n_{pl,s} = 1,$

$n_{pl,t} = MIN\left(\sqrt{R_{p,max} / R_p}\ ;\ K_{p,t}\right),$

$R_{p,max}$	constant, Table 1.3.1,
R_p	yield strength, Chapter 1.2,
$K_{p,b}$, $K_{p,t}$	plastic notch factors, Table 1.3.2.



Definition of the section factor $n_{pl,b}$ for bending of a notched bar, for instance.

Bending moment M_b, yield strength R_p, static component strength for bending $S_{SK,b}$, section factor $n_{pl,b} = S_{SK,b} / R_p$.

Light straight line: fictitious distribution of the stress calculated elastically. Solid angular line: real stress distribution when providing elastic ideal-plastic material behavior.

Table 1.3.1 Constant $R_{p,max}$ [*1].

Kind of material	Steel, GS	GGG	Aluminum alloys.
$R_{p,max}$ / MPa	1050	320	250

Table 1.3.2 Plastic notch factors $K_{p,b}$ and $K_{p,t}$.

Cross-section	Bending $K_{p,b}$	Torsion $K_{p,t}$
rectangle [*1]	1,5	-
circle	1,70 [*2]	1,33 [*3]
circular ring	1,27 [*4]	1 [*5]
I-section or box	[*6]	-

Para el ejemplo los parámetros de diseño son:

$$S_{SK,zd} = f_\sigma \cdot R_m / K_{SK,zd} ,$$
$$S_{SK,b} = f_\sigma \cdot R_m / K_{SK,b} ,$$
$$T_{SK,s} = f_\tau \cdot R_m / K_{SK,s} ,$$
$$T_{SK,t} = f_\tau \cdot R_m / K_{SK,t} .$$

Design factor

Flexión → $K_{SK,b} = \dfrac{1}{1{,}250\,(1)} = \mathbf{0{,}800}\ \ (\mathbf{1{,}000}).$

Torsión → $K_{SK,t} = \dfrac{1}{1{,}250\,(1)} = \mathbf{0{,}800}\ \ (\mathbf{1{,}000}).$

4 COMPONENT STATIC STRENGTH

Component static strength for bending and torsion

Component static strength for bending resulting from the tensile strength and the design factor:

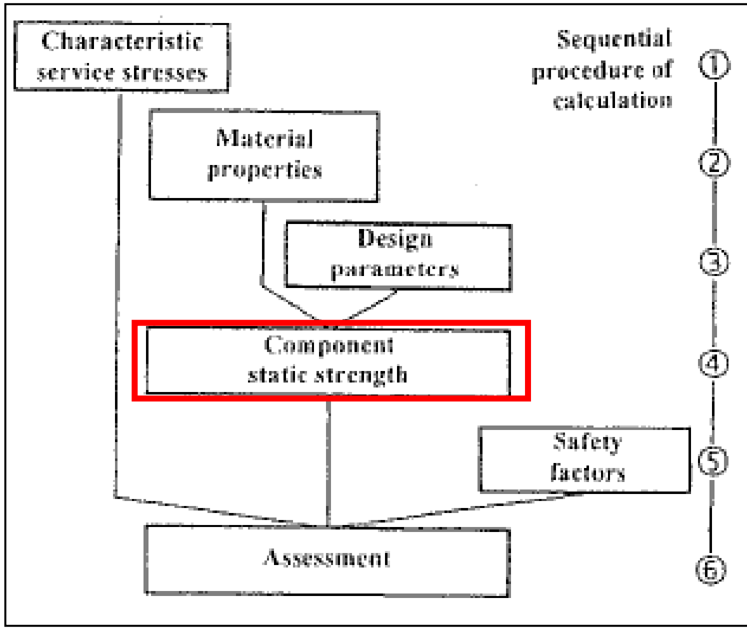
$f_\sigma = 1,$

$$S_{SK,b} = \frac{1 \cdot 895\,\text{MPa}}{0{,}800\,(1)} = \mathbf{1119}\ \ (895)\ \text{MPa}$$

Component static strength for torsion resulting from the shear strength factor f_τ, the tensile strength and the design factor:

$f_\tau = 0{,}58,$

$$T_{SK,t} = \frac{0{,}58 \cdot 895\,\text{MPa}}{0{,}800\,(1)} = \mathbf{646}\ \ (519)\ \text{MPa}. \quad (\ldots\ldots,$$



SAFETY FACTORS

Safety factors j_m and j_p for steel (not for GS) and for ductile wrought aluminum alloys ($A_5 \geq 12{,}5$ %).

j_m ◊1 j_p ◊2 j_{mt} ◊3 j_{pt} ◊4		Consequences of failure severe	 moderate ◊5
Probability of occurrence of the characteristic service stress values	high	2,0 **1,5** *1,5* *1,0*	1,75 **1,3** *1,3* *1,0*
	low ◊6	1,8 **1,35** *1,35* *1,0*	1,6 **1,2** *1,2* *1,0*

◊1 referring to the tensile strength R_m or to the strength at elevated temperature R_{mT},

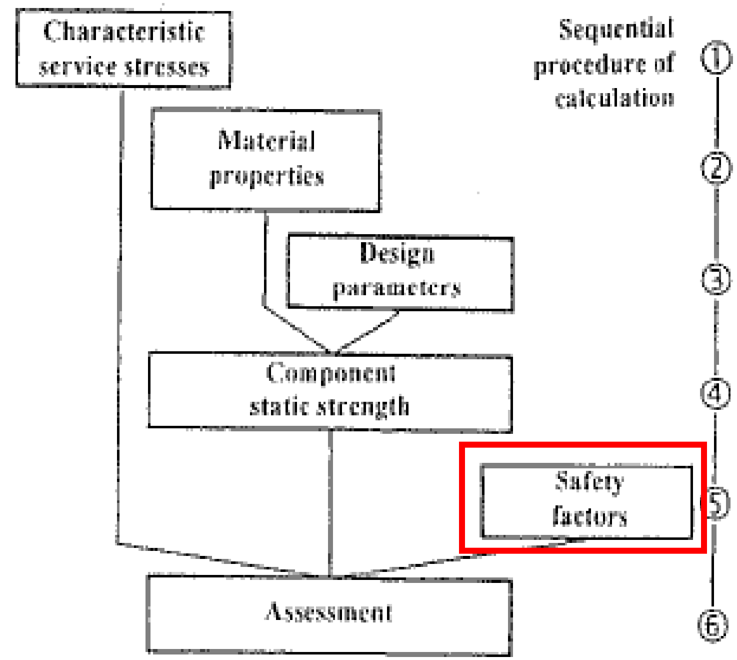
◊2 referring to the yield strength R_p or to the hot yield strength $R_{p,T}$,

◊3 referring to the creep strength $R_{m,Tt}$,

◊4 referring to the creep limit $R_{p,Tt}$.

◊5 moderate consequences of failure of a less important component in the sense of "no catastrophic effects" being associated with a failure; for example because of a load redistribution towards other members of a statically undeterminate system. Reduction by approximately 15 %.

◊6 or only infrequent occurrences of the characteristic service stress values, for example stresses due to an application of proof loads or due to loads during an assembling operation. Reduction by approximately 10 %.



Total safety factor

From the individual safety factors the total safety factor j_{ges} is to be derived *[4]:

$$j_{ges} = \mathrm{MAX}\left(\frac{j_m}{K_{T,m}}, \frac{j_p}{K_{T,p}} \cdot \frac{R_m}{R_p}, \frac{j_{mt}}{K_{Tt,m}}, \frac{j_{pt}}{K_{Tt,p}} \cdot \frac{R_m}{R_p}\right),$$

j_m … safety factors, Table 1.5.1 and 1.5.2,

$K_{t,m}$ … temperature factors, Chapter 1.2.5 *[5].

SAFETY FACTORS

In general there is

$$j_m = 2{,}0\ ,\quad j_p = 1{,}5\ .$$

For moderate consequences of failure and high probability of occurrence of the characteristic stress, however, there is

$$j_m = \mathbf{1{,}75}\ ,\quad j_p = \mathbf{1{,}3}.$$

For normal temperature there is

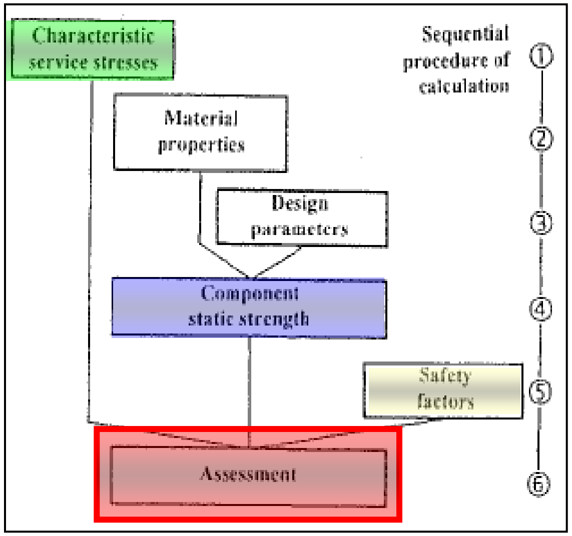
$$K_{T,m} = K_{T,p} = 1,$$

and in Eq. (1.5.4) the terms 3 and 4 have no relevance:

$$R_p = 685\ \mathrm{MPa}\ ,$$
$$R_m = 895\ \mathrm{MPa}\ ,$$

$$j_{ges} = \mathrm{MAX}\left(1{,}75; 1{,}3 \cdot \frac{895}{685}\right)$$
$$= \mathrm{MAX}\ (1{,}75;\ 1{,}70) = \mathbf{1{,}75}.$$

ASSESSMENT



Degree of utilization

In the context of the present Chapter the degree of utilization is the quotient of characteristic service stress (extreme stress $S_{max,ex,zd}$, ...) divided by the allowable static stress at the reference point *4.

$$a_{SK,zd} = \left| \frac{S_{max,ex,zd}}{S_{SK,zd} \, / \, j_{ges}} \right| \leq 1,$$

$$a_{SK,b} = \left| \frac{S_{max,ex,b}}{S_{SK,b} \, / \, j_{ges}} \right| \leq 1,$$

$$a_{SK,s} = \left| \frac{T_{max,ex,s}}{T_{SK,s} \, / \, j_{ges}} \right| \leq 1,$$

$$a_{SK,t} = \left| \frac{T_{max,ex,t}}{T_{SK,t} \, / \, j_{ges}} \right| \leq 1,$$

6 ASSESSMENT

Maximum stresses for bending and for torsion, see above,

$$S_{max,ex,b} = 150 \text{ MPa}, \quad T_{max,ex,t} = 150 \text{ MPa}.$$

Component static strength for bending and for torsion, see above,

$$S_{SK,b} = 1108 \ (895) \text{ MPa}, \quad T_{SK,t} = 642 \ (519) \text{ MPa}.$$

Degrees of utilization

Individual types of stress, bending and torsion

$$a_{SK,b} = \frac{150}{1119 \ (895)/1,75} = \mathbf{0,235} \ \ (\mathbf{0,294}), \qquad (1.6.1)$$

$$a_{SK,t} = \frac{150}{646 \ (519)/1,75} = \mathbf{0,406} \ \ (\mathbf{0,506}).$$

Combined types of stress

Rod-shaped (1D) non-welded components

$$a_{SK,Sv} = q \cdot a_{NH} + (1 - q) \cdot a_{GH} \leq 1,$$

where *8

$$a_{NH} = \frac{1}{2} \cdot \left(|s| + \sqrt{s^2 + 4 \cdot t^2} \right),$$

$$a_{GH} = \sqrt{s^2 + t^2},$$

$$s = a_{SK,zd} + a_{SK,b},$$

$$t = a_{SK,s} + a_{SK,t},$$

Grado utilización

$a_{SK,zd}, \ldots$ degree of utilization, Eq. (1.6.1),

and

$$q = \frac{\sqrt{3} - (1/f_\tau)}{\sqrt{3} - 1} \quad *9,$$

f_τ shear strength factor, Table 1.2.5.

