winLIFE 4.0 2018

FKM QUICKCHECK

STC-Traffic Engineering / Germany

Inhalt

1. Theory / FKM-Guideline (winLIFE QUICK CHECK)

1.1. Capabilities and goals

winLIFE QUICK CHECK enables the following:

- Proof according to FKM-guideline: static proof, fatigue proof and endurance proof for welded and non-welded components for the proportional case. The proof according to FKM always refers to ONE single verification point .
- Endurance proof: general case including non-proportional stress cases for non-welded and welded components (NOT according to FKM). The proof for ALL (surface)-nodes of a FE-calculation can be carried out. Therefore, this procedure is especially suitable for the case you have to search for the critical point first or a larger number of points shall be examined.

winLIFE QUICK CHECK should be as simple as possible to use and therefore the documentation has also been kept as short and simple as possible. The winLIFE user, however, also has access to the complete winLIFE help for all modules. The complete documentation is automatically installed with the program, the winLIFE QUICK CHECK documentation can be found as a pdf-file on the CD and can be printed.

winLIFE QUICK CHECK is delivered with macros for FEMAP. The Viewer4winLIFE (optional) enables a direct data transfer. This means it is possible to select the reference-points to be calculated directly in it.

1.2. Proof according to FKM Guideline

We tried to transpose essential parts of the FKM-Guideline in the calculation module in winLIFE literally. Please note that we did not transpose the part of the FKM-Guideline regarding nominal stress. We documented this procedure in the following with direct reference to the FKM-Guideline. Differences from the FKM-Guideline are indicated.

To enable a direct comparison with the original the numbers of the chapter headlines and the numbering of the tables are given in this documentation.

This documentation cannot and shall not replace the original guideline with all its sensible information. However, this documentation shall describe the calculation process in a way the user can comprehend it. According to the objective it was necessary to include all data and calculations of the FKM-Guideline identically.

1.2.1. Scope (0.0)

For components made of iron and aluminium material produced by rolling, forging, casting or by metal cutting process or by welding.

For component temperatures and material strength:

Material	Temperature Range [^{O}C]	Max. Strength [MPa]
Steel	-40 bis 500	1250
Iron Casting Material	-25 bis 500	
Aluminium Material	-25 bis 200	610

1.2.2. Technical Background (0.1)

Details see guideline

1.2.3. Required proofs (0.2)

The static proof is sufficient in case of a pure static stress. For fatigue stress, however, the static proof as well as the fatigue strength proof is ALWAYS necessary.

The proof of the FKM-Guideline refers to ONE verification point. To show the FKM-Guideline in winLIFE as exactly as possible the calculation is carried out for this SINGLE verification point. Therefore, all of your details and data refer to this one.

However, you often don't know the point for which the proof shall be made. Therefore, you have to search this point first. To enable the determination of this point, winLIFE practices the following procedure.

Instead of a verification point you can choose a file from a FE-analysis with stress results which can include (nearly) any number of (surface-) node points. Now you are able to calculate all of these points. The input data you created for ONE verification point are used for all points. Strictly spoken, therefore the result is only correct for the verification point. However, this procedure helps you to limitate the critical ranges with little input work.

We designed the proofs for a survival probability of 97,5%.

1.2.4. Stresses and component types (0.3)

1.2.5. Stress characteristics (0.3.1)

The stress characteristics have to be calculated for the verification point. There is a need to differ between welded and non-welded components. The stresses can be determined analytically or by means of elastic FEM-method or with the boundary element method.

All stresses – also the stress amplitude – are signed initially. The sign of the stress amplitudes is only important in case of superimposition of several stress components.

Only local stresses are considered in the verification point.

Accordingly, the component strength values (bearable stresses) are also only determined as local stresses.

1.2.6. Nominal stresses (0.3.2)

Nominal stresses are not covered in winLIFE – in contrast to the FKM-guideline

1.2.7. Local stresses (0.3.3)

1.2.7.1. Non-welded components

Only linear elastic stresses are considered. We assume that the critical verification points lie in the surface.

You can manually enter the stress components. If seam welds are calculated you always have to indicate a normal unit vector lying in the surface vertical to the weld transition notch.

If a FE-system is used the stress components and the normal unit vector can be taken automatically.

If you enter the stresses manually the coordinate system should show in the verification point a z-axle vertical to the surface and should point into the inside of the component. The normal unit vector has to lie in the x-y-plane.

An even stress state is given if no load is put into the surface so that σ_x σ_y and τ_{xy} can be different to zero whereas σ_z must be zero.

The principal stresses σ_I and σ_{II} can also be different from zero whereas σ_{III} can only be different from zero if a load is put into the surface.

The following is valid for the static strength proof:

- For ductile materials (rolled steel and forged steel, GS, alu-wrought materials) the stresses can be calculated with either variation.
- For semi-ductile and brittle materials (GJS, GJM, GJL and aluminium cast) with different pressure and tensile strength the proof is always based on the principal stresses.

1.2.7.2. Welded components

winLIFE uses the local strain concept which uses the extrapolated structural stress. The extrapolated structural stress can be either determined by means of the FE-model or the user can input the data as well.

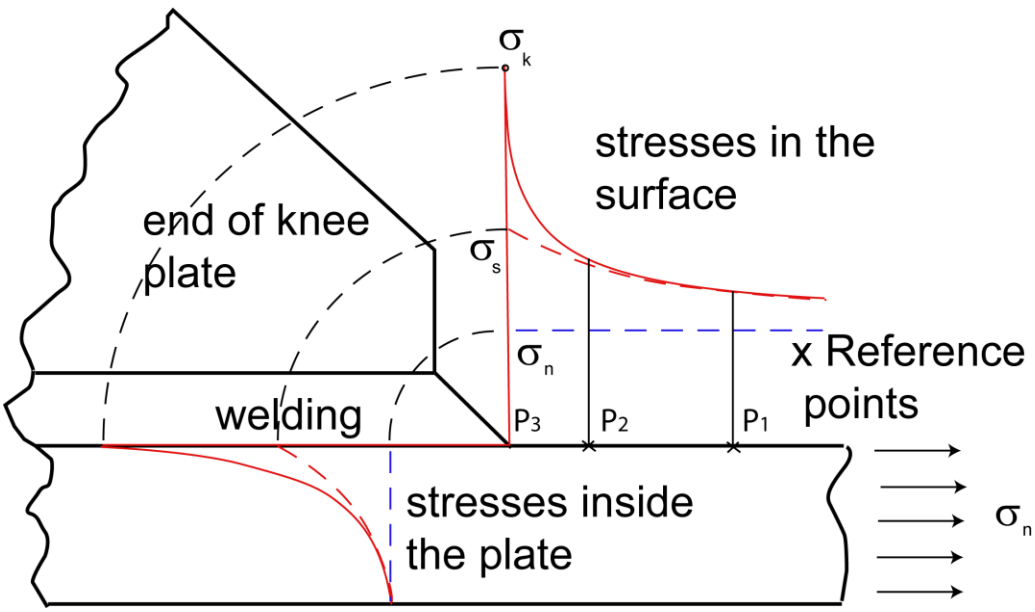


Figure 1: Methods for the extrapolation of stresses on the weld transition notch: P1, P2 reference point, P3 location of the extrapolated value.

The stress tensors of 2 (P1, P2) or three reference points are extrapolated on the weld transition notch (P3) and the resulting stress tensor with the normal unit vector is multiplicated vertical to the weld transition notch.

1.2.8. Uniaxial and multiaxial stresses (0.3.4)

The stresses occurring on the verification point can result from the superposition of several individual loadings.

1.2.8.1. Static proof

You should use the most inconvenient combination of loadings so that only one static load case is resulting for the proof. It is necessary for you to find this most inconvenient load case for the proof. Therefore, you possibly will have to examine several variations.

1.2.8.2. Proof of fatigue strength

It is necessary to take stresses variable in time into consideration before you start the proof (duration-, time- and fatigue strength under variable stress amplitude). The temporal correlation is very important for this procedure. We distinguish between:

- proportional stresses
- synchronous stresses
- non proportional stresses

1.2.8.3. Proportional stresses

The principal stress direction is not changing and the hypothesis for the equivalent stress can be applied.
It is important to respect the signs during the superposition.

1.2.8.4. Synchronous stresses

At synchronous stresses the amplitudes are proportional, the mean stress, however, is not proportional. As the influence of the mean stress is low in comparison with the amplitude the calculation is nearly permissible.

1.2.8.5. Non-proportional stresses

The principal stress direction is changing and you cannot carry out a damage calculation according to the FKM-guideline.

You can apply the procedure of the critical cutting plane like it is implemented in winLIFE MULTIAXIAL. For this procedure you need to know the time courses of the loading and the resulting stresses.

1.3. Proof of the fatigue limit for the non-proportional case (NOT regulated in FKM)

The proof for ***non-proportional*** loadings with local stresses is excluded from the FKM-guideline and we recommend to carry out the proof according to the procedure of the critical cutting plane.

Therefore, a cutting plane related worst case consideration is carried out. The fatigue stress proof is realized in the Quick-Check module.

Proof according to FKM-Guideline

The

Static proof

and the

Fatigue test (endurance strength and time endurance test)

for non-welded and welded components under proportional loading is carried out according to the FKM guideline using ***local stresses*** created for example with the aid of the FEM.

This procedure can be seen in the following two diagrams:

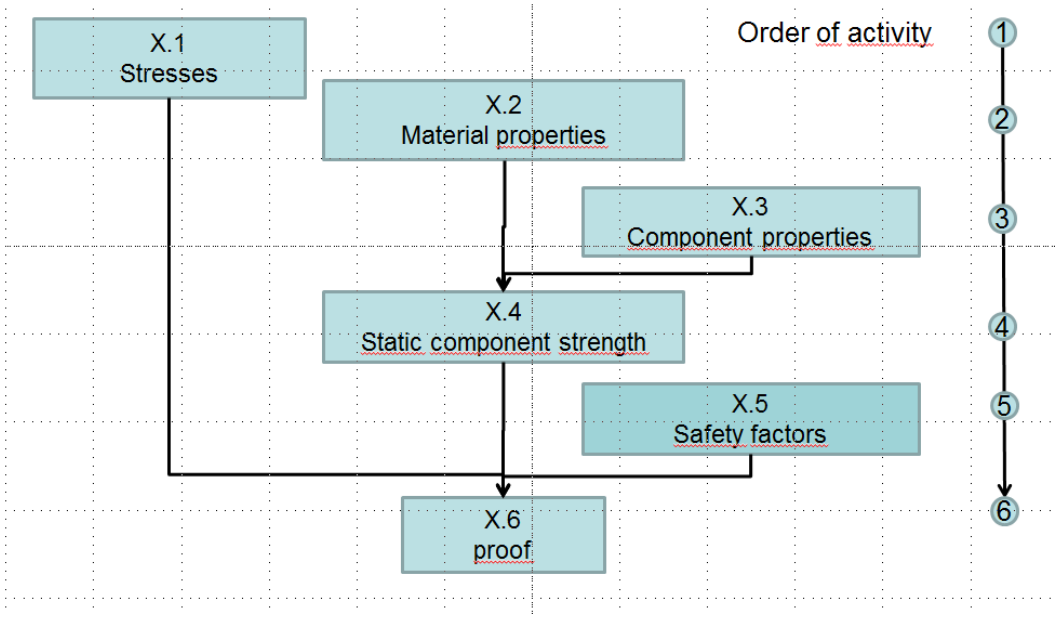


Figure 2: Flowchart for the static proof according to FKM guideline

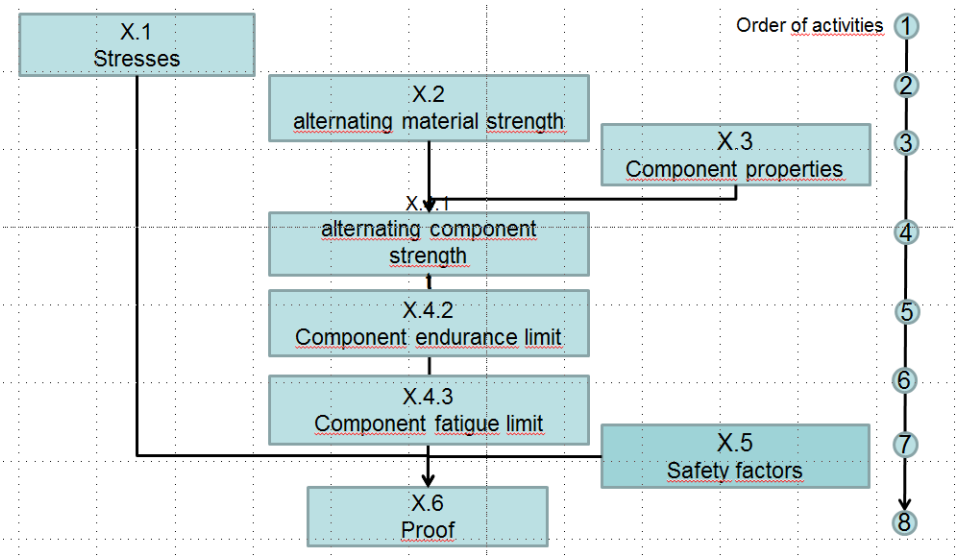


Figure 3: Flowchart for the fatigue endurance test according to FKM guideline

2. Static proof using local stresses acc. to FKM

2.1. General (3.0)

2.1.1. Welded components

You have to distinguish between base materials (BM), heat-affected zone (HAZ) and weld seam (WS).

You only need to take the HAZ into consideration in case of strengthened and hardened aluminium material which show a reduction of the tensile stress or of the offset limit (softening) under influence of temperature. You have to carry out the following proofs on a weld seam joint:

2.1.1.1. Steel and non-softening aluminium materials

BM: Carry out the proof with the equivalent stress in the same way like you do for a non-welded component.

WS: Carry out the proof with the equivalent stress in the seam weld in case of primary stressed seams. It is not necessary for you to carry out the proof in the weld seam for secondary stressed seams (no power flux through the seam). If you have weld seams only stressed by a stress which is parallel to the seam you do not have to carry out the proof either.

2.1.1.2. Softening aluminium material

HAZ (BM): Carry out the proof with the equivalent stress in BM/HAZ like you do for a non-welded component. BM and HAZ have to be proofed. The proof in the HAZ is relevant, if the stresses in the HAZ are larger or equal to the stresses in the BM.

WS: Carry out the proof with the equivalent stress in the seam weld in case of primary stressed seams.

It is not necessary for you to carry out the proof in the weld seam for secondary stressed seams (no power flux through the seam). If you have weld seams only stressed by a stress which is parallel to the seam you do not have to carry out the proof either.

You can determine the extension of the weld seam by the help of its width b_{wez} according to the following table.

2.2. Charakteristic stress values (3.1)

2.2.1. General (3.1.0)

2.2.2. Non-welded components (3.1.1)

NOTE: see FKM-guideline chapter 3.1.1

The static proof is carried out in winLIFE using local stresses (on the surface) only. These are (usually) taken from a linear elastic FE-calculation. The user can also enter the stress tensor manually.

At the critical point of the component surface there is an even state of stress (provided that no force is being lead into the surface). This is defined with

$\sigma_x,\ \sigma_y,\ \tau = \tau_{xy}$ (equation 3.1.1.)

or the 3 main stress.

$\sigma_1,\ \sigma_2,\ \sigma_3,$ (equation 3.1.2.)

The main stress σ_3 is generally zero except for the case the surface is stressed.

2.2.3. Local equivalent stress

NOTE: see FKM-guideline chapter 3.1.1

Ductile materials

For ductile materials (f_t = 1/ sqrt(3)) the von Mises criterion applies.

Even state of stress:

$$\sigma_v = \sigma_{GH} = \sqrt{\frac{1}{2}\left(\sigma_x^2 - \sigma_x\sigma_{xy} + \sigma_y^2 + 3\tau_{xy}\right)} = \sqrt{\left(\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2\right)}$$ (equation 3.1.3)

Dimensional state of stress:

$$\sigma_v = \sigma_{GH} = \sqrt{\frac{1}{2}\left((\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)\right)}$$

$$\sigma_v = \sigma_{GH} = \sqrt{\frac{1}{2}\left((\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_{x1})^2\right)}$$ (equation 3.1.4)

If you use FEM-files the von Mises criterion will be calculated by means of the stress tensor.

Semi ductile or brittle materials

For semi ductile or brittle materials the following applies:

$\sigma_v = q * \sigma_{NH} + (1-q) * \sigma_{GH}$ (equation 3.1.5)

$$q = \frac{\sqrt{3} - \frac{1}{f_t}}{\sqrt{3} - 1}$$ (equation 3.1.6)

q = Parameter for the ductility

f_t = Shear durability factor

Table 3.1.1: Values of q in dependance from various materials and shear durability factor f_τ

	Steel alu-wrought	GJS	GJM Alu-Cast	GJL
f_τ	0,577	0,65	0,75	1
q	0	0,264	0,544	1

In particular for σ_{NH}

- the principal stress with the largest amount is used

from the formula:

$\sigma_i = \sigma_i / (f_{\sigma,i} * K_{NL,i})$ (equation 3.1.7)

f_σ pressure durability factor

K_{NL} grey-cast factor

I index of the stress component

Even state of stress

$$\sigma_{NH,q} = \frac{1}{2}[|\overline{\sigma_1} + \overline{\sigma_2}| + |\overline{\sigma_1} - \overline{\sigma_2}|] = MAX\{|\overline{\sigma_1}|; |\overline{\sigma_2}|\}$$ (equation 3.1.8)

$$\sigma_{GH,q} = \sqrt{\left(\overline{\sigma_1}^2 - \overline{\sigma_1}\overline{\sigma_2} + \overline{\sigma_2}^2\right)}$$

Triaxial state of stress

$$\sigma_{GH,a} = MAX\{|\overline{\sigma_1}|; |\overline{\sigma_2}|; |\overline{\sigma_3}|\}$$ (equation 3.1.9)

$$\sigma_v = \sigma_{GH} = \sqrt{\frac{1}{2}\left((\overline{\sigma_1} - \overline{\sigma_2})^2 + (\overline{\sigma_2} - \overline{\sigma_3})^2 + (\overline{\sigma_3} - \overline{\sigma_2})^2\right)}$$

Note for ductile material:

KNL=1; f_σ=1; f_τ=1; q=0

Multiaxiality

Degree of multiaxiality:

$$h = \frac{\sigma_H}{\sigma_v}$$ (equation 3.1.10)

σ_H	hydrostatic state of stress
$\sigma_v = \sigma_{GH}$	equivalent stress hypothesis

with

$$\sigma_H = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3) = \frac{1}{3}(\sigma_x + \sigma_y + \sigma_z)$$ (equation 3.1.11)

2.2.4. Welded components (3.1.2)

2.2.4.1. General (3.1.2.0)

Structural stresses are used to calculate weld seams. The FKM-guideline is not very clear in this point. It is spoken of local nominal stresses. Corresponding to the latest state of technology (IIW-guideline) structural stresses are used here. You will find the description in the following chapter.

2.2.4.2. Proof using structural stresses (3.1.2.1)

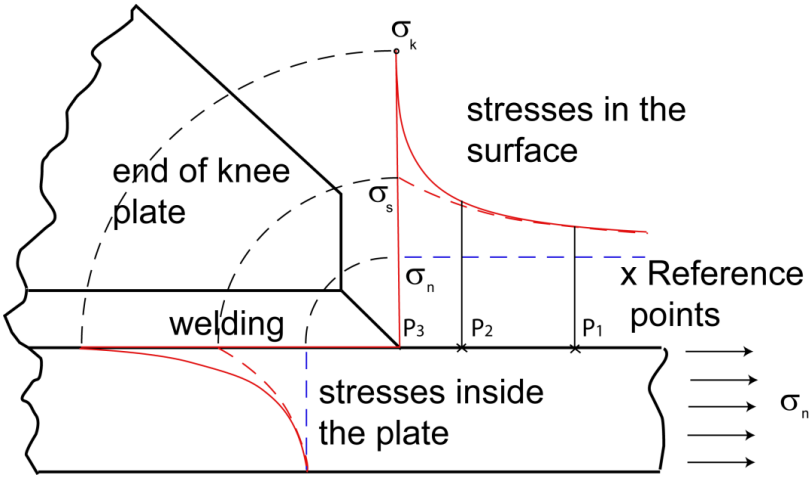


Figure 2-1: Definition of the stresses for the calculation of a weld seam (σs = structural stress, σk = notch stress, σn = nominal stress)

To determine the structural stresses reference points (2 or 3) P1 and P2 should exist in a distance from the weld seam. This distance depends on the wall thickness.

$$\overrightarrow{P_1} = \begin{pmatrix} x_1 \\ y_1 \\ z_1 \end{pmatrix} \quad ; \overrightarrow{P_2} = \begin{pmatrix} x_2 \\ y_2 \\ z_2 \end{pmatrix}$$

In this point the stress sensors $\mathbf{S_{P1,i}}$ and $\mathbf{S_{P2,i}}$ need to be known at any time.

The following picture shows point P_3, which lies in the weld transition notch. The fatigue life is to be predicted for this point. The points P_2 and P_1 are lying vertical to the weld transition notch and in the surface in distance from x- and y-times of the value of the sheet thickness (e.g. x=0,5 t, y=1,5 t after GL). You also require a unit vector n which lies in the surface and vertical to the weld seam (see picture below).

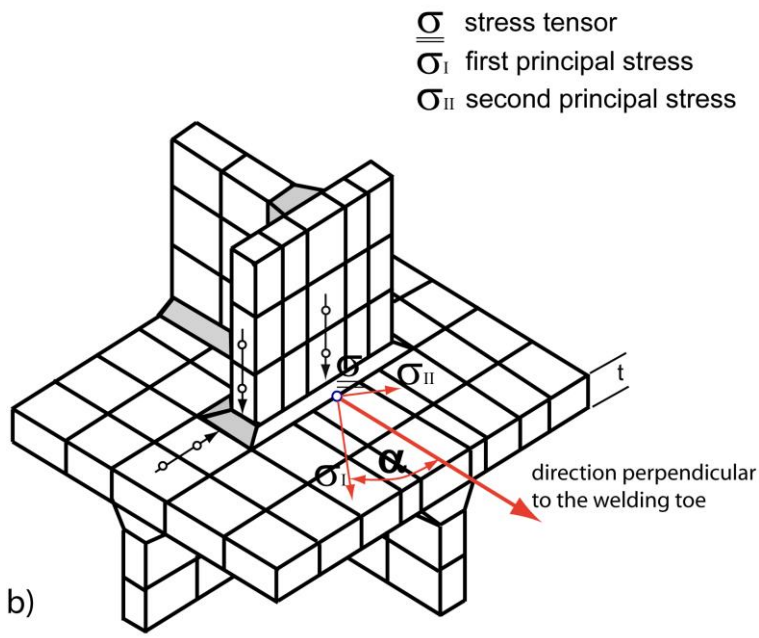


Figure 2-2: Weld seam of a sheet connection with main stresses and normal unit vector in the surface.

The stress tensor in the node k resulting from the unit load case is defined as:

$$S_{ki,e} = \begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{bmatrix}$$

From the stress tensors of the two points P_1 and P_2 the stress tensor for point P_3 is extrapolated in the weld transition notch. There are two possibilities: the linear extrapolation and the quadratic one.

All components of the stress tensor are extrapolated according to the following equations:

In case of linear extrapolation and a distance of the reference points of 0,4t and 1,0t the following applies:

$\mathbf{S}_s = 1{,}67\ \mathbf{S}_{0,4t} - 0{,}67\ \mathbf{S}_{1,0t}$

This calculation approach is recommended in case the element length at the hot-spot is not larger than 0,4t.

In case of linear interpolation but with distances of 0,5t and 1,5t the following applies:

$\mathbf{S}_s = 1{,}5\ \mathbf{S}_{0,5t} - 0{,}5\ \mathbf{S}_{1,5t}$

This calculation approach is recommended by GL.

In case of quadratic extrapolation and a distance of the reference points of 0,4t, 0,9t and 1,4t the following applies:

$\mathbf{S}_s = 2{,}52\ \mathbf{S}_{0,4t} - 2{,}24\ \mathbf{S}_{0,4t} + 0{,}72\ \mathbf{S}_{1,4\,t}$

This calculation approach is recommended in case a significant non-linear stress increase is expected at the hot-spot.

If you want to use other distances, just enter the multipliers in the FEMAP post-processor.

The extrapolation is carried out by means of the pre-processor (available for FEMAP). The stress tensor S_s in point P_3 is multiplied with the direction unit vector n according to the following equation:

$$\overrightarrow{s_{ki}} = \begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{bmatrix} * \vec{n} = \begin{pmatrix} s_\varphi \\ \tau_{\varphi 1} \\ \tau_{\varphi 2} \end{pmatrix}$$

$\overrightarrow{s_{ki}}$ represents the vector projected in normal direction. You get the normal stress component as a result of the following scalar product:

$s_\varphi = \overrightarrow{s_{ki}} * \vec{n}$ **(corresponds to σ_r according to terminology of the FKM guideline)**

The resulting entire shear stress can be calculated with the help of Pythagoras according to the following equation:

$\tau_\varphi = \sqrt{\left|s_{ki}\right|^2 - s_\varphi^2}$ **(corresponds to t τ_r according to terminology of the FKM guideline)**

The damage accumulation calculations are carried out independently from one another and separately for shear stresses and normal stresses in each case. Afterwards the two damage shares can be added weighted. The weight factors are different depending on the set of rules you use and therefore a consultation with the certifier is recommended.

This procedure is supposed to be suitable for the case the largest principal stress includes an angle smaller than +45 degree to the normal unit vector. To determine if this condition is fulfilled the angle is plotted for every time step in a diagram. Now you are able to decide by means of the graph if this condition is fulfilled or not.

BM and WS

The state of stress in the sheet metal is nearly even. Calculate the equivalent stress from the individual components of the stress like you do for a non-welded component.

The von Mises criterion applies for ductile materials. The strength hypothesis applies for basic material that can be welded. The calculation is carried out by the principal stresses.

Weld Seam WS

The stress components

$\sigma_{||}$
$\sigma_{\perp}$
$\tau_{\perp}$

relating to the seam are to be determined. The determination is carried out with the help of the structural stresses. The method for the calculation of the structural stresses is defined in chapter XYZ. If you enter the stresses manually you also have to indicate the normal unit vector besides the stress values. Usually the normal unit vector is 1,0,0. Due to data compatibility the normal unit vector it necessary.

$\sigma_{||}$ is not used for the static strength test. The shear stresses $\tau_{\perp}$ occurring in the fillet welds can also be regarded as normal stresses $\sigma_{\perp}$ In the following the calculation is done with $\sigma_{\perp}$

The stresses have to be increased for seam welds which do not cover the cross section totally (a<t, fillet weld, Y-weld) or for eccentrical WS corresponding to the ratio of the plate sickness to the weld sickness respectively to the influence of the eccentricity.

From the individual stress components an equivalent stress value is to be calculated corresponding to the empirical strength hypothesis according to DIN18800.

$\sigma_{vw}=\sqrt{\sigma_{\perp}^2+\tau_{||}^2}$

2.2.4.3. Proof using notch stresses (3.1.2.2)

Using notch stresses in the static strength test is restrained to construction steel. The weld seam is modelled in detail corresponding to the concept of Radai with a weld transition notch radius of 1 mm [ ]. A sufficiently fine net is to be used.

The equivalent stress according to Mises is used at the verification point.

The degree of multiaxiality

$$h_{wk} = \frac{\sigma_{HwK}}{\sigma_{vwK}}$$

with the hydrostatic stress

σ_{HwK} =(σ1,wK+σ2,wK)*0,3333

is also to be determined. If the proof is carried out with the notch stress concept the division between basic material and weld seam is missing.

2.3. Material characteristics (3.2)

2.3.1. General (3.2.0)

Note: see FKM-guideline chapter 3.2.1.0

The material sample is a non-notched, polished round sample with diameter of

d_0 = 7.5mm.

The standard values are the equivalent to a mean survival probability of $P_Ü$ = 97.5% and depend on the effective diameter d_{eff} . Component values apply for the effective diameter d_{eff} . These, however, may have a different survival probability.

Component-standard values are valid for the effective diameter d_{eff} for a survival probability of 97.5%.

2.3.2. Non-welded components (3.2.1)

2.3.2.1. General (3.2.1.0)

All material strength values are valid for a non-notched, polished round sample with a diameter of

d_0 = 7.5mm.

The standard values for semi-finished parts ($d_{eff,N}$) and component standard values (d_{eff}) are not the same. Component values can be standard values, drawing values or actual values.

It is however possible to consider the individual characteristics of a component and the component standard values can be calculated using the semi-finished standard values, as shown in the following chapter.

2.3.2.2. Standard values for semi-finished products (3.2.1.1)

Semi-finished or sample piece standard values ($R_{m,N}$,$R_{p,N}$) are valid for the effective diameter deff,N and have a survival probability of $P_Ü$=97.5 %

$R_{m,N}$ is the minimum value or the guaranteed value or the lower limit of the from-to range for the smallest semi-finished (wrought material) or for the sample piece (cast material) according to the material standard.

$R_{p,N}$ is the minimum value or the guaranteed value for the smallest semi-finished material or for the sample piece according to the material standard.

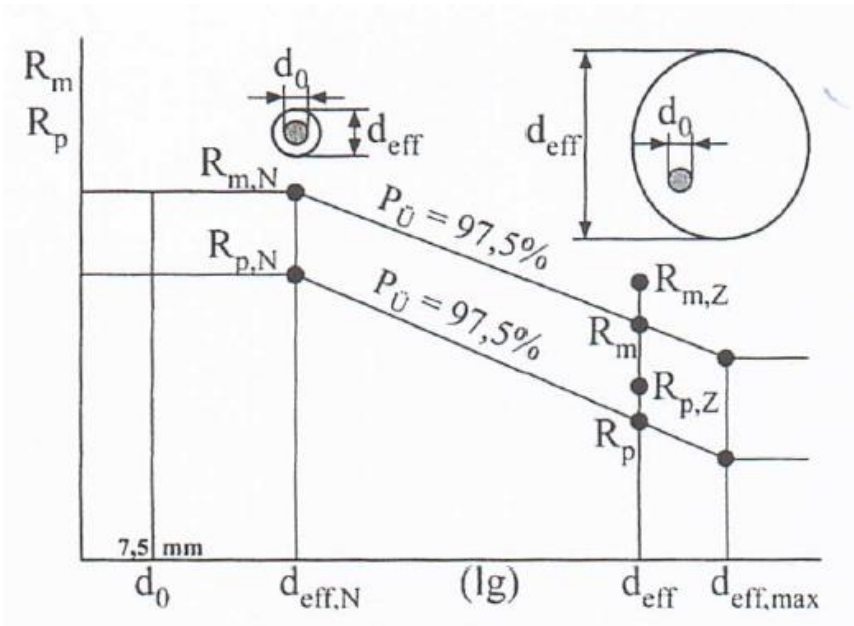


Figure 2-1: Standard values, component values and component standard values (see FKM guideline chapter 3.2.1.2

2.3.2.3. Standard component values (3.2.1.2)

The component standard values R_m, R_p are valid for the effective component diameter $d_{eff\,a}$ and the survival probability $P_Ü$=97.5 % for the entirety of all components.

With Rm and Rp it is possible to carry out a strength proof valid for the entirety of all components (not limited to a certain component).

The component standard values R_m, R_p can be calculated from the semi-finished standard values $R_{m,N}$, $R_{p,N}$ or from the component drawing values $R_{m,Z}$, $R_{p,Z}$

The calculation of the component standard values from the semi-finished standard values, the anisotropy factor and the technological scaling factor is described in the following chapter and is valid for the individual component.

2.3.2.4. Standard component values based on semi-finished standard values

Component standard value of the tensile strength R_m

$$R_m = K_{d,m} * K_A * R_{m,N}$$

Component standard value of the yield point R_p:

$$R_p = K_{d,p} * K_A * R_{p,N}$$

$K_{d,m}$ $K_{p,m}$ = technological scaling factor

K_A = anisotropy factor

$R_{m,N}$ = semi-finished standard value

2.3.2.5. Standard component values based on component values according to the drawings

Not dealt with

Actual component values (3.2.1.3)

Not dealt with

2.3.2.6. Technological size factor (3.2.1.4)

With the technological size factor, the material durability which reduces most with the increasing size of the component is taken into account.

Steel and cast iron materials

GJL

$$d_{eff} \leq 7.5mm \rightsquigarrow K_{d,m} = 1.207$$

$$d_{eff} > 7.5mm \rightsquigarrow K_{d,m} = K_{d,p} = 1.207 \left(\frac{d_{eff}}{7.5mm}\right)^{-0.1922}$$

Stainless steel:

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

For all other steel and cast iron materials:

$$d_{eff} \leq d_{eff,N,m} \rightsquigarrow K_{d,m} = K_{d,p} = 1$$

$$d_{eff,N,m} < d_{eff} < d_{eff,max,m} \rightsquigarrow K_{d,m} = \frac{1 - 0.7686\ a_{d,m}\ log10(\frac{d_{eff}}{7.5})}{1 - 0.7686\ a_{d,m}\ log10(\frac{d_{eff,N,m}}{7.5})}$$

For rolled steel $d_{eff,max}$ = 250, for all other it is within the material standard.

Aluminium wrought material:

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

Aluminium cast material:

$$d_{eff} \leq d_{eff,N,m} = d_{eff,N,p} = 12mm \rightsquigarrow K_{d,m} = K_{d,p} = 1$$

$$12mm < d_{eff} < d_{eff,max,m} = d_{eff,max,p} = 150mm \rightsquigarrow K_{d,m} = K_{d,p} = 1.1 \left(\frac{d_{eff}}{7.5mm}\right)^{-0.2}$$

$$d_{eff} \geq d_{eff,max,m} = d_{eff,max,p} = 150mm \rightsquigarrow K_{d,m} = K_{d,p} = 0.6$$

Defining the effective diameter d_{eff}

Case 1

This is for components, including forged parts, made of quenched and tempered steel, case hardened alloy steel and nitrated nitrating steel, from tempered cast steel, GGG, GT and GG.

Generally

$d_{eff} = 4*V/O$

is valid with the volume V and the surface O of the component part being considered.

Case 2

This is for components, including forged parts, made of unalloyed structural steel, rolled fine grained steel, normalised high alloy steel, common cast iron and aluminium material. The effective diameter d_{eff} is the same as the diameter or the wall thickness of the component.

Material group *1	$d_{eff,N,m}$ $d_{eff,N,p}$ [mm]	$a_{d,m}$ $a_{d,p}$ *2
Unalloyed structural steel DIN EN 10 025	40 40	0.15 0.3
Fine grain structural steel DIN 17 102	70 40	0.2 0.3
Fine grain	100	0.25

structural steel DIN EN 10 113	30	0.3
Heat treatable steel, quenched and tempered DIN EN 10 083-1	16 *3 16	0.3 0.4
Heat treatable steel, annealed DIN EN 10 083-1	16 16	0.1 0.2
Case hardening steel, blank-hardened DIN EN 10 084	16 16	0.5 0.5
Nitrided steel, quenched and tempered DIN EN 10 085	40 40	0.25 0.30
Stainless steel DIN EN 10 088-2 *4	-	-
Steel for larger forged pieces, quenched & tempered SEW 550 *5	250 250	0.2 0.25
Steel for larger forged pieces, annealed SEW 550	250 250	0 0.15

Material group	$d_{eff,N,m}$ $d_{eff,N,p}$ [mm]	$a_{d,m}$ $a_{d,p}$ *2
Cast steel DIN 1681	100 100	0.15 0.3
Heat treatable cast steel, air hardened DIN 17 205	300 *1 300	0.15 0.3
Heat treatable cast steel, liquid hardened DIN 17 205 Type Nos. 1, 3, 4 *2	100 100	0.3 0.3
As above Type Nr. 2 *3	200 200	0.15 0.3
As above Type Nos. 5, 6, 8	200 200	0.15 0.3
As above Type Nos. 7, 9	500 500	0.15 0.3
GGG DIN EN 1563	60 60	0.15 0.15
GT *4 DIN EN 1562	15 15	0.15 0.15

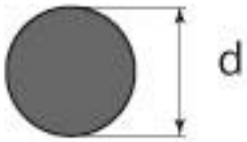
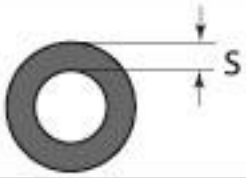
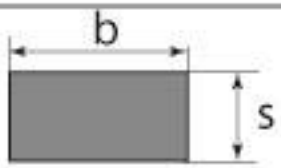
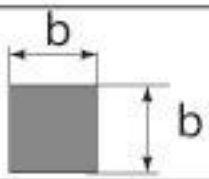
No	Querschnitt Cross section	D_eff Fall 1 Case 1	D_eff Fall 2 Case 2
1		d	d
2		2s	s s
3		2s	s
4		$\frac{2bs}{b+s}$	s
5		b	b

Figure 2-2: : Effective diameter (according to FKM)

2.3.2.7. Anisotropy factor (3.2.1.5)

Note: see FKM guideline chapter 3.2.1.5

The anisotropy factor takes into consideration, that for rolled and forged components the material durability transverse tot he favoured matching direction is less that in the favoured matching direction (rolling direction).

Cast iron and aluminium materials

Multiaxial stresses and shear stresses

Longitudinal to the favoured matching direction

$$K_A = 1$$

Steel

R_m in MPa	up to 600	600 to 900	900 to 1200	over 1200
K_A	0.90	0.86	0.83	0.80

Aluminium wrought material

R_m in MPA	up to 200	200 to 400	400 to 600
K_A	1	0.95	0.9

Figure 2-3: Table 1.2.4 taken from FKM-guideline chapter 3.2.15

2.3.2.8. Compressive strength factor and shear strength factor (3.2.1.6)

Note: see FKM-guideline chapter 3.2.1.6

The ***compressive strength factor*** takes into account that compressive stresses ($R_{c,m}$, $R_{c,p}$) in general, have a higher material strength

$$R_{c,m} = f_\sigma R_m$$
$$R_{c,p} = f_\sigma R_p$$

For ***Shear stresses*** the tensile strength R_m and the yield point R_p are replaced by the shear strength $R_{s,m}$ and the shear yield point $R_{s,p}$.

$$R_{s,m} = f_\tau R_m$$
$$R_{s,p} = f_\tau R_p$$

Material group	f_σ for tension	f_σ for pressure	f_τ
Structural steel	1	1	0.577 *1
Stainless steel	1	1	0.577
Forging steel	1	1	0.577
Other steel types	1	1	0.577
GS	1	1	0.577
GJS	1	1.3	0.65
GJM	1	1.5	0.75
GJL	1	2.5	1.0 *2
Aluminium wrought material	1	1	0.577
Aluminium cast material	1	1.5	0.75

Figure 2-4: Table 1.2.5 taken from the FKM-guideline

2.3.2.9. Temperature factors (3.2.1.7)

Note: see FKM-guideline chapter 3.2.1.7

Normal Temperatures: $K_{T,m} = 1$

Material	from °C	to °C
Fine grain structural steel	-40	60
Other steel	-40	100
Cast iron material	-25	100
Hardened aluminium material	-25	50
Non-hardened aluminium material	-25	100

Figure 2-5: Table taken from the FKM-guideline

Lower temperatures are beyond the scope of this rule.

Temperature factor, short term values

Higher temperatures: Steel and cast iron materials up to 500 °C

Aluminium materials up to 200 °C

Aluminium materials: $K_{T,m} = K_{T,p} = 1 - a_{T,D} * 10^{-3} * (T_{[°C]} - 50)$

Fine grained steel: $K_{T,m} = K_{T,p} = 1 - 1{,}2 * 10^{-3} * T_{[°C]}$

GJL $K_{T,m} = K_{T,p} = 1 - 2{,}4 * 10^{-3} * (T_{[°C]})$

Other steel apart from stainless steel Stahl: $K_{T,m} = K_{T,p} = 1 - 1{,}7 * 10^{-3} * (T_{[°C]} - 100)$

GS $K_{T,m} = K_{T,p} = 1 - 1{,}5 * 10^{-3} * (T_{[°C]} - 100)$

Hardable aluminium alloys $K_{T,m} = K_{T,p} = MAX(1 - 4{,}5 * 10^{-3} * (T_{[°C]} - 50); 0{,}1)$

Non-hardable aluminium material $K_{T,m} = K_{T,p} = MAX(1 - 4{,}5 * 10^{-3} * (T_{[°C]} - 100); 0{,}1)$

Temperature factor, long term values

Note: see FKM-guideline chapter 3.2.1.7

Higher temperatures:	For steel and cast iron materials up to 500 °C
$K_{Tt,p} = 10^{(a_{Tt,p} + b_{Tt,p} * P_p + c_{Tt,p} * P_p^2)}$	$K_{Tt,m} = 10^{(a_{Tt,m} + b_{Tt,m} * P_m + c_{Tt,m} * P_m^2)}$

$$P_m = 10^4 \cdot (T/°C + 273) \cdot [C_m + \lg(t/h)]$$

$$P_p = 10^4 \cdot (T/°C + 273) \cdot [C_p + \lg(t/h)]$$

$a_{Tt,m}$,…..C_p constants according to the table

T = Temperature in °C

T = Time in use [h] for T

Steel ✧2	Non-alloyed structural steel ✧3	Fine grain structural steel ✧4	Heat treatable steel ✧5
Creep strength			
aTt,m	–0,994	–1,127	–3,001
bTt,m	2,485	2,485	3,987
cTt,m	–1,260	–1,260	–1,423
C_m	20	20	24,27
Creep limit			
aTt,p	–5,019	–6,352	–3,252
bTt,p	7,227	9,305	5,942
cTt,p	–2,636	–3,456	–2,728
C_p	20	20	17,71

Cast iron materials	GS ✧6	GJM ✧7	GJL ✧8
Creep strength			
aTt,m	–7,524	2,50	–1,46
bTt,m	9,894	–1,83	2,36
cTt,m	–3,417	0	–0,90
C_m	19,57	20	25
Creep limit			
aTt,p	–10,582	0,12	
bTt,p	8,127	1,52	
cTt,p	–1,607	–1,28	
C_p	35,76	18	

Figure 2-6: Table 1.2.5 taken from the FKM-guideline

Temperature factor, long term values

Higher temperatures: Aluminium materials up to 200 °C

$K_{Tt,m}$ read from Fig. 1.2.4, taken from the FKM–guideline

$K_{Tt,p}$ has until now not been set, but we can presume that the quotient $R_{p,Tt}/j_{pt}$ == $R_{m,Tt}/j_{mt}$

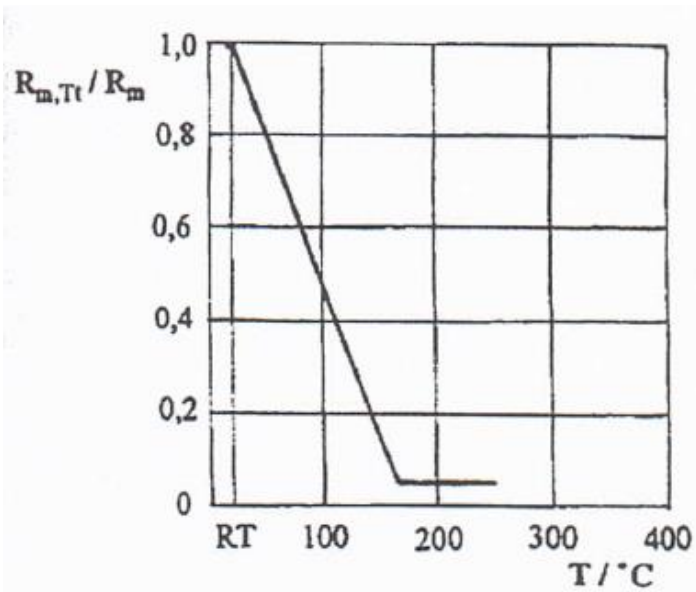


Figure 2-7: (Fig. 1.2.4 from FKM)

2.3.3. Welded components (3.2.2)

2.3.3.1. General (3.2.2.0)

All material strength values are valid for the measurements indicated in the material tables for the basic material BW.

Technological size factor K_d and anisotropy factor K_A are not applicable for welded components. For the materials groups like limited weldable and stainless steel, for iron- and aluminium casting the calculation is considered as provisional and therefore has to be used with caution.

2.3.3.2. Static strength values for rolled steel and cast steel (3.2.2.1)

Tensile strength Rm and yield point Re for the basic material in welded components made of rolled steel and cast steel depending on the thickness of the product according to DIN 18800: please see table 5.1.24.

2.3.3.3. Static strength values for aluminium (3.2.2.2)

Static values like Rm 0,2-yield point $R_{p,0,2}$ for the basic material BM in welded components made of aluminium depending on semi-finished product and material condition according to DIN 4113: see table 5.1.25

2.3.3.4. Compression- and shear strength factor (3.2.2.3)

The compression strength factor f_σ is to be chosen according to the following table (according to FKM 3.2.5):

Materials group	f_σ for tension	f_σ for compression	f_τ
Case hardening steel	1	1	0,577
Stainless steel	1	1	0,577
Forged steel	1	1	0,577
Further steel	1	1	0,577
GS	1	1	0,577
GJS	1	1,3	0,65
GJM	1	1,5	0,75
GJL	1	2,5	1
Alu-wrought material	1	1	0,577
Alu-cast material	1	1,5	0,75

Figure3: Compression strength factor f_σ taken from FKM-guideline, table 3.2.5

and the shear strength factor f_t for the HAZ and BM is chosen according to the following table:.

Materail	f_t
Steel, BM	0,577
Aluminium, BM, HAZ	0,577

Figure 4: Shear strength factor f_t taken from FKM-guideline, table 3.2.8

2.3.3.5. Temperature factors (3.2.2.4)

See non-welded materials.

2.3.3.6. Softening factor (3.2.2.5)

Caused by the welding process softening may occur at welded components made of aluminium. This is taken into account by using the softening factor

$\rho_{WEZ}<=1$

Please take the values from f table 5.1.25 of the FKM-guideline.

2.3.4. Design parameters (3.3)

2.4. General (3.3.0)

The construction characteristic values for non-welded and welded components are to be calculated separately. The following difference has to be made:

n_{pl} Plastic support factor. Load-bearing reserves are recorded after exceeding the yield strength.

K_{NL} Grey cast iron factor for taking the different behaviour in case of tension and pressure into account

α_w Weld seam factor to record the reduction of the strength of the weld seam (BM or HAZ)

2.4.1. Non-welded components (3.3.1)

2.4.1.1. Plastic support factor (3.3.1.1)(section factor)

Note: see FKM-guideline chapter 3.3

With the construction characteristic values, the plastic reserves of the material are taken into account -> n_{pl}

K_{NL} grey cast iron factor for considering the various pull-push behaviour of GJL

Austenitic steel in annealed condition

$n_{pl,x} = K_p$

All other materials

$n_{pl,x} = MIN (sqrt(E * \varepsilon_{ertr} / R_p);K_p)$

ε_{ertr} = tolerable total expansion

E = elasticity module

R_p = yield point

K_p = plastic stress concentration factor

ε_{ertr} = tolerable total extension

$h <= 1/3\ \varepsilon_{ertr} = \varepsilon_{ref}$ = A, for ductile materials (f_t = 0,577)

= 0,4 * A, for semi-ductile and brittle materials

$h > 1/3\ \ \varepsilon_{ertr} = \varepsilon_0 + 0,3\ ((\varepsilon_{ref} - \varepsilon_0) / 0,3)^{3-h}$

ε_0 = minimum tolerable total expansion

taken from table 3.3.1

taken from the FKM-guideline

Mechanical marginalised layer hardening

is not taken into consideration

marginalised layer hardening with ε_{ref} = 1 %

Material group	10-5 E [MPa]	$\varepsilon_{0\,[\%]}$	
		A>=6%	A<=5%
Steel, GS	2,1	5	
GJS	1,7	4	R_p/E
GJM	1,8	2	
GJL	1,0	-	
Alumin.wrought	0,7	5	
Alumin.cast	0,7	2	

Figure 2-8: (Table 3.3.1 from FKM)

K_p = Plastic stress concentration factor = three dimensional load / elastic limit load

where the stresses are constant in the cross section K_p = 1

particular case cast iron = $K_p = 2*f_\sigma / (1+f_\sigma)$

If the three-dimensional load and the elastic limit load are not known, then K_p can be estimated from the stress concentration factor

$K_p = K_{t,zd}$; $K_{t,s}$; $K_{p,b} * K_{t,b}$; $K_{p,t} * K_{t,t}$

These are generally more conservative because the yield conditions have not been recorded due to the multiaxiality.

Mechanical marginalised layer hardening is not taken into consideration.

Marginalised layer hardening with ε_{ref} = 1 %

2.4.2. Welded components (3.3.2)

2.4.2.1. Plastic support factor (3.3.2.1)

The consideration of the plastic support factor causes an improvement of the fatigue life. If you do not use the plastic support factor the result will be on the safe side.

The plastic support factor must only be considered in case of

- through-welded seams
- double-sided not through-welded seams but cross-section covering seams (for example double fillet weld)

The plastic support factors are the same for BM, HSZ and W. As the plastic support factors may only be taken into consideration in the case of welds covering the cross-section, they can be calculated based on the cross-sectional dimensions of the sheets.

For non-ductile materials of low elongation at break A<6% no plastic support factor shall be applied:

$n_{pl}=1$

Calculate the plastic support factors for ductile materials (A>=6%) as follows:

Proof using structural stresses

Steel and non-softening aluminium materials

$$n_{pl,x} = MIN (sqrt(E * \varepsilon_{ertr} / R_p);K_p)$$

Softening aluminium materiales

$$n_{pl,x} = MIN (sqrt(E * \varepsilon_{ertr} /(\rho_{WEZ} *R_p);K_p)$$

ε_{ertr} = tolerable total extension

E = elastic modulus

R_p = yield strength

P_{WEZ} = softening factor

K_p = plastic notch factor

Material Group	Steel, GS	GJS	GJM	Wrought aluminium	Cast aluminium
E [MPa]	210000	170000	180000	70000	70000
ε_{ertr} [%]	5	4	2	5	2

Figure 5: E-Modul and total tolerable extension according to FKM table 3.3.3

Proof using notch stresses

The use of notch stresses in the proof of static strength is only possible for structural steels.

$$n_{pl,wK} = MIN (sqrt(E * \varepsilon_{ertr} / R_p);K_p)$$

ε_{ertr} = tolerable total extension

E = elastic modulus

R_p = yield strength

P_{WEZ} = softening factor

K_p = plastic notch factor

The tolerable extension depends on the multiaxiality.

The following applies to $h_{wK}<1/3$:

$\varepsilon_{ertr,wK} = \varepsilon_{ref,wK}$

The following applies to $h_{wK}>1/3$:

$$\varepsilon_{ertr;Wk} = \varepsilon_{0,wK} + 0{,}3 * \left(\frac{\varepsilon_{ref,wK} - \varepsilon_{0,wK}}{0{,}3}\right)^{3\,h_{wk}}$$

$\varepsilon_{0,wK}$ minimum of the tolerable extension at high multiaxiality

$\varepsilon_{ref,wK}$ reference point = tolerable extension in case of uniaxial stress state

h_{wK} degree of multiaxiality

Strength range	$\varepsilon_{0,wK}$	$\varepsilon_{ref,wK}$
R_{P02} < 460 MPa	0,05	0,17
460 MPa<R_{P02}<690	0,05	0,14

2.4.2.2. Special case of „plastic spot“

The tolerable extension in relevant for the case the plastic zone is surrounded by a large elastic area and the fully plastic limit load is very high:

Steel and non-softening aluminium materials

$n_{pl,x}$ = sqrt(E * ε_{ertr} / R_p)

Softening aluminium materials

$n_{pl,x}$ = sqrt(E * ε_{ertr} /(ρ_{WEZ} *R_p)

2.4.2.3. Plastic form factor

Calculation analog to non-welded components.

2.4.2.4. Surface treatment

In case of mechanically surface treated components calculate n_{pl} in the same way you calculate components without surface treatment.

2.4.2.5. Weld seam factor (3.3.2.2)

The weld seam factor for steel and cast iron materials results from table 3.3.5 (FKM) and for aluminium materials from table 5.1.26 (FKM).

<table>
<tr><th>Weld</th><th>Weld quality</th><th>Stress type</th><th>S235
GS200
GS240
G17Mn5+QT</th><th>S275
P275</th><th>S355
P355
G20MN5+N
G20Mn5+Q</th><th>S420
S460
S460</th><th>S690</th></tr>
<tr><td rowspan="3">full penetration weld or with back weld</td><td>all</td><td>compression</td><td rowspan="2">1,0</td><td rowspan="2">1,0</td><td rowspan="2">1,0</td><td rowspan="2">1,0</td><td rowspan="2">0,9</td></tr>
<tr><td>verified</td><td rowspan="2">tension or shear</td></tr>
<tr><td>not verified</td><td rowspan="3">0,95</td><td rowspan="3">0,85</td><td rowspan="3">0,8</td><td rowspan="3">0,7</td><td rowspan="3">0,55</td></tr>
<tr><td>partial penetration or fillet weld</td><td>all</td><td>compression/ tension or shear</td></tr>
</table>

The following applies to butt joints of sectional steel made of S235JR (obsolete: ST. 37-2) and S235JRG1 (obsolete USt 37-2) with t>16 mm under tension load:

α_w=0,55

Component strength (3.4)

Note: see FKM-guideline chapter 3.4

2.4.3. Non-welded components (3.4.1)

$$\sigma_{SK} = R_p * n_{pl}$$

2.4.4. Welded components (3.4.2)

2.4.4.1. General (3.4.2.0)

Calculate the values of the component strength separately for the BM, HAZ and WS depending on the material (steel or aluminium).

Base material BM and heat affected zone HAZ

Steel and non-softening aluminium materials:

The following applies to the base material of welded components:

$\sigma_{SK} = R_p * n_{pl}$

n_{pl} section factor

R_p yield strength

The HAZ is not taken into account.

Softening aluminium materials

The following applies as well to the base material: $\sigma_{SK} = R_p * n_{pl}$
Provided the stresses in the HAZ are not smaller than those in the BM, the proof of the HAZ is relevant.

The following applies to the HAZ:

$\sigma_{SK} = R_p * n_{pl} * \rho_{WEZ}$

n_{pl} section factor

R_p yield strength

ρ_{WEZ} softening factor

Weld seam WS

Steel and non-softening aluminium materials

$\sigma_{SK} = R_p * n_{pl} * \alpha_w$

R_p yield strength

α_w weld seam factor

K_p plastic form factor

Softening aluminium materials

R_p yield strength

α_w weld seam factor

ρ_{WEZ} softening factor

K_p plastic form factor

Proof using notch stresses

Only permitted for structural steel

$\sigma_{SK} = R_p * n_{pl,wK}$

R_p	yield strength
$n_{pl,wK}$	plastic section factor

2.5. Safety factors (3.5)

Note: see FKM-guideline chapter 3.5

2.5.1. General (3.5.0)

Calculate the safety factors separately for welded and non-welded components.

Partial safety factors are determined which will finally be summarized in a total safety factor.

The safety factors refer to the load (existing stress) and the material (tolerable stress).

j_s load factor

j_F material factor

The total safety factor is the product of both partial safety factors.

$j = j_s * j_F$

j_S = load factor. If the load presumption is considered safe, then the value is 1. Other factors are described in chapter 5.7.

The material factor results from a basic safety factor and further partial safety factors.

The safety factors are related to the survival probability for the strength values of 97.5 %

2.5.2. Individual safety factors (3.5.1)

2.5.2.1. Basic safety factors

The following basic safety factors are used for the proof of the static strength:

$_m$ = safety against fracture for normal and short-term temperatures

j_p = safety against flow or normal and short-term temperatures

j_{mt} = safety against fracture for long-term high temperatures

= 1 in case of normal temperatures

j_p = safety against flow for long-term high temperatures

= 1 in case of normal temperatures

The safety factors in the following table apply to ductile (A>6%) and non-ductile (A<6%) materials.

j_m J_p J_{mt} j_{pt}		Consequences of damage		
		high	mean	low
Probability of the occurance of the stress or the stress combination	high	2,0 **1,5** 1,5 1,0	1,85 **1,4** 1,4 1,0	1,75 **1,3** 1,3 1,0
	low	1,8 **1,35** 1,35 1,0	1,7 **1,25** 1,25 1,0	1,6 **1,2** 1,2 1,0

Figure 2-6: Safety factors taken from the FKM-guideline, table 3.5.1

2.5.2.2. Partial safety factors for cast components

j_z= additional safety factor for cast components; factor for non-welded components = j_G

GS,GJS, GJM, GJL, aluminium cast resulting from unavoidable mistakes

j_G = 1,4 castings that have not been subject to non-destructive testing

j_G = 1,25 castings that have been subject to non-destructive testing

2.5.2.3. Partial safety factor for welded components

For aluminium components an additional safety factor shall be taken into consideration.

j_w=1,13 (aluminium)

j_w=1 (rolled steel and cast iron)

2.5.2.4. Partial safety term for non-ductile cast components

Δj additional partial safety factor for non-ductile cast components (A < 6%), for the case you have to calculate with local stresses.

Δj = 0,5 – sqrt(A/ 24 %)

(only in the case of local stresses)

2.5.3. Total safety factor (3.5.2)

Calculating the total safety factor

$$j_{ges} = j_s \cdot \left[j_z \cdot MAX\left(\frac{j_v}{K_{T,m}} \cdot \frac{R_p}{R_m}; \frac{j_p}{K_{T,p}}; \frac{j_{mt}}{K_{Tt,m}} \cdot \frac{R_p}{R_m}; \frac{j_{pt}}{K_{Tt,p}} \right) + \Delta j \right]$$

2.5.3.1. Special cases

$R_p/R_m <= 0{,}75$	$j_{ges} = j_s \cdot j_z \cdot MAX\left(1; \frac{j_p}{K_{T,p}}; 1; \frac{j_{pt}}{K_{Tt,p}}\right)$
$R_p/R_m > 0{,}75$	$j_{ges} = j_s \cdot j_z \cdot MAX\left(\frac{j_v}{K_{T,m}} \cdot \frac{R_p}{R_m}; 1; \frac{j_{mt}}{K_{Tt,m}} \cdot \frac{R_p}{R_m}; 1\right)$

j_s	load factor
j_m	individual safety factors
$K_{t,m}$	temperature factors
R_m,R_p	tensile strength and yield strength
j_z	additional partial safety factor for cast or welded components, here jG and jw shall not be applied in combination, only jG (BM and HAZ) or jw (WS)
Δj	additional safety term for nun-ductile material

2.6. Proof (3.6)

Note: see FKM-guideline chapter 3.6

2.6.1. General (3.6.0)

2.6.2. Non-welded components (3.6.1)

2.6.2.1. Degree of utilisation of the equivalent stress (3.6.1.1)

Proof is evident if the capacity utilisation of the equivalent stress is maximum 1.

a_{SK}= abs (σ_v / (σ_{SK} / j_{ges})) <= 1

2.6.2.2. Control of multiaxiality (3.6.1.2)

If there is a high degree of multiaxiality, then the capacity utilisation of the hydrostatic stress also has to be controlled, for pulling as well as for pressure.

(Usually, this is not the case, particularly if on the free component surface)

$a_{SH,Zug}$= abs (σ_H / ($\sigma_{SH,Zug}$ / j_{ges})) <= 1

degree of multiaxiality: h > h_{max} (1.333) und h < h_{min} (-1.333)

capacity utilisation of the hydrostatic stress

for ductile materials:

$\sigma_{SH,Zug}$ = 1.333 * $\sigma_{SK,Zug}$ und $\sigma_{SH,Druck}$ = -1.333 * $\sigma_{SK,Druck}$

Semi-ductile and brittle materials

$\sigma_{SH,Zug}$ = $K_{NL,Zug}$ / (0.75+0.65*q) * $\sigma_{SK,Zug}$

$\sigma_{SH,Druck}$ = $f_{\sigma,Druck}$ * $K_{NL,Druck}$ / (0.75+0.65*q) * $\sigma_{SK,Druck}$

Note: Special case: h = h_{max} (1.333) and h = h_{min} (-1.333)

2.6.3. Welded components (3.6.2)

2.6.3.1. General (3.6.2.0)

For welded components all proofs have to be carried out separately for the different areas (BM, HAZ,WS).

2.6.3.2. Base material BM and heat affected zone HAZ (3.6.2.1)

Steel and non-softening aluminium materials

$a_{SK} = (\sigma_v / (\sigma_{SK} / j_{ges})) <= 1$

Softening aluminium materials

$a_{SK} = (\sigma_v / (\sigma_{SK} / j_{ges})) <= 1$

2.6.3.3. Weld seam (WS) (3.6.2.2)

Proof using structural stresses

Steel and non-softening aluminium materials

$a_{SK} = (\sigma_{vw} / (\sigma_{SK,w} / j_{ges})) <= 1$

Softening aluminium material

$a_{SK} = (\sigma_{vw} / (\sigma_{SK,w} / j_{ges})) <= 1$

Proof using notch stresses

Structural steel

$a_{SK,wK} = (\sigma_{vwK} / (\sigma_{SK,wK} / j_{ges})) <= 1$

3. Fatigue strength proof according to FKM (4)

Note: see FKM-guideline chapter 4

3.1. General (4.0)

3.2. Stress Characteristics (4.1)

3.2.1. General (4.1.0)

The amplitude and the mean stress of the collective are determined in this chapter. Tensile stresses have positive signs and compression stresses have negative signs. Also the amplitude has a sign which is necessary in case of superposition of several load cases.

3.2.2. Non-welded components (4.1.1)

Note: s. FKM-guideline chapter. 4.1.1

Local stresses at the unloaded surface represent a even state of stress and therefore they have to exist as follows:

σ_x, σ_y, $\tau = \tau_{xy}$,

In case of local stresses at the unloaded surface use these three principal stresses:

σ_1, σ_2, σ_3

3.2.3. Welded components (4.1.2)

3.2.3.1. Proof using structural stresses (4.1.2.1)

In order to carry out the proof use structural stresses resulting from extrapolation on the weld transition notch and vertical and parallel projection to the weld seam. These are the stresses:

$\sigma_{||}$ nominal stress parallel to the weld seam
$\sigma_{\perp}$ nominal stress vertical to the weld seam
$\tau_{\perp}$ shear stress vertical to the weld seam

Generally it is not necessary to consider the BM, HAZ and WS separately to carry out the proof of the fatigue strength like you have to do in the proof of static strength.

3.2.3.2. Proof using notch stresses (4.1.2.2)

With the help of the concept “Radaj R1” you can carry out the proof. Therefore you need to illustrate in detail the weld seam with an equivalent radius of 1 mm.

3.2.4. S-N curve characteristics (4.1.3)

Note: see FKM-guideline chapter 4.1.2.2

The S-N curve shown in double logarithmic way, is made up of the endurance curve which runs horizontally to the right of the bending point II and the two time strength degrees with the slopes k and k_{II}.

The coordinates of the bending points

$$N_D, \sigma_{AK}$$

and

$$N_{D,II}, \sigma_{AK,II}$$

are important reference points.

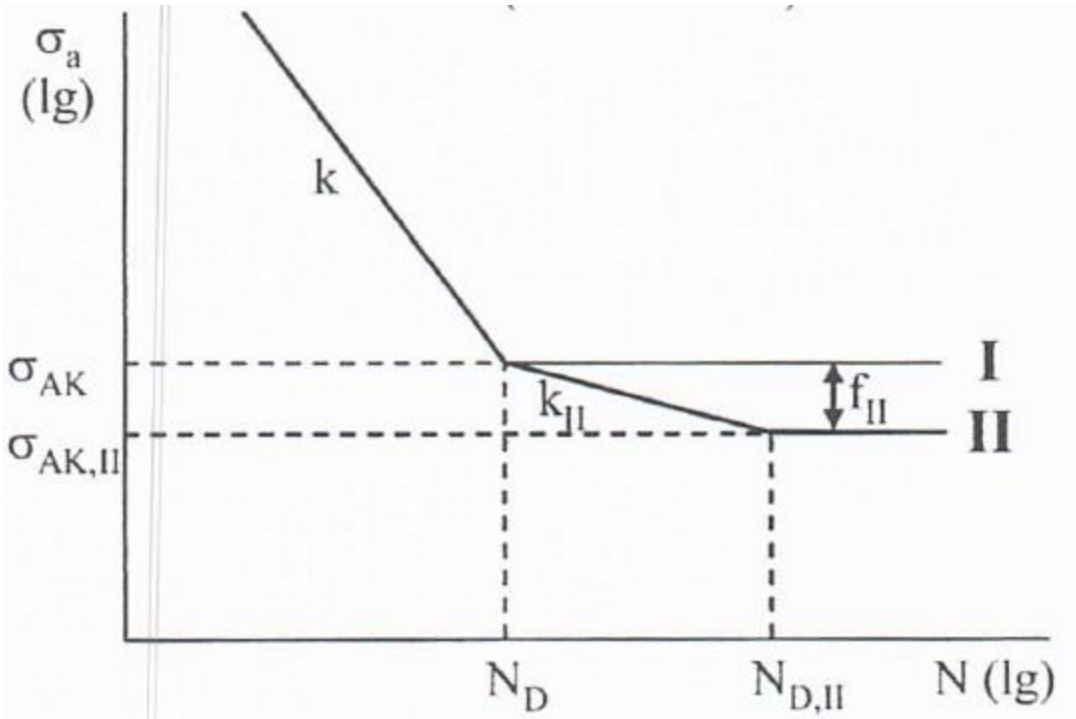


Figure 3-1: ranges of S-N curve with descriptions

3.2.5. Adapting the stress collectives in the component S-N curve (4.1.4)

Note: see FKM-guideline chapter 4.1.4

A real stress collective often has mean stresses, whereas the S-N curve is usually for pure alternating stress so that a conversion to R=-1 is necessary. Furthermore, it makes sense to use damage-equal stress amplitude which replaces the whole collective.

3.2.5.1. Conversion to stress ratio R = -1

States of stress where there is a mean stress are converted to damage-equal stress amplitudes WITHOUT mean stress (R=-1). This is done by amplitude transformation because for the S-N curve R=-1. This is realized with factor $K_{AK,I}$.

$\sigma_{a,W,i} = \sigma_{a,i} / K_{AK,i}$

3.2.6. Conversion to equivalent stress amplitude (4.1.5)

An equivalent stress amplitude replaces the whole collective with one single stress amplitude with a load cycle of the left bending point. The largest collective value is $\sigma_{a,1}$ and the operational strength factor is K_{BK}.

$\sigma_{äqu} = \sigma_{a,1} / K_{BK}$

Using the equivalent stress amplitude, the procedure is identical to the verification for fatigue strength.

3.3. Material characteristics (4.2)

Note: see FKM-guideline chapter 4.2

3.3.1. Non-welded components (4.2.1)

The material alternating strength without constructive influence but considering the component size, is ascertained by:

$$\sigma_{W,zf} = f_{W,\sigma} * R_m$$

$$\tau_{W,zf} = f_{W,\tau} * \sigma_{W,zf}$$

Material group	$fw,_{\sigma}$	$fw,_{\tau}$
Structural steel	0.40 *2	0.577 *2*3
Stainless steel	0.40*4	0.577
Forging steel	0.40*4	0.577
Other steel types	0.45	0.577
GS	0,34	0.577
GJS	0,34	0.65
GJM	0,30	0.75
GJL	0,34	1.0 *5
Aluminium wrought material	0,30*6	0.577
Aluminium cast material	0,30 *6	0.75

Figure 3-2: Reduction factors according to FKM guideline

3.3.2. Welded components (4.2.2)

There are no special material characteristics existing for welded components. Corresponding design factors are used instead.

3.3.2.1. Temperature factor (4.2.3)

The temperature factor applies to welded and non-welded components:

Normal Temperatures: $K_{T,D}$ = 1

(When the temperature increases, the component alternating strength gets less)

The factor $K_{T,D}$ is not incorporated in the component alternating strength, but in in the safety factor.

Material	from °C	to °C
Fine grain structural steel	-40	60
Other steel	-40	100
Cast iron material	-25	100
Hardened aluminium material	-25	50
Non-hardened aluminium material	-25	100

Figure 3-3: Table taken from the FKM-guideline lower temperatures are beyond the utilisation range

Lower temperatures:

Lower temperatures below the given range, are beyond the range of use provided for in the FKM-guideline

Higher temperatures: **For steel and cast iron materials up to 500 °C**

For aluminium materials up to 200 °C

Aluminium materials: $K_{T,D} = 1 - a_{T,D} * 10^{-3} * (T_{[°C]} - 50)$

Fine corned structural steel: $K_{T,D} = 1 - 10^{-3} * T_{[°C]}$

GJS (1,6), GJM (1,3) , GJL (1,0) $K_{T,D} = 1 - a\_TD * 10^{-3} * (T_{[°C]})$

Other steel apart from stainless steel $K_{T,D} = 1 - 1{,}4 * 10^{-3} * (T_{[°C]} - 100)$

GS $K_{T,D} = 1 - 1{,}2 * 10^{-3} * (T_{[°C]} - 100)$

Aluminium material $K_{T,D} = 1 - 1{,}2 * 10^{-3} * (T_{[°C]} - 50)$

(The static proof has other temperature factors)

3.4. Construction factor (4.3)

Note: see FKM-guideline chapter 4.3

3.4.1. Non-welded components (4.3.1)

$$K_{WK,\sigma} = \frac{1}{n_\sigma} * (1 + \frac{1}{\tilde{K}_f} * (\frac{1}{K_R} - 1)) * \frac{1}{K_V * K_S * K_{NL}}$$

$$K_{WK,\tau} = \frac{1}{n_\tau} * (1 + \frac{1}{\tilde{K}_f} * (\frac{1}{K_R} - 1)) * \frac{1}{K_V * K_S}$$

K_t	stress concentration factor for tension/pressure / bending / shear / torsion
$n_{(r/d)}$	support factor for tension/pressure / bending / shear / torsion
K_R	roughness factor for tension/pressure / shear
K_V	marginalised layer factor
$K_{NL,E}$	constants for GJL
K_S	protective layer factor
$\tilde{K}_f$	estimated value of notch factor

3.4.2. Notch factors (4.3.1.2)

3.4.2.1. Estimated value of notch factors for local stresses

(Only necessary if the surface roughness is to be taken into consideration)

$$\tilde{K}_f = MAX(K_{t,\sigma} / n_\sigma ; 1)$$

$$\tilde{K}_f = MAX(K_{t,\tau} / n_\tau ; 1)$$

Approximation formula for $K_t = MAX(10^{0,066-0,36*lg(r/b)};1)$

r = notch radius, if not given, use $r=2/G_\sigma$ or $r=1/G_\tau$

b = wall thickness, if not given

b = deff/2 (heat-treated tempering steel, case hardened steel, tempered and nitrated nitrating steel, tempered cast steel, GJS, GJM, GJL)

b = deff (non-alloy construction steel, fine corned construction steel, normally tempered tempering steel, cast steel and aluminium material)

$n_{\tau,\sigma}$ see next slide. It is also possible to use the values from the table:

Material group	Steel Alumin. wrought	GS	GJS	GJM	GJL
	2.0	2.0	1.5	1.2	1.0

Table 4.3.1 from FKM-guideline

3.4.2.2. Support factor $n_{\tau/\sigma}$

The total support factor is made up of these following factors:

$n_\sigma = n_{st} * n_{vm} * n_{bm}$

3.4.2.3. Support factor n_{st} (static)

Note: see FKM-guideline chapter 4.3.1.3.2

The static support factor ***nst = (Aref,st/Aσ,st)1/kst***

is the same for all types of stress

Consideration of the size influence

The ratio of the highly stressed surface $A_{\sigma,st}$ and a reference sample $A_{ref,st}$ (cylindrical round sample, D = 8mm, p = 20mm -> 500 mm²)

The highly stress surface $A_{\sigma,st}$ for simple geometries is defined in the FKM-guideline

The Weibull exponent k_{st}, can be taken from the

FKM Table 2.3.2 / 4.3.3

Material group	Steel	GS	GJS GJM GJL	Alumin. wrought	Alumin. cast
k_{st}	30	15	10	20	10

3.4.2.4. Support factor n_{vm} (deformation mechanical)

Support factor n_{vm}

- is the same for all types of stress
- takes into consideration the macro support effect according to Neuber
- is for ductile steels and wrought aluminium alloy -> otherwise $n_{vm} = 1$

$n_{vm} = \mathrm{sqrt}(1 + E*\varepsilon_{pl,W}/\sigma_W * n_{st}^{(1/n'-1)})$

n‘ for steel = 0,15; wrought aluminium alloy = 0,1

$\varepsilon_{pl,W}$ permanently bearable alternating plastic strain

wrought aluminium alloy $1{,}6*10^{-5}$

Steel $R_m < 630 = 2 * 10^{-4}$

Steel $R_m >= 630 = 2 * 10^{-4} * (1-0{,}375(R_m / 630 - 1)$

3.4.2.5. Support factor n_{bm} for local stresses (fracture mechanical)

Includes the slower growth of fatigue tears in a load field with gradients, as against a homogenous field with equal stresses

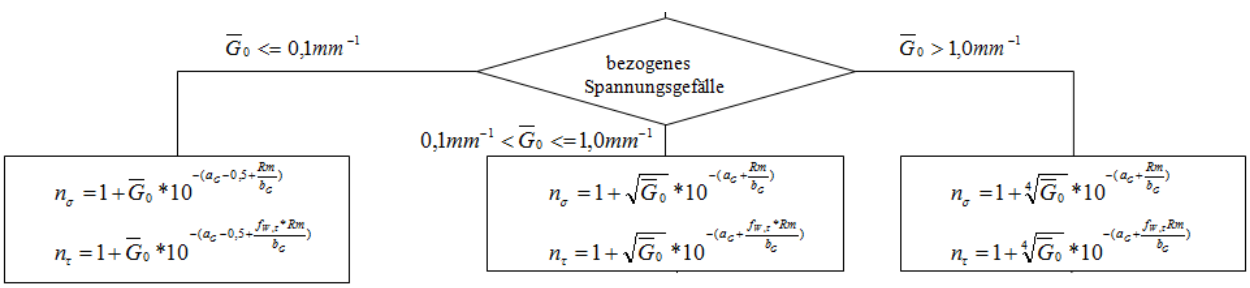
$$n_{bm} = \frac{5+\sqrt{G \cdot mm}}{5 \cdot n_{vm} \cdot n_{st} + \frac{R_m}{R_{m,bm}} \sqrt{\frac{7{,}5+\sqrt{G \cdot mm}}{1+0{,}2 \cdot \sqrt{G \cdot mm}}}}$$

G applied drop in stresses

$R_{m,bm}$ reference tension strength -> steel = 680 MPa; aluminium = 270 Mpa

3.4.2.6. Support factor $n_{\tau/\sigma}$ according to Sieler

Uses the applied drop in stresses



	Einsatzstahl	nicht.rost.S.	SchmiedeS.	FeinkornbausS.	Walzstahl	Undef.	Stahlguß	Grauguß	Späroguß	Temperguß	Aluknet	Aluguß
	[steel]	[not rust steel]	[forge steel].	[fine grain steel].	[low alloy steel]	[undefined].	[cast steel]	[gray iron]	[GGG]	[malleable iron]	[alu]	[cast alu]
aG	0,50	0,4	0,50	0,50	0,5	0,5	0,25	-0,05	0,05	-0,05	0,05	-0,05
bG	2700	2400	2700	2700	2700	2700	2000	3200	3200	3200	850	3200

Figure 3-4: table 2.3.6 / 4.3.5 from FKM-guideline

3.4.3. The applied drop in stresses G_σ (Nominal stress)

Note: see FKM-guideline chapter 4.3.1.3.3

The related stress gradient G_σ (local stresses)

Formula

$$G_\sigma = \frac{1}{\sigma_{1a}} \cdot \frac{\Delta\sigma_a}{\Delta s} \quad G_\tau = \frac{1}{\tau_{1a}} \cdot \frac{\Delta\tau_a}{\Delta s}$$

If there is no FE calculation, use

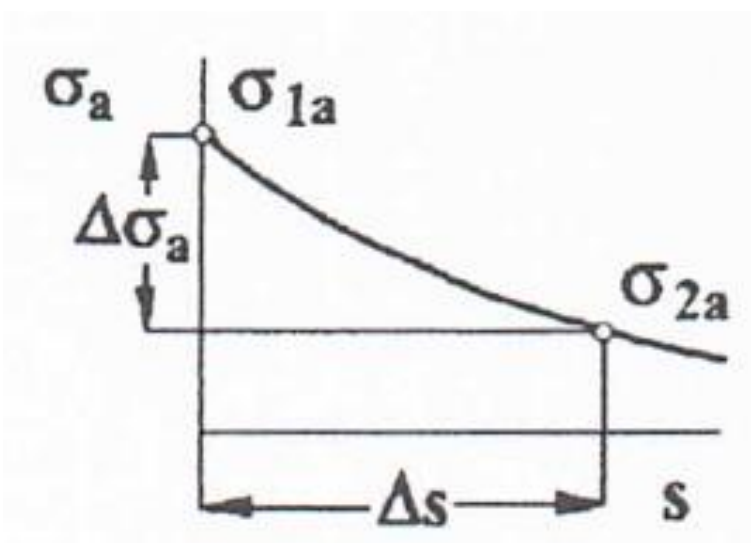


Figure 3-5: Reference points for ascertaining the applied stress gradients

G_σ = 2/r+2/d and G_τ = 1/r+2/d

In this case for overlapped notches, $G = G_1 + G_2$

(The distance between both notches should be smaller than 2r)

The applied drop in stresses will automatically be calculated if you use VIEWER4WINLIFE. The algorithm is described at another place in this manual.

3.4.4. Roughness factor

Polished sample has $K_{R,\sigma/\tau} = 1$

Mill scale, forging skin and cast skin is $K_{R,\sigma/\tau} = 200\ \mu m$

$$K_{R,\sigma} = 1 - a_{R,\sigma*} \lg(R_{z[\mu m]}) * \lg(2 * \frac{Rm}{R_{m,N,\min}})$$

$$K_{R,\tau} == 1 - f_{W,\tau} * a_{R,\sigma*} \lg(R_{z[\mu m]}) * \lg(2 * \frac{Rm}{R_{m,N,\min}})$$

	Einsatzstahl [steel]	nicht.rost.S. [not rust steel]	SchmiedeS. [forge steel].	FeinkornbausS. [fine grain steel].	Walzstahl [low alloy steel]	Undef. [undefined].	Stahlguß [cast steel]	Grauguß [gray iron]	Späroguß [GGG]	Temperguß [malleable iron]	Aluknet [alu]	Aluguß [cast alu]
aRs	0,22	0,22	0,22	0,22	0,22	0,22	0,20	0,06	0,16	0,12	0,22	0,20
RmNmin	400	400	400	400	400	400	400	100	400	350	133	133

Figure 3-6: Table 2.3.6 / 4.3.5 taken from FKM-guideline

Less favourable for boundary hardened components and when the crack initiation place is on the edge because of the higher tensile strength (R_m).

If the notch factors have been determined from experiments, then the roughness factor does not need to be taken into consideration.

Unless there is a clear difference between sample and component

$$K^{\sim}_{R,\sigma/\tau} = K_{R,\sigma/\tau}(R_z) \ / \ K_{R,\sigma/\tau}(R_{z,Probe})$$

3.4.5. Welded components (4.3.2)

3.4.5.1. General (4.3.2.0)

The following design characteristics are decisive for welded components.

FAT⊥	fatigue class
$f_{FAT,\sigma}$	factor for conversion from fatigue class to component fatigue limit
f_t	thickness factor
K_v	marginalised layer factor

3.4.5.2. Fatigue class (FAT) and conversion factor (4.3.2.1)

Apply the fatigue classes (FAT) to normal stresses in steel, cast iron and aluminium materials vertical and parallel and to shear stresses. The fatigue class corresponds to the double amplitude with the reference number of cycles $N_{c..}$ The stress ratio between the reference number of cycles and S-N curve depends on the exponent k.

The fatigue class (FAT) represents the amplitude of the stress with the reference number of cycles. The reference number of cycles comes to $N_C=2*10^6$ cycles using FKM-guideline. The point of deflection of S-N curve differs from that! Carry out the conversion from reference number of cycles to the number of cycles at the bending point according to the following equations:

$$f_{FAT,\sigma} = \left(\frac{N_C}{N_{D,\sigma}}\right)^{\frac{1}{k_\sigma}}$$

$$f_{FAT,\tau} = \left(\frac{N_C}{N_{D,\tau}}\right)^{\frac{1}{k_\tau}}$$

Normal stress

Component	$N_{D,\sigma}$	$N_{D,II,\sigma}$	k_σ	$k_{II,\sigma}$	$f_{II,\sigma}$	k_τ
Steel and cast iron material (WL-Typ 1)						
Non-welded	10^6		5			
welded	$5\ 10^6$		3			
Aluminium material and austentic steel (WL-Typ 2)						
Non-welded	10^6	10^8	5	15	0,74	
welded	$5\ 10^6$		3			

Shear stress

Component	$N_{D,\tau}$	$N_{D,II,\tau}$	k_τ	$k_{II,\tau}$	$f_{II,\tau}$	k_τ
Steel and cast iron material (WL-Typ 1)						
Non-welded	10^6		8			
welded	10^8		5			
Aluminium material and austentic steel (WL-Typ 2)						
Non-welded	10^6	10^8	8	25	0,83	
welded	10^8		5			

$N_{D,\sigma}$, $N_{D,\tau}$	Number of cycles at the bending point of the component S-N curve
N_C	Reference number of cycles of the fatigue class 0 2 * 10^6
k_σ , k_τ	Exponent of the S-N curve

$f_{FAT,\sigma}$=1/2,71 = 0,37

$f_{FAT,\tau}$=1/4,37 = 0,23

3.4.5.3. Thickness factor (4.3.2.2)

The following applies to case A of the FKM-guideline which corresponds to the IIW-recommendations:

To sheet matal <= 25 mm applies as follows:

f_t=1,0

To sheet metal thickness t>25 mm applies as follows:

$$f_t = \left(\frac{25\ mm}{t}\right)^n$$

Choose exponent n according to the following table:

	Type of welded joint	n
Fall A4/B4	Cross loaded cross- and T-shocks, sheet metals with horizontal stripes, as welded	0,3
Fall A3/B3	Cross loaded cross- and T-shocks, sheet metals with horizontal stripes, weld transition grinded	0,2
Fall A2/B2	Cross loaded butt joints, as welded	0,2
Fall A1/B1	Butt joints, sheet even grinded, base material, longitudinal loaded weld seams or welded-on pieces	0,1

3.4.6.