[7] The applied strength hypothesis for combined types of stress is a combination of the normal stress criterion (NH) and the v. Mises criterion (GH). Depending on the ductility of the material the combination is controlled by a parameter q as a function of f_τ according to Eq. (1.6.7) and Table 1.6.1. For steel is q = 0 so that only the v. Mises criterion is of effect. For GGG is q = 0,264 so that both the normal stress criterion and the v. Mises criterion are of partial influence.

Ejemplo

Combined types of stress

$f_\tau = 1/\sqrt{3}$,

$q = 0$,

$s = a_{SK,b} = 0{,}235 \quad (0{,}294)$,

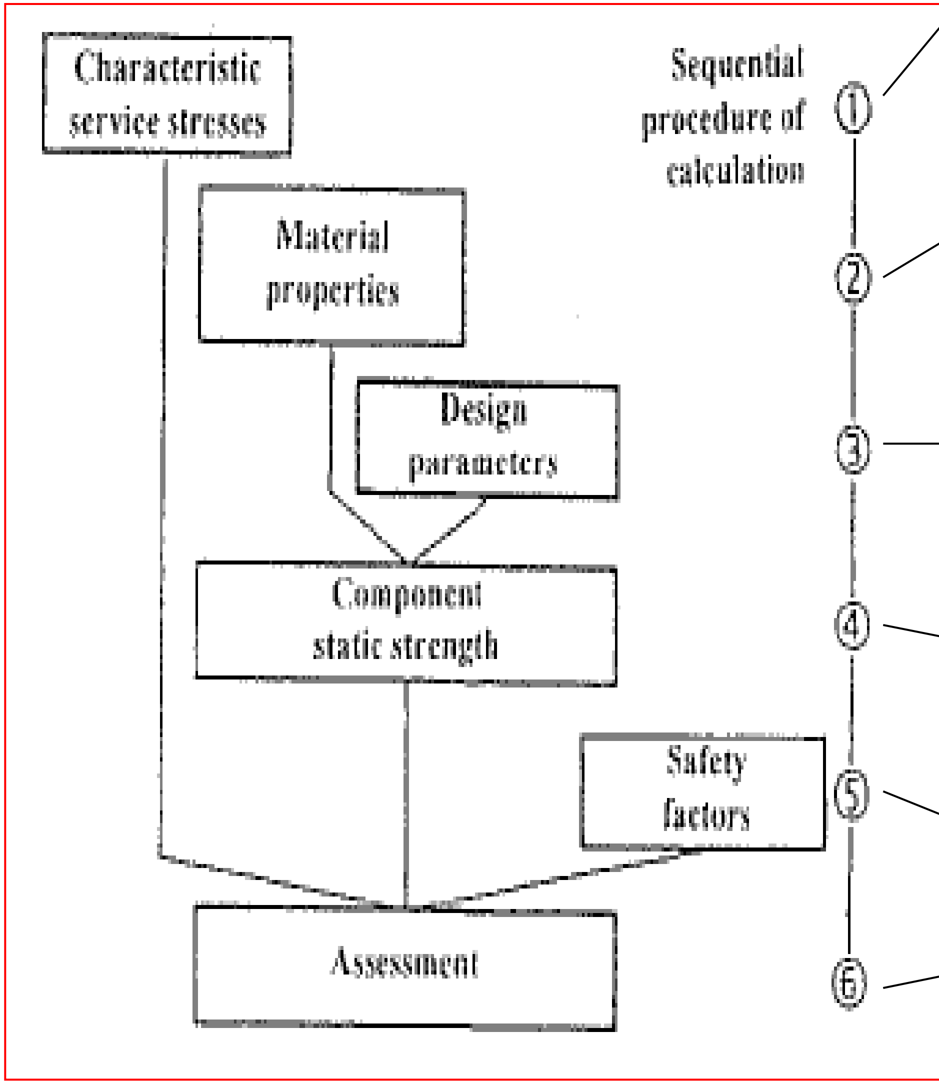
$t = a_{SK,t} = 0{,}406 \quad (0{,}506)$,

$a_{GH} = \sqrt{0{,}235\,(0{,}294)^2 + 0{,}406\,(0{,}506)^2}$

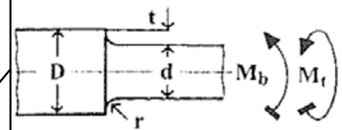
$= 0{,}469 \quad (0{,}585)$,

$a_{SK,Sv} = \mathbf{0{,}469} \quad \mathbf{(0{,}585)}$.

Ejemplo - Síntesis



$S_b = \pm S_{a,b} = \pm 150$ MPa,
$T_t = T_{m,t} \pm T_{a,t} = 50$ MPa $\pm$ 100 MP



Maximum stresses

$$S_{max,ex,b} = + S_{a,b} = \mathbf{150}\ \text{MPa},$$
$$T_{max,ex,t} = T_{m,t} + T_{a,t} = \mathbf{150}\ \text{MPa}.$$

Tensile strength and yield strength for the standard dimension

$$R_{m,N} = 1000\ \text{MPa},\quad R_{p,N} = 800\ \text{MPa}.$$
$$R_m = 0{,}895 \cdot 1 \cdot 1000\ \text{MPa} = \mathbf{895}\ \text{MPa},$$
$$R_p = 0{,}841 \cdot 1 \cdot 800\ \text{MPa} = \mathbf{672}\ \text{MPa}.$$

$$K_{SK,b} = \frac{1}{1{,}250\ (1)} = \mathbf{0{,}800}\ \ (\mathbf{1{,}000}).$$
$$K_{SK,t} = \frac{1}{1{,}250\ (1)} = \mathbf{0{,}800}\ \ (\mathbf{1{,}000}).$$

$$S_{SK,b} = \frac{1 \cdot 895\text{MPa}}{0{,}800\ (1)} = \mathbf{1119}\ \ (\mathbf{895})\ \text{MPa}.$$
$$T_{SK,t} = \frac{0{,}58 \cdot 895\text{MPa}}{0{,}800\ (1)} = \mathbf{646}\ \ (\mathbf{519})\ \text{MPa}.$$

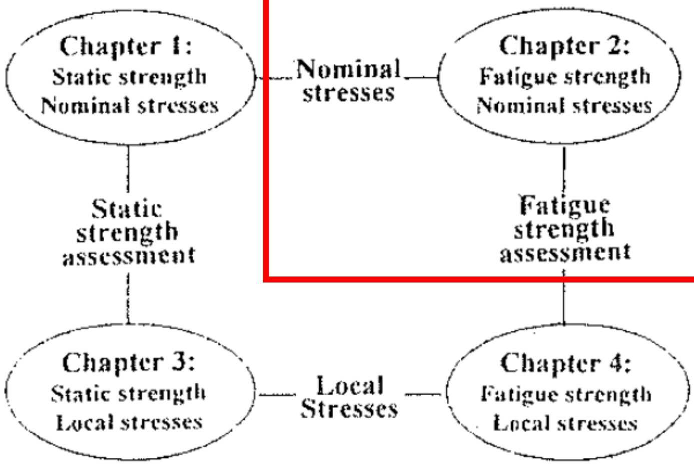
$$j_{ges} = \mathbf{1{,}75}.$$

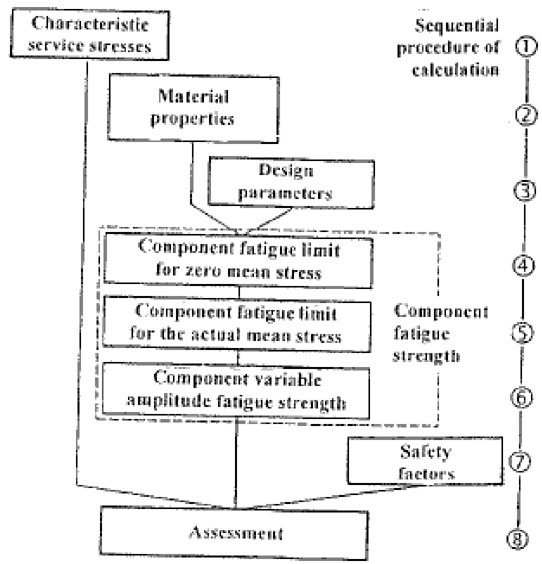
$$a_{SK,Sv} = \mathbf{0{,}469}\ \ (\mathbf{0{,}585}).$$

The degree of utilization of the component static strength is 47 % (or without section factor 59 %). The assessment of the static strength is achieved.

- Evaluación de la Resistencia a la Fatiga.

Organización de la Guía





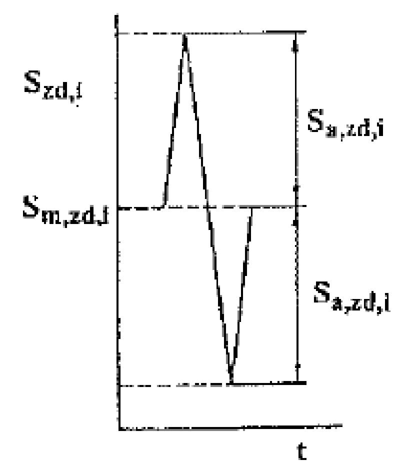
General

According to this chapter the parameters of the service stress spectra are to be determined. Spectra are applicable for $\overline{N} > 10^4$ cycles approximately.

Relevant are the stress spectra of the individual stress components. They are specified by a number of steps, i = 1 to j , giving the amplitudes $S_{a,zd,i}$, ... and the related mean values $S_{m,zd,i}$, ... of stress cycles, Figure 2.1.1, as well as the related numbers of cycles n_i according to the required fatigue life *1.

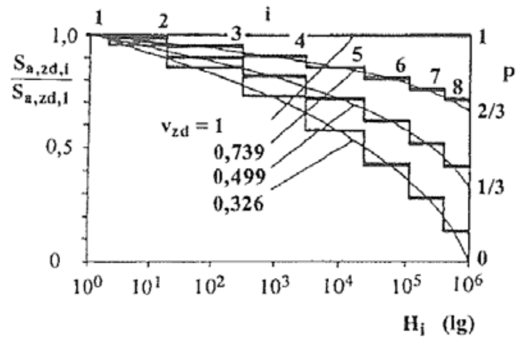
Example:
stress cycle (axial stress),
stress ratio:

$$R_{zd,i} = \frac{S_{m,zd,i} - S_{a,zd,i}}{S_{m,zd,i} + S_{a,zd,i}}$$



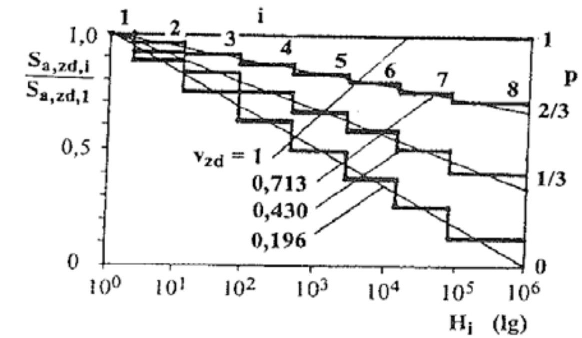
Distribución binomial

Distribución exponencial

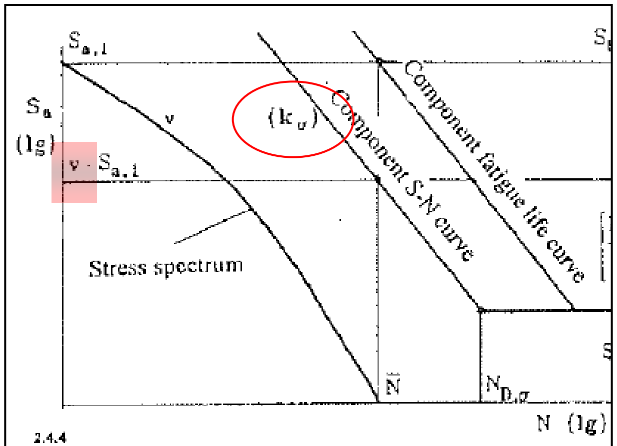


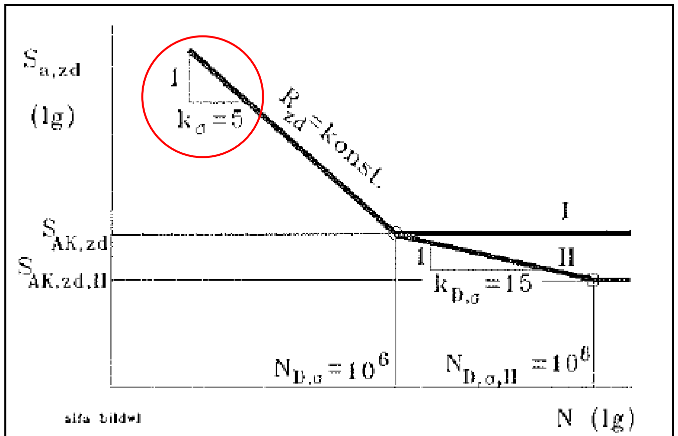
Step i	$S_{a,i} / S_{a,1}$			hi	H_i
p	0	1/3	2/3		
1	1	1	1	2	2
2	0,950	0,967	0,983	16	18
3	0,850	0,900	0,950	280	298
4	0,725	0,817	0,908	2720	3018
5	0,575	0,717	0,858	20000	23000
6	0,425	0,617	0,808	92000	115000
7	0,275	0,517	0,758	280000	395000
8	0,125	0,417	0,708	604982	1000000

Standard stress spectra.



Step i	$S_{a,i} / S_{a,1}$			hi	H_i
p	0	1/3	2/3		
1	1	1	1	2	2
2	0,875	0,917	0,958	10	12
3	0,750	0,833	0,917	64	76
4	0,625	0,750	0,875	340	416
5	0,500	0,667	0,833	2000	2400
6	0,375	0,583	0,792	11000	13400
7	0,250	0,500	0,750	61600	75000
8	0,125	0,417	0,708	924984	1000000

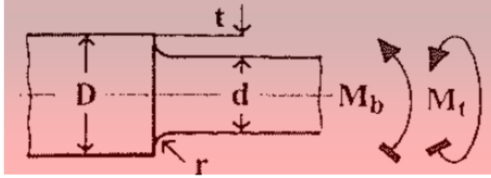


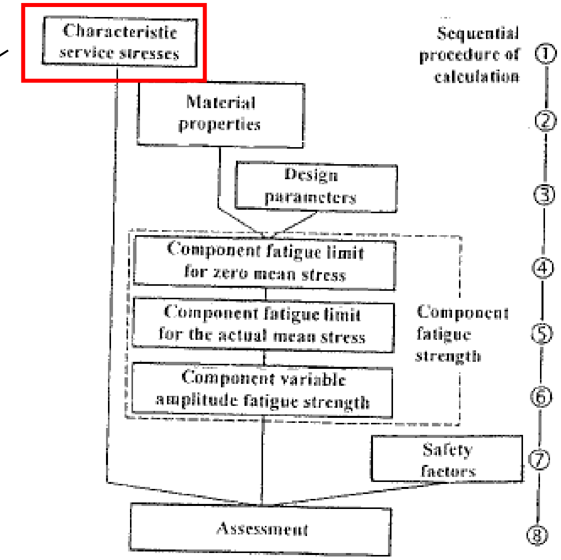


The damage potential is defined by *5 *9,

$$v_{zd} = {}^{k\sigma}\sqrt{\sum_{i=1}^{j} \frac{h_i}{\bar{\bar{H}}} \cdot \left(\frac{S_{a,zd,i}}{S_{a,zd,1}} \right)^{k\sigma}}$$

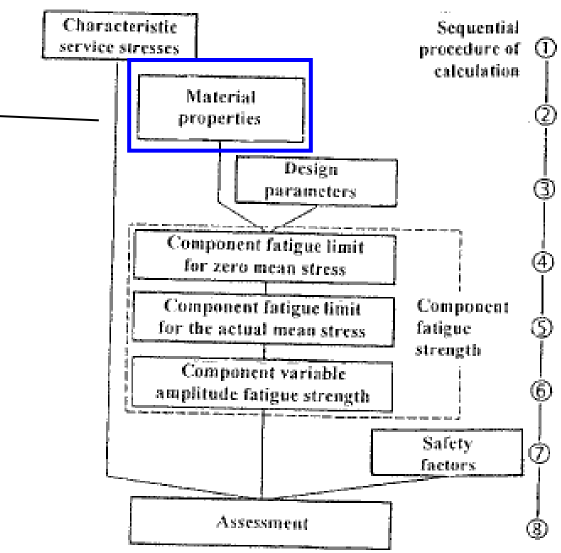
$$S_b = \pm S_{a,b} = \pm 150 \text{ MPa},$$
$$T_t = T_{m,t} \pm T_{a,t} = 50 \text{ MPa} \pm 100 \text{ MPa}.$$





For non-welded components the values according to standards of the material fatigue strength for completely reversed normal stress and shear stress *3 and for a number of cycles $N \geq N_{D,\sigma} = N_{D,\tau} = 10^6$ are *4

$$\sigma_{W,zd} = f_{W,\sigma} \; R_m \, ,$$
$$\tau_{W,s} = f_{W,\tau} \cdot \sigma_{W,zd} \, ,$$



Fatigue strength factors for completely reversed normal stress, $f_{W,\sigma}$, and shear stress, $f_{W,\tau}$ *1.

Kind of material	$f_{W,\sigma}$	$f_{W,\tau}$
Case hardening steel	0,40 *2	0,577 *2 *3
Stainless steel	0,40 *4	0,577
Forging steel	0,40 *4	0,577
Steel other than these	0,45	0,577
GS	0,34	0,577
GGG	0,34	0,65
GT	0,30	0,75
GG	0,30	0,85
Wrought aluminum alloys	0,30 *5	0,577
Cast aluminum alloys	0,30 *5	0,75

Ejemplo

$R_m = 895$ Mpa ,

$f_{W,\sigma} = 0{,}45$,

$\sigma_{W,zd} = 0{,}45 \cdot 895 \text{ MPa} = \mathbf{403}$ **Mpa**

$f_{W,\tau} = 0{,}58$,

$\tau_{W,s} = 0{,}58 \cdot 403 \text{ MPa} = \mathbf{233}$ **Mpa** .

Design parameters

$$S_{WK,zd} = \sigma_{W,zd} / K_{WK,zd} ,$$
$$S_{WK,b} = \sigma_{W,zd} / K_{WK,b} \, ^{*2} ,$$
$$T_{WK,s} = \tau_{W,s} / K_{WK,s} ,$$
$$T_{WK,t} = \tau_{W,s} / K_{WK,t} ,$$

$K_{WK,zd}$ ... design factor, (

$$\sigma_{W,zd} = f_{W,\sigma} \; R_m ,$$
$$\tau_{W,s} = f_{W,\tau} \cdot \sigma_{W,zd} ,$$

2.3.1.1 Non-welded components

Rod-shaped (1D) and shell-shaped (2D) non-welded components are to be distinguished.

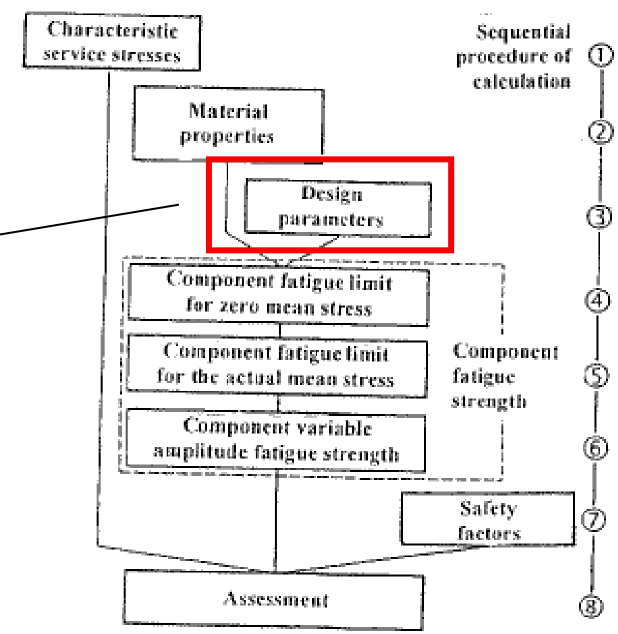
The design factors of rod-shaped (1D) non-welded components for axial, for bending, for shear and for torsional stresses are [*1], (2.3.1)

$$K_{WK,zd} = \left(K_{f,zd} + \frac{1}{K_{R,\sigma}} - 1 \right) \cdot \frac{1}{K_V \cdot K_S \cdot K_{NL,E}} ,$$

$$K_{WK,b} = \left(K_{f,b} + \frac{1}{K_{R,\sigma}} - 1 \right) \cdot \frac{1}{K_V \cdot K_S \cdot K_{NL,E}} ,$$

$$K_{WK,s} = \left(K_{f,s} + \frac{1}{K_{R,\tau}} - 1 \right) \cdot \frac{1}{K_V \cdot K_S} ,$$

$$K_{WK,t} = \left(K_{f,t} + \frac{1}{K_{R,\tau}} - 1 \right) \cdot \frac{1}{K_V \cdot K_S} .$$



Factores

K_{WK}: diseño - K_f: fatiga muesca K_R: rugosidad K_V: Tratamiento superficial K_S: coatings
K_{NL}: Comportamiento no lineal (GG)

Kf: fatiga muesca → a desarrollar

Fatigue notch factors computed from stress concentration factors

$$K_{f,zd} = \frac{K_{t,zd}}{n_\sigma(r)},$$

$$K_{f,b} = \frac{K_{t,b}}{n_\sigma(r) \cdot n_\sigma(d)}$$

$$K_{f,s} = \frac{K_{t,s}}{n_\tau(r)},$$

$$K_{f,t} = \frac{K_{t,t}}{n_\tau(r) \cdot n_\tau(d)}$$

$K_{t,zd}$ …	stress concentration factor according to type of stress,
$n_\sigma(r)$ …	K_t-K_f ratio of the component for normal stress or for shear stress as a function of r,
$n_\sigma(d)$, …	K_t-K_f ratio of the component for normal stress or for shear stress as a function of d,
r	notch radius at the reference point,
d	diameter or width of the net notch section.