To case B applies the following:

To sheet metal <= 10 mm applies:

f_t=1,1

To sheet metal 10 mm < t <= 25 mm applies:

$$f_t = \left(\frac{25\ mm}{t}\right)^{0,1}$$

To sheet metal > 25 mm applies:

$$f_t = \left(\frac{25\ mm}{t}\right)^n$$

Choose the exponent according to the table mentioned above.

3.4.7. Marginalised layer factor

	Process	Non-notched components *3	Notched components
without = $K_V = 1$ with -> according to table. For aluminium the values for cast iron materials can be used approximately. Taken from the FKM-guideline Table 2.3.8	Thermal process		
	Inductive hardening Flame hardening Hardening depth 0.9 ….1.5 mm surface hardness 51 to 64 HRC	1.20 – 1.50 (1.30 – 1.60)	1.50 – 2.50 (1.60 – 2.80)
	Iron cast material		
	Nitriding	1.10 (1.15)	1.3 (1.9)
	Case hardening	1.1 (1.2)	1.2 (1.5)
	Compact rolling	1.1 (1.2)	1.3 (1.5)
	Shot peening	1.1 (1.1)	1.1 (1.4)
	Inductive hardening, flame hardening	1.2 (1.3)	1.5 (1.6)

	Process	Non-notched components *3	Notched components
without = $K_V = 1$ with -> according to table. For aluminium the values for cast iron materials can be used approximately. Taken from the FKM-guideline Table 2.3.8	Steel		
	Chemical-thermal process		
	Nitriding Hardening depth 0.1 ….0.4 mm surface hardness 700….1000 HV 10	1.10 – 1.15 (1.15 – 1.25)	1.30 – 2.00 (1.90 – 3.00)
	Case hardening Hardening depth 0.2 ….0.8 mm surface hardness 670….750 HV 10	1.10 – 1.50 (1.20 – 2.00)	1.20 – 2.00 (1.50 – 2.50)
	Carbon nitriding Hardening depth 0.2 ….0.4 mm surface hardness minimum 670 HV 10	(1.80)	
	Mechanical process		
	Compact rolling	1.10 – 1.25 (1.20 – 1.40)	1.30 – 1.80 (1.50 – 2.20)
	Shot peening	1.10 – 1.20 (1.10 – 1.30)	1.10 – 1.50 (1.40 – 2.50)

Figure 3-7: table 2.3.8 taken from FKM-guideline

3.4.8. Protective layer factor

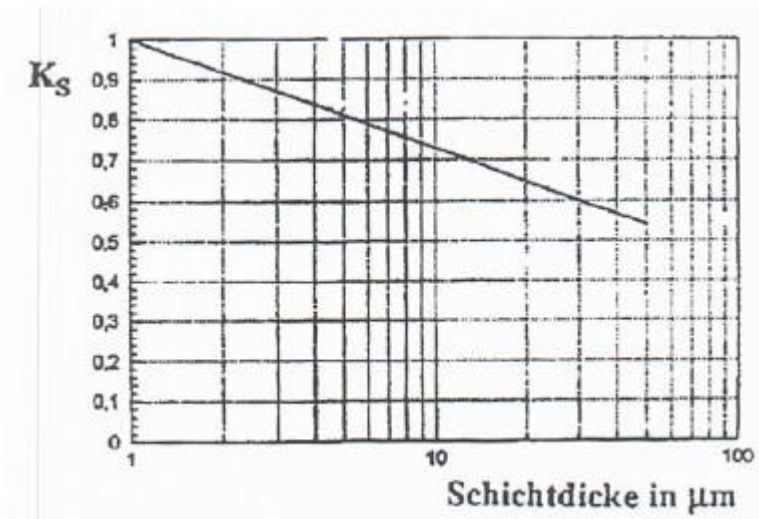
This takes into account a protective layer of a component of aluminium material.

All other materials is $K_S = 1$

Diagram 2.3-4

Taken from the

FKM-guideline

Figure 3-8: Diagram 2.3-4 taken from the FKM-guideline	

3.4.9. Factor KNL,E

The constants $K_{NL,E}$ are to consider the non-linear stress strain behaviour of GJL, either for bending or if the loading is essentially bending.

All other materials is $K_{NL,E} = 1$

Material	GG -100	GG -150	GG -200	GG -250	GG -300	GG -350
$K_{NL,E}$	1,075		1,05		1,025	

Figure 3-9: Taken from table 2.3.9 of the FKM-guideline

Is used for welded and non-welded components.

3.5. Component strength (4.4)

Note: see FKM-guideline chapter 4.4

Summary

Component Alternating strength taking into consideration the construction factors from the material alternating strength

Component Endurance strength taking into consideration the mean stress factors from the component alternating strength

Component Fatigue strength taking into consideration the fatigue strength factor

(Stress collective, component S-N curve) from the component endurance strength

Utilisation degree =

existing stress amplitude / (component fatigue strength * safety

3.5.1. Component alternating strength (4.4.1)

3.5.1.1. Non-welded components (4.4.1.1)

Taking into consideration the construction factors

$$S_{WK,zd/by/bz} = 1/K_{WK,zd/by/bz} * \sigma_{W,zd}$$
$$T_{WK,,sy/sz/t} = 1/K_{WK,sy/sz/t} * \tau_{W,s}$$

Note: Difference nominal stress and local stresses -> S u. σ

$$\sigma_{WK} = 1/K_{WK} * \sigma_{W,zd}$$
$$\tau_{WK} = 1/K_{WK} * \tau_{W,s}$$

3.5.1.2. Welded components (4.4.1.2)

The following equations apply to the alternating strength at the bending point:

3.5.2.

Normal stresses vertical to the weld seam

$$\sigma_{WK,\perp} = FAT_{\perp}\, f_{FAT,\sigma}\, f_t\, K_V\, K_{NL,E}$$

Normal stresses parallel to the weld seam

$$\sigma_{WK,\parallel} = FAT_{\parallel}\, f_{FAT,\sigma}\, f_t\, K_V\, K_{NL,E}$$

Shear / Torsion

$$\tau_{WK} = FAT_{\tau}\, f_{FAT,\tau}\, f_t\, K_V$$

The normal stress characteristics apply to the number of cycles $N_{D,\sigma} = 5\ 10^6$, the shear stress characteristic applies to $1 * 10^8$.

$FAT_{\perp}$	fatigue class
$f_{FAT,\sigma}$	factor for conversion from fatigue class to component fatigue limit
f_t	thickness factor
K_v	marginalised layer factor
$K_{NL,E}$	constant for GJL

3.5.3. Component fatigue limit (4.4.2)

3.5.3.1. General (4.4.2.0)

The calculation applies to non-welded and welded components using different input values in each case.

In the FKM-guideline the stress ratio R is calculated for the largest amplitude of the collective and for all levels of collective the stress ratio R is assumed to be equal in order to simplify this matter.

However, winLIFE calculates for each level of collective the individual stress ratio and takes these values into consideration regarding the calculation. Normally, this “exact” way leads to small differences only. The reason is on the one hand that the stress ratio within a collective usually doesn’t fluctuate very much and on the other hand the biggest damage is mostly caused by the largest amplitude.

3.5.3.2. Non-welded components (4.4.2.1)

3.5.3.3. Amplitude of the fatigue limit (4.4.2.1.1)

Amplitude of the component fatigue limit depending on the mean stress

$$S_{AK,zd/by/bz} = K_{AK,zd/by/bz} * S_{WK,zd/by/bz}$$

$$T_{AK,sy/sz/t} = K_{AK,sy/sz/t} * S_{WK,sy/sz/t}$$

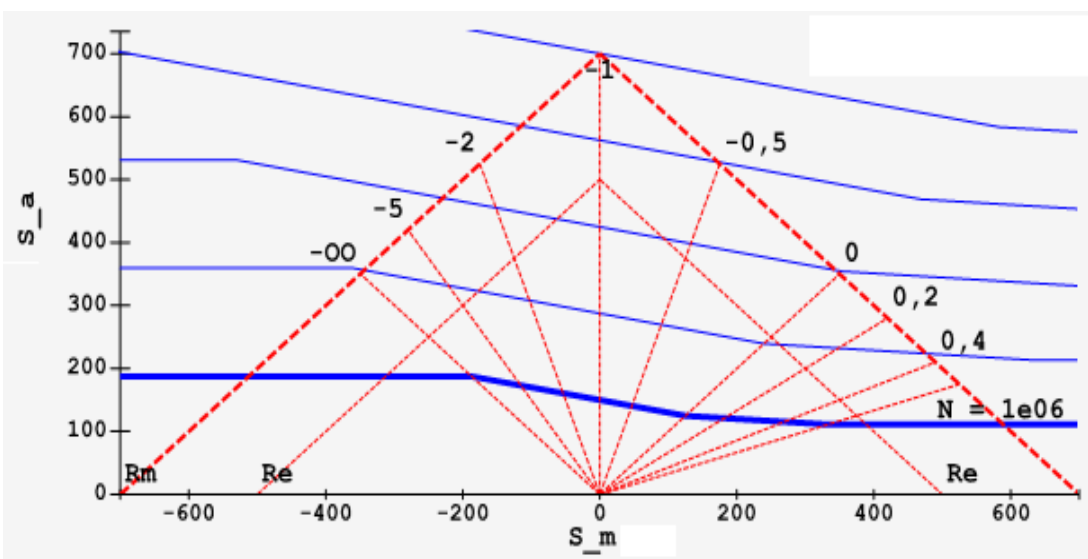


Figure 3-10: Haigh-diagram: amplitude of stress versus mean stress (asymmetrical to the ordinate)

3.5.4. Mean stress sensitivity (4.4.2.1.2)

The component mean stress sensitivity describes with the mean stress factor the changes to the amplitude of the component endurance strength in conjunction with the mean stress.

$$M_\sigma = a_M * Rm * 10^{-3} + b_M$$
$$M_\tau = f_{W,\tau} * M_\sigma$$

	Einsatzstahl [steel]	nicht.rost.S. [not rust steel]	SchmiedeS. [forge steel].	FeinkornbausS. [fine grain steel].	Walzstahl [low alloy steel]	Undef. [undefined].	Stahlguß [cast steel]	Grauguß [gray iron]	Späroguß [GGG]	Temperguß [malleable iron]	Aluknet [alu]	Aluguß [cast alu]
AM	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0	0,35	0,35	1	1
BM	-0,1	-0,1	-0,1	-0,1	-0,1	-0,1	0,05	0,5	0,08	0,13	-0,04	0,2

Figure 3-11: table from FKM guideline

Residual stress factor (4.4.2.1.3)

You only need to consider the residual stress factor for non-welded components if you calculate the mean stress factor. For that case the residual stress factor is:

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

Mean stress sensitivity (4.4.2.2.2) and residual stress factor (4.4.2.2.3)

Residual stresses	$K_{E,\sigma}$	M_σ	$K_{E,\tau}$	M_τ [*1]
high	1,00	0	1,00	0
moderate	1,26	0,15	1,15	0,09
low	1,54	0,30	1,30	0,17

[1] To shear stresses applies: $M_\tau = f_{W,\tau} \cdot M_\sigma$, $f_{W,\tau} = 0{,}577$

Calculate the mean stress factor $K_{A,K}$ by means of the amplitude transformation.

3.5.4.2. Fatigue limit diagram (4.4.2.3)

3.5.5. Mean stress range normal stresses

Range I R > 1, pressure threshold range

Range II -∞ <= R -> 1 pressure threshold range

-1 <= R <= 0 reversed tension range

Range III 0 < R < 0.5 low pulsating range

Range IV R >= 0.5 high pulsating range

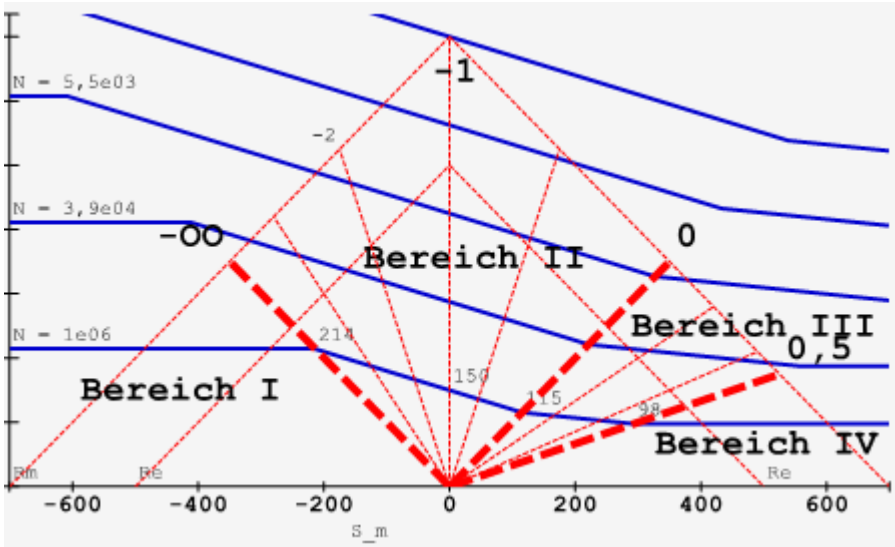


Figure 3-12: Haigh diagram for normal stresses with marked different ranges

3.5.6. Mean stress range shear stresses

Range I R > 1, non-applicable

Range II other lower limit

-1 <= R <= 0 reversed tension range

Range III 0 < R < 0.5 low pulsating range

Range IV R >= 0.5 high pulsating range

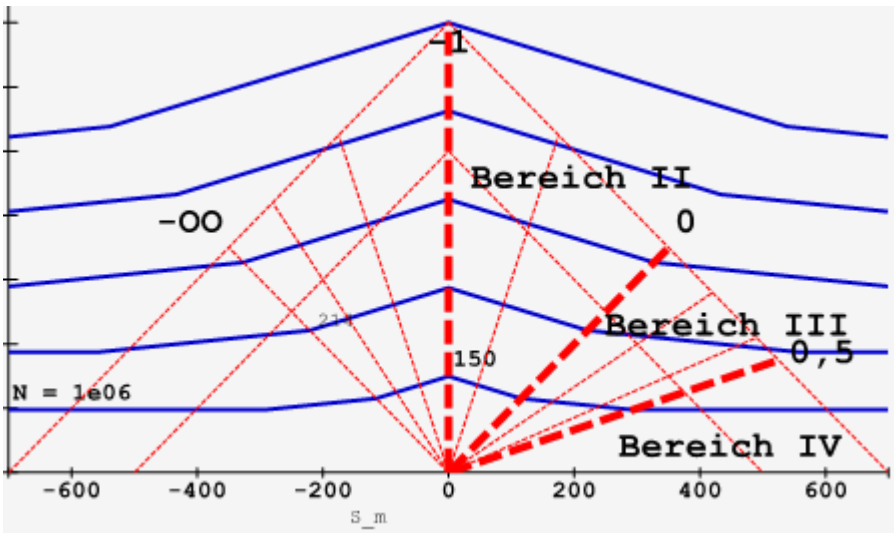


Figure 3-13: Haigh-diagram for shear stresses

3.5.7. Mean stress factor (4.4.2.4)

Mean stress factor depends on a possible increase in utilisation load.

F1 → Mean stress S_m constant

F2 → Stress ratio R constant

$$S_m / S_a = (1+R)/(1-R)$$

F3 → Minimum stress S_{min} constant

F4 → Maximum stress S_{max} constant

Range I $$K_{AK} = \frac{1}{1-M_\sigma}$$	Range II $$K_{AK} = \frac{1}{1+M_\sigma \cdot S_m / S_a}$$

Range III $$K_{AK} = \frac{3+M_\sigma}{(1+M_\sigma)\cdot(3+M_\sigma\cdot S_m / S_a)}$$	Range IV $$K_{AK} = \frac{3+M_\sigma}{3\cdot(1+M_\sigma)^2}$$

Shear stresses → only R >= -1 and indication 's' (Shear) and 't' (torsion)

Overloading

The FKM-guideline defines cases of overloading F1, F2, F3, F4. For these cases the mean load or the stress ratio for example are constant. Due to the calculation method of the FKM-guideline this difference of cases is necessary because the stress ratio for one collective is standardly considered to be constant. The collectives need to be adjusted accordingly to realise the boundary conditions by means of the simplified algorithm.

However, winLIFE does not use the simplification (constant R for the total collective) but considers the stress ratios of the individual levels of collective for each level correctly. winLIFE defines the cases of overloading in such a way that the corresponding collectives are given. In our opinion the advantage of this procedure is a better transparency.

3.5.7.1. Individual or equivalent mean stress (4.4.2.5)

Note: see FKM guideline chapter 4.3.2.5

Non-welded components

The following sizes apply to normal and shear stresses:

σ_{min} σ_{max} σ_a σ_m

and

τ_{min} τ_{max} τ_a τ_m

Welded components

$\sigma_{min,\perp}$ …. $\sigma_{min,\parallel}$, …., bzw. $\tau_{min,\perp}$,… **,..,.**

Individual mean stress

All sizes arise from the mean stress and the amplitude

$S_{min} = S_m - S_a$

$S_{max} = S_m + S_a$

$R_n = S_{min} / S_{max}$

A distinction is made between individual mean stress and comparative mean stress

Comparative mean stresses are used in the typical case of bending or torsion -> (priority individual mean stress)

Equivalent mean stress

An equivalent mean stress is created in case of "bending and torsion", which is typical in machine design, and in familiar cases with normal and shear stresses. This equivalent mean stress enables in the next step the calculation of the equivalent stresses $\sigma_{min,v}$ $\sigma_{max,v}$ as well as the calculation of the stress ratio R_v. The following applies

$\sigma_{min,v} = \sigma_{m,v} - \sigma_a$

$\sigma_{max,v} = \sigma_{m,v} + \sigma_a$

$R_v = \sigma_{min,v} / \sigma_{max,v}$

Equivalent mean stress for normal stress

$$\sigma_{m,v} = q \cdot \sigma_{m,v,NH} + (1-q) \cdot \sigma_{m,v,GH}$$ equation 4.4.33.

with

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

$$\sigma_{m,v,NH} = 1/2\left(|\sigma_m| + \sqrt{\sigma_m^2 + 4\tau_m^2}\right)$$

$$\sigma_{m,v,GH} = \sqrt{\sigma_m^2 + 3 \cdot \tau_m^2}$$

q= constante

	Steel alu-wrought	GJS	GJM Alu-cast	GJL
$f_{w,\tau}$	0,577	0,65	0,785	1
q	0	0,264	0,544	1

σ_m ,τ_m individual mean stress

For shear stress:

$$\tau_{m,v} = f_{w,\tau} \cdot \sigma_{m,v}$$

Non-welded components

Determine the equivalent mean stress for non-welded components only for the values $\sigma_{m,x} + \sigma_{m,y} + \sigma_{m,z} \geq 0$ according to the equation 4.4.33. The following applies:

$\sigma_m = \sigma_{m,x} + \sigma_{m,y} + \sigma_{m,z}$ equation 4.4.36

$\tau_m = \tau_{m,yz} + \tau_{m,xz} + \tau_{m,xy}$

$\sigma_{m,x}$,... individual mean stresses, chapter. 4.1.

Insert the values $\sigma_{m,x}$, $\sigma_{m,y}$, $\sigma_{m,z}$, $\tau_{m,yz}$, $\tau_{m,xz}$, $\tau_{m,xy}$ into equation 4.4.36 with the correct signs because their effects may become added or subtracted.

Welded components

Calculate the equivalent mean stress for welded components only for the values $\sigma_{m,\perp} \geq 0$ and $\sigma_{m\parallel} 0$ (or the other way round) according to the equation 4.4.33. The following applies:

$\sigma_m = \sigma_{m,\perp}$ oder $\sigma_{m=} \sigma_{m,\parallel}$
$\tau_m = \tau_m$

$\sigma_{m,\perp}$ individual mean stresses

Preference of the individual mean stress

If the equivalent mean stress for a single type of stress is smaller than the individual mean stress (according to equation 4.4.33) calculate this type of stress using the individual mean stress.

3.6. Component Fatigue Strength (4.4.3)

3.6.1.1. General (4.4.3.0)

Component Fatigue Strength taking into account the stress collective, the collective shape and the component S-N curve.

Single step collective → Fatigue strength proof or time yield proof

Multiple step collective → operational strength proof or equivalent stress amplitude leads to Fatigue strength proof.

3.6.1.2. Non-welded components (4.4.3.1)

$\sigma_{BK} = K_{BK,\sigma} * \sigma_{AK}$ equation 4.4.38

$\tau_{BK} = K_{BK,\tau} * \tau_{AKt}$

$K_{BK,\sigma}$, $K_{BK,\tau}$ Fatigue strength factor for the respective stress component considering equation 4.4.42

σ_{AK} τ_{AKt} Component fatigue limit

Calculate equation 4.4.38 at the reference point separately for each stress component.

3.6.1.3. Welded components (4.4.3.2)

$\sigma_{BK,\perp} = K_{BK,\perp} * \sigma_{AK,\perp}$ equation 4.4.39

$\sigma_{BK,\parallel} = K_{BK,\parallel} * \sigma_{AK,\parallel}$

$\tau_{BK} = K_{BK,\tau} * \tau_{AK}$

$K_{BK,\perp}$, …… Fatigue strength factor considering equation Gl. 4.4.42

$\sigma_{AK},\perp$,….. Component fatigue limit

3.6.1.4. Restriction of the maximum amplitude of the component fatigue strength (4.4.3.3)

The bearable value of the amplitude of the fatigue strength σ_{BK} is restricted by the static strength σ_{SK} as well as by the component yield strength.

Non-welded components

$\sigma_{BK,max} = 0{,}75 * R_p * n_{pl}$

$\tau_{BK,max} = 0{,}75 * f_t * R_p * n_{pl}$

Welded components

$\sigma_{BK,max,\perp} = 0{,}75 * R_p * n_{pl} * \alpha_w * \rho_{WEZ}$

$\sigma_{BK,max,\parallel} = 0{,}75 * R_p * n_{pl} * \alpha_w * \rho_{WEZ}$

$\tau_{BK,max} = 0{,}75 * R_p * n_{pl} * \alpha_w * \rho_{WEZ}$

R_p	yield strength
f_t	shear strength factor
n_p	plastic support factors
α_w	weld seam factor
ρ_{WEZ}	softening factor

The following applies to each stress component:

If $\sigma_{BK} >= \sigma_{BK,max}$ then

$\sigma_{BK} = \sigma_{BK,max}$ and $K_{BK} = \sigma_{BK,max} / \sigma_{AK}$

K_{BK}	fatigue strength factor
σ_{BK}	component fatigue strength
σ_{AK}	component fatigue limit

3.6.2. Component S-N curve (4.4.3.4)

Normal stress

component	$N_{D,\sigma}$	$N_{D,II,\sigma}$	$k_{,\sigma}$	$k_{II,\sigma}$	$f_{II,\sigma}$
steel and cast iron material (WL Typ I)					
non-welded	10^6	-	5		
welded	$5 * 10^6$	-	3		
aluminium material and austenitic steel (WL Typ II)					
non-welded	10^6	10^8	5	15	0,74
welded	$5 * 10^6$		3		

Shear stress

component	$N_{D,\tau}$	$N_{D,II,\tau}$	$k_{,\tau}$	$k_{II,\tau}$	$f_{II,\tau}$
steel and cast iron material (WL Typ I)					
non-welded	10^6	-	8	-	-
welded	10^8	-	5	-	-
aluminium material and austenitic steel (WL Typ II)					
non-welded	10^6	10^8	8	25	0,83
welded	10^8	-	5	-	-

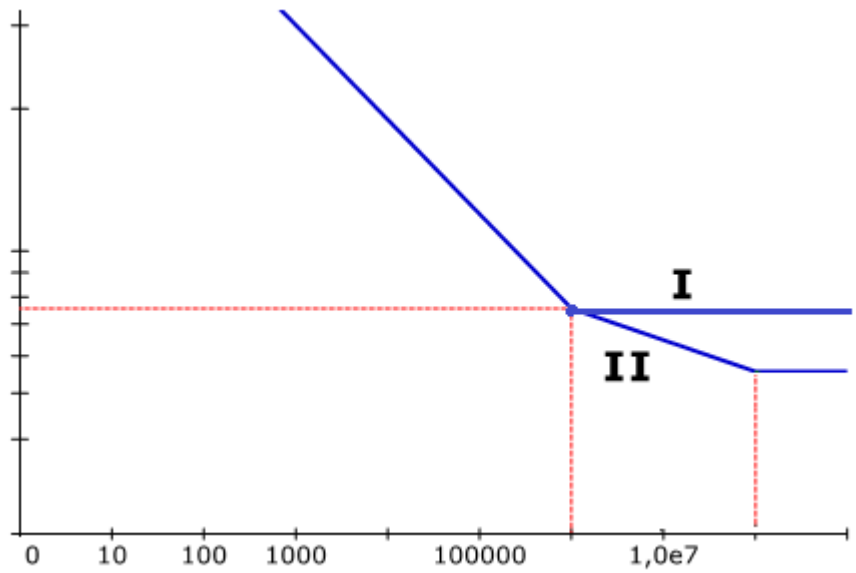


Figure 3-1: Distinction between the S-N curves

3.6.3. Fatigue strength factor – single step collective (4.4.3.5.1)

Component S-N curve type I

$N < N_D$ proof of the fatigue strength for finite life $$K_{BK} = \left(\frac{N_D}{N_{D,II}}\right)^{\frac{1}{k_{II}}}$$

$N >= N_D$ proof of endurance limit $$K_{BK} = 1$$

Component S-N curve type II

$N < N_D$ proof of the fatigue strength for finite life $$K_{BK} = \left(\frac{N_D}{N}\right)^{\frac{1}{k_{II}}}$$

$N_D < N < N_{D,II}$ proof of the fatigue strength for finite life * $K_{BK} = (\frac{N_D}{N})^{\frac{1}{k}}$

$N = N_{DI}$ proof of endurance limit $K_{BK} = 1$

$N >= N_{D,II}$ boundary stress amplitude * $K_{BK} = (\frac{N_D}{N})^{\frac{1}{k}}$

3.6.4. Fatigue strength factor – multiple step collective (4.4.3.5.2)

Carry out the calculation preferably using the “consistent version of Miner’s rule” or, in a simplified manner, using “elementary version of Miner’s rule”.

Component S-N curve type I / II

$$K_{BK} = \left(\frac{A \cdot N_D \cdot D_m}{N}\right)^{\frac{1}{k}}$$

S-N curve type I: the value must not become smaller than 1

S-N curve type II: the value must not be calculated smaller than * (take a look at the previous chart)

A = distance between fatigue life curve and S-N curve, correspondingly for Miner’s elementary version or Miner’s consistent version

D_m = effective Miner’s sum

$$D_m = MAX\left(D_{m,\min}; MIN\left(1; \frac{2}{\sqrt[4]{A}}\right)\right)$$

	$D_{m,\ min}$
Steel, GS, Aluminium, *not welded*	0,3
Welded components	0,5
GJS, GJM, GJL *not welded*	1,0

Table 2.4.4 taken form FKM-guideline

A – distance fatigue life curve – S-N curve

Miner’s elementary version for component S-N curve type I / II

$$A_{ele} = \frac{1}{\sum_{i=1}^{j} \frac{n_i}{N} \left(\frac{S_{a,i}}{S_{a,1}}\right)^k}$$

Miner’s consistent version for component S-N curve type I / II

2 different iterative procedures in each case -> see guideline

3.7. Safety factors (4.5)

3.7.1. General (4.5.0)

The safety factors refer to a fatigue value survival probability of 97.5 %

j_S = load factor, if the load assumption is considered to be safe, the value is „1“. Other factors are described in chapter 5.7.

3.7.2. Non-welded components (4.5.1)

3.7.2.1. Steel- and wrought aluminium materials (4.5.1.1)

Safety factors depending on damage consequences and possibilities of inspection.

j_F		Damage consequences		
		high	medium	low
Regular inspection	no	1.5	1.4	1.3
	yes	1.35	1.25	1.2

Table 4.5.1, taken from the FKM-guideline

3.7.2.2. Cast iron and cast aluminium materials (4.5.1.2)

In addition, when using cast material you need to consider the material safety factor j_G.

	j_G
Castings not subject to non-destructive testing	1,4
Castings subject to non-destructive testing	1,25
High quality cast components	1,0

Table 4.4.2 taken from FKM-guideline: material safety factors for non-welded components

3.7.3. Welded components (4.5.2)

j_F		Damage consequences		
		high	medium	low
Regular inspection	no	1,4	1,25	1,15
	yes	1,2	1,1	1,0

Table 4.5.3: Material safety factors for welded components

3.7.4. Total safety factor (4.5.3)

$j_D = j_S * j_F / K_{T,D}$

for cast parts

$j_D = j_S * j_F * j_G / K_{T,D}$

j_S	load safey factor
j_F	material safey factor
j_G	cast factor
$K_{T,D}$	temperature factor

3.8. Proof (4.6)

3.8.1. General (4.6.0)

Carry out the proof of the fatigue strength using local stresses for each individual stress component according to chapter 4.6.1.

Carry out the proof of the fatigue strength using local stresses for the combined stress according to chapter 4.6.2.

The calculation applies to welded and non-welded components.

3.8.1.1. Degree of utilisation

Carry out the proof by means of the cyclic degree of utilisation which is defined as follows:

- existing stress amplitude σ_a divided by
- allowable amplitude of the fatigue strength

must be carried out for the reference point.

The allowable amplitude of the fatigue strength is the quotient of:

- critical amplitude of the component fatigue strength σ_{BK} and
- total safety factor j_D

Indicate all amplitudes with a positive value. Therefore, also the total degree of utilisation is always positive.

3.8.1.2. Superposition

A superposition is necessary if several stress components act at the reference point. The given equations represent empirical interaction equations which apply to proportional stress and approximately to synchronous stresses. In case of turning principal stresses you must not use a superposition.

3.8.2. Individual stress types (4.6.1)

3.8.3. Calculate the cyclic degree of utilisation of non-welded components for normal and shear stresses for all stress components.

3.8.4. The proof is done if all required degrees of utilisation are 1 at the maximum.

Individual degrees of utilisation for individual types of stress

$a_{BK,\sigma} = \sigma_{a,\ zd/by/bz} / (\sigma_{BK,\ zd/by/bz} / j_D) <= 1$ (equation 4.6.3)

$a_{BK,\tau\ t} = \tau_{a,1} / (\tau_{BK} / j_D) <= 1$

In case of components with normal stresses vertical and parallel to the seam weld as well as shear stresses, the following applies:

$a_{BK,\perp} = \sigma_{a,\perp,1} / (\sigma_{BK,\perp} / j_D)) <= 1$

$a_{BK,\parallel} = \sigma_{a,\parallel,1} / (\sigma_{BK,\parallel} / j_D)) <= 1$ (equation 4.6.4)

$a_{BK,\tau} = \text{abs}(\tau_{a,1} / (\tau_{BK,\tau} / j_D)) <= 1$

$\sigma_{a,1}$,..... highest stress amplitude, depending on the type of stress

$\sigma_{BK,....}$ related fatigue strength

j_D total safety factor

3.8.5. Combined types of stress (4.6.2)

3.8.6. Proportional and synchronous stresses (4.6.2.1)

The cyclic degree of utilisation for non-welded components results from the sum of the degree of utilisation according to the normal stress hypothesis and the von Mises criterion. Both proportions are controlled by constant q, depending on the ductility of the material.

$$a_{BK,\sigma v} = q \cdot a_{NH} + (1-q) \cdot a_{GH} \leq 1$$ (equation 4.6.5)

	Steel, wrought aluminium	GJS	GJM, cast aluminium	GJL
$f_{w,\tau}$	0,577	0,65	0,785	1
q	0	0,264	0,544	1

Table 4.6.1: values of q depending on $f_{w,\tau}$ (taken from FKM-guideline)

$$q = \frac{\sqrt{3} - (1/f_{w,\tau})}{\sqrt{3} - 1}$$ (equation 4.6.12)

The relation between 1 and $f_{w,\tau}$ is given by the above mentioned equation.

The following applies to the local state of stress:

$$a_{NH} = MAX\left(\left|a_{BK,\sigma 1}\right| + \left|a_{BK,\sigma 2}\right| + \left|a_{BK,\sigma 3}\right|\right)$$ (equation 4.6.6)

$$a_{GH} = \sqrt{\frac{1}{2}\left[\left(a_{BK,\sigma 1} - a_{BK,\sigma 2}\right)^2 + \left(a_{BK,\sigma 2} - a_{BK,\sigma 3}\right)^2 + \left(a_{BK,\sigma 3} - a_{BK,\sigma 1}\right)^2\right]}$$ (equation 4.6.7)

Mit:

$S_{a,1} = a_{BK,\sigma 1}$

$S_{a,2} = a_{BK,\sigma 2}$ (equation 4.6.8)

$S_{a,3} = a_{BK,\sigma 3}$

$a_{BK,\sigma 1}, \ldots$ cyclic degree of utilisation

The following applies to even state of stresses:

$$a_{NH} = 1/2 * \left(\left|s_{\sigma x} + s_{\sigma y}\right| + \sqrt{\left(s_{\sigma x} - s_y\right)^2 + 4\tau_a^2}\right)$$ (equation 4.6.9)

$$a_{GH} = \sqrt{s_{ax}^2 + s_{ay}^2 - s_{ax} \cdot s_{ay} + \tau_a^2})$$ (equation 4.6.10)

with

$$s_{ax} = a_{BK,\sigma x}$$

$$s_{ay} = a_{BK,\sigma y} \qquad \text{(equation 4.6.11)}$$

$$\tau_{az} = a_{BK,\tau}$$

$a_{BK,\sigma x}$,…. cyclic degree of utilisation (equation. 4.6.3)

3.8.7. Special cases

3.8.7.1. Non-ductile aluminium material (A<6%)

q=0,5

3.8.7.2. Surface hardened components

Do not apply to mechanical surface treatment.

q=1

3.8.7.3. Welded components

$$a_{BK,v} = 1/2 * \left(\left| s_{\sigma\perp} + s_{\parallel} \right| \sqrt{\left(s_{\sigma\perp} - s_{\parallel}\right)^2 + 4\tau_a^2} \right) <= 1 \qquad \text{(equation 4.6.13)}$$

with

$$s_{a\perp} = a_{BK,\perp}$$

$$s_{a\parallel} = a_{BK,\parallel} \qquad \text{(equation 4.6.14)}$$

$$\tau_a = a_{BK,\tau}$$

$a_{BK,\perp}$,…….cyclic degree of utilisation

3.8.7.4. Rules of signs

Insert the cyclic degrees of utilisation of the individual stress types by using the signs of the amplitudes at the reference point.

concordant effect -> positive signs

discordant effect -> different signs

If the amplitudes act concordantly the degree of utilisation will increase, if discordant signs appear the degree of utilisation will decrease.

3.8.8. Local stresses / compound, non-proportional

Compound types of stress with non-proportional stress:

Is currently subject to research:

Simultaneous occurrence of maximum stress:

Addition of part collective in stress direction

For each load, the degree of utilisation is to be calculated

Addition of all utilisation rates to one total degree of utilisation

Time-displaced occurrence of maximum stress:

Addition of part collective in direction of alternating -> dimensioning collective

Calculation of the degree of utilisation

Compound stress types with non-proportional stress:

Time correlated occurrence of maximum stress:

Procedure same as for as proportional and synchronous, for want of better knowledge

Without previous knowledge and experience, use the procedure “Simultaneous occurrence of maximum stress”.

Procedure for rotating principal stresses:

Cutting plane procedure -> degree of utilisation depending on the angle

3.8.9. Multiple load Cases

If multiple load cases are selected in the FE dialog, then the node stresses are added to a resultant load case. The multipliers are applied to the individual components. For this resulting load case, the related stress gradients are then calculated.

3.9. Proof of the endurance limit (general case – non proportional, not synchronous)

The proof according to the FKM-guideline includes a large number of parameters in the analysis so that the proof is relatively laborious and requires a lot of knowledge of the user. To carry out the proof of the endurance limit winLIFE offers an alternative which enables the user to get a result by entering a few inputs only. The operation is therefore very easy. This proof is also available for non-welded and welded components.

3.9.1. Motivation for the proof of the endurance limit

Many FEM users wish to make fatigue life predictions. They often, however, have hardly any information on the load spectrum, the S-N curves, surface, isotropy etc. Despite this, they still wish to make at least a rough estimate on whether any fatigue strength problems are to be expected. The proof of the endurance limit can help to answer such questions. If it is possible to safely show that in a worst-cast-scenario the stress is below the endurance limit, then this result is often sufficient and more extensive fatigue strength tests can be dispensed with.

The proof of the endurance limit cannot give you a result regarding the fatigue life, but a prediction whether the worst-case-scenario is below the endurance limit or not. For the case it is below you will get the result by how much the wort-case scenario is below the endurance limit. If the proof of the endurance limit is not fulfilled, it will be necessary to carry out much more detailed fatigue life tests. For this test you will need, in particular, the loads and their time relation.

3.9.2. Theory of the proof of safety against endurance limit

3.9.2.1. Proportional case

The program module winLIFE QUICK CHECK provides the functionality for the proof of the endurance limit. Results can be achieved with very little action by the user. The proof is based on FEM calculations and for every load F_i (force, torque, temperature), which has an effect on the component you must have a static FEM-calculation for the maximum value (upper load F_{oi}).

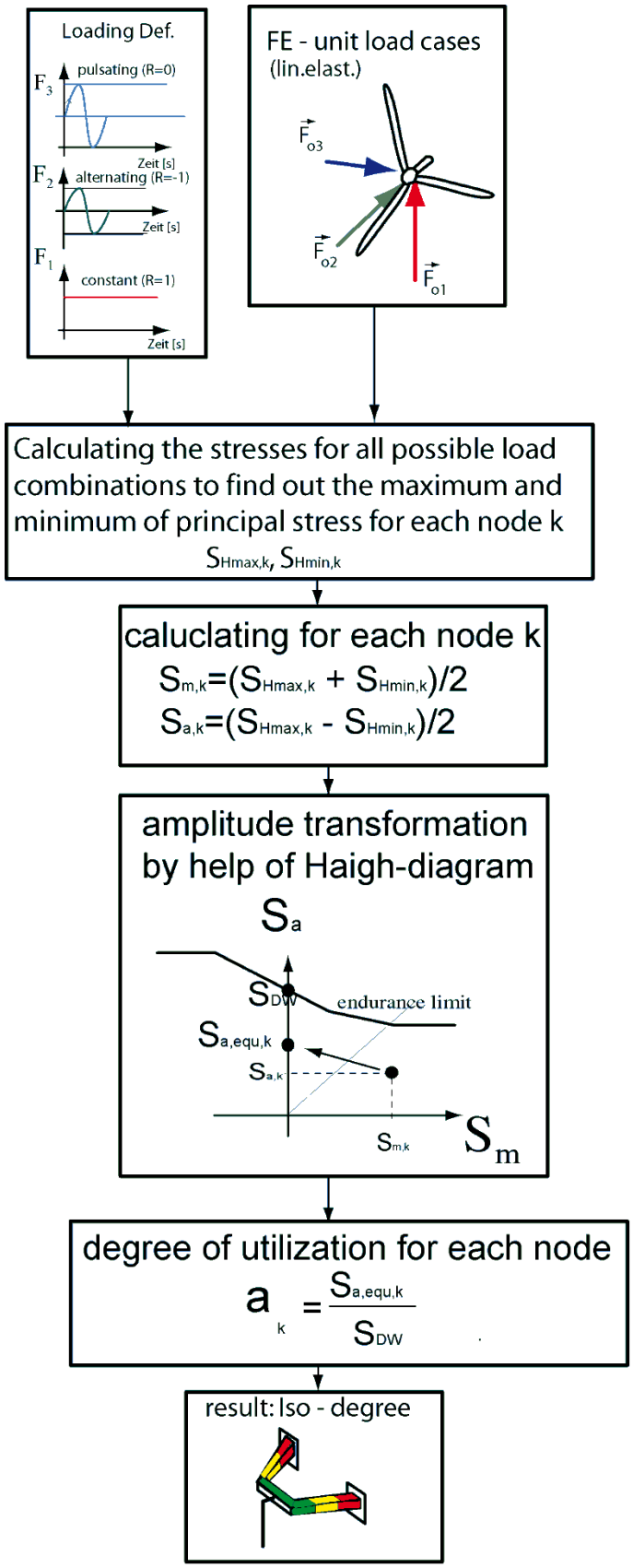
For each load having an effect on the component, only

- the mean load and amplitude or
- a constant load

is taken into account. The number of load cycles is not considered in the calculation. The stress tensors of however many nodes you require – e.g. all surface nodes – are used for the analysis.