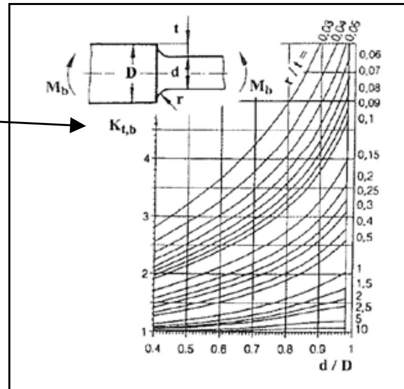
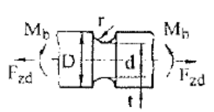
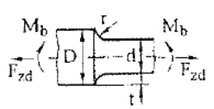
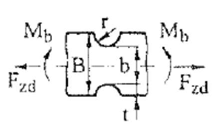
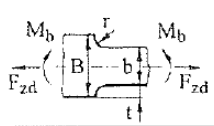
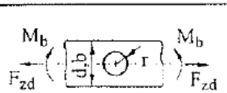


Figure 5.2.5 Stress concentration factors for round bars with shoulder fillet in bending, r > 0, d / D < 1.

(5.2.7)

Related stress gradients $\overline{G}_\sigma(r)$ and $\overline{G}_\tau(r)$ for simple structural details [*1].

Structural detail	$\overline{G}_\sigma(r)$ [*2*3]	$\overline{G}_\tau(r)$ [*4]
	$\frac{2}{r} \cdot (1+\varphi)$	$\frac{1}{r}$
	$\frac{2,3}{r} \cdot (1+\varphi)$	$\frac{1,15}{r}$
	$\frac{2}{r} \cdot (1+\varphi)$ [*5]	-
	$\frac{2,3}{r} \cdot (1+\varphi)$ [*5]	-
 Round specimen or flat member	$\frac{2,3}{r}$ [*5]	-

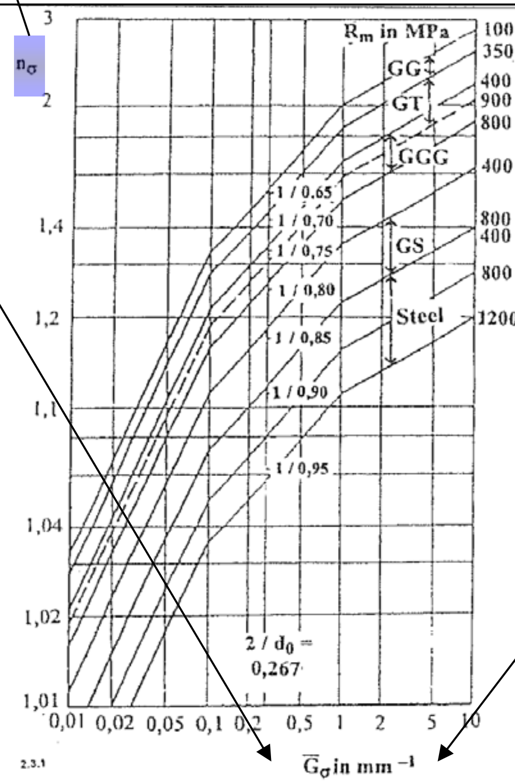


Figure 2.3.1 K_t-K_f ratios n_σ for normal stress.

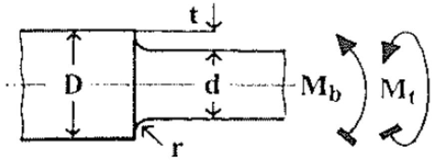
Related stress gradients

The related stress gradients as a function of the notch radius r at the reference point, $\overline{G}_\sigma(r)$ and $\overline{G}_\tau(r)$, are to be determined from Table 2.3.3. The related stress gradients from bending and torsion as a function of the diameter or width d at the notch net section are

$$\overline{G}_\sigma(d) = \overline{G}_\tau(d) = 2 / d. \qquad (2.3.17)$$

?

DESIGN PARAMETERS



$$K_{WK,zd} = \left(K_{f,zd} + \frac{1}{K_{R,\sigma}} - 1\right) \cdot \frac{1}{K_V \cdot K_S \cdot K_{NL,E}},$$

$$K_{WK,b} = \left(K_{f,b} + \frac{1}{K_{R,\sigma}} - 1\right) \cdot \frac{1}{K_V \cdot K_S \cdot K_{NL,E}},$$

$$K_{WK,s} = \left(K_{f,s} + \frac{1}{K_{R,\tau}} - 1\right) \cdot \frac{1}{K_V \cdot K_S},$$

$$K_{WK,t} = \left(K_{f,t} + \frac{1}{K_{R,\tau}} - 1\right) \cdot \frac{1}{K_V \cdot K_S}.$$

$$K_{WK,b} = 1{,}374 + 1 / 0{,}857 - 1 = \mathbf{1{,}541}$$

$$K_{WK,t} = 1{,}134 + 1 / 0{,}917 - 1 = \mathbf{1{,}224}$$

$$\sigma_{W,zd} = f_{W,\sigma} \cdot R_m,$$
$$\tau_{W,s} = f_{W,\tau} \cdot \sigma_{W,zd},$$

Component fatigue limit for completely reversed stress

$$S_{WK,zd} = \sigma_{W,zd} / K_{WK,zd},$$
$$S_{WK,b} = \sigma_{W,zd} / K_{WK,b}\ ^{*2},$$
$$T_{WK,s} = \tau_{W,s} / K_{WK,s},$$
$$T_{WK,t} = \tau_{W,s} / K_{WK,t}, \qquad (2.4.1)$$

$\sigma_{W,zd}$, $\tau_{W,s}$ material or weld specific fatigue limit for completely reversed stress, 2.2.1,

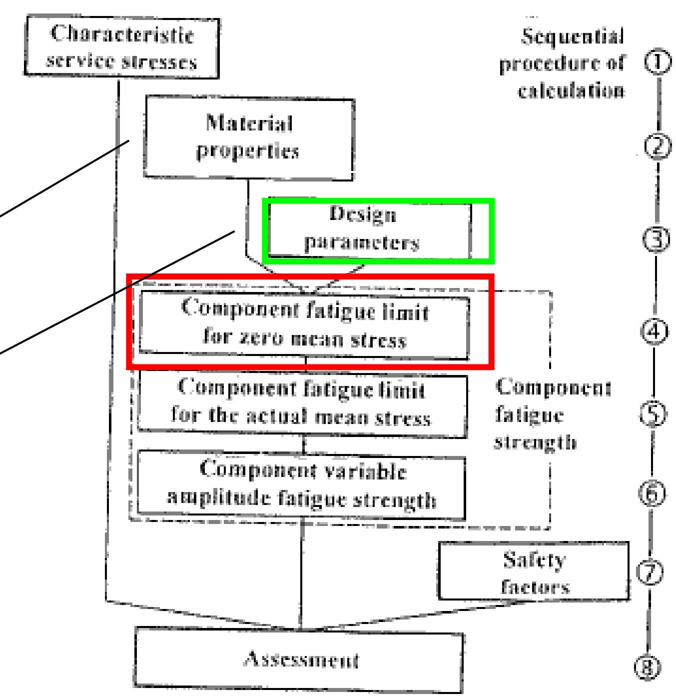
$K_{WK,zd}$ ... design factor, Chapter 2.3.1.

Ejemplo

Component fatigue limit for completely reversed bending and torsional stress

$$S_{WK,b} = 403\ \text{MPa} / 1{,}541 = \mathbf{261}\ \text{MPa}$$

$$T_{WK,t} = 233\ \text{MPa} / 1{,}224 = \mathbf{190}\ \text{MPa}.$$



Atención: *MATERIAL PROPERTIES* $R_{m,N} = 1000$ MPa, $R_{p,N} = 800$ MPa.

Component fatigue limit according to mean stress

Rod-shaped (1D) components

The mean stress dependent amplitudes of the component fatigue limit of rod-shaped (1D) components for axial, for bending, for shear and for torsional stress are

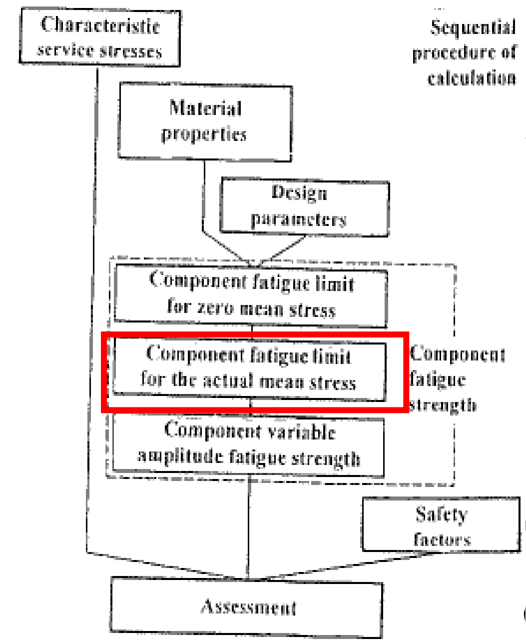
$$S_{AK,zd} = K_{AK,zd} \cdot K_{E,\sigma} \cdot S_{WK,zd}\,,$$
$$S_{AK,b} = K_{AK,b} \cdot K_{E,\sigma} \cdot S_{WK,b}\,,$$
$$T_{AK,s} = K_{AK,s} \cdot K_{E,\tau} \cdot T_{WK,s}\,,$$
$$T_{AK,t} = K_{AK,t} \cdot K_{E,\tau} \cdot T_{WK,t}\,,$$

$K_{AK,zd}$ ... mean stress factor,
$K_{E,\sigma}$ ... residual stress factor, (
$S_{WK,zd}$ ... component fatigue limit for completely reversed stress,

Recordar

$$\sigma_{W,zd} = f_{W,\sigma} \cdot R_m\,,$$
$$\tau_{W,s} = f_{W,\tau} \cdot \sigma_{W,zd}\,,$$

$$S_{WK,zd} = \sigma_{W,zd} / K_{WK,zd}\,,$$
$$S_{WK,b} = \sigma_{W,zd} / K_{WK,b}\ {}^{*2}\,,$$
$$T_{WK,s} = \tau_{W,s} / K_{WK,s}\,,$$
$$T_{WK,t} = \tau_{W,s} / K_{WK,t}\,,$$



Residual stress factor

The residual stress factor for non-welded components is

$$K_{E,\sigma} = K_{E,\tau} = 1.$$

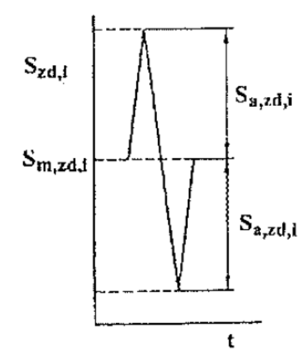
Type of overloading

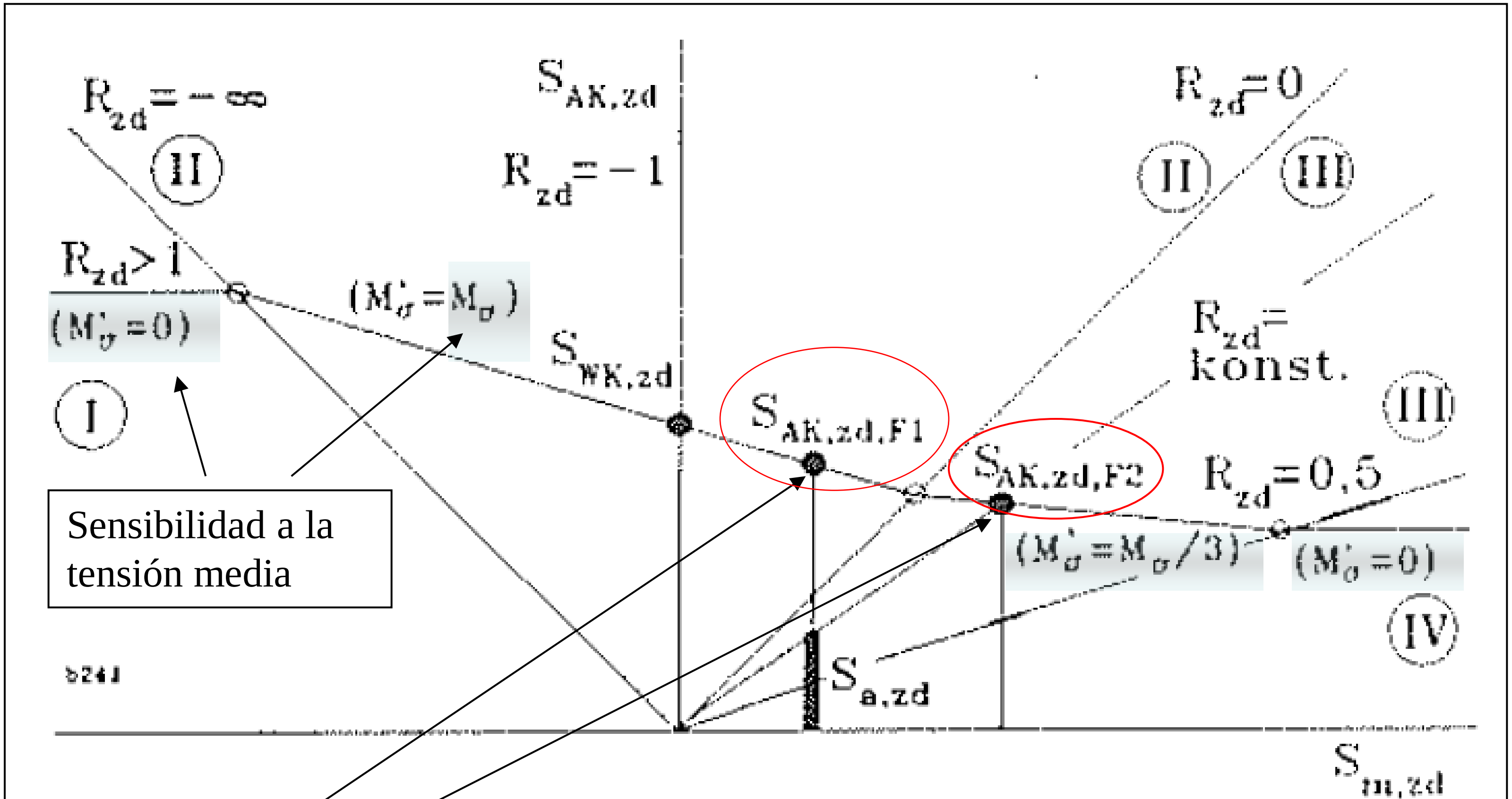
The mean stress factor $K_{AK,zd}$, ... is dependent on the type of overloading, F1 to F4. It distinguishes the way

- Type F1:
  the mean stress $S_{m,zd}$ remains the same,
- Type F2:
  the stress ratio R_{zd} remains the same,
- Type F3:
  the minimum stress $S_{min,zd}$ remains the same,
- Type F4:
  the maximum stress $S_{max,zd}$ remains the same.

Stress cycle
Example:
stress cycle (axial stress),
stress ratio:

$$R_{zd,i} = \frac{S_{m,zd,i} - S_{a,zd,i}}{S_{m,zd,i} + S_{a,zd,i}}.$$





$$S_{AK,zd} = K_{AK,zd} \cdot K_{E,\sigma} \cdot S_{WK,zd} \,,$$
$$S_{AK,b} = K_{AK,b} \cdot K_{E,\sigma} \cdot S_{WK,b} \,,$$
$$T_{AK,s} = K_{AK,s} \cdot K_{E,\tau} \cdot T_{WK,s} \,,$$
$$T_{AK,t} = K_{AK,t} \cdot K_{E,\tau} \cdot T_{WK,t} \,,$$

Amplitude of the component fatigue strength as a function of mean stress or stress ratio (Haigh diagram), described in four fields of mean stress

Example: Normal stress, types of overloading F1 and F2.

Given: Component fatigue strength for completely reversed stress $S_{WK,zd}$, service stress amplitude $S_{a,zd}$, stress ratio R_{zd},

Derived: Amplitudes of the component fatigue limit $S_{AK,zd}$ for the types of overloading F1 and F2.

Calculation for the type of overloading F2 *4

In case of a possible overload in service the stress ratio R_{zd} remains the same.

Normal stress:

Field I: $R_{zd} > 1$:

$$K_{AK,zd} = 1 / (1 - M_\sigma),$$

Field II, $-\infty \leq R_{zd} \leq 0$ *5:

$$K_{AK,zd} = \frac{1}{1 + M_\sigma \cdot S_{m,zd} / S_{a,zd}},$$

Field III, $0 < R_{zd} < 0{,}5$:

$$K_{AK,zd} = \frac{\dfrac{1 + M_\sigma/3}{1 + M_\sigma}}{1 + \dfrac{M_\sigma}{3} \cdot \dfrac{S_{m,zd}}{S_{a,zd}}},$$

Field IV, $R_{zd} \geq 0{,}5$:

$$K_{AK,zd} = \frac{3 + M_\sigma}{3 \cdot (1 + M_\sigma)^2},$$

Mean stress sensitivity

The mean stress sensitivity M_σ or M_τ, in connection with the mean stress factor, describes to what extent the mean stress affects the amplitude of the component fatigue strength.

For non-welded components the mean stress sensitivity for normal stress and for shear stress, applicable in case of normal or elevated temperature, is

$$M_\sigma = a_M \cdot 10^{-3} \cdot R_m / MPa + b_M,$$
$$M_\tau = f_{W,\tau} \cdot M_\sigma,$$

a_M, b_M constants,

$f_{W,\tau}$ shear fatigue strength factor, Table 2.2.1.

Constants a_M and b_M.

Kind of material	Steel *1	GS	GGG	GT	GG
a_M b_M	0,35 - 0,1	0,35 0,05	0,35 0,08	0,35 0,13	0 0,5

Kind of material	Wrought aluminum alloys	Cast aluminum alloys
a_M b_M	1,0 - 0,04	1,0 0,2

Equivalent mean stress

In the case "bending and torsion", which is typical for numerous applications in machine design, and in similar cases, where normal stresses are combined with shear stresses, the variables $S_{min,zd,v}$, $S_{max,zd,v}$ and $R_{zd,v}$ are to be used. They are derived from an equivalent mean stress $S_{m,v}$, to be computed as a function of the respective individual mean stress values.

For normal stress there is

$$S_{min,zd,v} = S_{m,v} - S_{a,zd} ,$$
$$S_{max,zd,v} = S_{m,v} + S_{a,zd} ,$$
$$R_{zd,v} = S_{min,zd,v} / S_{max,zd,v} ,$$

$S_{a,zd}$ individual stress amplitude,
$R_{zd,v}$ equivalent stress ratio,
$S_{min,zd,v}$ equivalent minimum stress,
$S_{max,zd,v}$ equivalent maximum stress.

For bending, shear and torsion the appropriate variables are $S_{min,b,v}$, ..., $R_{b,v}$, $T_{min,s,v}$, ..., $R_{s,v}$ or $T_{min,t,v}$, ..., $R_{t,v}$

Fatigue strength factors for completely reversed normal stress, $f_{W,\sigma}$, and shear stress, $f_{W,\tau}$ [1].

Kind of material	$f_{W,\sigma}$	$f_{W,\tau}$
Case hardening steel	0,40 [2]	0,577 [2] [3]
Stainless steel	0,40 [4]	0,577
Forging steel	0,40 [4]	0,577
Steel other than these	0,45	0,577
GS	0,34	0,577
GGG	0,34	0,65
GT	0,30	0,75
GG	0,30	0,85
Wrought aluminum alloys	0,30 [5]	0,577
Cast aluminum alloys	0,30 [5]	0,75

[1] $f_{W,\sigma}$ and $f_{W,\tau}$ are valid for a number of cycles $N = 10^6$

The equivalent mean stress, for normal stress is

$$S_{m,v} = q \cdot S_{m,v,NH} + (1 - q) \cdot S_{m,v,GH}.$$

where

$$q = \frac{\sqrt{3} - (1/f_{\tau})}{\sqrt{3} - 1} ,$$

$$S_{m,v,NH} = \frac{1}{2} \cdot \left(|S_m| + \sqrt{S_m^2 + 4 \cdot T_m^2} \right) ,$$

$$S_{m,v,GH} = \sqrt{S_m^2 + 3 \cdot T_m^2} .$$

Values of q as dependent on $f_{W,\tau}$ [1].

	Steel, wrought Al alloys	GGG	GT, cast Al alloys	GG
$f_{W,\tau}$	0,577	0,65	0,75	0,85
q	0	0,264	0,544	0,759

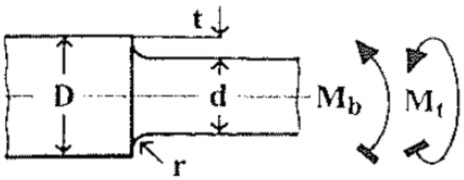
[1] Exceptions: For non-ductile wrought aluminum alloys (elongation A < 12,5 %) q = 0,5 , for surface hardened or welded components q = 1.

For shear stress there is

$$T_{m,v} = f_{W,\tau} \cdot S_{m,v} .$$

$f_{W,\tau}$ shear strength factor,

$S_b = \pm S_{a,b} = \pm 150$ MPa,
$T_t = T_{m,t} \pm T_{a,t} = 50$ MPa $\pm$ 100 MPa.