To describe the material you only need the endurance limit and its dependence on the mean stress.

To calculate the safety against the endurance limit, a calculation of all possible combinations of the stress tensors is carried out and superimposed. The process is shown in the following picture.


Loading Def.
pulsating (R=0)
Zeit [s]
alternating (R=-1)
Zeit [s]
constant (R=1)
Zeit [s]
FE - unit load cases
(lin.elast.)
Calculating the stresses for all possible load combinations to find out the maximum and minimum of principal stress for each node k
SHmax,k, SHmin,k
caluclating for each node k
Sm,k=(SHmax,k + SHmin,k)/2
Sa,k=(SHmax,k - SHmin,k)/2
amplitude transformation by help of Haigh-diagram
Sa
SDW
endurance limit
Sa,equ,k
Sa,k
Sm,k
Sm
degree of utilization for each node
result: Iso - degree

(Figure 3-2: schematic process of the proof of the endurance limit (Worst Case Szenario)

The maximum and minimum occurring principal stress is ascertained from the results of all the superpositions. From this, a principal mean stress and a principal stress amplitude are calculated and then transformed into an equivalent amplitude $S_{a,equ}$ with the aid of the mean stress sensitivity M. The endurance limit S_{DW} of the S-N curve is divided by the equivalent amplitude which gives you the safety against endurance limit. The reciprocal value of the safety against the endurance limit is the degree of efficiency $a = S_{a,equ}/S_{DW}$.

The maximum load (= upper load) F_{oi} for each individual loading condition i must be put on the FE-model. The results of the FE calculation are the stress tensors $S_{ki,o}$ for each node To obtain the lower load F_{ui} use the following formula with the stress ratio R and F_{oi}

$$F_{ui} = F_{oi} * R_i$$

The stress tensor for the lower load can be calculated simply with the aid of the following formula:

$$\underline{\underline{S}}_{ki,u} = \frac{F_{ui}}{F_{oi}} \underline{\underline{S}}_{ki,o} = R \underline{\underline{S}}_{ki,o}$$

Now the permutations p(i) of all imaginable load combinations are calculated just in case the stresses were superposed unfavourably. In this way, the result takes into account the worst case and is therefore on the safe side. In order to define the most unfavourable stress superposition, the following load condition combinations must be examined.

Load type	Number of combinations to be examined	Variation 1	Variation 2	
alternating (R=-1)	2	+1	-1	
pulsating (R=0)	2	+1	0	
constant (R=1)	1	+1		
any R	2	+1	R	

A simple example for a pure pull-push loading is shown in the following diagram and it makes the procedure clear. If you only consider the condition on the surface then there will be an even stress condition. This can be shown simply in a Mohr`s circle and the principal stress is obvious.

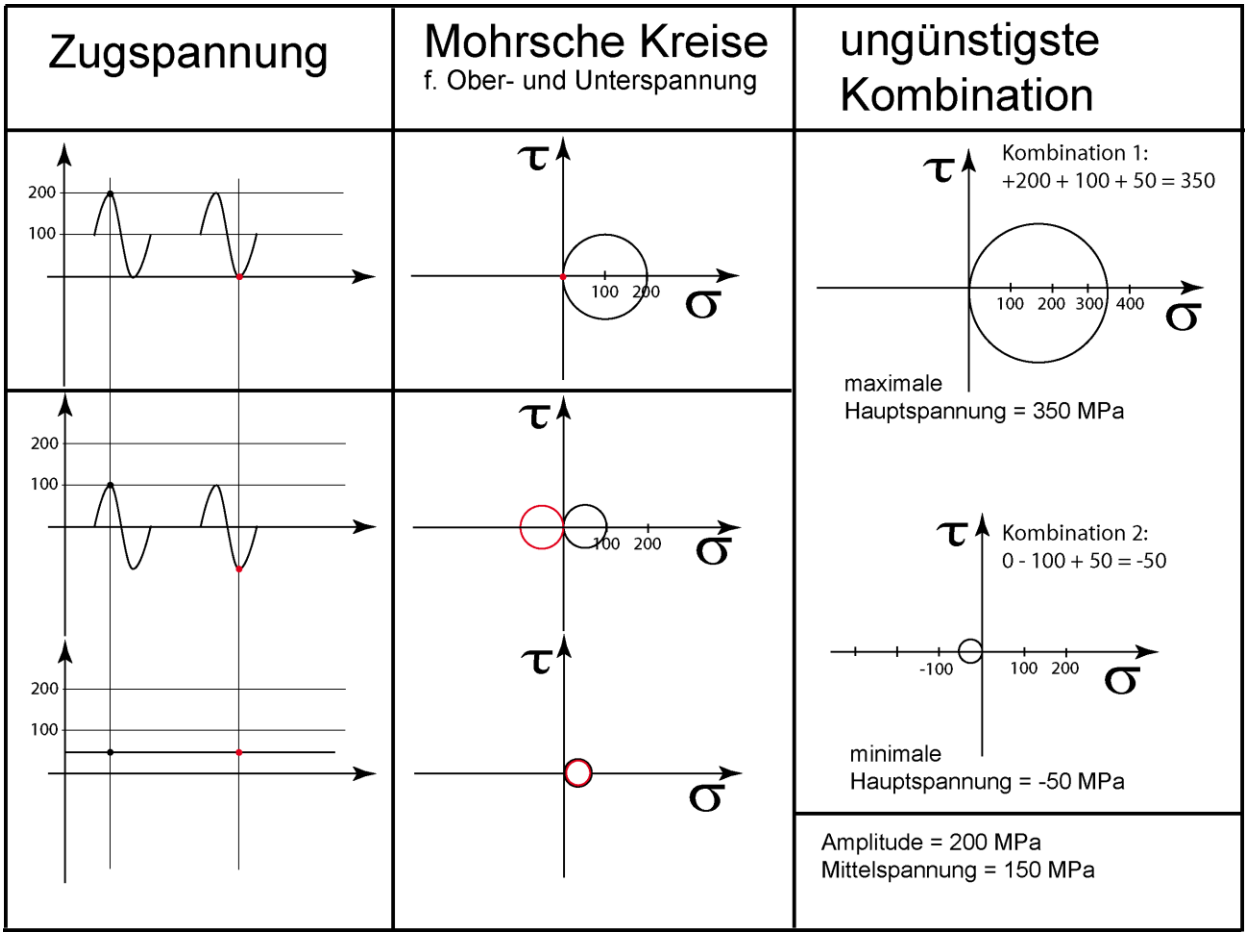


Figure 3-3: Plot of the results of threee load case combinations for a worst-case analysis

Within every node, each stress tensor S_{kiu} und S_{kio} has a largest and a smallest principal stress. Since the time path of the loads i is not known, winLIFE QUICK CHECK examines all imaginable load condition combinations and looks for the largest and the smallest of all the combinations. Using the principal stress as a damage relevant size makes it much easier but this is sufficient for an estimate.

The largest and the smallest principal stresses S_{Hmax} and S_{Hmin} are used to determine the amplitude and the mean stress using the following formula:

$$S_{m,k} = (S_{Hmax,k} + S_{Hmin,k})/2$$

$$S_{a,k} = (S_{Hmax,k} - S_{Hmin,k})/2$$

An equivalent alternating stress $S_{a,equ,k}$ is then calculated from the stress amplitude and the mean stress with the aid of the amplitude transformation. The endurance limit S_{DW} divided by this alternating stress amplitude then gives you the safety against endurance limit. The reciprocal value of the safety against the endurance limit is the degree of efficiency a = $S_{a,equ,k} / S_{DW}$. The results of the safety against endurance limit and the degree of efficiency are written in the winLIFE export file and can either be shown on the screen or printed out

If the degree of efficiency is < 1 then you can presume that it is not necessary to calculate the fatigue life.

If the degree of efficiency is nearly or even above 1, then a more detailed analysis and a fatigue life prediction is necessary.

3.9.2.2. Multiaxial case

3.9.2.3.

As in the proportional case calculate all load case combinations and use the procedure of the critical cutting plane for each combination. In the next step determine the maximum range of oscillation and the related mean stress in the cutting plane by means of the normal stress hypothesis. Then calculate the equivalent amplitude by using the amplitude transformation. In the last step divide the result by the endurance limit and you will get the value of the degree of utilisation.

Apply this procedure if you use the data format of the plate element. This data format ensures the existence of an exact even state of stress. If you use OP2-files the format of the plate element will always be calculated and therefore an even state of stress is guaranteed.

3.9.3. Proof of Safety against Endurance Limit for Weldings

Seam weldings are often where the failure takes place. Resulting from this it is very often necessary to investigate seam weldings in a component. winLIFE QUICK CHECK together with FEMAP assists the user efficiently in the solution of this problem if

- the FEA model consists only of plate elements, t
- all surfaces have different properties
- the geometries of the weldings are not modelled sondern die verschweißten Bauteile stoßen stumpf aufeinander

By help of the winIFE-macros in FEMAP all lines where surfaces with different properties have contact are identified. On these lines typically the weldings are located. For all elements on the border of such a contact line the element stress tensor is multiplied with the normal unit vector perpendicular to the welding and in the surface of the plate. As a result the stress vector is got which contains the normal stress and the shear stress.

For the endurance limit analysis only the normal stress is used in the way described in the chapter before. The shear stress is ignored.

Because of these simplifications the result only can be a rough estimation of hot spots. In those cases, where the calculated safety against endurance limit is high enough and it is not a safety relevant component the result may be sufficient and a more detailed calculation may be avoided.

If these conditions are not fullfilled a more detailed investigation using the structural-concept or R1-concept may follow using winLIFE-BASIC and winLIFE MULTIAXIAL.

4. User Interface QUICK CHECK

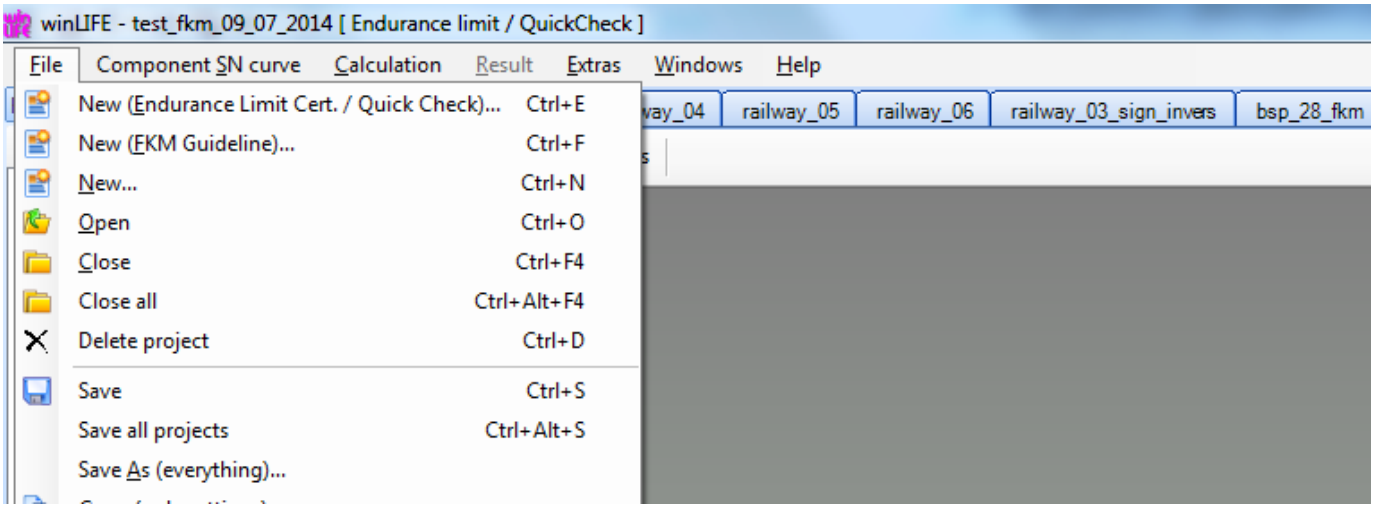


Figure 4-1: Menu to create a new project

To create a new project the user has to select the useful type of project.

Menu item	Kind of analysis	Kind of component	
NEw (FKM Guideline)	Static proof according FKM Fatigue proof according FKM **Only for ONE proof point (node/element)**	Non welded	
NEW (Endurance Limit Cert./ QUICK CHECK)	Endurance Limie proof as a Worst Case Analysis NOT ACCORDING TO FKM. **For all (nodes, elements) of the surface**	Welded or non-welded	Proportional or not proportional
NEW	For all other winLIFE modules **For any number of nodes/elements**	Welded or non-welded	

Figure 4-2: options and the functionallity

For the proofs according to FKM and Endurance Limit Cert (not FKM) the proeject type QUICK CHECK is used. Only if this is shown in the status line on top this calculation procedure is possible. QUICK CHECK needs remarkably less data and simplifies the user handling.

4.1. File

The items in this menu are limited in the case of a QUICK CHECK projekt type. If the item is not avaialble a message appears.

4.1.1. FILE / New (Endurance Limit Cert. / QUICK CHECK)

This selection creates a project for Endurance Limit Certifictation NOT ACOORDING TO FKM. You can use this for proportional and non-proportional cases. Only the Endurance limit is proofed. It can be used for weldings and non-welded components. The advantage is that the user can perform this calculation with a very limited data.

You can analyse **all nodes/elements of** a FE-structure in one step.

4.1.2. File / New (FKM Guideline / QUICK CHECK)

This selection creates a QUICK CHECK project with settings for the static FKM proof and fatigue FKM proof.
This procedure is strongly according to FKM guideline but only for non-welded components.

You can only analyse **ONE node/element (proof point)** in one step.

4.1.3. File / copy to normal project

A QUICK CHECK project only performs a simplified Calculation (only reduced data are necessary) and often stands on the beginning of the work. If you want to overcome the limitations of the QUICK CHECK project at first you have to transform this project into a normal project. Based on this you can use the more detailed procedures in the other winLIFE modules beside QUICK CHECK.

4.2. Component S-N curve

The material data for static and for fatigue proof are created here.

4.2.1. Component S-N curve / New

The following mask appears. The fields include start data only to show the data structure. User`s input overwrites these data.

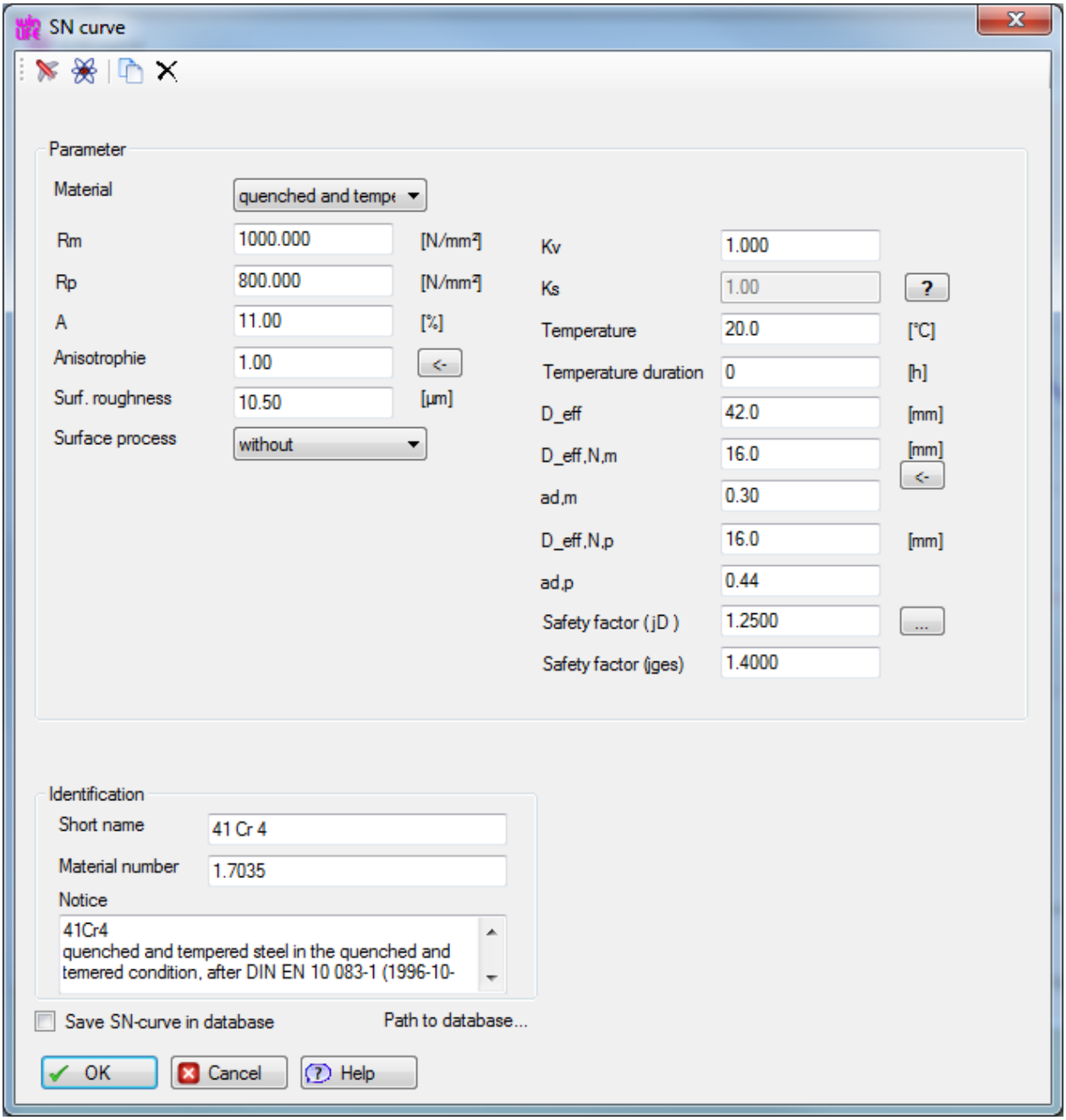


Figure 4-3: Window to create the material and life data

4.2.2. Component S-N curve / Load

The database which contains the user data and the example data of winLIFE is opened and the user can load one material from it.

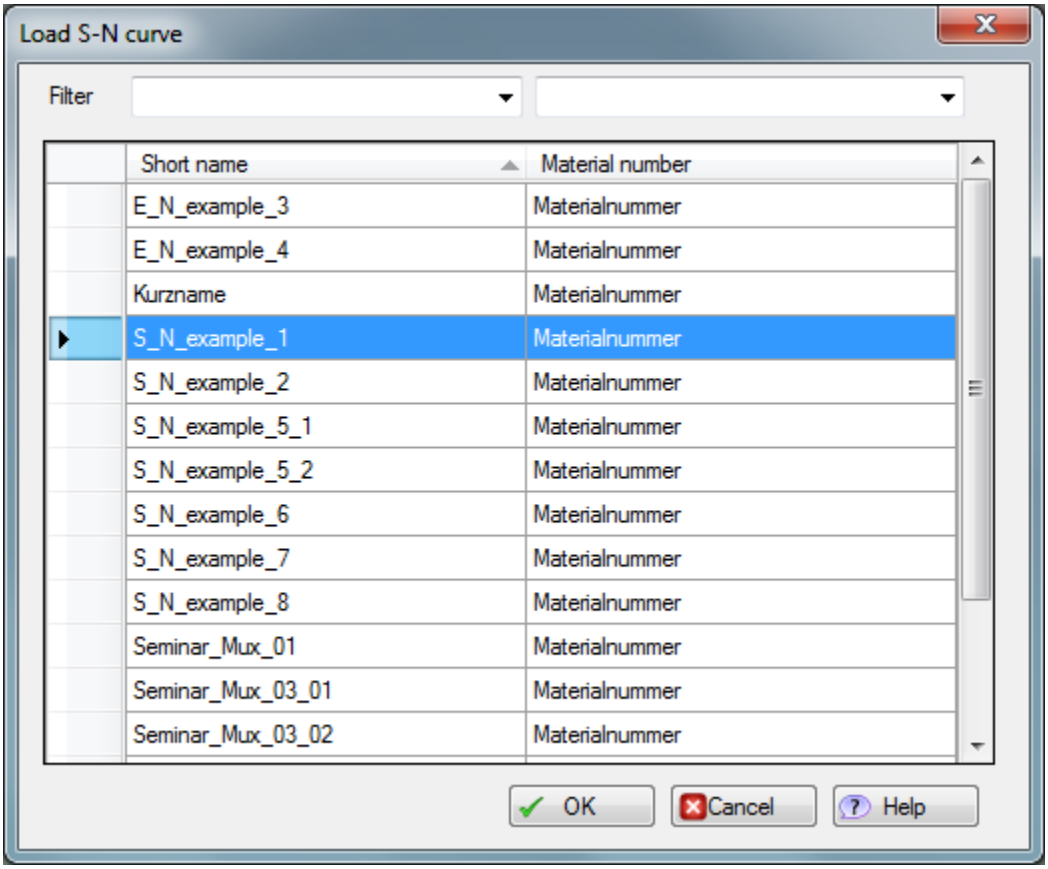


Figure 4-4: Window to select an existing the S-N curve from the user data base.

4.2.3. Component S-N curve / Load FKM

The FKM-database is shown and you can select from it material data. You can use only the ***actual*** (newest) data set from FKM and this is recommended to do if you begin with a new project. If you want to work with older projects and you want to get the data sets from the old FKM database you should select ***previous***. If you want both select ***all***.

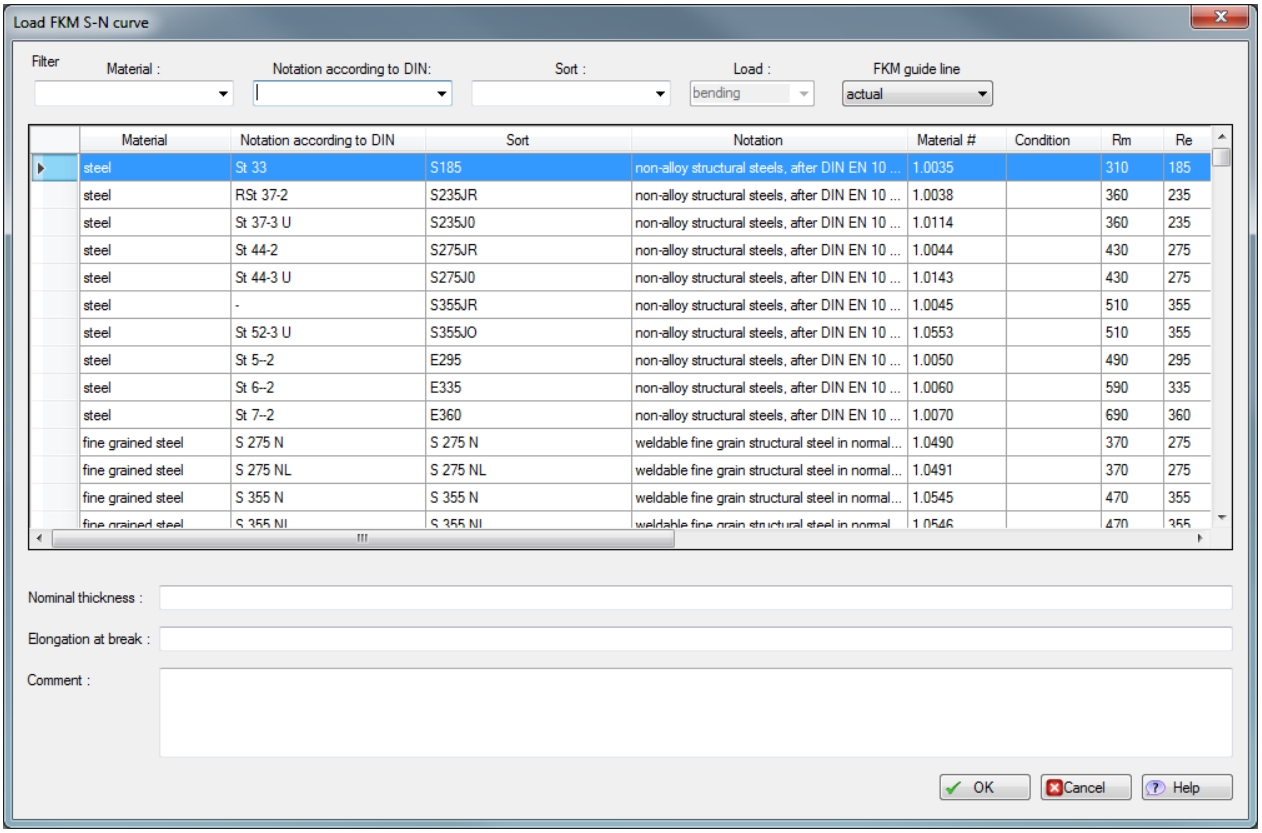


Figure 4-5: Window to select an S-N curve from the FKM data base.

4.2.4. Component S-N curve / Edit

You can modify the selected S-N curve using the input mask. If you want to change the endurance limit you have to to it inside the data tree.

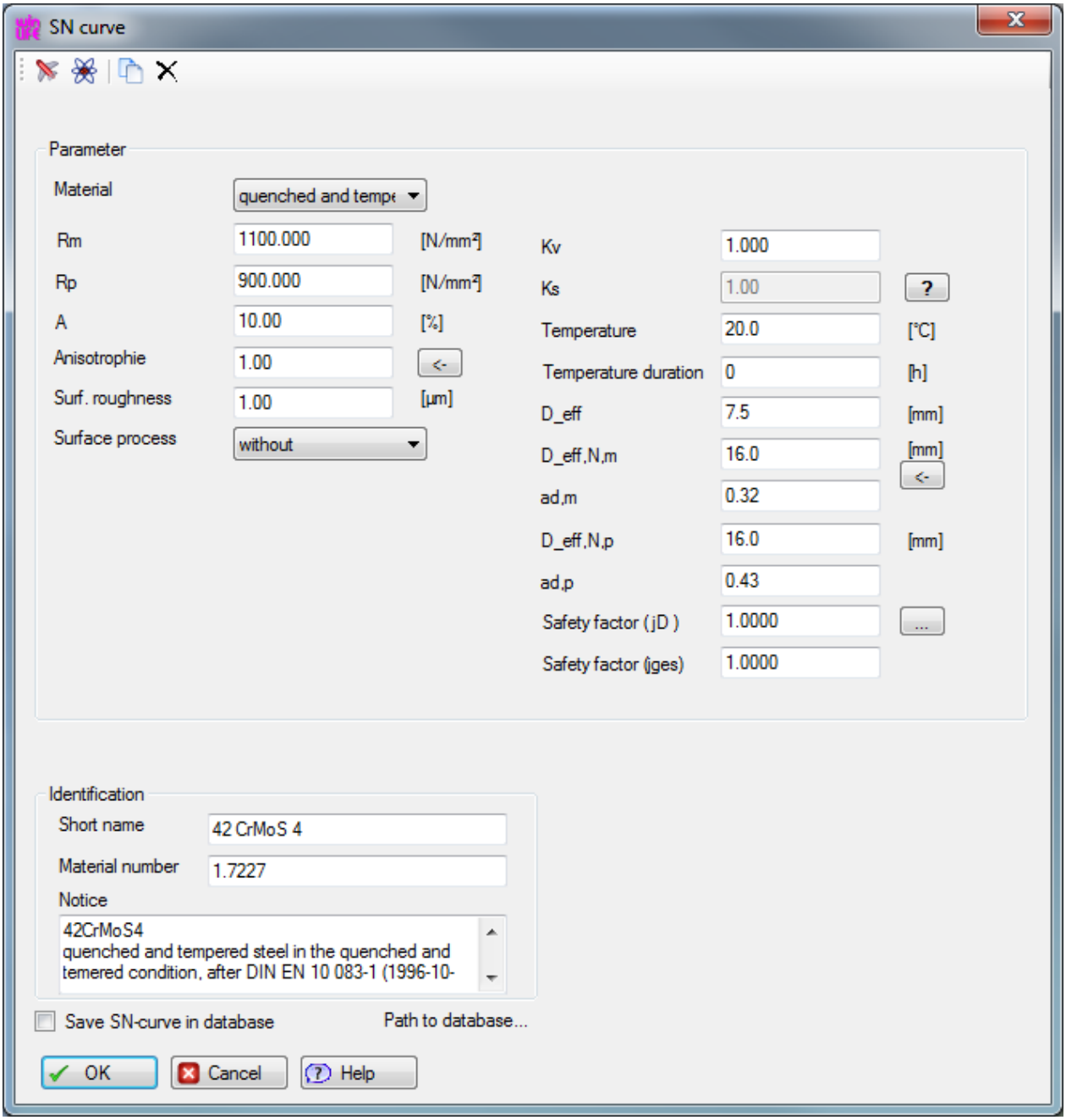


Figure 4-6: Window to edit the material and life data

4.2.5. Component S-N curve / Edit professional

If you use winLIFE QUICK CHECK the standard input mask is strongly reduced to only those values which are needed for the endurance limit certification or the static prove.

Sometimes it is wished to cancel these limitations and get all possebilities of the S-N curve generator. In this case you must select:

Component S N curve / Edit professional

Please note that changes and limitations are now possible which no more meet the FKM-standard for the endurance limit certifiication and static prove.

4.2.6. Component S-N curve / S-N curve

A graphic view of the S-N curve is shown.

4.2.7. Component S-N curve / Haigh FKM

A graphic view of the Haigh-diagram is shown.

4.2.8. Component S-N curve / Delete in database

You can select a data and delete it from the database.

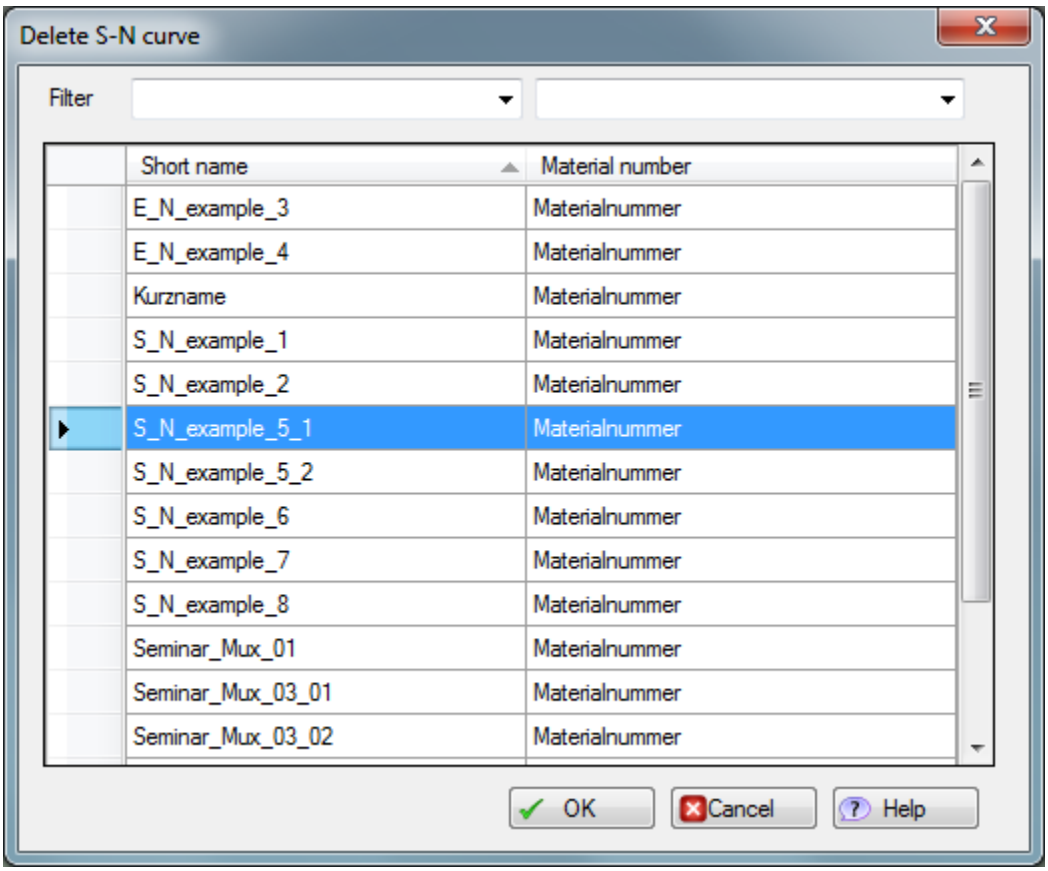


Figure 4-7: Selection to delete a data set from the user database

4.2.9. Component S-N curve / Material Database

You can open the Material database according to the Local Strain approach.

4.3. Calculation

This menu item opens an input mask where you can enter the data for calculation. You can read in data from FEA software, which must exist in the winLIFE-format. But you can also enter manually stresses.

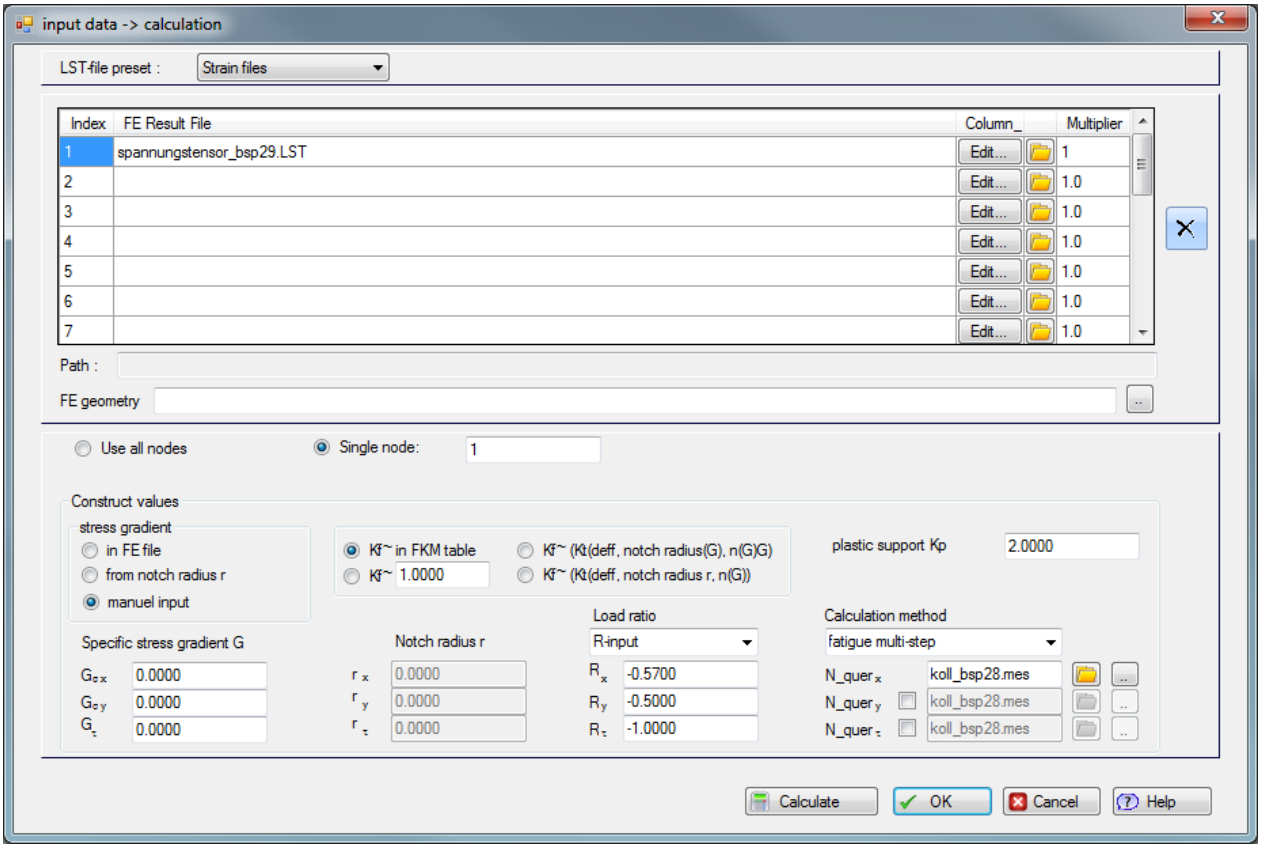


Figure 4-8: Window to select a Result-file from FEA and further inputs for calculation

Clicking on the EDIT-Button a further window opens where you can enter stress data.

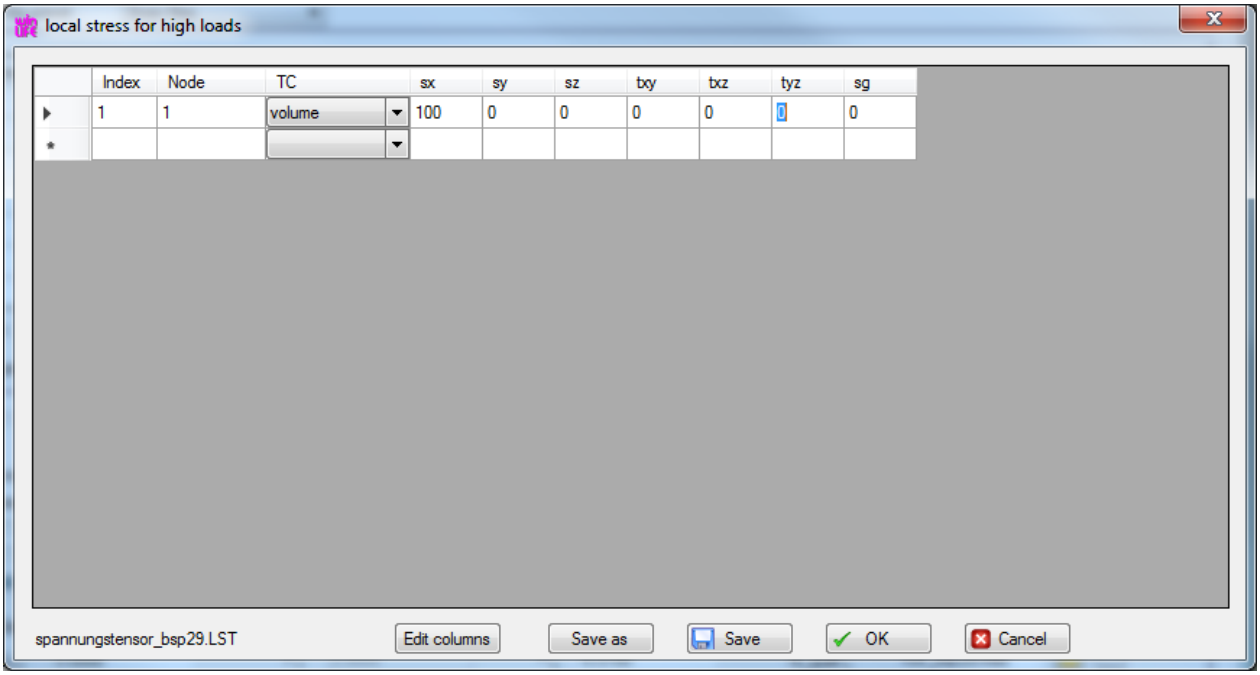


Figure 4-9: Defining the components of a stress tensor

The other input fields are self explaining.

If you click the button ***Calculation*** it starts and writes the results immediately on a result page.

The input values, intermediate results, equations and final results are shown.

.

```
Werkstoffkennwerte
                Rm:  8.95422E+02  Kdm:  8.95422E-01  KA:  1.00000E+00  RmN:  1.00000E+03  (3.2.1)
                Rp:  6.72407E+02  Kdp:  8.40509E-01  KA:  1.00000E+00  RpN:  8.00000E+02
Spannungen aus der Summe der Lastfälle
                sx:  4.40000E+01  sy:  2.47000E+02  sz:  0.00000E+00
                txy:  1.67000E+02  tyz:  0.00000E+00  txz:  0.00000E+00


Statischer Festigkeitsnachweis für den Knoten 1
Temperaturfaktor
                KT,m = KT,p:  1,00000E+00
Hauptspannungen
                h1:  3.40926E+02  h2:  0.00000E+00  h3: -4.99258E+01
hydrostatische Spannung sigma_H
                sigma_H:  9.70000E+01  (3.1.11)
Duktilitätsfaktor q, Festigkeitsfaktor f_sigma, Gussfaktor KNL
                q:  0.00000E+00  f_sigma:  1.00000E+00  KNL:  1.00000E+00  Zug
                q:  0.00000E+00  f_sigma:  1.00000E+00  KNL:  1.00000E+00  Druck
Vergleichsspannung
                sigma_v:  3.68435E+02  (3.1.4)
Mehrachsigkeit
                h:  2.63276E-01  sigma_H:  9.70000E+01  sigma_GH:  3.68435E+02  (3.1.10)
plastische Stüzzahl - npl
                eps_ref:  1.10000E-01  A:  1.10000E+01  E:  2.10000E+05  Kp:  1.95000E+00  (3.3.4)
                eps_ertr:  1.10000E-01  eps_0:  5.00000E+00  (3.3.3)
                npl:  1.95000E+00  (3.3.2)
Bauteilfestigkeit - sigma_SK
                sigma_SK:  1.31119E+03  (3.4.1)
Vergleichsauslastungsgrad - aSK
                aSK:  3.93388E-01  sigma_v:  3.68435E+02  sigma_SK:  1.31119E+03  jges:  1.40000E+00  (3.6.1)
    max.        aSK:  3.93388E-01
Der statische Festigkeitsnachweis wurde erbracht.
```

Figure 4-10: detailed overview of the results of the static proof

```
Ermuedungsfestigkeitsnachweis

Bauteil-Normwerte
   4.2.1        sigma_W,zd: 4.02940E+02 fW,sigma: 4.50000E-01   Rm: 8.95422E+02
Temperaturfaktor KT,D
   4.2.4        KT,D: 1.00000E+00

Spannungsart: Sigma 1
Stuetzzahlen nach Stieler - Normalspannung
   4.3.7        n_sigma: 1.00000E+00    G_sigma: 0.00000E+00    Rm: 8.95422E+02 aG: 5.00000E-01 bG: 2.70000E+03
Schaetzwert der Kerbwirkungszahl
   4.3.2        Kfs_sigma: 2.00000E+00  Kt_sigma: 1.00000E+00   n_sigma: 1.00000E+00
Rauheitsfaktor
  4.3.21        KR_sigma: 8.56780E-01   aR_sigma: 2.20000E-01   r_t: 1.00000E+01        Rm: 8.95422E+02 Rm,N,min: 4.00000E+02
Konstruktionsfaktoren
   4.3.1        KWK_sigma: 1.08358E+00  Kf~: 2.00000E+00        KV: 1.00000E+00 KS: 1.00000E+00 KNL,E: 1.00000E+00
Bauteil-Wechselfestigkeit
   4.4.1        sigma_WK: 3.71860E+02   sigma_Wzd: 4.02940E+02  KWK_sigma: 1.08358E+00
Mittelspannungsempfindlichkeit
   4.4.5        M_sigma: 2.13398E-01    aM: 3.50000E-01 bM:-1.00000E-01
Mittelspannungsfaktor
4.4.8 - 4.4.12          KAK_sigma: 7.27506E-01  R: 1.00000E+00  sm/sa:    Infinity
Amplitude der Bauteil-Dauerfestigkeit
   4.4.4        sigma_AK: 2.70531E+02
ertragbare Nennwerte der Amplitude
  4.4.38        sigma_BK: 2.70531E+02   KBK_sigma: 1.00000E+00
Maximalwert der Amplitude
  4.4.40        sigma_BKmax: 8.73960E+02
Nachweis - einzelne Spannungsarten
   4.6.3        aBK_sigma1: 0.00000E+00 sa: 0.00000E+00 jD: 1.25000E+00 sigma_BK: 2.70531E+02
```

```
Spannungsart: Sigma 2
Stuetzzahlen nach Stieler - Normalspannung
   4.3.7        n_sigma: 1.00000E+00    G_sigma: 0.00000E+00    Rm: 8.95422E+02 aG: 5.00000E-01 bG: 2.70000E+03
Schaetzwert der Kerbwirkungszahl
   4.3.2        Kfs_sigma: 2.00000E+00  Kt_sigma: 1.00000E+00   n_sigma: 1.00000E+00
Rauheitsfaktor
  4.3.21        KR_sigma: 8.56780E-01   aR_sigma: 2.20000E-01   r_t: 1.00000E+01        Rm: 8.95422E+02 Rm,N,min: 4.00000E+02
Konstruktionsfaktoren
   4.3.1        KWK_sigma: 1.08358E+00  Kf~: 2.00000E+00        KV: 1.00000E+00 KS: 1.00000E+00 KNL,E: 1.00000E+00
Bauteil-Wechselfestigkeit
   4.4.1        sigma_WK: 3.71860E+02   sigma_Wzd: 4.02940E+02  KWK_sigma: 1.08358E+00
Mittelspannungsempfindlichkeit
   4.4.5        M_sigma: 2.13398E-01    aM: 3.50000E-01 bM:-1.00000E-01
Mittelspannungsfaktor
4.4.8 - 4.4.12          KAK_sigma: 7.27506E-01  R:         NaN  sm/sa:         NaN
Amplitude der Bauteil-Dauerfestigkeit
   4.4.4        sigma_AK: 2.70531E+02
ertragbare Nennwerte der Amplitude
  4.4.38        sigma_BK: 2.70531E+02   KBK_sigma: 1.00000E+00
Maximalwert der Amplitude
  4.4.40        sigma_BKmax: 8.73960E+02
Nachweis - einzelne Spannungsarten
   4.6.3        aBK_sigma2: 0.00000E+00 sa: 0.00000E+00 jD: 1.25000E+00 sigma_BK: 2.70531E+02

Spannungsart: Sigma 3
Stuetzzahlen nach Stieler - Normalspannung
   4.3.7        n_sigma: 1.00000E+00    G_sigma: 0.00000E+00    Rm: 8.95422E+02 aG: 5.00000E-01 bG: 2.70000E+03
Schaetzwert der Kerbwirkungszahl
   4.3.2        Kfs_sigma: 2.00000E+00  Kt_sigma: 1.00000E+00   n_sigma: 1.00000E+00
Rauheitsfaktor
  4.3.21        KR_sigma: 8.56780E-01   aR_sigma: 2.20000E-01   r_t: 1.00000E+01        Rm: 8.95422E+02 Rm,N,min: 4.00000E+02
Konstruktionsfaktoren
   4.3.1        KWK_sigma: 1.08358E+00  Kf~: 2.00000E+00        KV: 1.00000E+00 KS: 1.00000E+00 KNL,E: 1.00000E+00
Bauteil-Wechselfestigkeit
   4.4.1        sigma_WK: 3.71860E+02   sigma_Wzd: 4.02940E+02  KWK_sigma: 1.08358E+00
Mittelspannungsempfindlichkeit
   4.4.5        M_sigma: 2.13398E-01    aM: 3.50000E-01 bM:-1.00000E-01
Mittelspannungsfaktor
4.4.8 - 4.4.12          KAK_sigma: 7.27506E-01  R: 1.00000E+00  sm/sa:   -Infinity
Amplitude der Bauteil-Dauerfestigkeit
   4.4.4        sigma_AK: 2.70531E+02
ertragbare Nennwerte der Amplitude
  4.4.38        sigma_BK: 2.70531E+02   KBK_sigma: 1.00000E+00
Maximalwert der Amplitude
  4.4.40        sigma_BKmax: 8.73960E+02
Nachweis - einzelne Spannungsarten
   4.6.3        aBK_sigma3: 0.00000E+00 sa: 0.00000E+00 jD: 1.25000E+00 sigma_BK: 2.70531E+02

Nachweis - zusammengesetzte Spannungsarten
   4.6.5        aBK_sigma_v: 0.00000E+00        aNH: 0.00000E+00        aGH: 0.00000E+00        q: 0.00000E+00

Der Ermuedungsfestigkeitsnachweis wurde erbracht.
```

Figure 4-11: detailed overview of the results of the endurance proof

4.3.1. Result / Protocol

This men item shows the result page.

4.3.2. Result / Viewer

If you used FEMAP or if you created the result file according to the defined rules you can show a graphic view of the utilization ratio.

5. Example 28 / shaft from FKM guideline

5.1. Task

The shaft shoulder taken from the FKM guideline, chapter 6.1 is re-calculated with the winLIFE FKM QUICKCHECK / *FKM* module. The diagram below shows the geometry of the shaft and the acting bending and torsion loads.

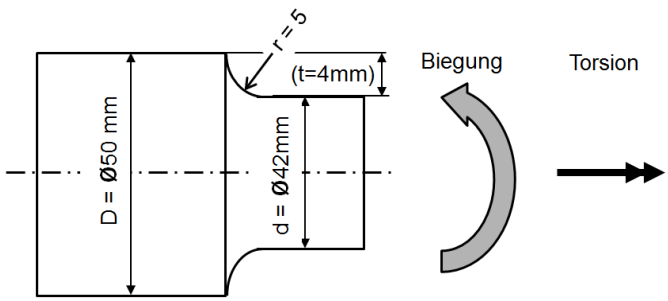


Figure 5-1: Diagram of the shaft shoulder with loads

5.2. Material-data and local stresses

The shaft is made of material 41 Cr 4. This is a heat-treated steel and the material here has been heat treated.

For the verification point, the following stresses are provided (compare with FKM guideline chapter 6.1.4):

$\sigma_{a,x}$ = 45MPa $\sigma_{m,x}$ = 0MPa

$\sigma_{a,y}$ = 247MPa $\sigma_{m,y}$ = 0MPa

$\tau_{a,xy}$ = 103MPa $\tau_{m,xy}$ = 64MPa

Local stresses are used for the stress analysis according to FKM in winLIFE 4.0 2018 .

5.3. Project: winLIFE QUICK CHECK FKM

In winLIFE the projects are now defined. For this you should select:

Menu *File* → *New (FKM stress analysis)…*

The following window shows the order of commands:

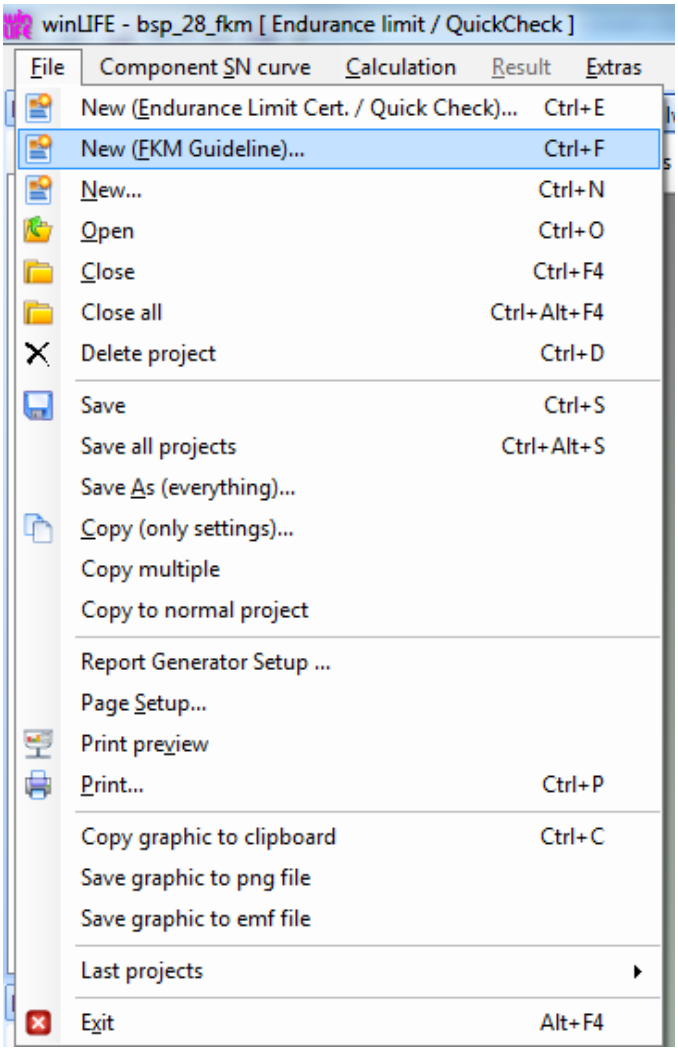


Figure 5-2: Selecting the stress analysis in winLIFE

A suitable file name for the winLIFE project is selected e.g.: shaft_shoulder_*FKM.wlf* .

The material‘s capacity to withstand stresses is defined in the menu S-N curve. The material 41 Cr 4 in heat treated state can be found and selected in the winLIFE FKM database.

Menu S-*N curve* → *Load FKM…*

The material 41 Cr 4 is entered in the following window according to DIN Standard. The material then appears and can be selected by clicking OK.

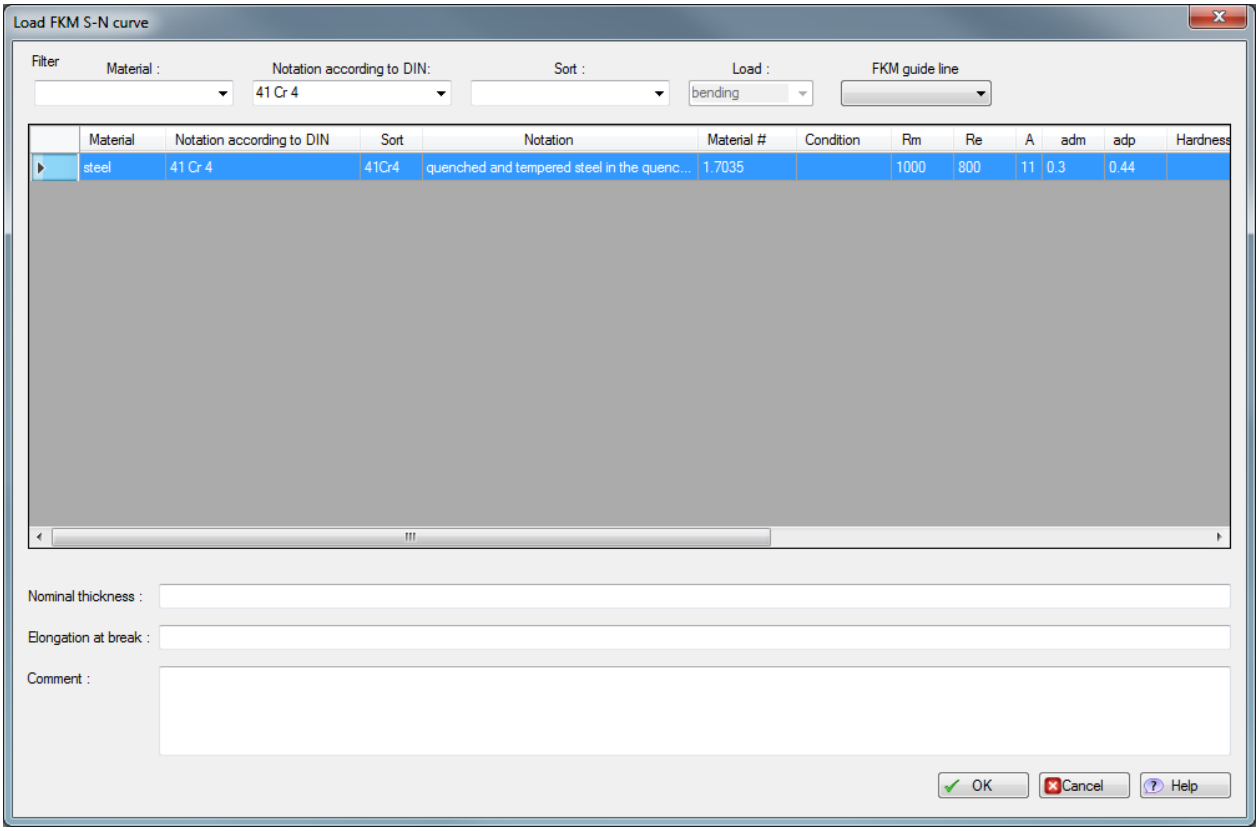


Figure 5-3: Selecting material from the FKM data base

The material characteristics required can be taken from the FKM guideline. The safety factor is set by appropriate entries in the window shown here. For the S-N curve, the following entries shown here can be entered.

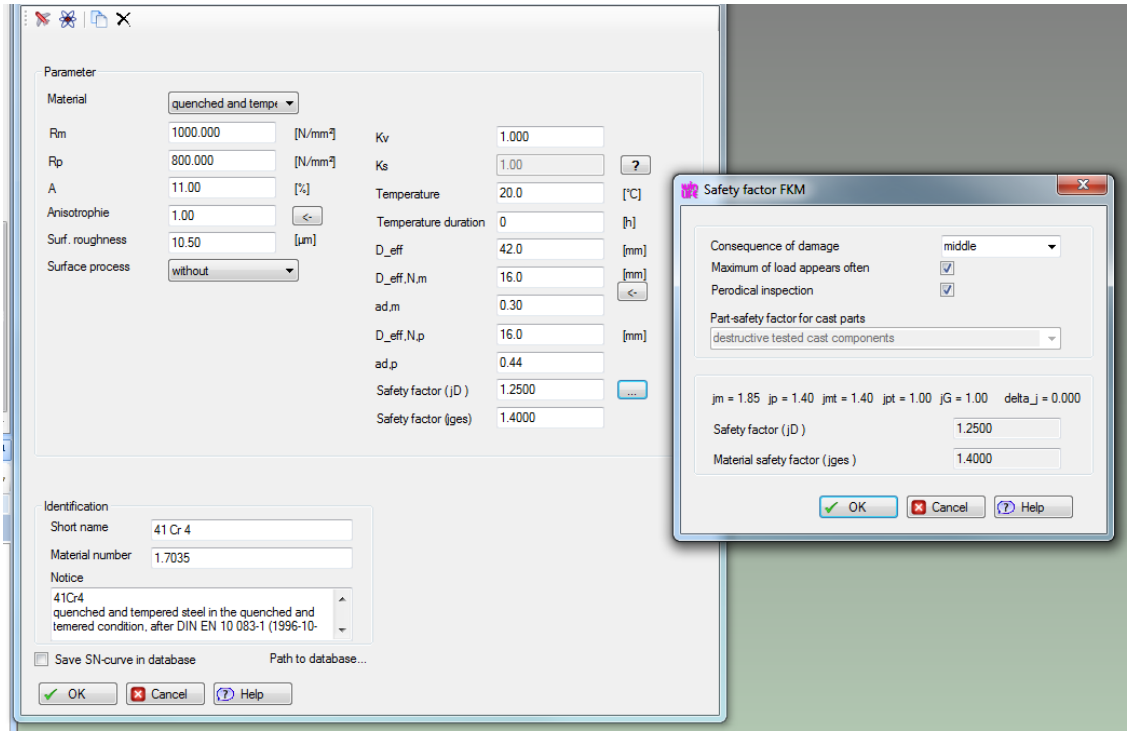


Figure 5-4: Material entries

From the entries just made, an S-N curve is created. Use the command

Menu *S-N curve* → *S-N curve*

to achieve the following result:

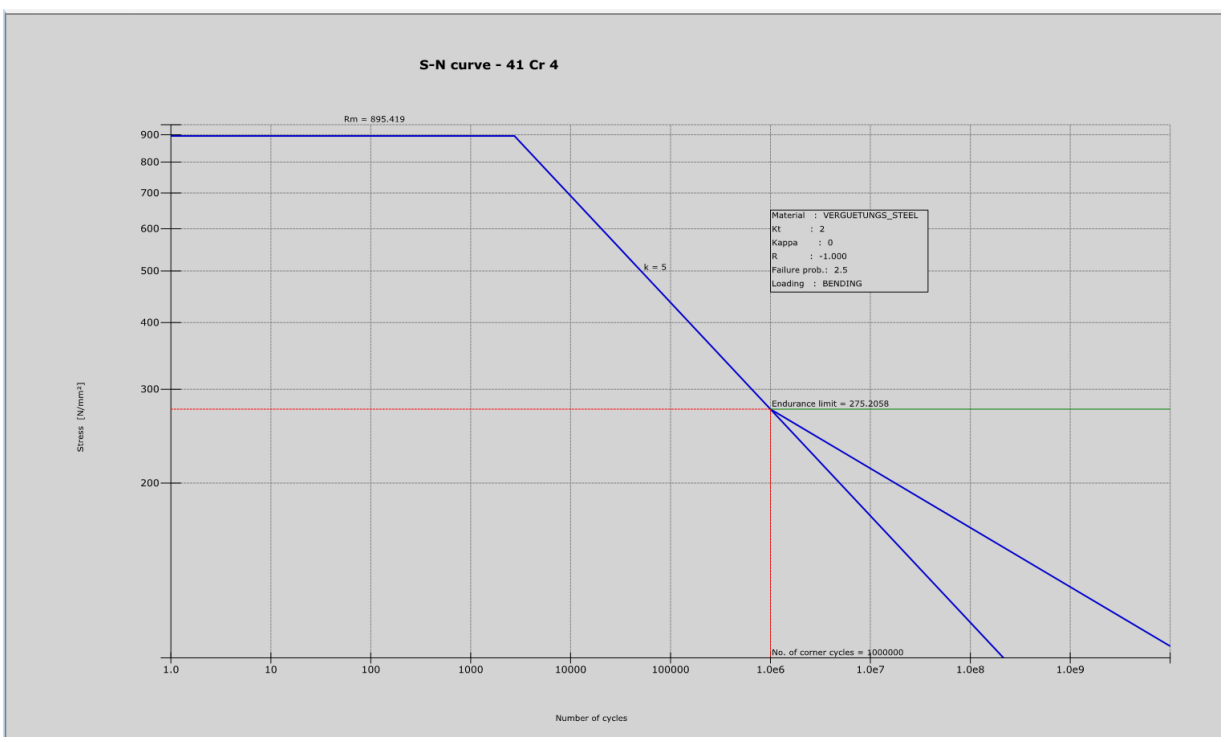


Figure 5-5: S-N curve for the material 41 Cr 4

Now follows the entries for the load. The procedure is documented here.

Menu *Calculation* → the diagram shown below appears

This is where to enter the load characteristics.

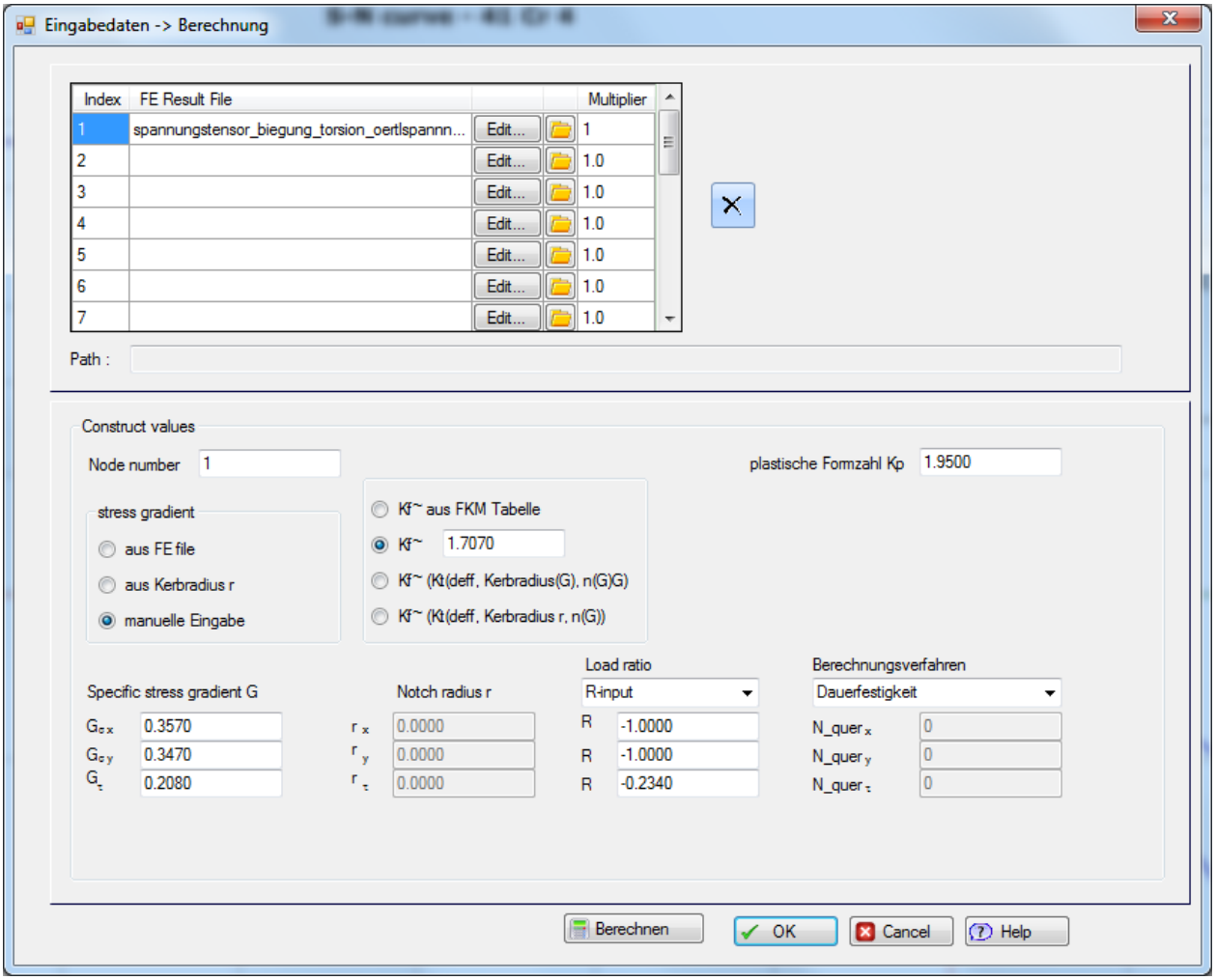


Figure 5-6: Entries in the calculation dialogue

First of all the entries are made for the local stresses at the verification point. To do this, click the *Edit…* tab (see diagram above). A new window opens. This is where the stress tensor is entered. In our case here which is an even stress state, the stress tensor for a plate element should be selected. In column TC select Plate in the drop-down list.

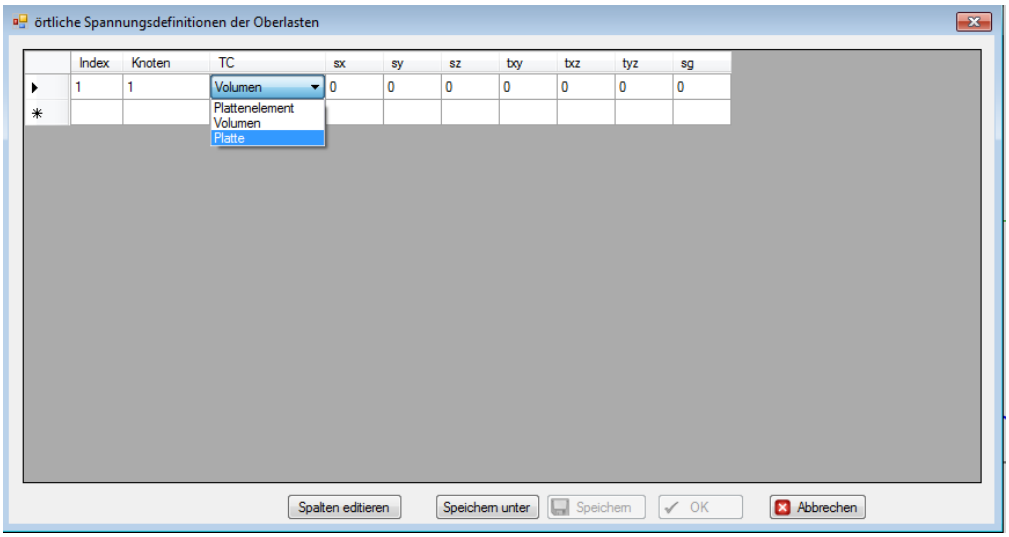


Figure 5-7: Entries for local stresses

The column headings now have to be prepared for the plate elements. To do this, use the button *edit columns*.

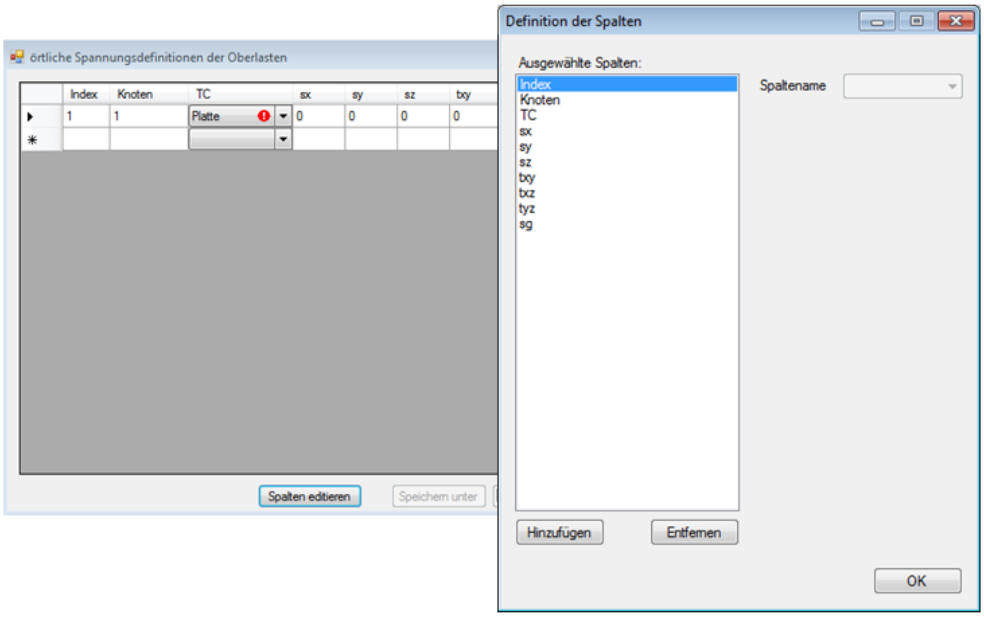


Figure 5-8: Defining the column headings

One after the other, click on *add* to select the required column names from the right-hand drop-down list. Three new columns are required, sxu, syu and txyu, as shown below.

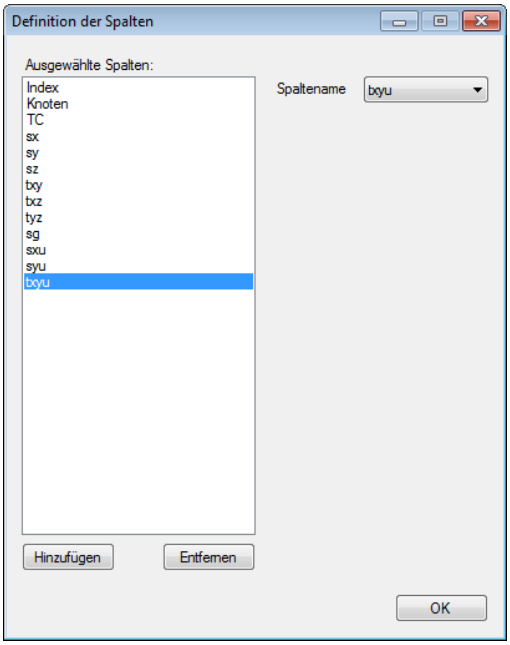


Figure 5-9: Defining the column headings

Having defined the three new headings, click *OK* and the stress tensor will appear in the chart.

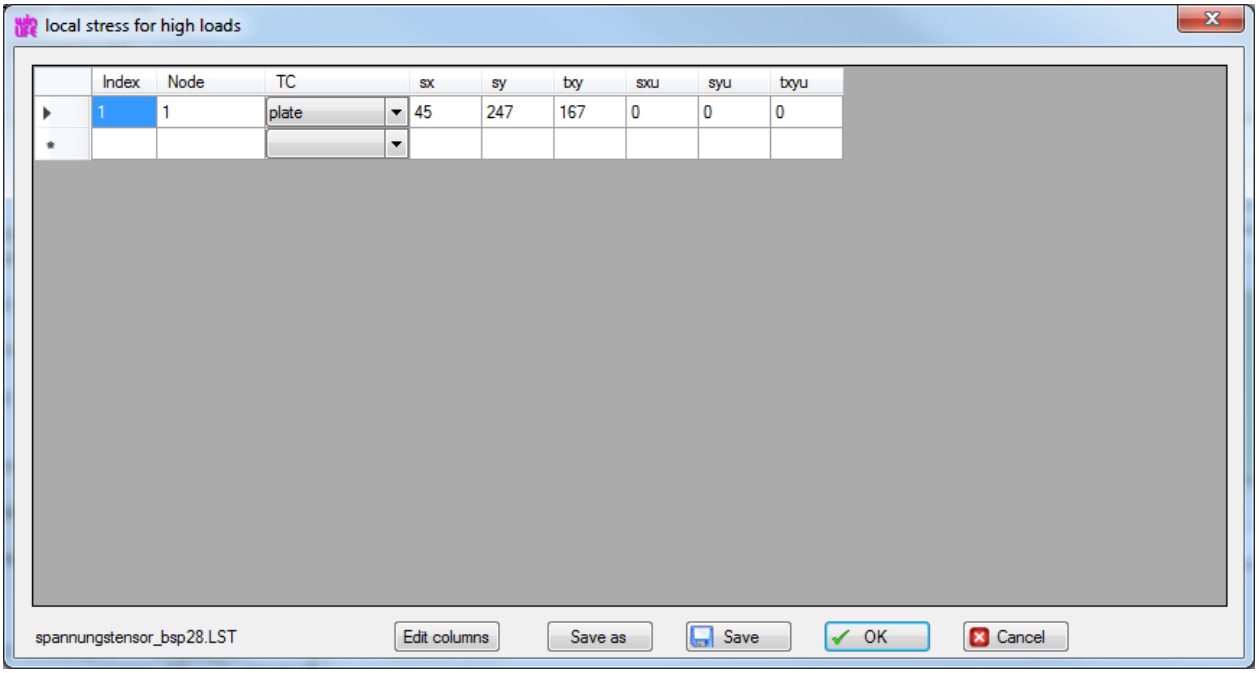


Figure 5-10: Entries for stress tensors

The file contains the stresses which occur at the verification point. The file should be saved by clicking the button *Save under*. In this example we have named the file *Stress_tensor_bending_torsion_local_stresses. LST*. But the user can of course select any name.

Now the further entries are made in the window shown below.

The yield support factor is determined according to the FKM guideline at 1.95. The related loss of stress can be calculated with the aid of the stresses at the neighbouring point (see FKM guideline chapter 6.1.4). The fatigue notch factor used here is 1.707 for the y-stress components since these stress components are considered important because of their value. The stress ratios and the calculation method, in this case *fatigue strength*, are also entered. The window should be filled in as in the diagram below.

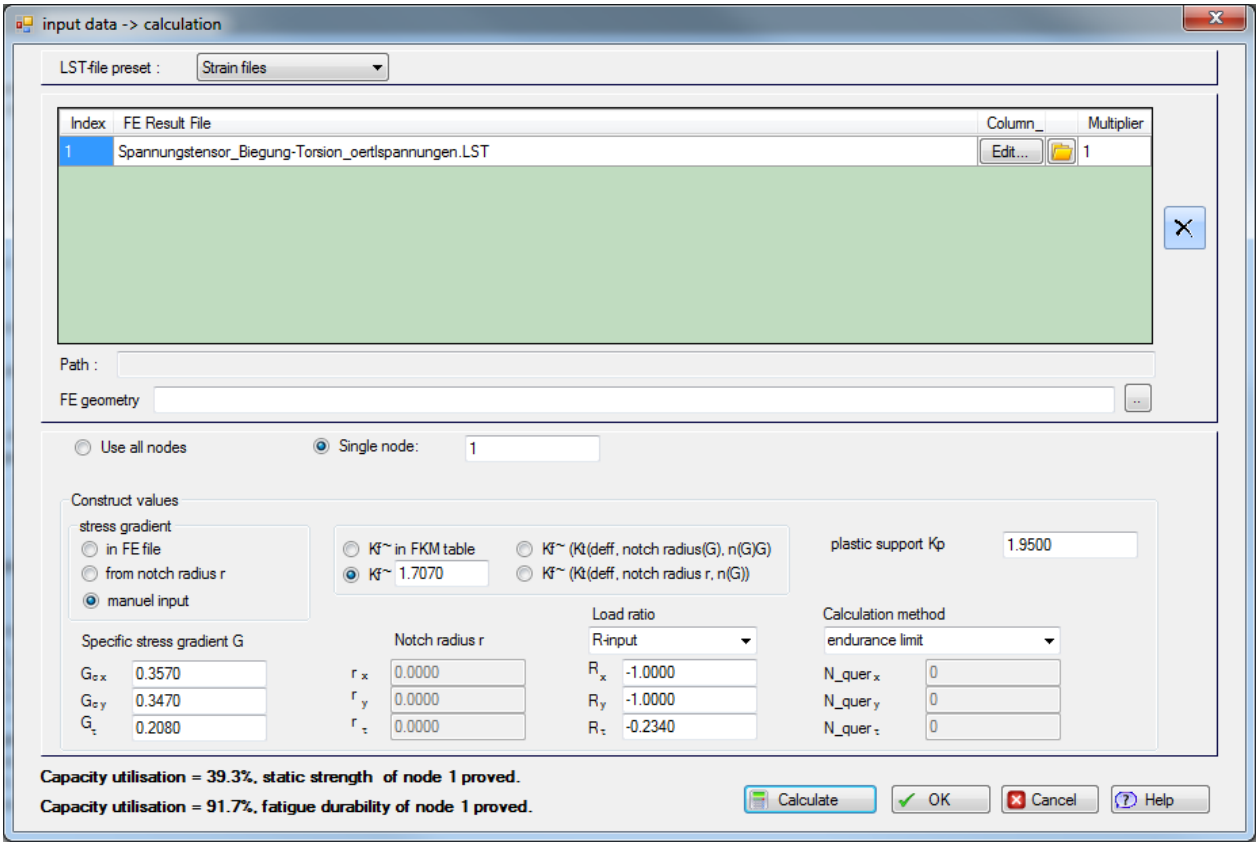


Figure 5-11: Calculation entries

The endurance calculation is carried out by clicking on the button *calculate*. The result for the utilisation rate for the static endurance is 39.3% and the fatigue strength is 91.7%. These important results are now shown bottom left.

5.4. Result

As well as the utilisation rate for the static endurance and fatigue strength, the protocol file in winLIFE also shows the interim results of the calculation. The winLIFE user can therefore follow the calculation and compare the interim steps with the equations from the FKM guideline.