$S_{m,v} = S_{m,v,GH} = \sqrt{3} \cdot 50$ MPa $= 86{,}6$ MPa ,

$T_{m,v} = 0{,}577 \cdot 86{,}6$ MPa $= 50$ MPa .

Calculation for the type of overloading F2.

Mean stress factor for bending

$S_{min,b,v} = 86{,}6$ MPa$-$ 150 MPa $= -63{,}4$ MPa ,
$S_{max,b,v} = 86{,}6$ MPa + 150 MPa = 236 MPa ,
$R_{b,v} = -0{,}267$,

Because of $-\infty < -0{,}267 \leq 0$ field II applies:

$M_\sigma = 0{,}213$,

$$K_{AK,b} = \frac{1}{1 + 0{,}213 \cdot 86{,}6 / 150} = 0{,}890 .$$

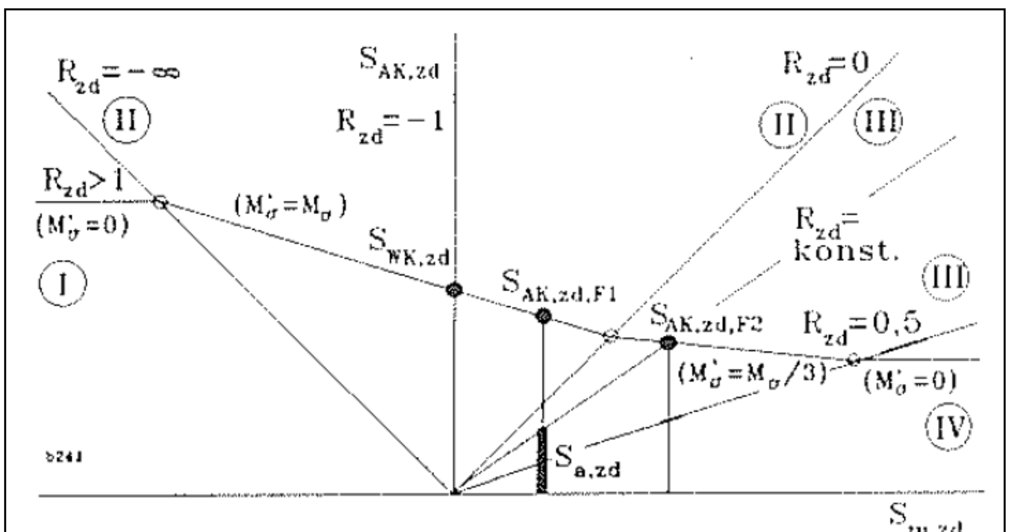
Mean stress factor for torsion

$T_{min,t,v} = 50$ MPa$-$ 100 MPa $= -50$ MPa ,
$T_{max,t,v} = 50$ MPa + 100 MPa = 150 MPa ,
$R_{t,v} = -0{,}333$,

Because of $-1 < -0{,}333 \leq 0$ field II applies:

$M_\tau = 0{,}123$,

$$K_{AK,t} = \frac{1}{1 + 0{,}123 \cdot 50 / 100} = 0{,}942 .$$



Residual stress factor for normal stress and for shear stress

$K_{E,\sigma} = K_{E,\tau} = 1$.

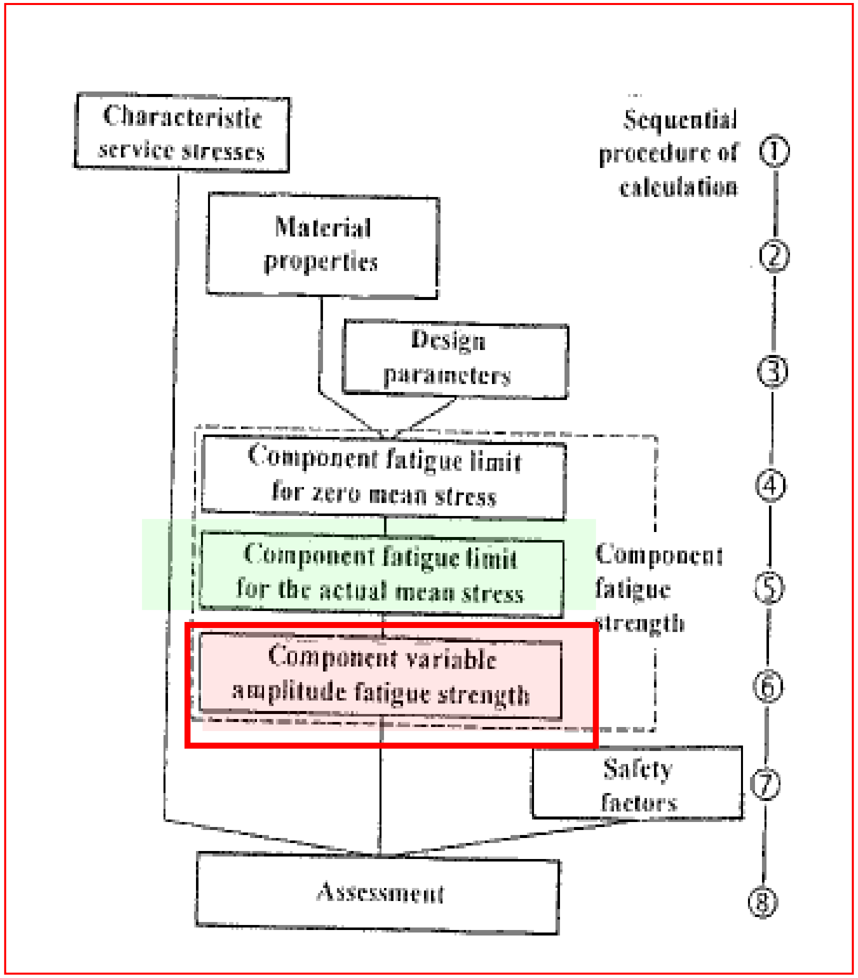
Amplitude of the component fatigue limit

The amplitude of the component fatigue limit results from the mean stress factor, the residual stress factor and the component fatigue limit for completely reversed bending and torsional stress:

$S_{AK,b} = 0{,}890 \cdot 1 \cdot 261$ MPa $=$ **233** MPa ,
$T_{AK,t} = 0{,}942 \cdot 1 \cdot 190$ MPa $=$ **179** MPa .

Component variable amplitude fatigue strength

It has to be distinguished, whether in case of a constant amplitude spectrum an assessment of the fatigue limit (or endurance limit) or an assessment of the fatigue strength for finite life is intended, or whether in case of a variable amplitude spectrum an assessment of the variable amplitude fatigue strength is intended [*2].

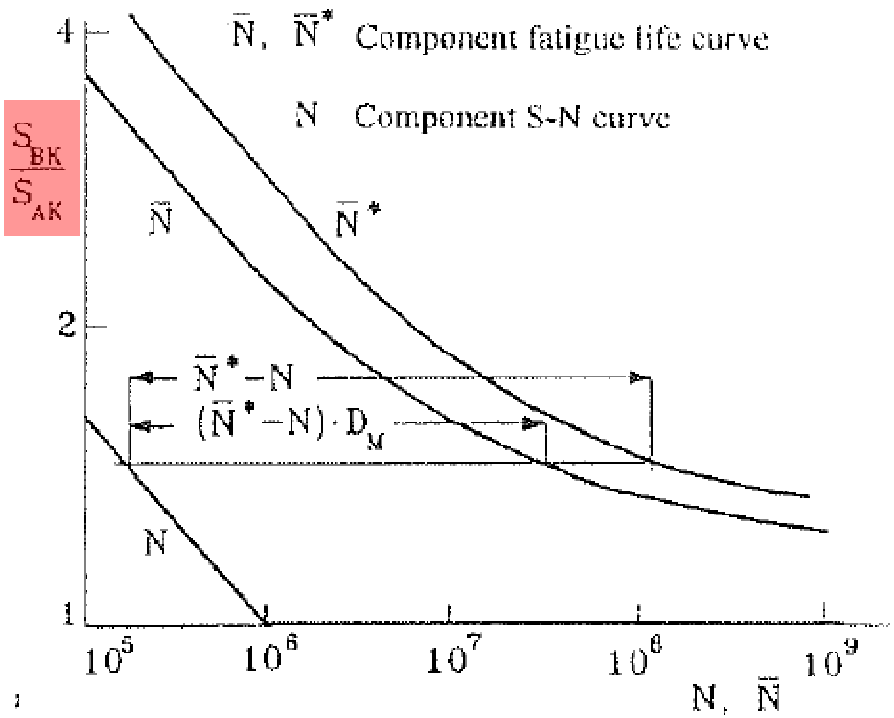


Rod-shaped (1D) components

$$S_{BK,zd} = K_{BK,zd} \cdot S_{AK,zd},$$
$$S_{BK,b} = K_{BK,b} \cdot S_{AK,b},$$
$$T_{BK,s} = K_{BK,s} \cdot T_{AK,s},$$
$$T_{BK,t} = K_{BK,t} \cdot T_{AK,t},$$

$K_{BK,zd}$ ... variable amplitude fatigue strength factor, Chapter 2.4.3.1,

$S_{AK,zd}$ ... component fatigue limit, In German the fatigue life curve is usually termed 'Gassner curve' and the constant amplitude S-N curve is usually termed 'Woehler curve'.



Component constant amplitude S-N curve, component fatigue life curve derived by the consistent version of Miner's rule, and influence of the critical damage sum D_M.

$$D = \sum_{i=1}^{m} \frac{n_i}{N_i} = 1$$

3 Critical damage sum D_M, recommended value.

	non-welded components	welded components
Steel, GS, Aluminum alloys	0,3	0,5
GGG, GT, GG	1,0	1,0

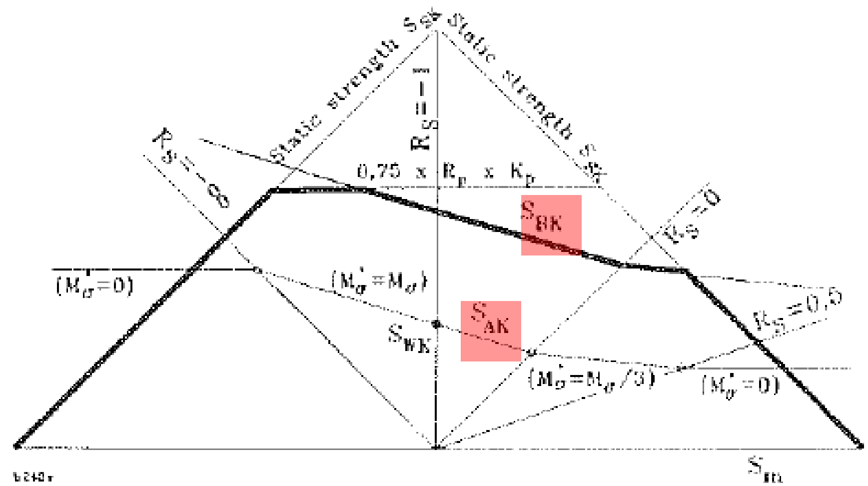


Figure 2.4.3 Restriction of the amplitudes of the variable amplitude fatigue strength, $S_{BK,t}$, or of the maximum value $S_m + S_{BK}$ and the minimum value $S_m - S_{BK}$ respectively, in relation to the yield strength, displayed in terms of the Haigh-diagram.

Calculation for a variable amplitude spectrum

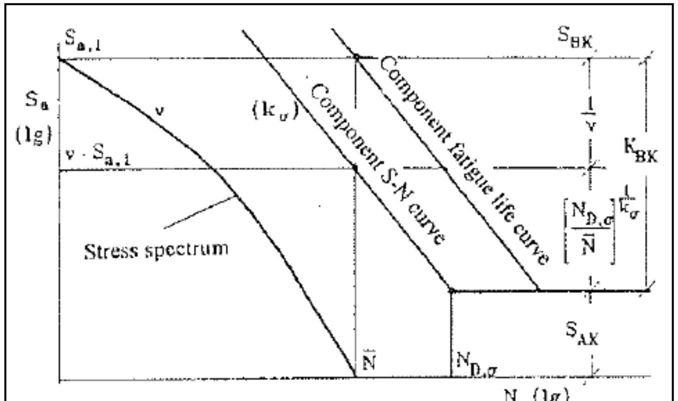
Elementary version of Miner's rule based on the damage potential

Using the elementary version of Miner's rule, Figure 2.4.4, the variable amplitude fatigue strength factor is to be computed directly as follows *5. The calculation applies to both component constant amplitude S-N curve model I and model II

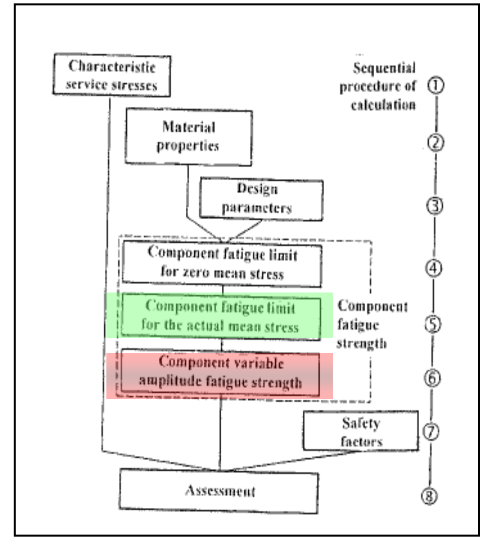
$$K_{BK,zd} = \left[\left(\frac{1}{(v_{zd})^{k\sigma}} - 1\right)\cdot D_M + 1\right]^{\frac{1}{k_\sigma}} \cdot \left(\frac{N_{D,\sigma}}{\overline{N}}\right)^{\frac{1}{k_\sigma}},$$

where the damage potential is *6 *7

$$v_{zd} = \sqrt[k_\sigma]{\sum_{i=1}^{j} \frac{h_i}{\overline{H}} \cdot \left(\frac{S_{a,zd,i}}{S_{a,zd,1}}\right)^{k_\sigma}}.$$



Elementary version of Miner's rule, component constant amplitude S-N curve model I, $D_M = 1$.



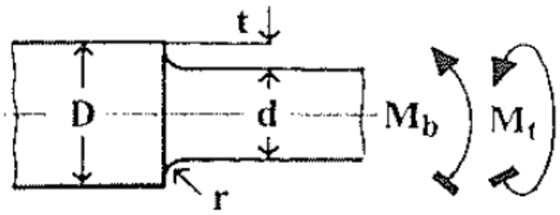
$$S_{BK,zd} = K_{BK,zd} \cdot S_{AK,zd},$$
$$S_{BK,b} = K_{BK,b} \cdot S_{AK,b},$$
$$T_{BK,s} = K_{BK,s} \cdot T_{AK,s},$$
$$T_{BK,t} = K_{BK,t} \cdot T_{AK,t},$$

Number of cycles at the knee point, slope of the component constant amplitude S-N curves, and values of $f_{II,\sigma}$ and $f_{II,\tau}$.

Normal stress

Component	$N_{D,\sigma}$	$N_{D,\sigma,II}$	k_σ	$k_{D,\sigma}$	$f_{II,\sigma}$
Steel and cast iron materials (S-N curve model I)					
non-welded	10^6	-	5	-	1,0
welded	$5 \cdot 10^6$	-	3	-	1,0
Aluminum alloys (S-N curve modell II)					
non-welded	10^6	10^8	5	15	0,74
welded	$5 \cdot 10^6$	-	3	-	1,0

$$S_b = \pm S_{a,b} = \pm 150 \text{ MPa},$$
$$T_t = T_{m,t} \pm T_{a,t} = 50 \text{ MPa} \pm 100 \text{ MPa}.$$

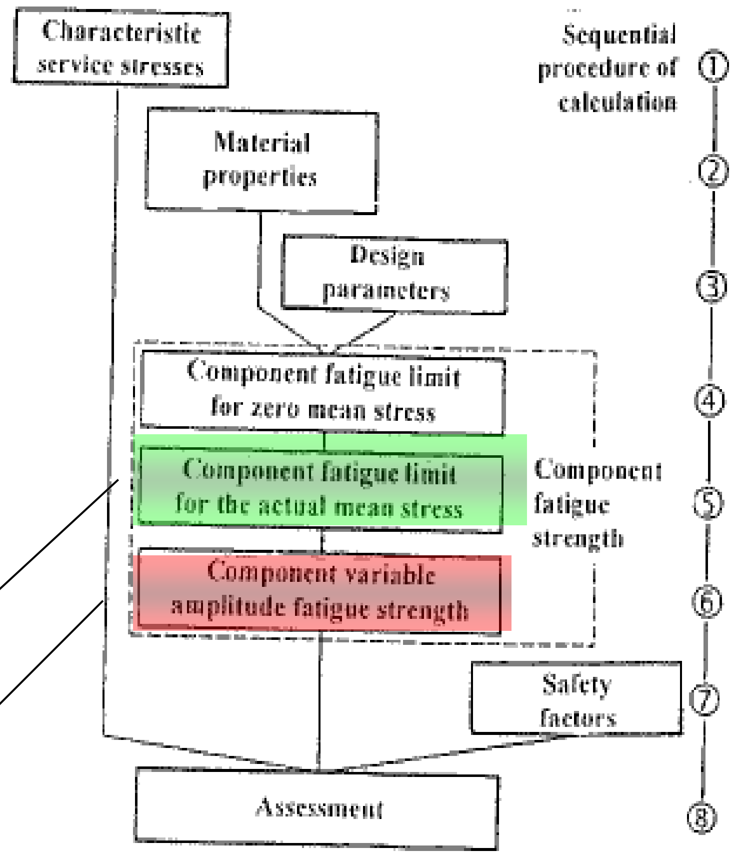


Considering the component constant amplitude fatigue limit, $N > N_{D,\sigma}$ and $N > N_{D,\tau}$, and the S-N curve model I (horizontal for $N > N_{D,\sigma}$ and $N > N_{D,\tau}$) the variable amplitude fatigue strength factors for bending and for torsion is

$$K_{BK,b} = K_{BK,t} = 1.$$

$$S_{AK,b} = 0{,}890 \cdot 1 \cdot 261 \text{ MPa} = \mathbf{233} \text{ MPa},$$
$$T_{AK,t} = 0{,}942 \cdot 1 \cdot 190 \text{ MPa} = \mathbf{179} \text{ MPa}.$$

$$S_{BK,b} = 1 \cdot 233 \text{ MPa} = \mathbf{233} \text{ MPa}.$$
$$T_{BK,t} = 1 \cdot 179 \text{ MPa} = \mathbf{179} \text{ MPa}.$$



Safety factors

Steel

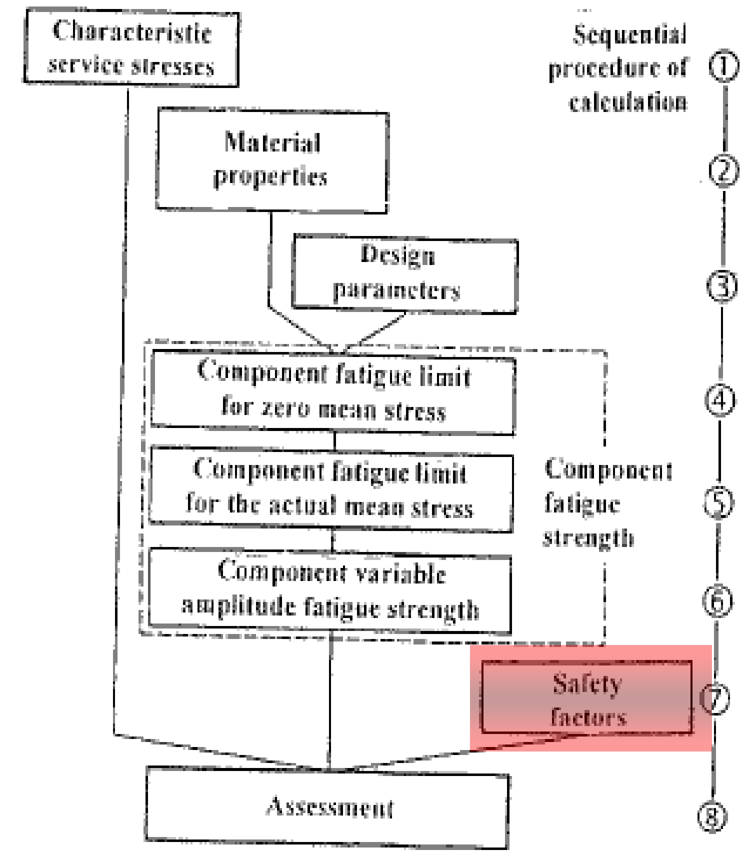
The basic safety factor concerning the fatigue strength is

$$j_D = 1{,}5.$$

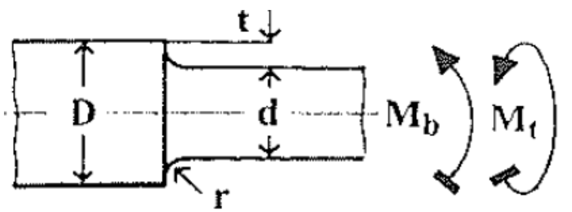
This value may be reduced under favorable con that is depending on the possibilities of inspection and on the consequences of failure, Table 2.5.1.