The following diagram shows an excerpt from the result protocol for the static strength test. Right at the bottom the utilisation rate is shown, in this case 39.3%.

```
Protokoll

Werkstoffkennwerte
                Rm:  8.95422E+02  Kdm:  8.95422E-01  KA:  1.00000E+00  RmN:  1.00000E+03  (3.2.1)
                Rp:  6.72407E+02  Kdp:  8.40509E-01  KA:  1.00000E+00  RpN:  8.00000E+02
Spannungen aus der Summe der Lastfälle
                sx:  4.50000E+01        sy:  2.47000E+02        txy:  1.67000E+02
                sxu:  0.00000E+00       syu:  0.00000E+00       txyu:  0.00000E+00


Statischer Festigkeitsnachweis für den Knoten 1
Temperaturfaktor
                KT,m = KT,p:  1,00000E+00  (3.2.22 - 3.2.27)
Hauptspannungen
                h1:  3.41167E+02        h2:  0.00000E+00        h3: -4.91666E+01
hydrostatische Spannung sigma_H
                sigma_H:  9.73333E+01  (3.1.11)
Duktilitätsfaktor q, Festigkeitsfaktor f_sigma, Gussfaktor KNL
                q:  0.00000E+00  f_sigma:  1.00000E+00  KNL:  1.00000E+00  (Zug)
                q:  0.00000E+00  f_sigma:  1.00000E+00  KNL:  1.00000E+00  (Druck)
Vergleichsspannung
                sigma_v:  3.68220E+02  (3.1.4)
Mehrachsigkeit
                h:  2.64335E-01         sigma_H:  9.73333E+01   sigma_GH:  3.68220E+02  (3.1.10)
plastische Stüzzahl - npl
                eps_ref:  1.10000E-01   A:  1.10000E+01  (3.3.4)
                eps_ertr:  1.10000E-01  eps_0:  5.00000E+00  (3.3.3)
                npl:  1.95000E+00       E:  2.10000E+05 Kp:  1.95000E+00  (3.3.2)
Bauteilfestigkeit - sigma_SK
                sigma_SK:  1.31119E+03  (3.4.1)
Vergleichsauslastungsgrad - aSK
                aSK:  3.93159E-01       sigma_v:  3.68220E+02   sigma_SK:  1.31119E+03  jges:  1.40000E+00  (3.6.1)
Der statische Festigkeitsnachweis wurde zu 39.3% erbracht.
```

Figure 5-12: Protocol of the endurance calculation, static proof

Now the part of the result protocol relevant to the fatigue endurance proof is shown. The rate of utilization related to the endurance is 91.7% as can be seen here in the bottom line.

```
Protokoll

Ermüdungsfestigkeitsnachweis für den Knoten 1
Bauteil-Normwerte
                sigma_W,zd:  4.02940E+02        fW,sigma:  4.50000E-01  Rm:  8.95422E+02  (4.2.1)
                tau_W,s:  2.32496E+02           fW,tau:  5.77000E-01
Temperaturfaktor
                KT,D:  1.00000E+00  (4.2.4)
Stützzahlen nach Stieler
                n_sigma_x:  1.08804E+00 G_sigma_x:  3.57000E-01 aG:  5.00000E-01        bG:  2.70000E+03  (4.3.8)
                n_sigma_y:  1.08680E+00 G_sigma_y:  3.47000E-01 aG:  5.00000E-01        bG:  2.70000E+03
                n_tau_xy:  1.09283E+00  G_tau_xy:  2.08000E-01  fW,t*Rm:  5.16659E+02
Schätzwert der Kerbwirkungszahl
                Kf~_sigma_x:  1.70700E+00       Kt_sigma_x:  1.00000E+00  (4.3.2)
                Kf~_sigma_y:  1.70700E+00       Kt_sigma_y:  1.00000E+00
                Kf~_tau_xy:  1.70700E+00        Kt_tau_xy:  1.00000E+00
Rauheitsfaktor
                KR_sigma:  8.56780E-01  aR_sigma:  2.20000E-01  r_t:  1.00000E+01       Rm,N,min:  4.00000E+02  (4.3.21)
                KR_tau:  9.17362E-01    fW,t*aR_sigma:  1.26940E-01
Konstruktionsfaktoren
                KWK_sigma_x:  1.00908E+00       KV:  1.00000E+00        KS:  1.00000E+00        KNL,E:  1.00000E+00  (4.3.1)
                KWK_sigma_y:  1.01024E+00       KV:  1.00000E+00        KS:  1.00000E+00        KNL,E:  1.00000E+00
                KWK_tau_xy:  9.63347E-01        KV:  1.00000E+00        KS:  1.00000E+00
Bauteil-Wechselfestigkeit
                sigma_x_WK:  3.99313E+02  (4.4.1)
                sigma_y_WK:  3.98857E+02
                tau_xy_WK:  2.41342E+02
Mittelspannungsempfindlichkeit
                M_sigma:  2.13398E-01   aM:  3.50000E-01        bM: -1.00000E-01  (4.4.5)
                M_tau:  1.23131E-01
Mittelspannungsfaktor
                KAK_sigma_x:  1.00000E+00       R: -1.00000E+00 sm/sa:  0.00000E+00  (4.4.8 - 4.4.12)
                KAK_sigma_y:  1.00000E+00       R: -1.00000E+00 sm/sa:  0.00000E+00
                KAK_tau_xy:  9.28994E-01        R: -2.34000E-01 sm/sa:  6.20746E-01
Amplitude der Bauteil-Dauerfestigkeit
                sigma_x_AK:  3.99313E+02  (4.4.4)
                sigma_y_AK:  3.98857E+02
                tau_xy_AK:  2.24206E+02
ertragbare Nennwerte der Amplitude
                sigma_x_BK:  3.99313E+02        KBK_sigma:  1.00000E+00  (4.4.38)
                sigma_y_BK:  3.98857E+02        KBK_sigma:  1.00000E+00
                tau_xy_BK:  2.24206E+02         KBK_tau:  1.00000E+00
Maximalwert der Amplitude
                sigma_BKmax:  9.83395E+02  (4.4.40)
                tau_BKmax:  5.67419E+02
Nachweis - einzelne Spannungsarten      jD:  1.25000E+00
                aBK_sigma_x:  1.40867E-01       sa:  4.50000E+01        sigma_BK:  3.99313E+02  (4.6.3)
                aBK_sigma_y:  7.74086E-01       sa:  2.47000E+02        sigma_BK:  3.98857E+02
                aBK_tau_xy:  5.74467E-01        sa:  1.03039E+02        tau_BK:  2.24206E+02
Nachweis - zusammengesetzte Spannungsarten
                aBK_sigma_v:  9.16527E-01       aNH:  1.11341E+00       aGH:  9.16527E-01       q:  0.00000E+00  (4.6.5)
Der Ermüdungsfestigkeitsnachweis wurde zu 91.7% erbracht.
```

Figure 5-13: Protocol of the endurance calculation, fatigue proof

5.5. Using Finite-Element results

You can use results from Nx NASTRAN, ANSYS or ABAQUS. Here we describe the use of NASTRAN results. (op2-Datei). The related stress gradient G is calculated automatically while importing the data from NASTRAN op2-file, the notch-effect value is got from the table out of FKM-guideline.

The plastic support value Kp was got from the FKM example. Customer who use the VIEWER4WINLIFE we recommend to read in the NASTRAN dat-file. In this case the results can be shown graphically.

Calculation time may consume some minutes if all nodes are selected.

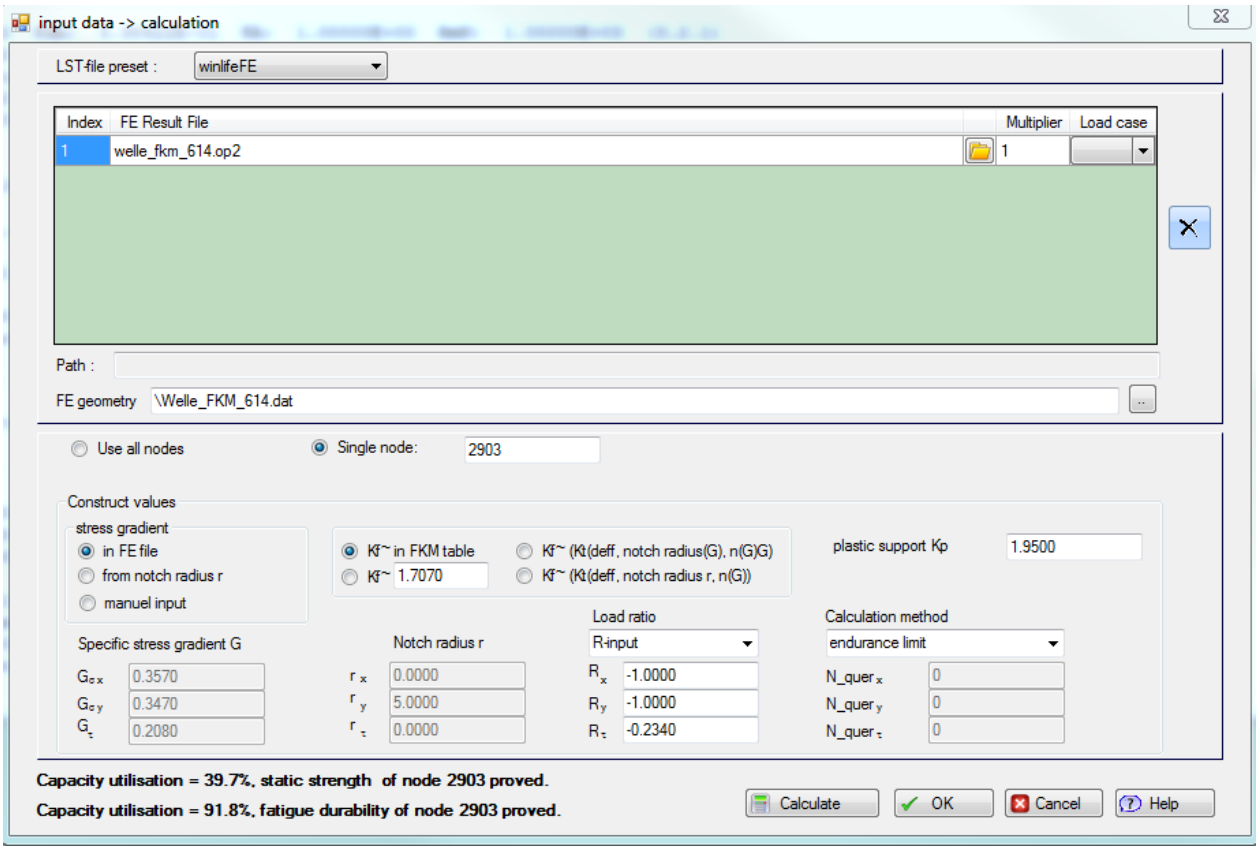


Figure 5-14: : Settings for use of NASTRAN results

The results for static utilisation are 39,7% and for fatigue durability 91,8% and are nearly the same as in the FKM guideline 39% (static) and 92% (dynamic). The visualisation of the utilisation ratio is shown in the next figures.

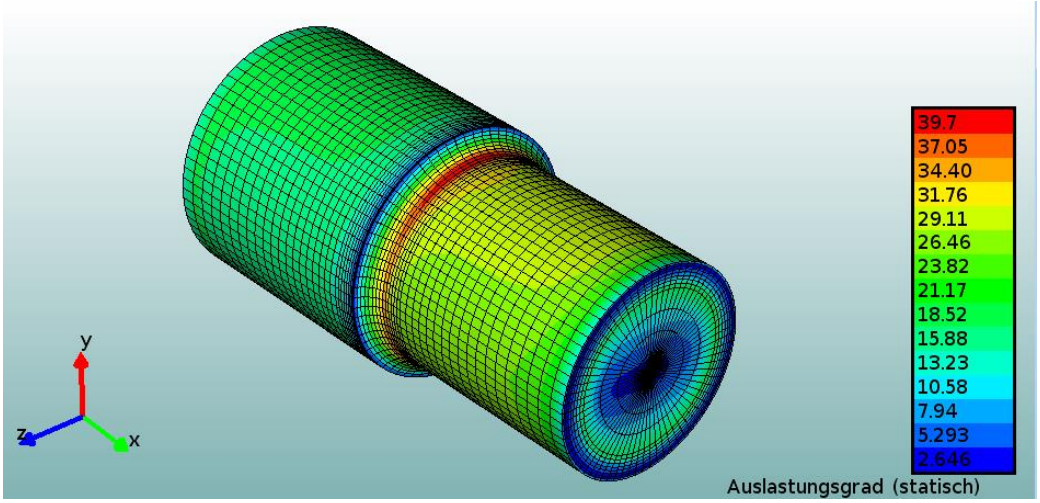


Figure 5-15: static utilisation ratio

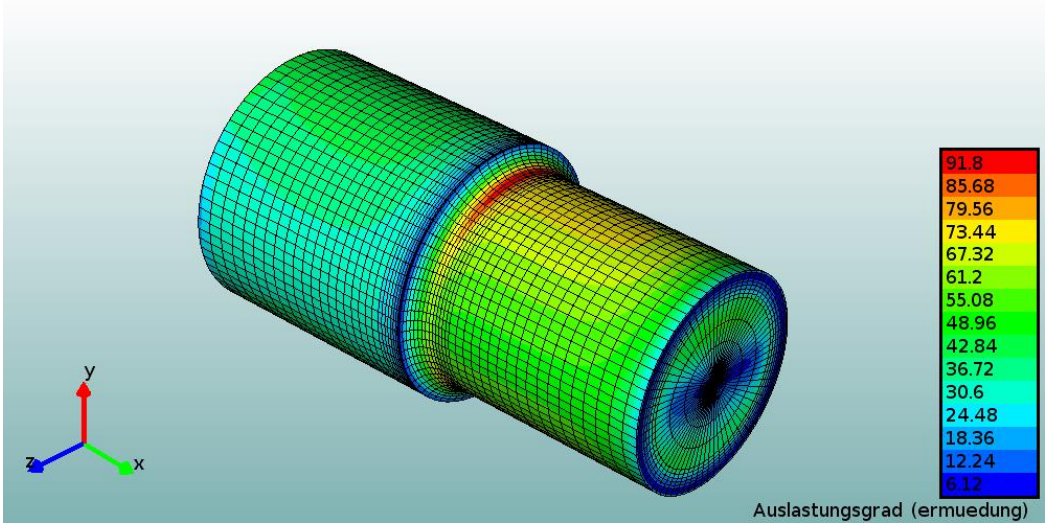


Figure 5-16: dynamic utilisation ratio

6. Example 29 / FKM Example Cast component

6.1. Aim

The cast component from chapter 6.2 of the FKM guideline is to be re-calculated with the winLIFE 4.0 2018 module *QUICK CHECK / FKM*. The diagram below shows the geometry of the component with the verification point.

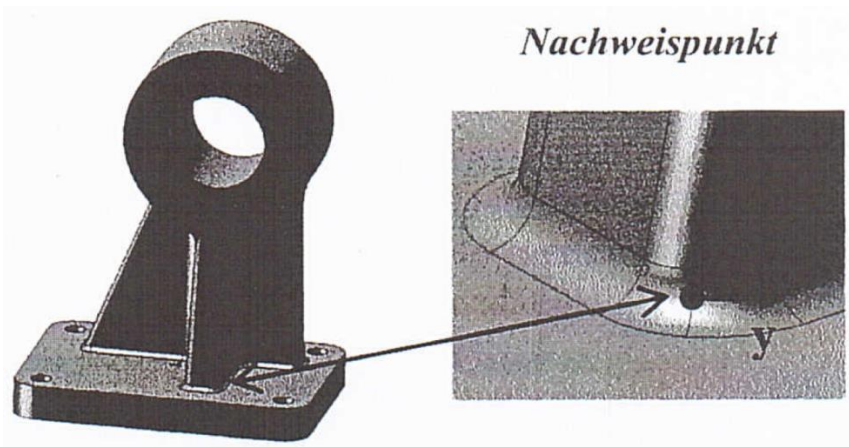


Figure Cast component [FKM guideline]

6.2. Material entries and local stresses

The bearing bracket is made of the material EN-GJL-250 (alt GG-25).

The surface roughness is R_z =200µm.

For the verification point the following stresses are provided in the FEM analysis (compare FKM-guideline chapter 6.2.0):

Upper load case:	Lower load case:
$\sigma_{x,O}$ = 60MPa	$\sigma_{x,U}$ = -34MPa
$\sigma_{y,O}$ = 16MPa	$\sigma_{y,U}$ = -8MPa

$\tau_{xy,O}$ = 1MPa $\tau_{xy,U}$ = -1MPa

Local stresses are used for the strength proof according to the FKM in winLIFE 4.0 2018.

6.3. Project construction in winLIFE, module QUICK CHECK / FKM

The project definition takes place in winLIFE 4.0 2018. To do this select:

Menu ***File / New (FKM strength proof)…***

The following window shows the order of commands:

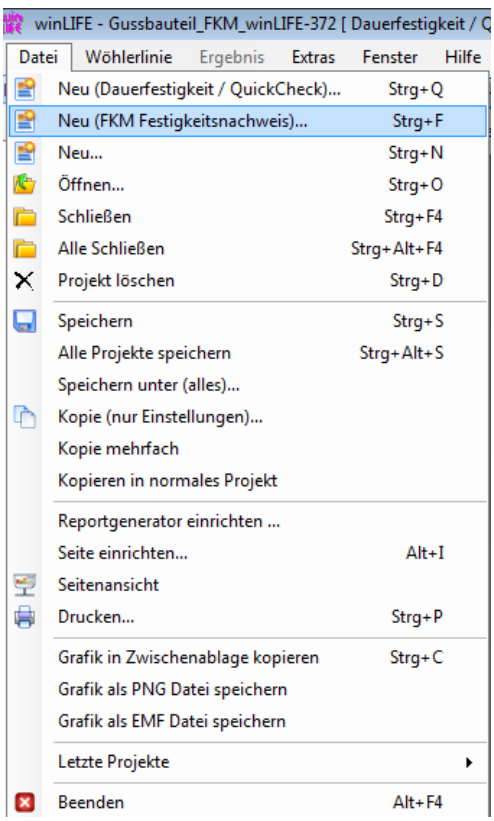


Figure Selection of the strength proof in winLIFE

The user now selects a file name for the winLIFE 4.0 2018 project e.g. a sutiable name such as: *cast_component_FKM.wlf* .

Next the durability of the material is set in the *S-N curve* menu.

The material EN-GJL-250 is listed in the winLIFE 4.0 2018 FKM data base and can be selected with:

Menu ***S-N curve / load FKM…***

A new window now opens and the material EN-GJL-250 is entered in the cell *Type*.

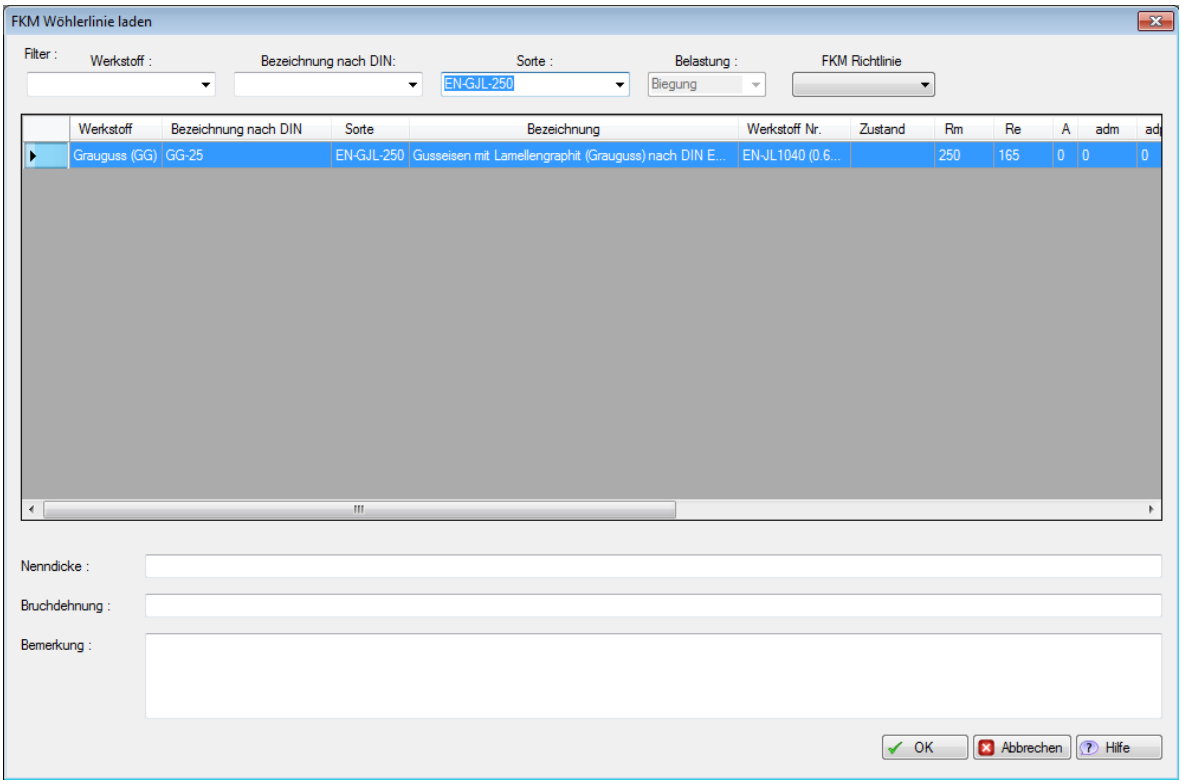


Figure Material selection from the FKM data base

The missing material parameters can be taken from the FKM guideline. The safety factor is determined here by the necessary entries in the window. Finally, the following diagram appears with the entries for the S-N curve.

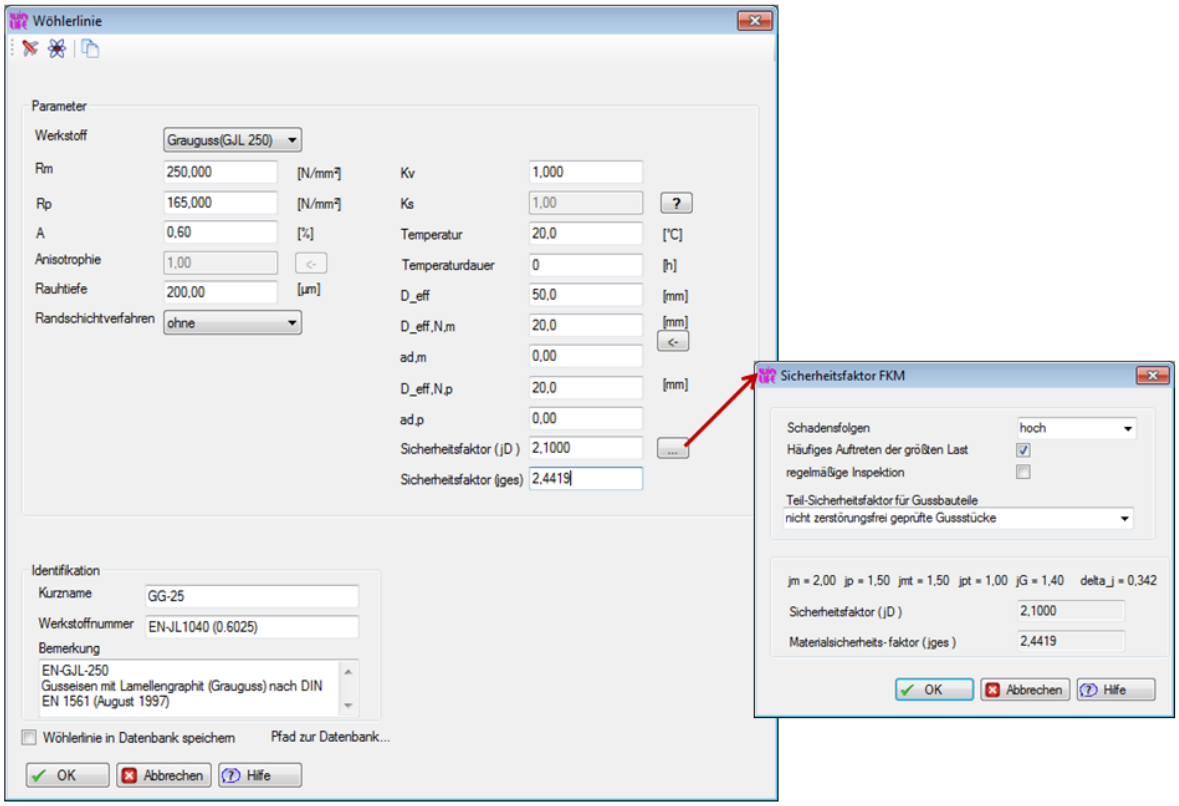


Figure Material parameters

With the entries just made, an S-N curve is created. This can be viewed with:

Menu ***S-N curve / S-N curve***

.

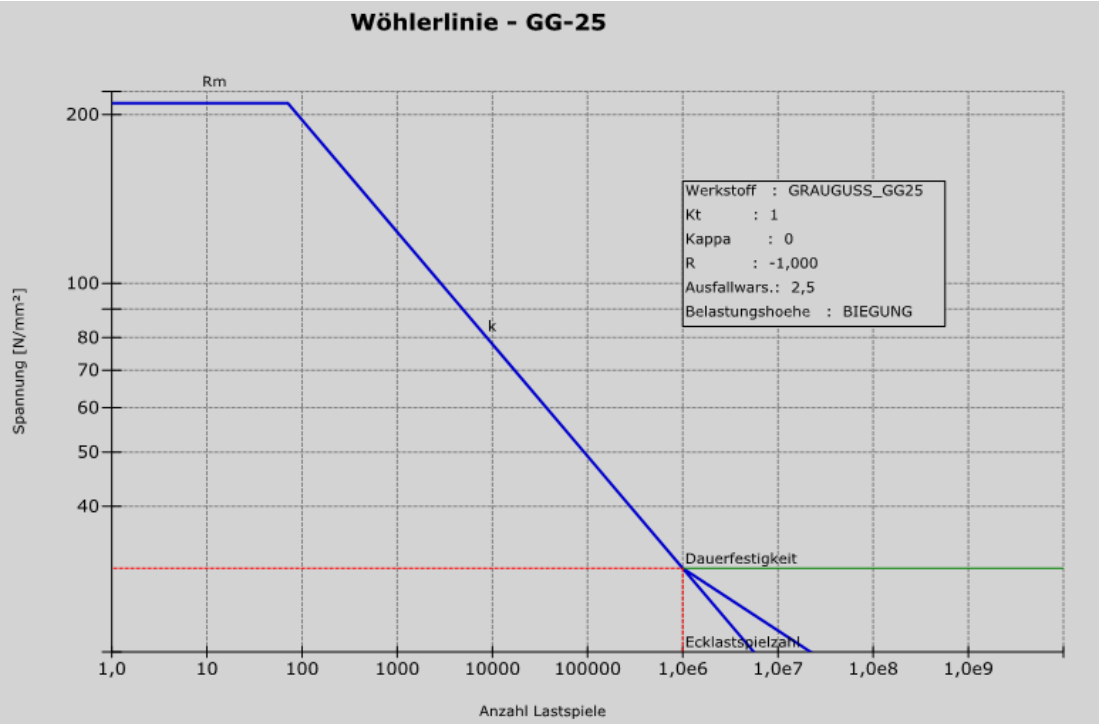


Figure S-N curve for the material EN-GJL-250 (GG-25)

The next step is to enter the loadings. Use:

Menu ***Calculation*** and the diagram shown below will appear.

This is where the loading is entered.

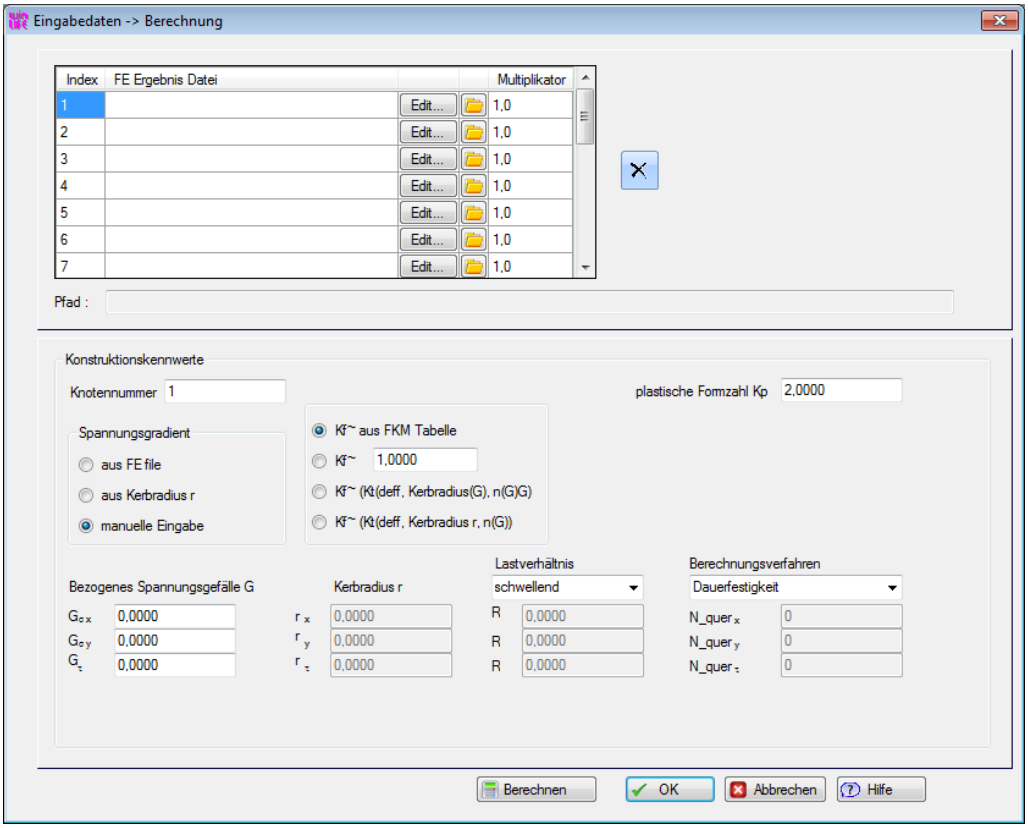


Figure Entries in calculation dialogue

Firstly, the local stresses at the verification point are entered. For this purpose, open the existing file *Stress_tensor.LST* by clicking the file symbol button in line 1 (diagram above). In this file the following principal stress is provided:

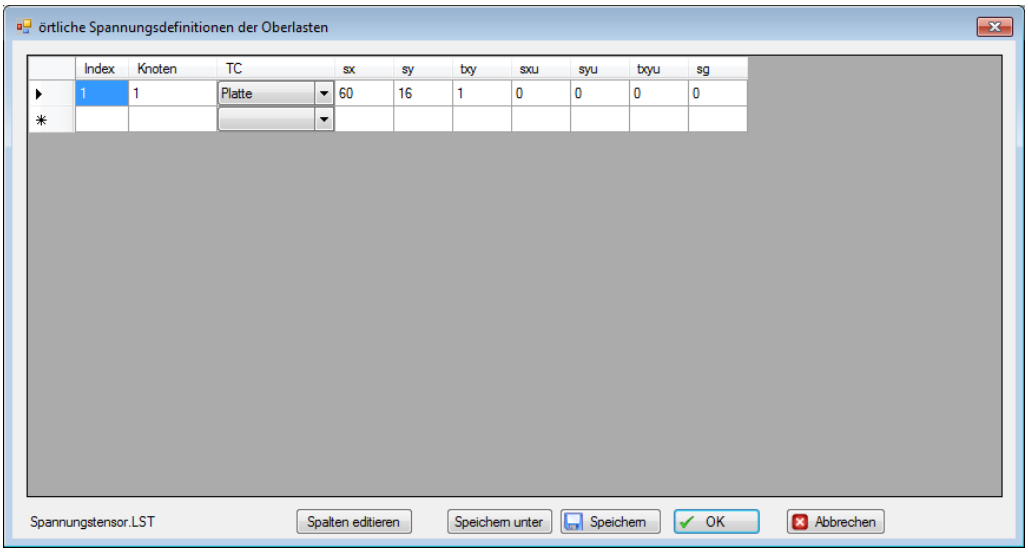


Figure Entering the local stresses

The file includes the stresses occurring at the verification point. winLIFE 4.0 2018 example 28 shows you how to create and alter a LST-file.

Now the other entries are made in the window shown below.

According to FKM, the value of the plastic stress concentration factor Kp does not need to be calculated. The plasticity number of the material is used for the plastic support factor. Further entries are then made for stress gradients and stress ratios and the type of calculation, in this case ***fatigue strength multi-stage***.

The multi-stage loading acting on the component is shown in tabular form (see diagram below). The same collective is acting for the three stress components x, y and τ according to the task.

Finally, the window should be filled in as shown in the diagram below.

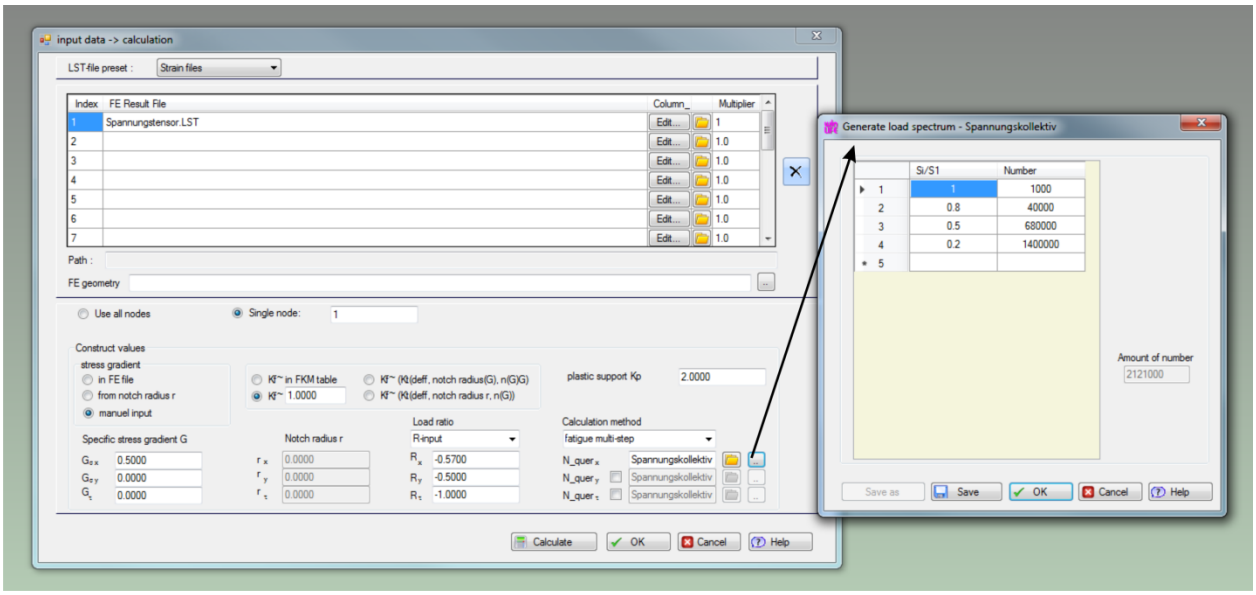


Figure Entering the stress collective

The strength calculation can now be started by clicking on the *Calculate* button. The results for the utilisation rate for the static strength is 93.1% and for the fatigue strength 92.2%. These results can be seen in the window to the left (shown below).

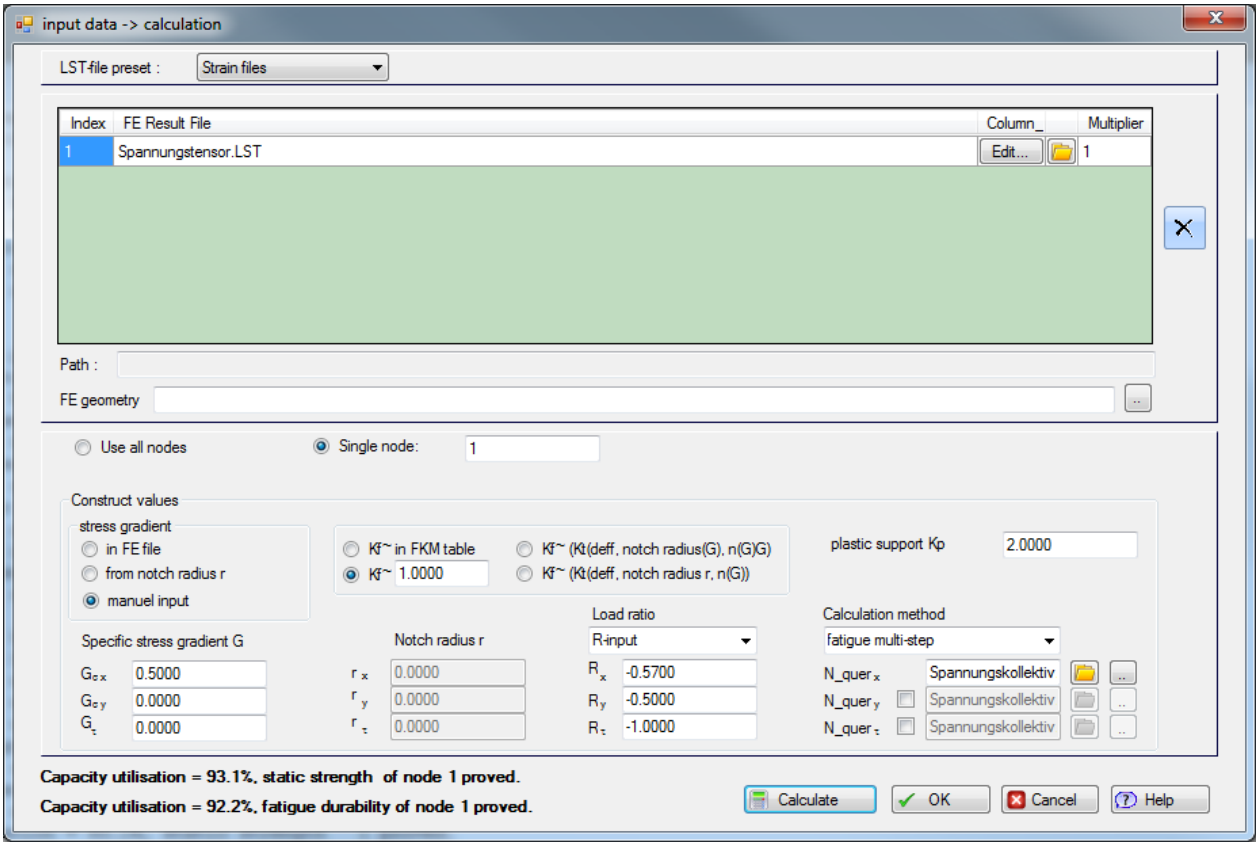


Figure Entries and results of the utilization rate

6.4. Results

As well as the utilisation rate for the static strength and fatigue strength, the protocol in winLIFE 4.0 2018 also shows the interim results of the calculation. The winLIFE 4.0 2018 user can therefore follow the calculation and the interim steps and compare these with the equations from the FKM guideline.

The following diagram shows an excerpt from the result protocol for the static strength proof. At the bottom the utilisation rate is listed, in this case 93.1%.

```
Protocol: C:\ProgramData\Documents\winLIFE\Examples\example_29\example_29.ptk
  29.02.2016 15:28:40

Material properties
                Rm:  2.09552E+02  Kdm:  8.38208E-01  KA:  1.00000E+00  RmN:  2.50000E+02  (3.2.1)
                Rp:  1.38304E+02  Kdp:  8.38208E-01  KA:  1.00000E+00  RpN:  1.65000E+02
Stresses resulting from all acting load cases
                sx:  6.00000E+01        sy:  1.60000E+01        txy:  1.00000E+00
                sxu:  0.00000E+00       syu:  0.00000E+00       txyu:  0.00000E+00


Static strength proof for node 1
Temperature factor
                KT,m = KT,p:  1,00000E+00  (3.2.22 - 3.2.27)
Principal stresses
                h1:  6.00227E+01        h2:  1.59773E+01        h3:  0.00000E+00
hydrostatic stress sigma_H
                sigma_H:  2.53333E+01  (3.1.11)
Ductility factor q, strength factor f_sigma, grey cast iron factor KNL
                q:  1.00000E+00  f_sigma:  1.00000E+00  KNL:  1.10000E+00  (push)
                q:  1.00000E+00  f_sigma:  2.50000E+00  KNL:  9.10000E-01  (pull)
Equivalent stress
                sigma_v:  5.45661E+01  (3.1.5)
Multiaxiality
                h:  4.70509E-01         sigma_H:  2.53333E+01   sigma_GH:  5.38424E+01  (3.1.10)
plastic support factor - npl
                eps_ref:  2.40000E-03   A:  6.00000E-01  (3.3.5)
                eps_ertr:  1.48097E-03  eps_0:  1.38304E-03  (3.3.3)
                npl:  1.03480E+00       E:  1.00000E+05 Kp:  2.00000E+00  (3.3.2)
component strength - sigma_SK
                sigma_SK:  1.43117E+02  (3.4.1)
Capacity utilisation of equivalent stress - aSK
                aSK:  9.31016E-01       sigma_v:  5.45661E+01   sigma_SK:  1.43117E+02  jges:  2.44189E+00  (3.6.1)
Capacity utilisation = 93.1%, static strength   1 proved.
```

Figure Protocol of the strength calculation, static proof

The diagram below is the excerpt from the result protocol which is relevant for the proof of the fatigue strength. The utilisation rate related to the fatigue strength is 92.2% as can be seen in the bottom line.

```
Component related standards
                sigma_W,zd:  7.12477E+01        fW,sigma:  3.40000E-01  Rm:  2.09552E+02  (4.2.1)
                tau_W,s:  7.12477E+01           fW,tau:  1.00000E+00
Temperature factor
                KT,D:  1.00000E+00  (4.2.4)
Support values according to Stieler
                n_sigma_x:  1.68234E+00 G_sigma_x:  5.00000E-01 aG: -5.00000E-02        bG:  3.20000E+03  (4.3.8)
                n_sigma_y:  1.00000E+00 G_sigma_y:  0.00000E+00 aG: -5.00000E-02        bG:  3.20000E+03
                n_tau_xy:  1.00000E+00  G_tau_xy:  0.00000E+00  fW,t*Rm:  2.09552E+02
Estimated notch value
                Kf~_sigma_x:  1.00000E+00       Kt_sigma_x:  1.00000E+00  (4.3.2)
                Kf~_sigma_y:  1.00000E+00       Kt_sigma_y:  1.00000E+00
                Kf~_tau_xy:  1.00000E+00        Kt_tau_xy:  1.00000E+00
Roughness factor
                KR_sigma:  9.14081E-01  aR_sigma:  6.00000E-02  r_t:  2.00000E+02       Rm,N,min:  1.00000E+02  (4.3.21)
                KR_tau:  9.14081E-01    fW,t*aR_sigma:  6.00000E-02
Component parameters
                KWK_sigma_x:  6.19316E-01       KV:  1.00000E+00        KS:  1.00000E+00        KNL,E:  1.05000E+00  (4.3.1)
                KWK_sigma_y:  1.04190E+00       KV:  1.00000E+00        KS:  1.00000E+00        KNL,E:  1.05000E+00
                KWK_tau_xy:  1.09399E+00        KV:  1.00000E+00        KS:  1.00000E+00
Component alternating strength
                sigma_x_WK:  1.15043E+02  (4.4.1)
                sigma_y_WK:  6.83825E+01
                tau_xy_WK:  6.51262E+01
Mean stress sensitivity
                M_sigma:  5.00000E-01   aM:  0.00000E+00        bM:  5.00000E-01  (4.4.5)
                M_tau:  5.00000E-01
Mean stress factor
                KAK_sigma_x:  8.79552E-01       R: -5.70000E-01 sm/sa:  2.73885E-01  (4.4.8 - 4.4.12)
                KAK_sigma_y:  8.57143E-01       R: -5.00000E-01 sm/sa:  3.33333E-01
                KAK_tau_xy:  1.00000E+00        R: -1.00000E+00 sm/sa:  0.00000E+00
Amplitude of component endurance limit
                sigma_x_AK:  1.01186E+02  (4.4.4)
                sigma_y_AK:  5.86136E+01
                tau_xy_AK:  6.51262E+01
bearable value of amplitude
                sigma_x_BK:  1.96938E+02        KBK_sigma:  1.94630E+00  (4.4.38)
                sigma_y_BK:  1.14080E+02        KBK_sigma:  1.94630E+00
                tau_xy_BK:  1.15287E+02         KBK_tau:  1.77021E+00
Maximum of amplitude
                sigma_BKmax:  1.07338E+02  (4.4.40)
        Limitation of maximum amplitude
                sigma_x_BK:  1.07338E+02        KBK_sigma_x:  1.06080E+00  (4.4.42)
        Limitation of maximum amplitude
                sigma_y_BK:  1.07338E+02        KBK_sigma_y:  1.83128E+00
                tau_BKmax:  1.07338E+02
        Limitation of maximum amplitude
                tau_xy_BK:  1.07338E+02 KBK_tau_xy:  1.64815E+00
Proof - individual stresses     jD:  2.10000E+00
                aBK_sigma_x:  9.21484E-01       sa:  4.71000E+01        sigma_BK:  1.07338E+02  (4.6.3)
                aBK_sigma_y:  2.34773E-01       sa:  1.20000E+01        sigma_BK:  1.07338E+02
                aBK_tau_xy:  1.95644E-02        sa:  1.00000E+00        tau_BK:  1.07338E+02
Proof - accumulated stresses
                aBK_sigma_v:  9.22041E-01       aNH:  9.22041E-01       aGH:  8.29635E-01       q:  1.00000E+00  (4.6.5)
Capacity utilisation = 92.2%, fatigue durability  1 proved.
```

ocuments\winLIFE\Examples\example_29

Figure Protocol of the strength calculation, fatigue proof

7. Example 30 / FKM Example Compressor flange

7.1. Aim

As a further example, the strength of a grey cast iron compressor flange is analysed. As the previous two examples, this example has also been taken from the FKM guideline (chapter 6.3).

The calculation is done using the winLIFE FKM QUICKCHECK */ FKM*. The diagram below shows the geometry of the component with the verification point (node point 99).

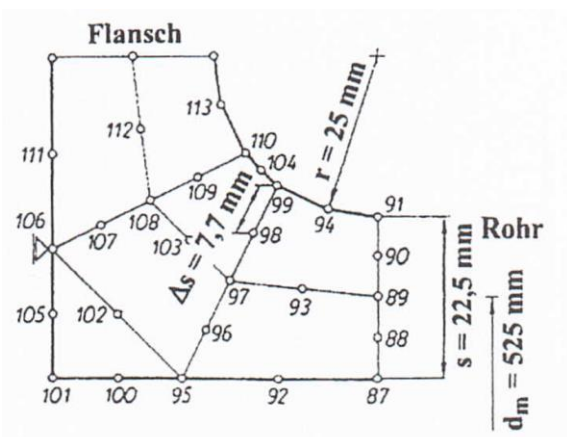


Figure FE-Model of the compressor flange [FKM guideline]

7.2. Material characteristics and local stresses

The compressor flange is made of material GJL-300 (alt GG-30).

The surface roughness is R_z = 200µm.

The following stresses are provided for the verification point (node point 99) in the directions 1 (longitudinal direction) and 2 (circumferential direction) (compare FKM-guideline chapter 6.3.0):

$\sigma_1 = \sigma_{1,m} \pm \sigma_{1,a}$ = 15,0MPa ± 18,6MPa

$\sigma_2 = \sigma_{2,m} \pm \sigma_{2,a}$ = 5,0MPa ± 6,2MPa

$\sigma_3 = 0$

Note: Local stresses are used for the proof of strength according to FKM in winLIFE 4.0 2018.

7.3. Environmental conditions

The compressor flange should be designed for temperatures of 380°C to 100.000h.

7.4. Project construction in winLIFE, Module QUICK CHECK / FKM

In winLIFE 4.0 2018 the project definition now takes place. For this, select:

Menu ***File/ New (FKM proof of strength)…***

The user selects a file name for the winLIFE 4.0 2018 project, e.g. a suitable name such as *compressor_flange_FKM.wlf* .

Next, the material is defined in the menu *S-N curve*. The material EN-GJL-300 can be found in the winLIFE 4.0 2018 FKM data base and can be selected as follows:

Menu ***S-N curve / Load FKM***…

A new window then opens and the material EN-GJL-300 is entered in the cell *Type.* The results of the material search appears and this can be accepted by clicking OK.

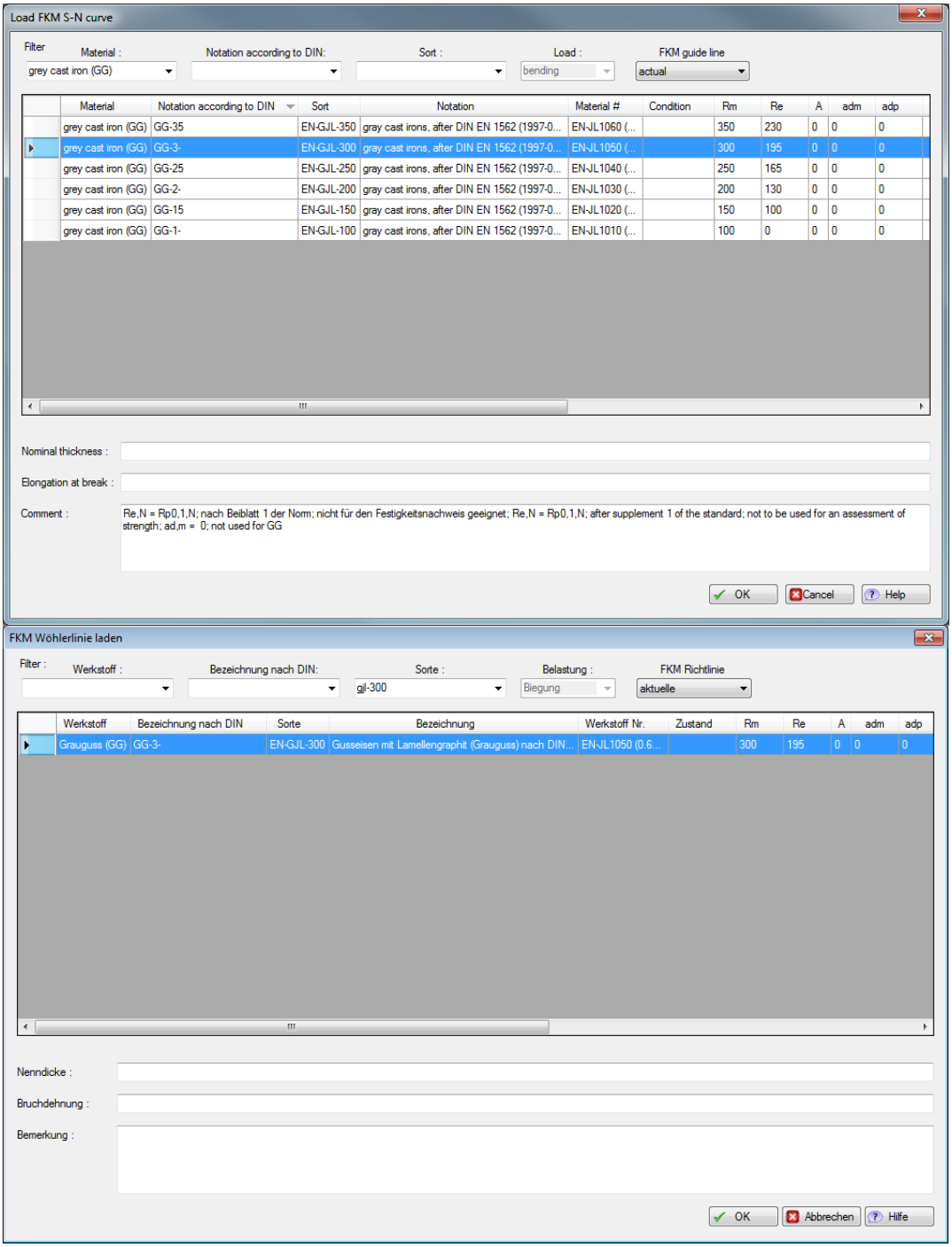


Figure Material selection from the FKM data base

The missing material parameters can be taken from the FKM guideline. The safety factor is determined here by the necessary entries in the window. Finally, the following diagram appears with the entries for the S-N curve.

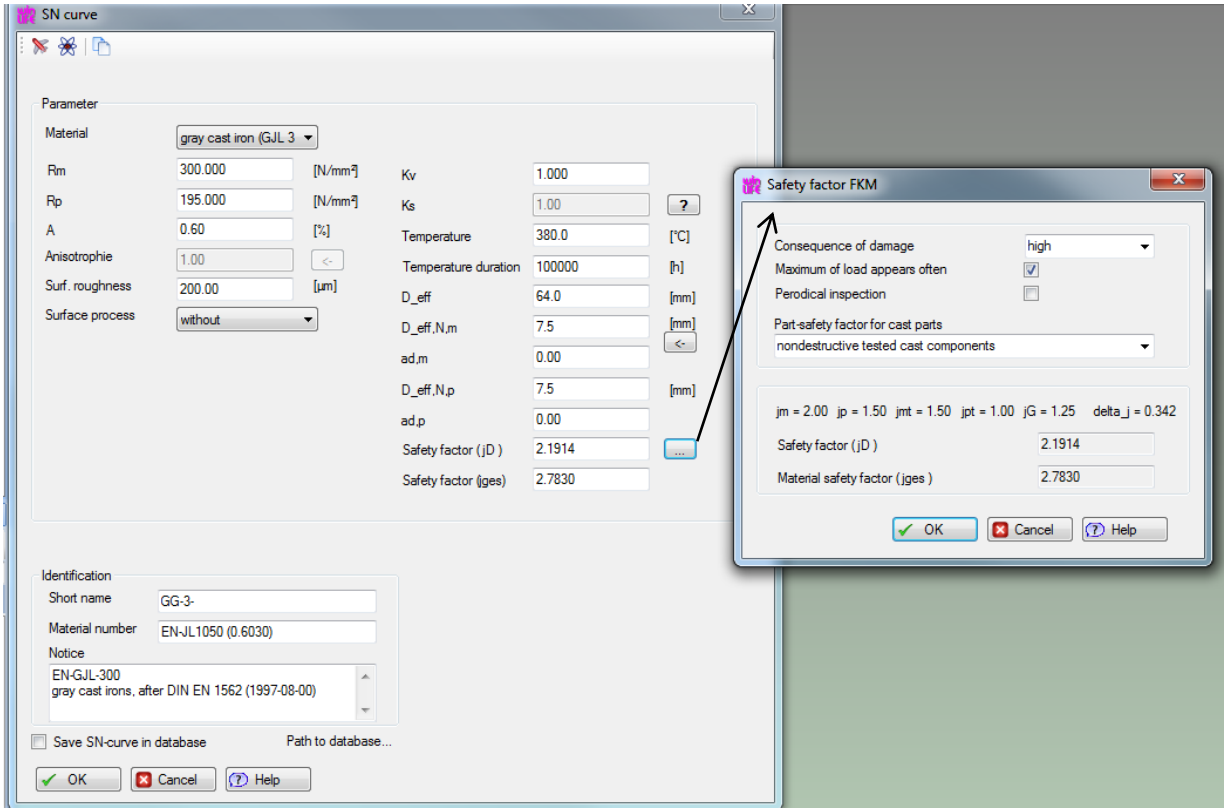


Figure Material parameters

The entries made result in the S-N curve which can be viewed using the command:

Menu ***S-N curve / S-N curve***

If required the S-N curve can be scaled. Use the right-hand mouse key above the axis and select *min/max-value* from the context menu.

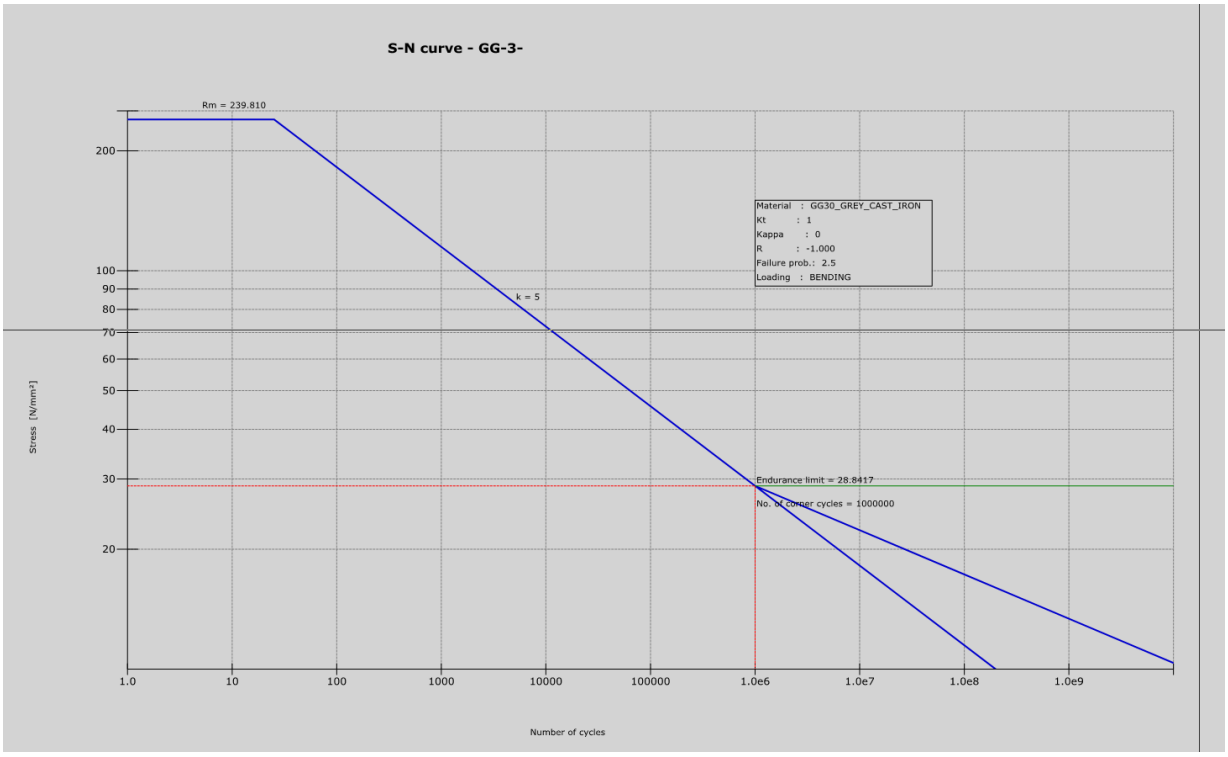


Figure S-N curve for material EN-GJL-300 (GG-30)

The next step is to enter the load:

Menu ***Calculation*** the window shown below appears

This is where you enter the information on the load.

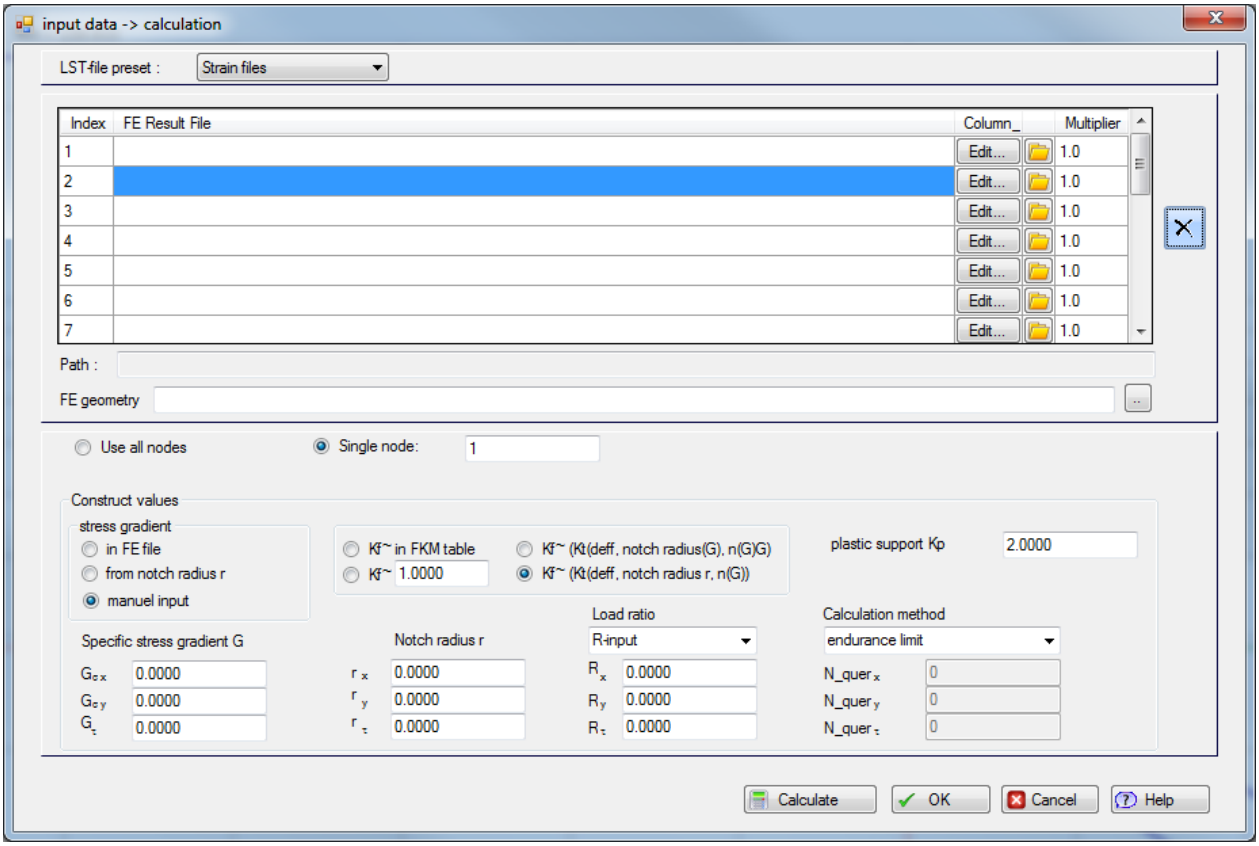


Figure Entries in calculation dialogue

Firstly the local stresses at the verification point are entered. For this purpose, open the existing file *Stress_tensor.LST* by clicking the file symbol button in line 1 (diagram above). In this file the following principal stresses are provided:

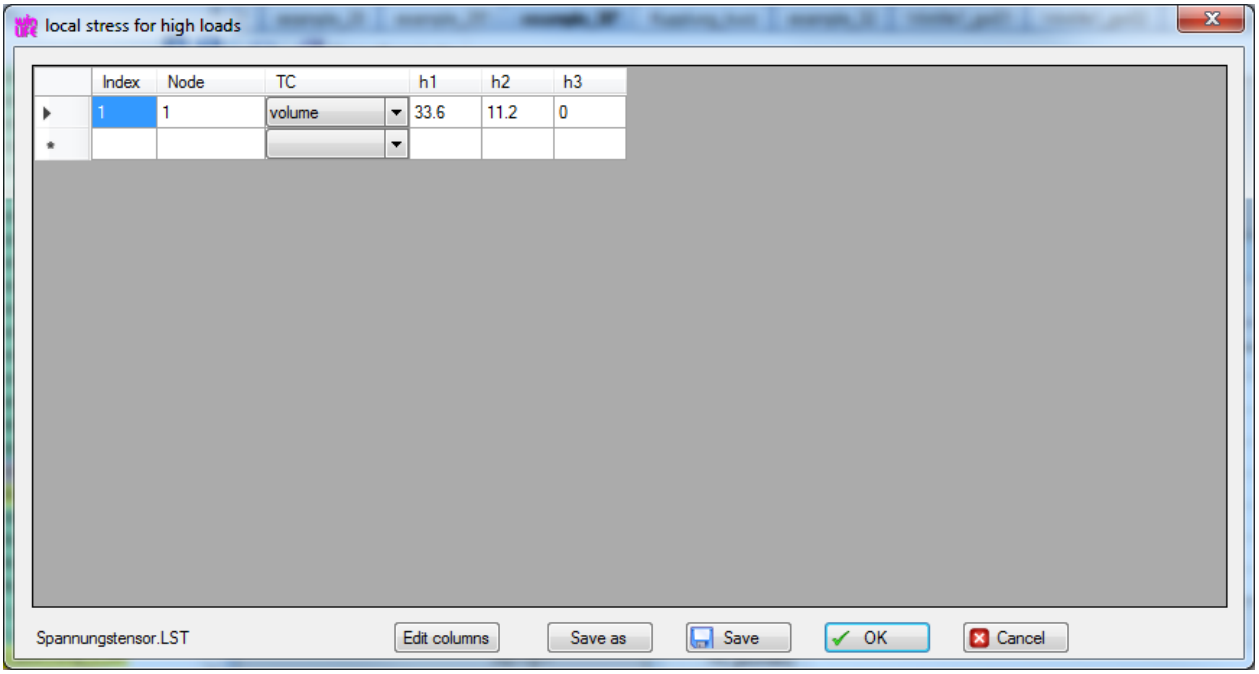


Figure Entering the local stresses

The file includes the stresses occurring at the verification point. winLIFE 4.0 2018 example 28 shows you how to create and alter a LST-file.

Now the other entries are made in the window shown below.

According to FKM, the value of the plastic stress concentration factor Kp does not need to be calculated. The plasticity number of the material is used for the plastic support factor. Further entries are then made for stress gradients and stress ratios and the type of calculation, in this case *fatigue strength*. Finally, the window should be filled in as shown in the diagram below.

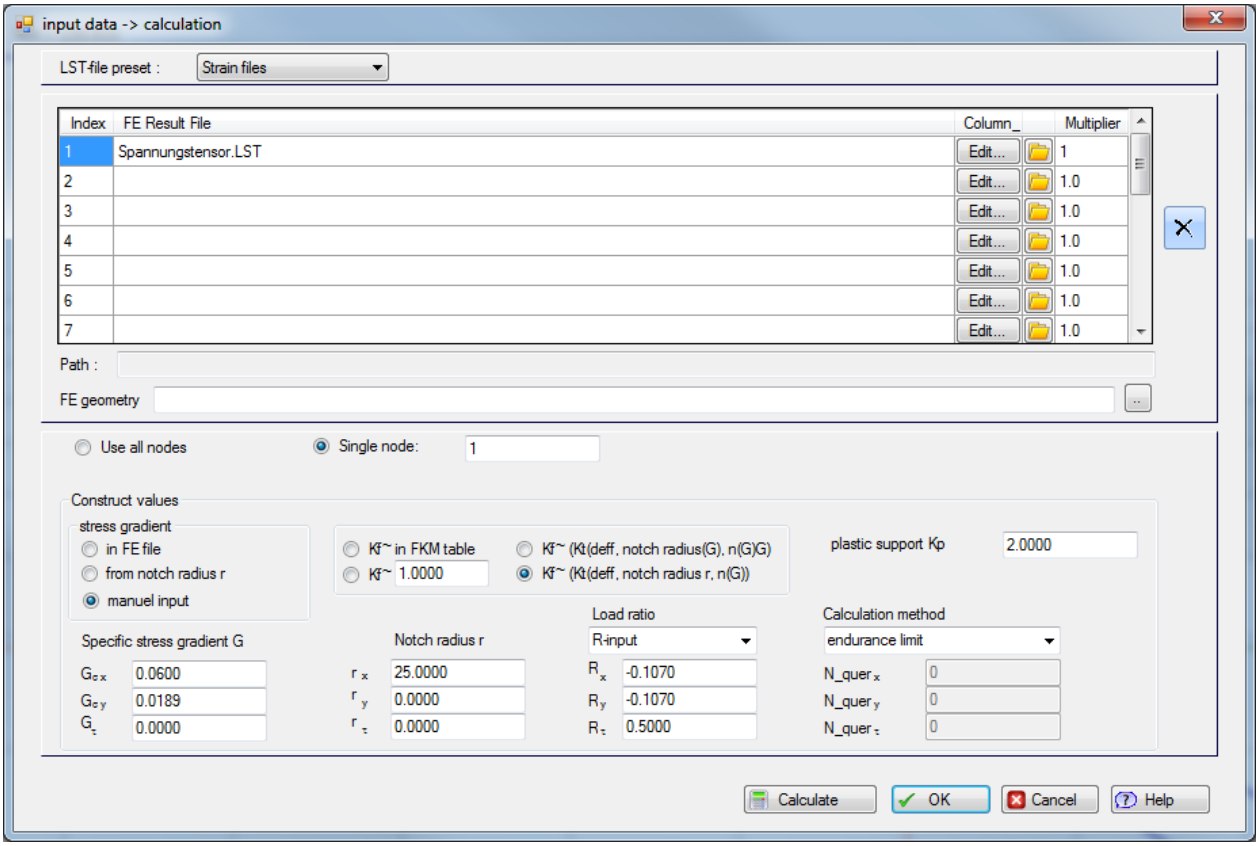


Figure Calculation entries

The strength calculation can now be started by clicking on the *Calculate* button. The results for the utilisation rate for the static strength is 56.4% and for the fatigue strength 63.6%. These results can be seen in the window to the left (shown below).

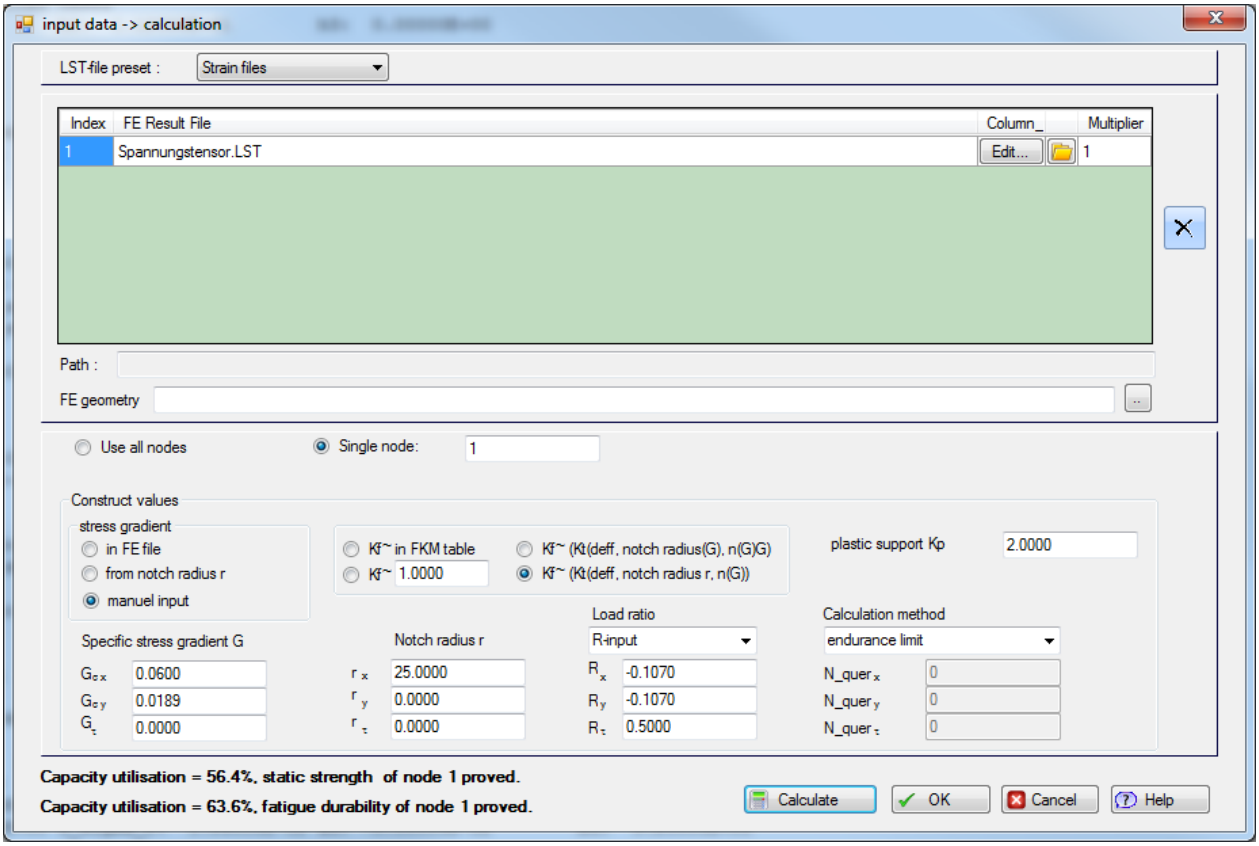


Figure Calculation entries and results of the component utilisation

7.5. Results

As well as the utilisation rate for the static strength and fatigue strength, the protocol in winLIFE 4.0 2018 also shows the interim results of the calculation. The winLIFE 4.0 2018 user can therefore follow the calculation and the interim steps and compare these with the equations from the FKM guideline.

The following diagram shows an excerpt from the result protocol for the static strength proof. At the bottom the utilisation rate is listed, in this case 56.4%.

```
Protocol: C:\ProgramData\Documents\winLIFE\Examples\example_30\example_30.ptk
  29.02.2016 15:50:56

Material properties
                Rm:  2.39810E+02  Kdm:  7.99367E-01  KA:  1.00000E+00  RmN:  3.00000E+02  (3.2.1)
                Rp:  1.55877E+02  Kdp:  7.99367E-01  KA:  1.00000E+00  RpN:  1.95000E+02
Stresses resulting from all acting load cases
                h1:  3.36000E+01        h2:  1.12000E+01        h3:  0.00000E+00


Static strength proof for node 1
Temperature factor
                KT,m = KT,p:  7,68960E-01  (3.2.22 - 3.2.27)
                KTt,m:  5,12067E-01  (3.2.29)
                KTt,p:  5,12067E-01  (3.2.29)
Principal stresses
                h1:  3.36000E+01        h2:  1.12000E+01        h3:  0.00000E+00
hydrostatic stress sigma_H
                sigma_H:  1.49333E+01  (3.1.11)
Ductility factor q, strength factor f_sigma, grey cast iron factor KNL
                q:  1.00000E+00  f_sigma:  1.00000E+00  KNL:  1.05000E+00  (push)
                q:  1.00000E+00  f_sigma:  2.50000E+00  KNL:  9.50000E-01  (pull)
Equivalent stress
                sigma_v:  3.20000E+01  (3.1.5)
Multiaxiality
                h:  5.03953E-01         sigma_H:  1.49333E+01   sigma_GH:  2.96324E+01  (3.1.10)
plastic support factor - npl
                eps_ref:  2.40000E-03   A:  6.00000E-01  (3.3.5)
                eps_ertr:  1.60031E-03  eps_0:  1.55877E-03  (3.3.3)
                npl:  1.01324E+00       E:  1.00000E+05 Kp:  2.00000E+00  (3.3.2)
component strength - sigma_SK
                sigma_SK:  1.57940E+02  (3.4.1)
Capacity utilisation of equivalent stress - aSK
                aSK:  5.63859E-01       sigma_v:  3.20000E+01   sigma_SK:  1.57940E+02  jges:  2.78300E+00  (3.6.1)
Capacity utilisation = 56.4%, static strength   1 proved.
```

Figure Protocol of the strength calculation, static proof

The diagram below is the excerpt from the result protocol which is relevant for the proof of the fatigue strength. The utilisation rate related to the fatigue strength is 63.6% as can be seen in the bottom line.

```
                q:  1.00000E+00  f_sigma:  2.50000E+00  KNL:  9.50000E-01  (pull)
Equivalent stress
                sigma_v:  3.20000E+01  (3.1.5)
Multiaxiality
                h:  5.03953E-01         sigma_H:  1.49333E+01   sigma_GH:  2.96324E+01  (3.1.10)
plastic support factor - npl
                eps_ref:  2.40000E-03   A:  6.00000E-01  (3.3.5)
                eps_ertr:  1.60031E-03  eps_0:  1.55877E-03  (3.3.3)
                npl:  1.01324E+00       E:  1.00000E+05 Kp:  2.00000E+00  (3.3.2)
component strength - sigma_SK
                sigma_SK:  1.57940E+02  (3.4.1)
Capacity utilisation of equivalent stress - aSK
                aSK:  5.63859E-01       sigma_v:  3.20000E+01   sigma_SK:  1.57940E+02  jges:  2.78300E+00  (3.6.1)
Capacity utilisation = 56.4%, static strength   1 proved.


Fatigue durability proof for node 1
Component related standards
                sigma_W,zd:  8.15354E+01        fW,sigma:  3.40000E-01  Rm:  2.39810E+02  (4.2.1)
Temperature factor
                KT,D:  8.55600E-01  (4.2.4)
Support values according to Stieler
                n_sigma_1:  1.17915E+00 G_sigma_1:  6.00000E-02 aG: -5.00000E-02        bG:  3.20000E+03  (4.3.7)
                n_sigma_2:  1.05643E+00 G_sigma_2:  1.89000E-02 aG: -5.00000E-02        bG:  3.20000E+03
Estimated notch value
                Kf~_sigma_1:  1.07901E+00       Kt_sigma_1:  1.27232E+00  (4.3.2)
                Kf~_sigma_2:  1.00000E+00       Kt_sigma_2:  1.00000E+00
Roughness factor
                KR_sigma:  9.05994E-01  aR_sigma:  6.00000E-02  r_t:  2.00000E+02       Rm,N,min:  1.00000E+02  (4.3.21)
Component parameters
                KWK_sigma_1:  9.06949E-01       KV:  1.00000E+00        KS:  1.00000E+00        KNL,E:  1.02500E+00  (4.3.1)
                KWK_sigma_2:  1.01932E+00       KV:  1.00000E+00        KS:  1.00000E+00        KNL,E:  1.02500E+00
Component alternating strength
                sigma_1_WK:  8.99008E+01  (4.4.1)
                sigma_2_WK:  7.99902E+01
Mean stress sensitivity
                M_sigma:  5.00000E-01   aM:  0.00000E+00        bM:  5.00000E-01  (4.4.5)
Mean stress factor
                KAK_sigma_1:  7.12584E-01       R: -1.07000E-01 sm/sa:  8.06685E-01  (4.4.8 - 4.4.12)
                KAK_sigma_2:  7.12584E-01       R: -1.07000E-01 sm/sa:  8.06685E-01
Amplitude of component endurance limit
                sigma_1_AK:  6.40619E+01  (4.4.4)
                sigma_2_AK:  5.69998E+01
bearable value of amplitude
                sigma_1_BK:  6.40619E+01        KBK_sigma:  1.00000E+00  (4.4.38)
                sigma_2_BK:  5.69998E+01        KBK_sigma:  1.00000E+00
Maximum of amplitude
                sigma_BKmax:  1.18455E+02  (4.4.40)
Proof - individual stresses     jD:  2.19140E+00
                aBK_sigma_1:  6.36178E-01       sa:  1.85976E+01        sigma_BK:  6.40619E+01  (4.6.3)
                aBK_sigma_2:  2.38333E-01       sa:  6.19920E+00        sigma_BK:  5.69998E+01
Proof - accumulated stresses
                aBK_sigma_v:  6.36178E-01       aNH:  6.36178E-01       aGH:  5.56689E-01       q:  1.00000E+00  (4.6.5)
Capacity utilisation = 63.6%, fatigue durability  1 proved.
```

Figure Protocol of the strength calculation, fatigue proof

8. Example 18a / Endurance Limit Certification using winLIFE QUICK CHECK

Note: For this example, the data including the FEMAP/NASTRAN model is provided on the winLIFE 4.0 2018-CD. Sub directory on CD: ***\examples_wl_30\examp_18\LST-Dateien***

In this documentation the creation of the FEA model in FEMAP is not descripted. But all data created by FEMAP are shipped on CD. The user can follow the example in winLIFE 4.0 2018 without additional necessary tasks.

The following steps for the example are shown in detail.

Examples 18 a and 18 b show the evidence repeatedly demanded by many users that the worst-case scenarios in winLIFE FKM QUICKCHECK can actually find real load-time histories that lead to the same utilisation ratio. Furthermore, in this example, the various project types and their conversion from a winLIFE FKM QUICKCHECK project to a normal project are also shown.

8.1.1. General rules to work with winLIFE

Rule 1:
You have to work through the menu from the left side to right.

Rule 2:
Menu points which can be used are set to active (active=black colour, inactive = grey colour). You only can use active menu points. These settings are set to avoid mistakes.

8.1.2. Start of winLIFE

Double clicking on the winLIFE 4.0 2018-Icon starts winLIFE 4.0 2018 as shown in the following Figure. In the top menu only, the item ***File*** is active. (black colour means active, grey colour means inactive)

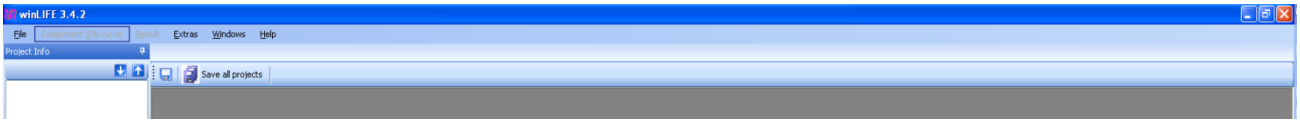


Figure Screen after starting winLIFE

8.1.3. Create a project

Select from the menu

File / New (Endurance Limit Cert.)

An window for the input of a file name opens. We enter

project_1

After closing the input window the winLIFE 4.0 2018 GUI changes as shown in the following Figure.

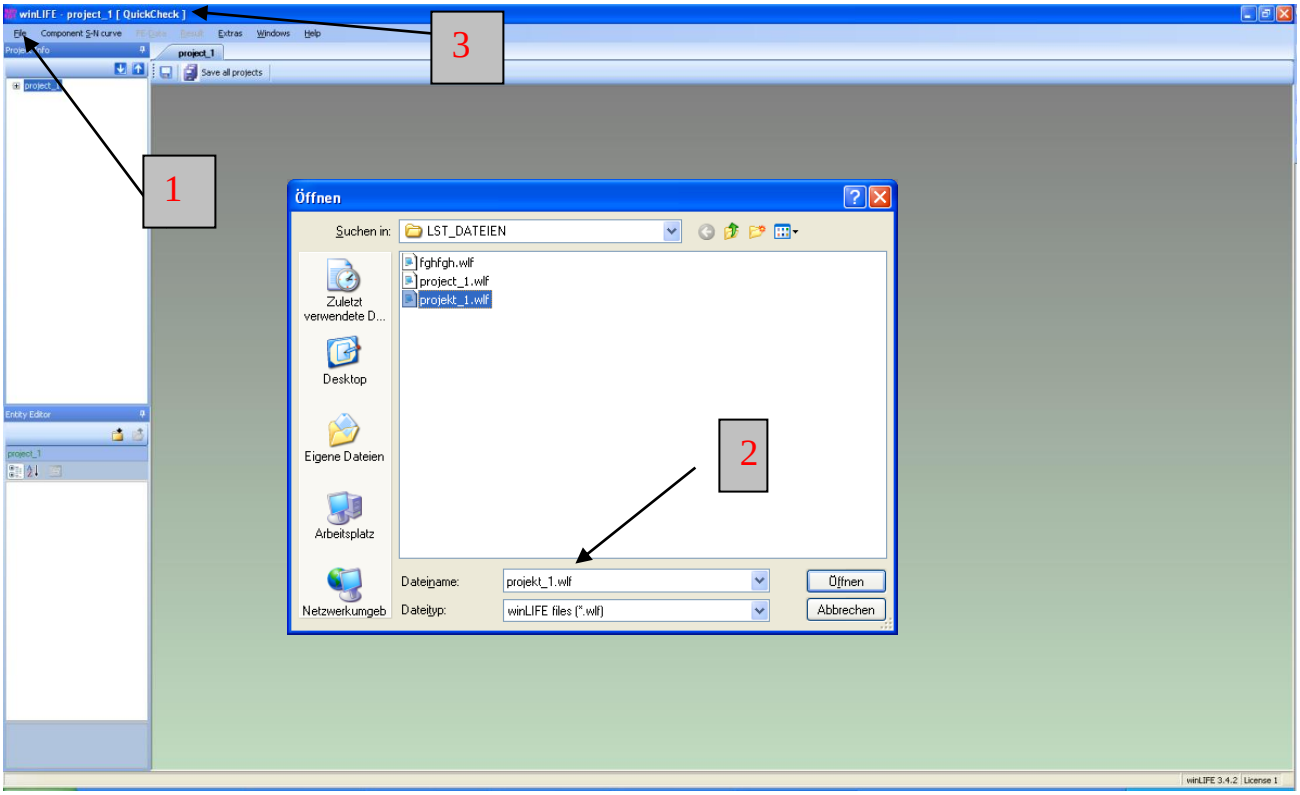


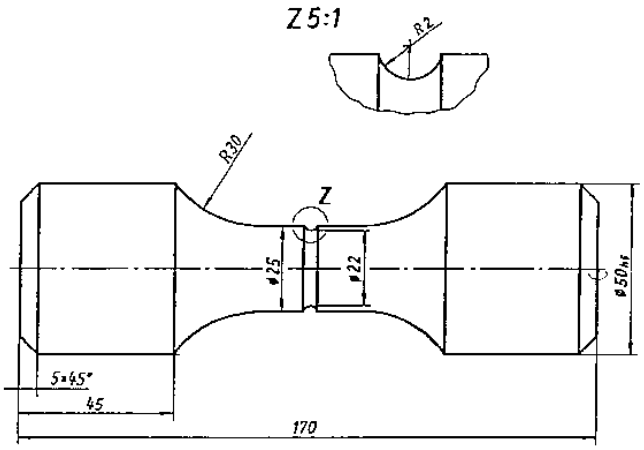
Figure Creating a project

Note: The project name is shown in the top of the screen. The menu item ***Component S-N curve*** has changed to active.