Safety factors for steel [3] (not for GS) and for ductile wrought aluminum alloys (A≥ 12,5 %).

j_D		Consequences of failure	
		severe	moderate [1]
regular inspections	no	1,5	1,3
	yes [2]	1,35	1,2



Ejemplo



For moderate consequence of failure and regular inspection, however, there is

$$j_D = 1{,}2 .$$

For normal temperature there is

$$K_{T,D} = 1 ,$$

and therefore

$$j_{ges} = 1{,}2 .$$

Assessment

Rod-shaped (1D) components

Individual types of stress

The degrees of utilization of rod-shaped (1D) components for variable amplitude types of stress like axial, bending, shear and torsional stress are

$$a_{BK,zd} = \frac{S_{a,zd,1}}{S_{BK,zd} / j_{erf}} \leq 1, \qquad (2.6.3)$$

$$a_{BK,b} = \frac{S_{a,b,1}}{S_{BK,b} / j_{erf}} \leq 1,$$

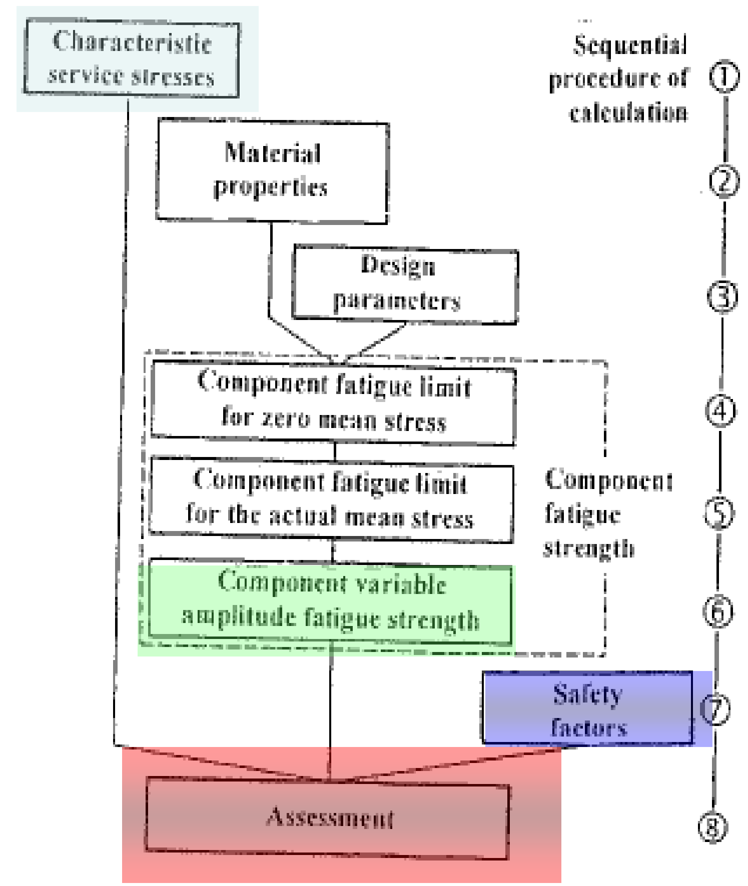
$$a_{BK,s} = \frac{T_{a,s,1}}{T_{BK,s} / j_{erf}} \leq 1,$$

$$a_{BK,t} = \frac{T_{a,t,1}}{T_{BK,t} / j_{erf}} \leq 1,$$

$S_{a,zd,1}$, ..., characteristic stress amplitude (largest stress amplitude in the spectrum) according to type of stress, Chapter 2.1.1.1 and Eq. (2.6.1) or (2.6.2),

$S_{BK,zd}$, ..., related amplitude of the component variable amplitude fatigue strength, Chapter 2.4.3,

j_{ges} total safety factor, Chapter 2.5.5.



Combined types of stress

The degree of utilization of rod-shaped components for combined types of stress is *[6]

$$a_{BK,Sv} = q \cdot a_{NH} + (1 - q) \cdot a_{GH} \leq 1,$$

where

$$a_{NH} = \frac{1}{2} \cdot \left(|s_a| + \sqrt{s_a^2 + 4 \cdot t_a^2} \right),$$

$$a_{GH} = \sqrt{s_a^2 + t_a^2},$$

$$s_a = a_{BK,zd} + a_{BK,b},$$

$$t_a = a_{BK,s} + a_{BK,t},$$

$a_{BK,zd}, \ldots$ degrees of utilization ;

$$q = \frac{\sqrt{3} - (1/f_{W,\tau})}{\sqrt{3} - 1},$$

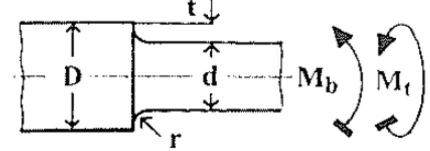
$f_{W,\tau}$ shear fatigue strength factor,

Values of q as dependent on $f_{W,\tau}$ *1.

	Steel, wrought Al alloys	GGG	GT, cast Al alloys	GG
$f_{W,\tau}$	0,577	0,65	0,75	0,85
q	0	0,264	0,544	0,759

*1 Exceptions: For non-ductile wrought aluminum alloys (elongation A < 12,5 %) q = 0,5 , for surface hardened or welded components q = 1.

Ejemplo



$$S_b = \pm S_{a,b} = \pm 150 \text{ MPa},$$
$$T_t = T_{m,t} \pm T_{a,t} = 50 \text{ MPa} \pm 100 \text{ MPa}.$$

Largest stress amplitudes for bending and for torsion, see above,

$$S_{a,b,1} = S_{a,b} = 150 \text{ MPa},$$
$$T_{a,t,1} = T_{a,t} = 100 \text{ MPa}.$$

Amplitude of the component variable amplitude fatigue strength for bending and for torsion, see above,

$$TS_{BK,b} = 233 \text{ MPa}, \quad T_{BK,t} = 179 \text{ MPa}.$$

Degrees of utilization

Individual types of stress, bending and torsion,

$$a_{BK,b} = \frac{150}{233/1,2} = \mathbf{0,773},$$

$$a_{BK,t} = \frac{100}{179/1,2} = \mathbf{0,670}.$$

$$a_{BK,zd} = \frac{S_{a,zd,1}}{S_{BK,zd} / j_{erf}} \leq 1,$$

$$a_{BK,b} = \frac{S_{a,b,1}}{S_{BK,b} / j_{erf}} \leq 1,$$

$$a_{BK,s} = \frac{T_{a,s,1}}{T_{BK,s} / j_{erf}} \leq 1,$$

$$a_{BK,t} = \frac{T_{a,t,1}}{T_{BK,t} / j_{erf}} \leq 1,$$

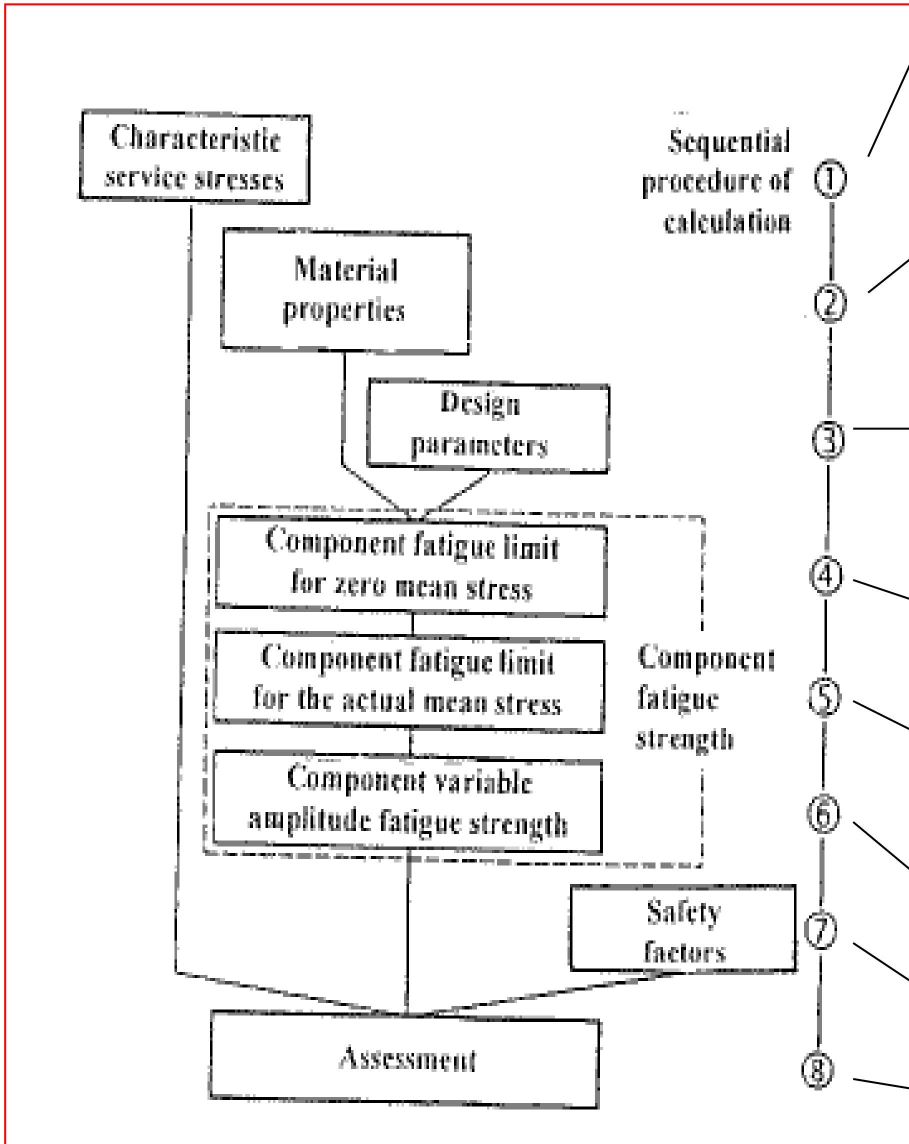
Combined types of stress

$$f_{W,\tau} = 1/\sqrt{3},$$
$$q = 0,$$
$$s_a = a_{BK,b} = 0,773,$$
$$t_a = a_{BK,t} = 0,670,$$
$$a_{GH} = \sqrt{0,773^2 + 0,670^2} = 1,023$$

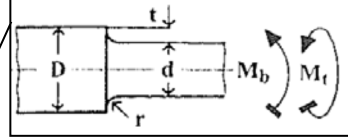
$$a_{BK,Sv} = \mathbf{1,023}$$

The degree of utilization of the component fatigue limit is 102 %.
The assessment of the fatigue limit is approximately achieved.

Ejemplo - Síntesis



① $S_b = \pm S_{a,b} = \pm 150$ MPa,
$T_t = T_{m,t} \pm T_{a,t} = 50$ MPa ± 100 MPa.



② $R_m = 895$ Mpa ,
$f_{W,\sigma} = 0{,}45$,
$\sigma_{W,zd} = 0{,}45 \cdot 895$ MPa $=$ **403** Mpa
$f_{W,\tau} = 0{,}58$,
$\tau_{W,s} = 0{,}58 \cdot 403$ MPa $=$ **233** Mpa .

③ $K_{WK,b} = 1{,}374 + 1 / 0{,}857 - 1 =$ **1,541**
$K_{WK,t} = 1{,}134 + 1 / 0{,}917 - 1 =$ **1,224**

④ $S_{WK,b} = 403$ MPa $/ 1{,}541 =$ **261** MPa
$T_{WK,t} = 233$ MPa $/ 1{,}224 =$ **190** MPa .

⑤ $S_{AK,b} = 0{,}890 \cdot 1 \cdot 261$ MPa $=$ **233** MPa ,
$T_{AK,t} = 0{,}942 \cdot 1 \cdot 190$ MPa $=$ **179** MPa .

⑥ $S_{BK,b} = 1 \cdot 233$ MPa $=$ **233** MPa .
$T_{BK,t} = 1 \cdot 179$ MPa $=$ **179** MPa .

⑦ $j_D =$ **1,2** .

⑧ $a_{BK,Sv} =$ **1,023**

The degree of utilization of the component fatigue limit is 102 %.
The assessment of the fatigue limit is approximately achieved.