8.2. Job Definition

8.2.1. Component Geometry

For the following component, the design drawing with dimension is shown an endurance limit certification is performed.



FE-model “notched shaft“

8.2.2. Component Load (Unit Loads)

The applied load on the component is affected by three dimensions, which result in each case in a nominal stress amplitude of 1 N/mm^2 in the notch.

loadcase no.	load description	unit load that creates 1 N/mm^2 nominal stress	variation in time	upper limit
1	tensile force	tensile force on end face in x-direction (axial) 380 N	constant	380 N * 20 = 7 000 N
2	bending	moment on end face in y-direction My = 1045 Nmm	alternating	1045 Nmm * 40 = 41 800 Nmm
3	torsion	moment in x-direction Mx = 2091 Nmm	pulsating	2091 Nmm * 30 = 62 730 Nmm

8.2.3. Material Data

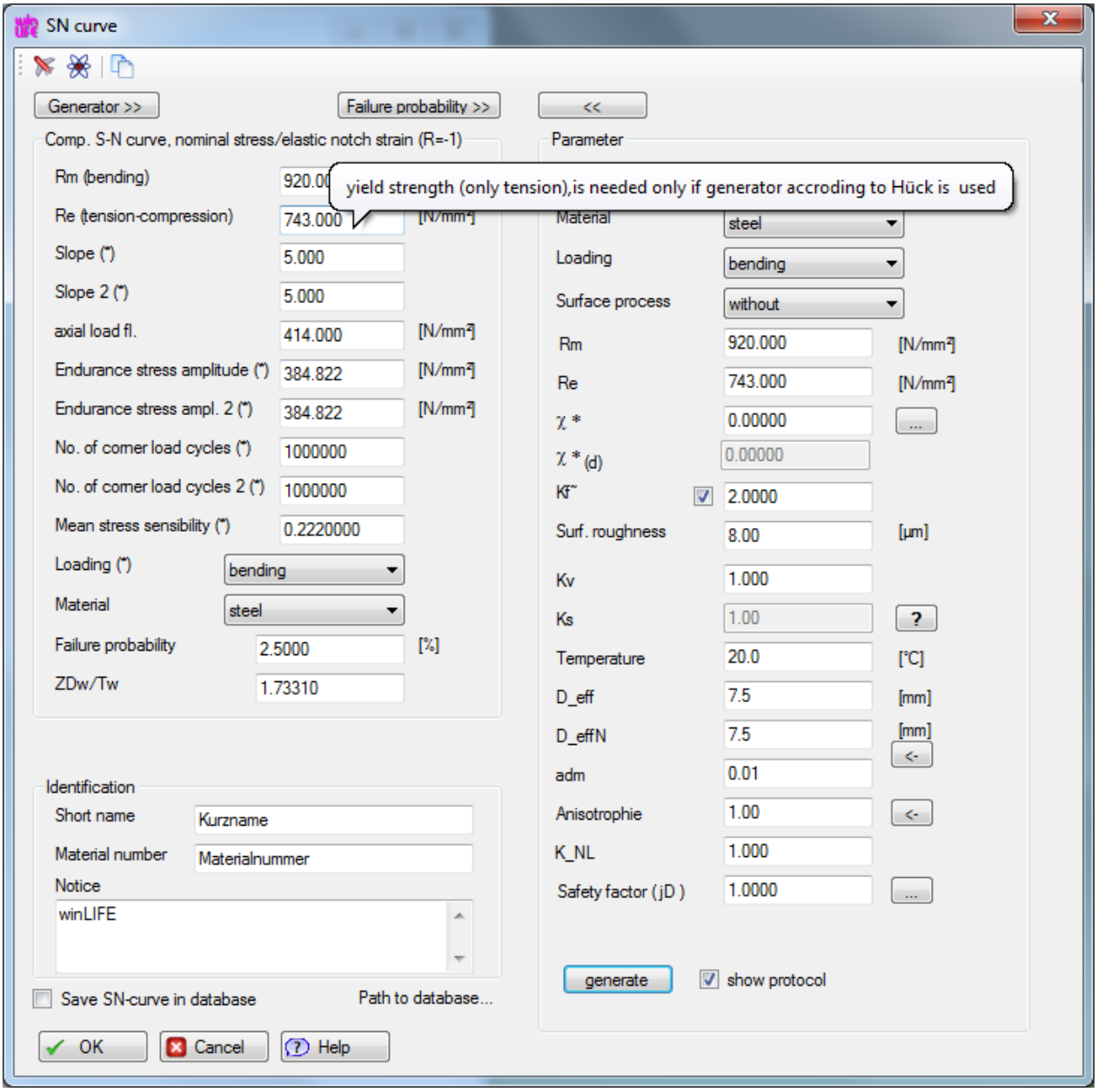
material data:	42 CrMoS 4V
surface, depth of roughness Rz	8 µm
mechanical data:	
tensile strength R_m	920 MPa
0.2 % elastic limit	743 MPa
modulus of elasticity	210 MPa

8.3. Generation of S-N Curve

We want to create a S-N curve based on the given material data according to the FKM-guideline. The given material is not available in the FKM- database and that is the reason why we use this example to show how the advanced S-N-curve generation is used.

Component S-N / Edit professional l

Click on the button Generator and you will see the following mask, where you enter the given material on the right-hand side. Then click on ***generate*** and the S-N curve data will appear on the left-hand side.



input of S-N curve

```
K_d,m          = 1.000 (D_eff < D_eff,N,m)

R_m            = 920.000
               = R_m,N * K_A * K_d,m
               = 920.000 * 1.000 * 1.000

K_T,D          = 1.000

Sigma_W,zd     = 414.000
               = f_W,sigma * R_m * K_T,D
               = 0.450 * 920.000 * 1.00

K_R,sigma      = 0.868 (axial load / bending)
               = 1 - alpha_F,sigma * lg(R_z[mue m]) * lg(2*R_m / R_m,N,min)
               = 1 - 0.220 * lg(8.000) * lg(2*920.000/400.000)

n_sigma        = 1.000 (axial load / bending)
               = 1 + G_0 * 10^-(a_G-0.5+R_m/b_G)
               = 1 + 0.000 * 10^-(0.500-0.5+920.000/2700.000)

K_WK,sigma     = 1.076
               = 1/n_sigma * (1 + 1/K_fu * (1/K_R - 1)) * 1/(K_V * K_S) =
               = 1/1.000 * (1 + 1/2.000 * (1/0.868 - 1)) * 1/(1.000 * 1.000)

S_WK           = 384.822
               = sigma_W,zd / K_WK,sigma / (J_C / K_T,D)
               = 414.000 / 1.076 / (1.000)

M_sigma        = 0.2220000
               = a_M * R_m * 10^-3 + b_M
               = 0.350 * 920.000 * 10^-3 + -0.100

k_sigma        = 5.000

N_D            = 1000000.000
```

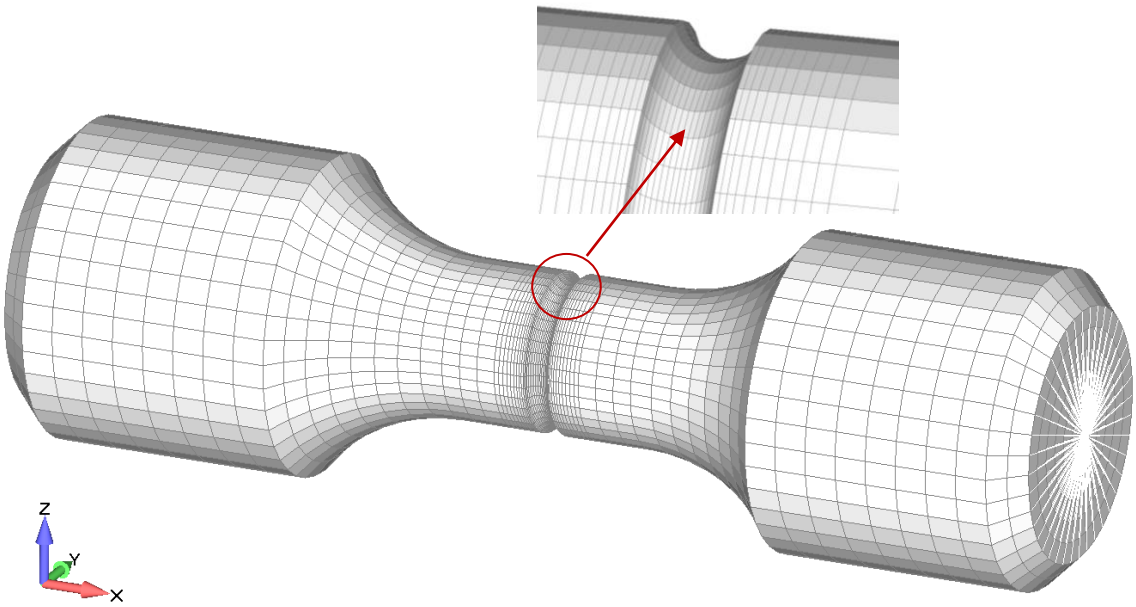
protocol file of the generation of the S-N curve

Because the rectangle ***show protocol*** was marked the protocol file as shown above is created. In enables to check the results.

For the following calculation the endurance stress of 384,822 MPa is needed.

8.4. Model Generation

The model is generated with a sufficient fine mesh in the notch. The following picture shows the FE-model with the mesh.



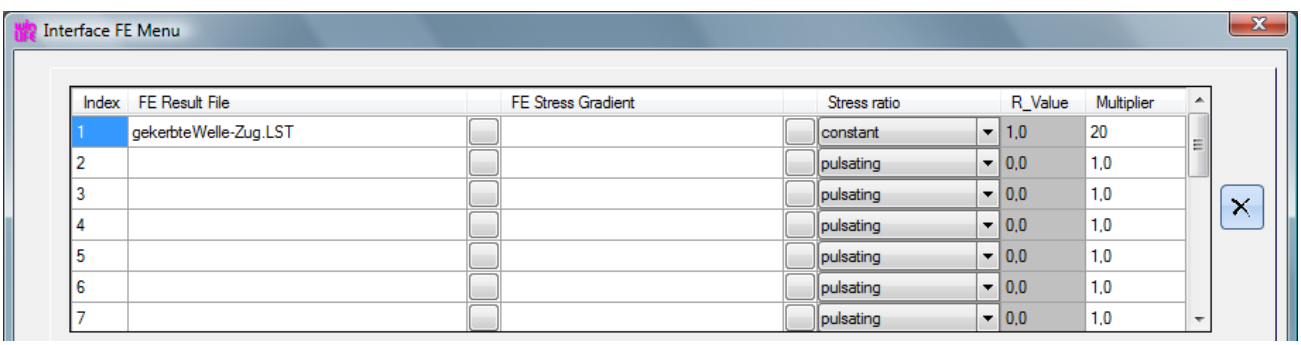
FE-model with fine mesh in the notch

8.5. Results for Stresses and Degrees of Utilization of Individual FE – Calculations with Femap / Nastran

Only for understanding at first the individual loadcases are shown because their results are easier to follow.

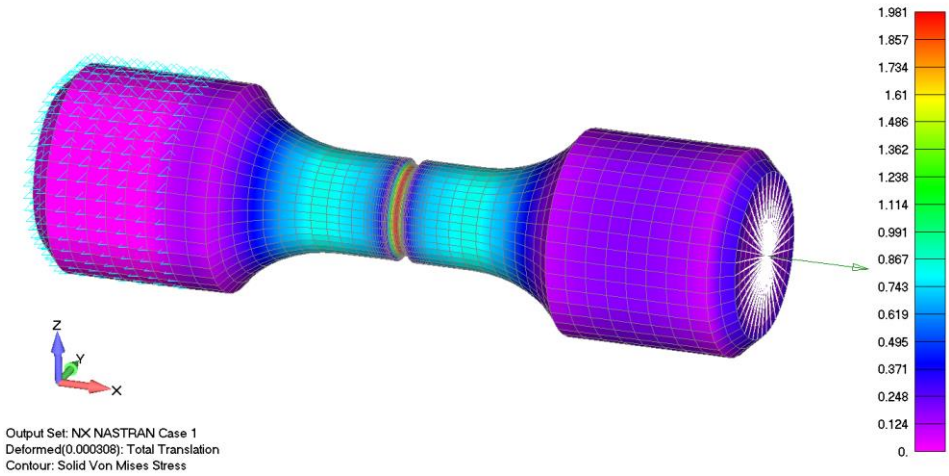
8.5.1. Loadcase Tension

The distribution of the von Mises equivalent stress is shown in the following picture. The nominal stress in the notch is 1N/mm², the load F_x is 350 N.

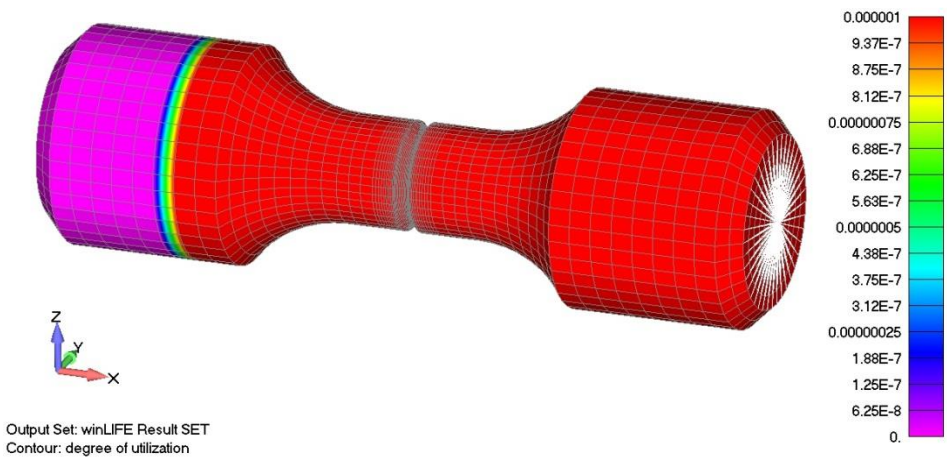


Index	FE Result File	FE Stress Gradient	Stress ratio	R_Value	Multiplier
1	gekerbteWelle-Zug.LST		constant	1,0	20
2			pulsating	0,0	1,0
3			pulsating	0,0	1,0
4			pulsating	0,0	1,0
5			pulsating	0,0	1,0
6			pulsating	0,0	1,0
7			pulsating	0,0	1,0

input of FE-file with Stress ratio and Multiplier



The nominal stress in the notch is 1N/mm^2, the load F_x is 380 N (graphic created in FEMAP).

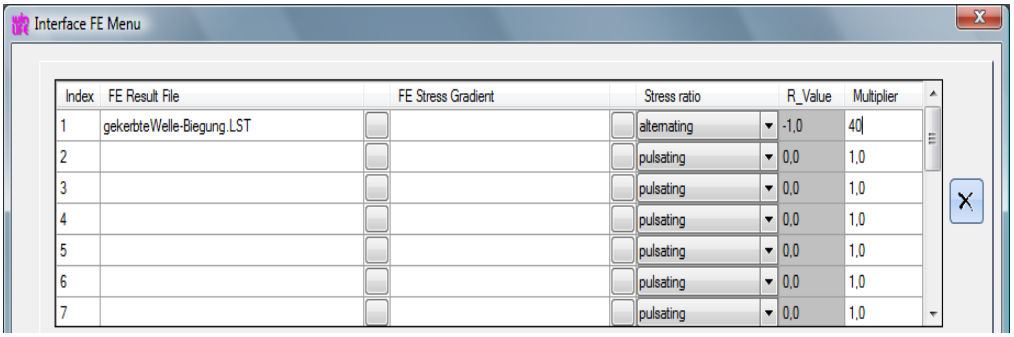


the degree of utilization for constant tensile stress in the notch is 20*1 N/mm^2, effected by the load F_x =20*380 N . One considers that the degree of utilization is nearly zero, since no stress range appears (graphic created in FEMAP).

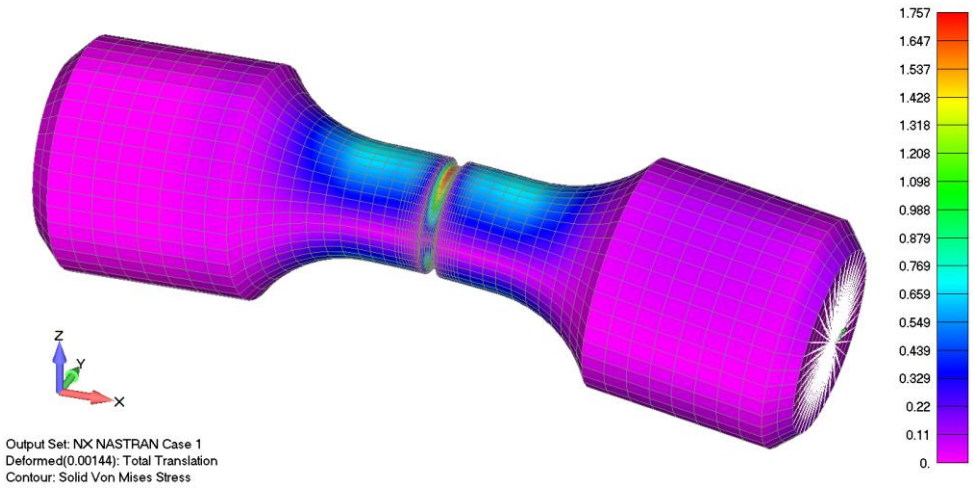
Note: The protocol file shows no amplitude because the load is constant.

8.5.2. Loadcase Bending

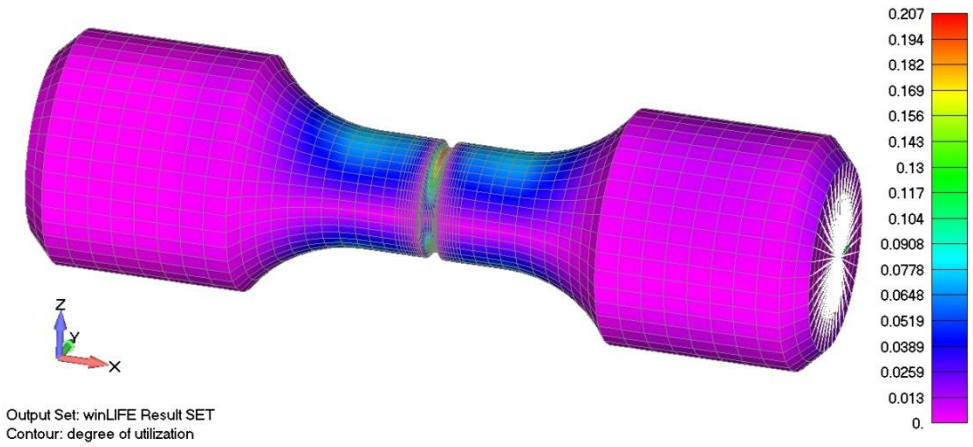
The distribution of the von Mises equivalent stress is shown in the following picture. The nominal stress in the notch is 1N/mm^2, the load M_y is 1045 Nmm.



input of FE-file with Stress ratio and Multiplier



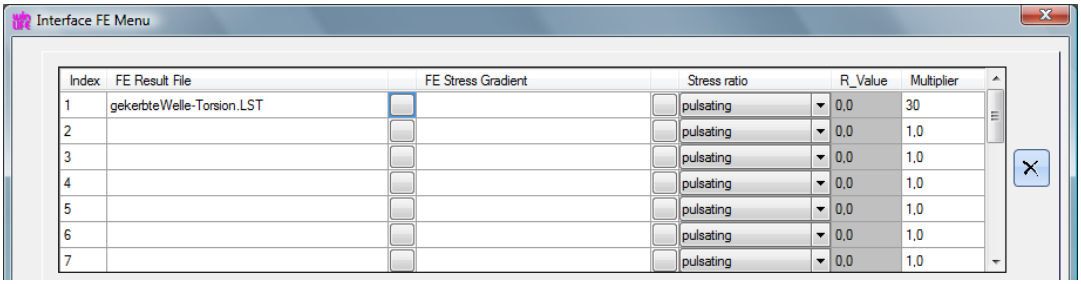
bending nominal stress in the notch is 1 N/mm^2, effected by the load M_y = 1045 Nmm (graphic created in FEMAP).



Degree of Utilization for the alternating bending stress in the notch = 40*1 N/mm^2, effected by the load M_y = 1045*40 Nmm.

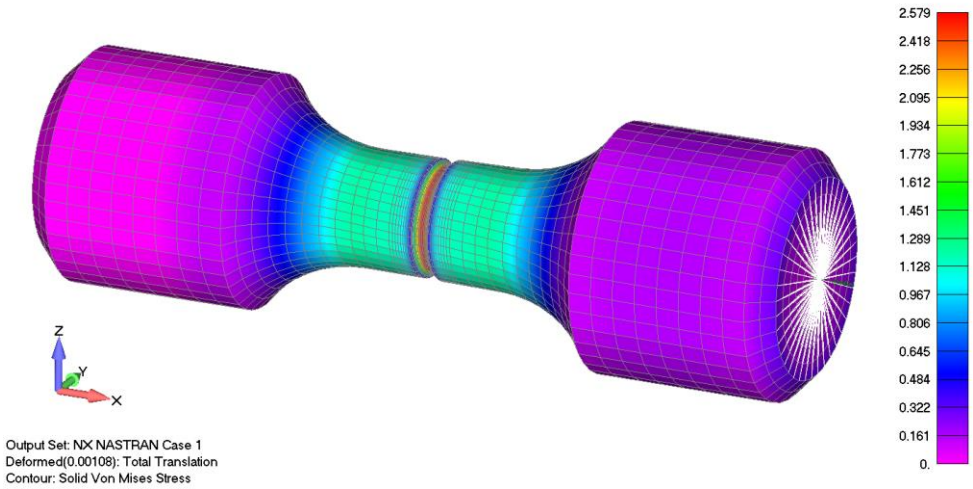
8.5.3. Loadcase Torsion

The distribution of the von Mises equivalent stress is shown in the following picture. The nominal stress in the notch is 1N/mm^2, the load M_x is 2091 Nmm.

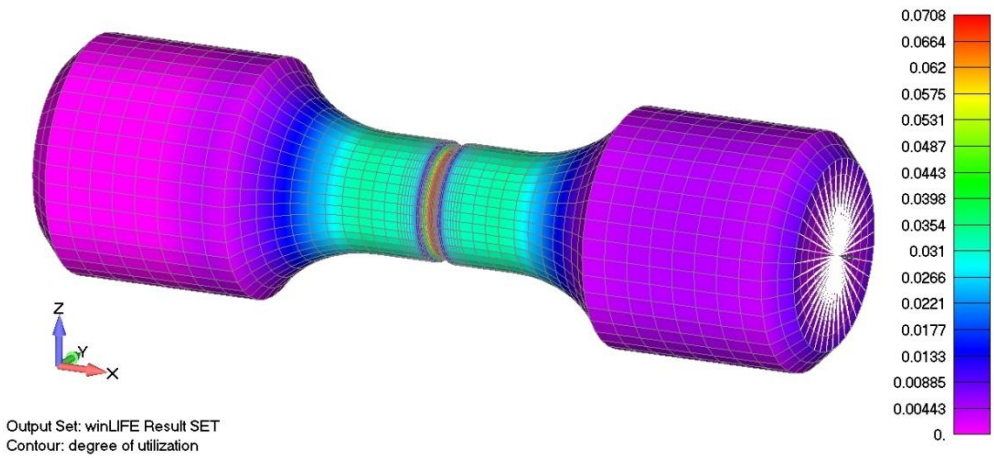


Index	FE Result File	FE Stress Gradient	Stress ratio	R_Value	Multiplier
1	gekerbteWelle-Torsion.LST		pulsating	0,0	30
2			pulsating	0,0	1,0
3			pulsating	0,0	1,0
4			pulsating	0,0	1,0
5			pulsating	0,0	1,0
6			pulsating	0,0	1,0
7			pulsating	0,0	1,0

input of FE-file with Stress ratio and Multiplier



Torsional nominal stress in the notch of 1 N/mm^2, effected by the load M_x =2091 Nmm (graphic created in FEMAP).

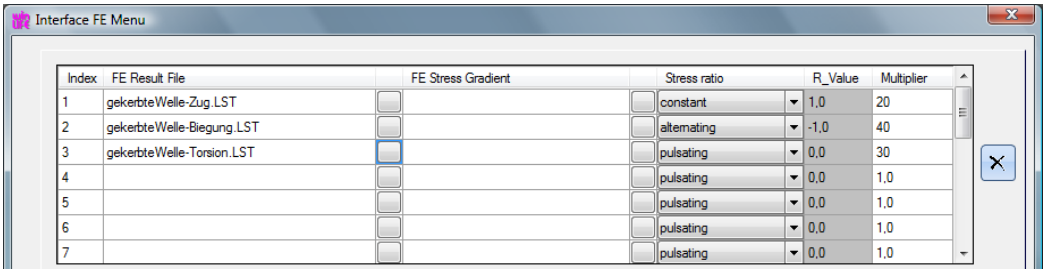


Degree of utilization for the pulsating Torsional nominal stress in the notch = 30*1 N/mm^2, effected by the load M_x = 2091*30 Nmm (graphic created in FEMAP).

8.6. Endurance Limit Certification

8.6.1. Interaction of all Loadcases

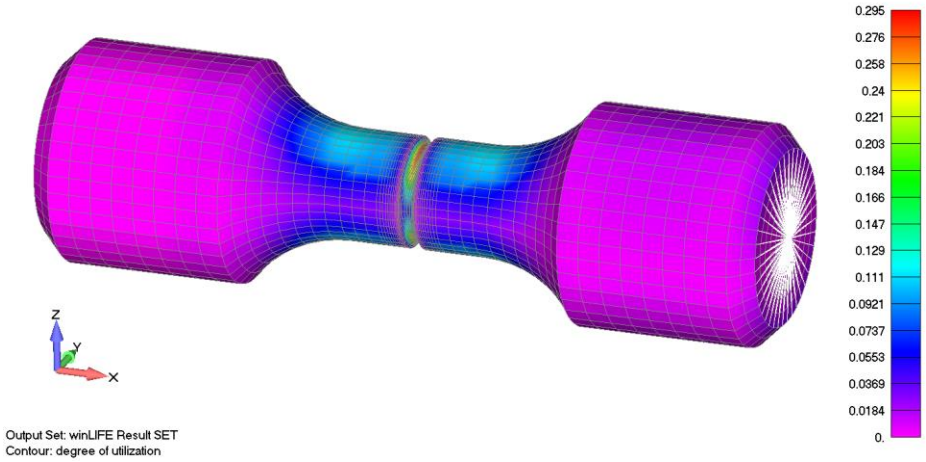
The interaction of all loadcases is achieved that in the input mask the loads are selected simultaneously.



Index	FE Result File	FE Stress Gradient	Stress ratio	R_Value	Multiplier
1	gekerbteWelle-Zug.LST		constant	1,0	20
2	gekerbteWelle-Biegung.LST		alternating	-1,0	40
3	gekerbteWelle-Torsion.LST		pulsating	0,0	30
4			pulsating	0,0	1,0
5			pulsating	0,0	1,0
6			pulsating	0,0	1,0
7			pulsating	0,0	1,0

input of FE-file with Stress ratio and Multiplier

The interaction of the three loadcases is designated by the resulting degree of utilization that is shown in the following picture. The degree of utilization of 1 signifies the endurance limit is reached. The here reached value of 0.295 means that the endurance limit is used to 29.5%. The safety to endurance limit corresponds to the inverse of the degree of utilization and is 1/0.295 = 3.38.



Degree of utilization for the three applied loads assuming the most disadvantageous superposition (graphic created in FEMAP).

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Conditions of use

10. Legal Liability

10.1. § 1 Subject of this Agreement

1.1 The buyer purchases the winLIFE Software from

Steinbeis GmbH & Co. KG for Technology Transfer

Represented by

Steinbeis Transfer Centre

New Technologies in Traffic Engineering

Rosenstr. 5, 89168 Niederstotzingen, Germany

- hereinafter referred to as the “seller” -

under the terms of use agreed to in this contract.

1.2 The source code for the software is not part of the subject of this agreement.

1.3 The nature of the software delivered by the seller is subject to the service description valid at the time of the software being despatched and which was available to the buyer at the time of the contract being finalised. The service provided by the seller is not expected to exceed this.

1.4 The general business terms & conditions of the buyer are not a subject of this contract, not even when an offer request, order or declaration of acceptance is attached and/or not contradicted.

10.2. § 2 Conditions of Use

2.1 Once the buyer has paid the total amount, the seller grants him use of the **winLIFE** software. The conditions of use are for a single licence, valid for an unlimited length of time, and not sub-licensable.

2.2 The buyer may only use the **winLIFE** software for internal business purposes or for other companies within the same concern, according to paragraph 15 of the AktG. Commercial sub-leasing of the software is not permitted.

2.3 The buyer is only permitted to copy the **winLIFE** software if this is necessary for use according to the contract. The buyer may make safety backup copies of the **winLIFE** software as necessary according to technical standards. Backup copies on mobile data storage media must be labelled as such and endorsed with the copyright of the original data storage medium.

2.4 The buyer is only permitted to make changes, extensions and other alterations to the **winLIFE** software as allowed by law according to paragraph 69c No.2 of the UrhG. The buyer is not permitted to execute his own rights and conditions of use other than stated in this contract.

2.6 Should the seller permit the buyer to make improvements or carry out maintenance on alterations (eg patches, alterations in the user instructions) or create a new version of the winLIFE software (eg update, upgrade, new user instructions) which replace former objects of the contract, then these alterations or new versions will also be subject to the rules of this contract.

2.7 If the seller produces a new version of the winLIFE Software then the seller's authorisation regarding the old winLIFE software in this contract becomes invalid as soon as the buyer uses the new winLIFE software. This is the case even when the seller does not explicitly demand the return of the old software. However, the seller allows the buyer a changeover period of three months in which both versions of the software can be used simultaneously.

10.3. § 3 Sales Price, Terms of Payment

3.1 The buyer purchases the rights of use as stated in the offer for the sales price also stated in the offer. The sales price complies with the offer on which this software sales contract is based. The buyer is only permitted to use the software according to the rights of use stated in this contract. Any other use requires prior consent in writing from the seller. In the case of multiple use without consent (in particular when the software is used simultaneously by a more users than agreed to) the seller has the right to invoice the additional use according to the seller's price list valid at that particular time unless the buyer can prove a lower sum of damage. This does not have any effect on other non-contractual compensation claims.

3.2 The sales price is due and must be paid in full when the software is delivered or provided.

3.3 In addition to the given price, VAT at the current rate must be paid.

3.4 The delivery prices include transport and packing for posted deliveries. For goods which are to be transferred on the net, the seller bears the costs of making the software accessible; the buyer bears the costs of the retrieval.

3.5 The ownership of surrendered copies remains subject to alteration until the payment has been made in full.

10.4. § 4 Installation, Training, Maintenance

4.1 When installing the **winLIFE** software, please read the installation notes included in the user documentation, in particular those regarding the hardware and software environment needed by the buyer. By installing the program onto his computer, the buyer commits himself to the terms of this contract. If the buyer does not agree to the terms, then the CDs and all other documentation is to be returned immediately. The purchase price will then be reimbursed from where it was purchased.

4.2 At the buyer's request the seller will assume the training and maintenance of the **winLIFE** software based on a separate contractual agreement and applicable price list. The seller is prepared to maintain the software based on the terms of a separate maintenance contract

10.5. § 5 Protection of Software and user documentation

5.1 Unless the buyer is granted specific rights within this contract then all rights regarding the **winLIFE** software (and all copies made by the buyer) – in particular the copyright, the patent rights and the technical protection rights – apply to the seller.

10.6. § 6 Transfer

6.1 The buyer is only permitted to pass the **winLIFE** software on to a third party provided he transfers the total product and renounces his own use of the software completely and finally.

6.2 A temporary transfer of the **winLIFE** software to a third party is not permitted either as a hard copy or otherwise.

6.3 If the buyer passes on data storage media, memory or other hardware on which objects of the contract (complete or partial, altered or edited) have been saved,

6.3.1 to third parties without being subject to a transfer according to paragraph 6 or

6.3.2 renounces his direct ownership hereof

then he carries the responsibility that the **winLIFE** software is completely deleted.

10.7. § 7 User Cooperation and Information Obligations

7.1 The buyer has informed himself of the essential function characteristics of the **winLIFE** software and carries the risk whether these are in accordance with his needs and wishes. If there is any doubt he should obtain qualified information from the seller.

7.2 It is the sole responsibility of the buyer to ensure that he has a working and – bearing in mind the additional storage requirements of the **winLIFE** software - sufficiently dimensioned hardware and software environment.

7.3 Before using it, the buyer is to test the **winLIFE** software extensively for its usage in the existing hardware and software configuration. This is also the case for software acquired within the framework of the guarantee.

7.4 The buyer is to make sufficient provisions for the case that the **winLIFE** software does not work properly, either wholly or partially (for example by making daily backups, error diagnoses, regular controls of the data results).

10.8. § 8 Time of Delivery and Performance, Acts of God

8.1 Unless otherwise agreed upon, the current version of the software will be delivered.

8.2 The seller delivers the goods according to his choice as follows:

8.2.1 He provides the buyer with (1) a copy of the software program on a computer-legible data storage medium, together with user documentation for each user according to section 2.1.

8.2.2 He makes the software available in a network where it can be retrieved and informs the buyer accordingly and provides user documentation for each user according to section 2.1.

8.3 The time of delivery and the passing of risk for material despatch are considered to be the time when the seller hands over the software and user documentation to the transport company. Otherwise it is the time when the software is made available in a network where it can be retrieved and the buyer is informed accordingly.

8.4 As long as the seller

8.4.1 is still waiting for cooperation or information from the buyer or

8.4.2 is delayed in his performance due to strikes or lock-outs in third-party companies or in the seller's company (in the latter case, however, only if the industrial action is legal), intervention through the authorities, legal bans or other circumstances that are no fault of his own (act of God).

then the times of delivery and performance are considered extended for the length of the hindrance ("time of non-use") and no breach of duty is regarded for the time of non-use. The seller is to immediately inform the buyer of such hindrances and their anticipated length. If an "act of God" continues continually for longer than three months then both parties are freed of their delivery duties.

10.9. § 9 Material and Warranty Defects, other Performance Failures, Statute of Limitations

9.1 The seller is liable for any material and warranty defects of the subject of agreement as in section 1.3 according to the terms and conditions of sale and for the fact that the buyer does not conflict the rights of third parties regarding the use of the subject of agreement to the extent of the contract.

The liability for the freedom of the subject of agreement by rightful third parties is, however, only valid for the country in which the subject of agreement is to be used, as agreed upon by the parties. Unless otherwise agreed upon, the country of liability is The Federal Republic of Germany.

9.2 In the case of material defect, the seller firstly provides supplementary performance. As decided by the seller, the buyer either receives new faultless software or the defect is corrected. A valid method of correction is also if the seller shows the buyer a reasonable possibility of correcting the failure.

In the case of legal defects the seller firstly provides supplementary performance. As decided by the seller, the buyer either receives a legally faultless possibility of use for the delivered subject of agreement or replaces it with an exchanged or altered subject of agreement of the same value.

9.3 The buyer is obliged to accept new software as long as its function remains the same and its acceptance does not lead to any considerable disadvantage.

9.4 If two attempts to provide supplementary performance fail, then the buyer is entitled to insist on an acceptable date for removal of defects. In doing so he must clearly and in writing state that he has the right, should the supplementary performance again be unsuccessful, to withdraw from the contract and/or demand compensation.

If the error cannot be corrected even in the period of grace, the buyer can withdraw from the contract or reduce the payment unless the failure is a "petit" failure. The seller is liable for compensation or replacement of correction measures carried out in vain within the limits stated in section 10.

9.5 If there are claims made by third parties which deter the buyer from assuming his rights of use as stated in the contract then the buyer is to inform the seller immediately and completely in writing. Herewith he authorises the buyer to dispute the matter with the third party either in court or out of court.

The seller is obliged to defend the claims at his own cost and to release the buyer from all costs and damages relating to the defence of the claims as long as these are not caused by his lack of duty.

9.6 The limitation period for all guarantee claims is one year beginning with the delivery or moment when the subject of agreement is made available. The same period is valid for other claims, of whatever manner, against the seller.

9.7 In the case of malice intent or gross negligence on the part of the seller, or in the case of fraudulent concealment regarding a fault, in cases of personal injury or legal faults as in § 438 Abs. 1 a BGB, and in guarantees (§ 444 BGB) the legal limitation period is valid. This also applies for claims according to the Product Liability Law.

10.10. § 10 Reliability

10.1 For all cases of contractual and ex-contractual reliability, the seller provides compensation only within the following limits:

10.1.1 In cases of intent totally, also if there are errors in the configuration guaranteed by the seller.

10.1.2 in cases of negligence only for the amount of the foreseeable damage caused by the negligence.

10.1.3 in other cases only to the extent of the typically foreseeable damage. If the typically foreseeable damage is higher than the purchase price of the **winLIFE** software for one damage case, then the buyer is obliged to inform the seller within 2 weeks of finalising the contract. In this case the seller has the right to withdraw from the contract unless a liability limit has otherwise been agreed to.

10.2 The liability limitation according to paragraph 10.1 does not apply to the liability for personal damage and for the liability according to the product liability law.

10.3 The seller is at liberty to raise objection to the contributory negligence (e.g. as in paragraph 7).

10.4 The statute of limitations is according to paragraph 9.6. The legal statutes of limitations apply to claims according to paragraphs 10.1.1 and 10.2. The statute of limitations for Part 1 begins at the time stated in paragraph 199 No.1 of the BGB. This comes into account at the latest at the event of the statutory period stated in paragraph 199 Nos.3 and 4 of the BGB.

10.5 As long as the liability according to these terms is excluded or limited, then this also applies for the personal liability of the organisation, the staff, representatives and sub-agents of the seller.

10.11. § 11 Secrecy, Data Protection

11.1 The parties of the contract are obliged to treat all the other party’s confidential information and company trade secrets which come to knowledge during the initiation and implementation of the contract confidentially for an unlimited period of time. These are only to be used for the implementation of this contract. The subject(s) of agreement and the performance agreed to in the contract are also matters which are included in the seller’s company trade secrets.

11.2 The buyer may only allow staff and other third parties access to the subject of agreement as long as this is necessary for the execution of the authorisation of use agreed to.

11.3 The above mentioned obligations are not valid for company trade secrets which

11.3.1 were already obvious or known to the other party at the time of conveyance.

11.3.2 became obvious after the time of conveyance through the contractual partner through no fault of the other contractual party.

11.3.3 became known to the other contractual party after conveyance by the contractual partner by a third person in a manner which is not illegal and without limitation in regard to secrecy or usage.

11.3.4 which have been developed by one of the contractual partners independently without using the trade secrets of the contractual partner.

11.3.5 which must be made public according to the law, authoritative decision or court order – providing the party releasing the information informs the contractual partner hereof immediately and supports him in the defence of such decisions or orders; or

11.3.6 as long as the contractual partner is permitted to use or pass on the trade secret due to urgent legal conditions or as a result of this contract.

11.4 The seller is to adhere to the rules of data protection, in particular when he is granted access to the buyer's company or to his hardware/software

10.12. § 12 Final Clause

12.1 Exclusive Place of Jurisdiction for all disputes relating to or resulting from this contract is the seller's business location. If the seller has a claim, he is also entitled to choose the Place of Jurisdiction and the buyer's business location. The right for both parties to apply for preliminary injunction legal protection from a court legally responsible remains untouched.

12.2 Only German law applies excluding UN-purchase laws (CISG).

12.3 The completion of the contract as well as any later alterations and additions must be in writing to be effective. That is also the case for changing this clause. It does not apply to verbal subsidiary agreements. All declarations by the parties are to be in writing.

12.4 Should a condition of this contract be or become invalid, or if there is an invalid time period or a gap, then the legality of the other conditions remains untouched hereby. As long as the invalidity does not violate §§ 305ff. BGB (Validity of General Business Terms and Conditions) then instead of the invalid condition, a valid condition is agreed to which is nearest to that intended by the parties in a commercial sense. The same applies in the case of a gap. In the case of an unacceptable period, the legally acceptable period becomes valid. If there is a violation to §§ 305ff. BGB then the parties shall find an amicable solution in terms of paragraph 2.

11. Glossary of Terms

12. Index

Keine Indexeinträge gefunden.