



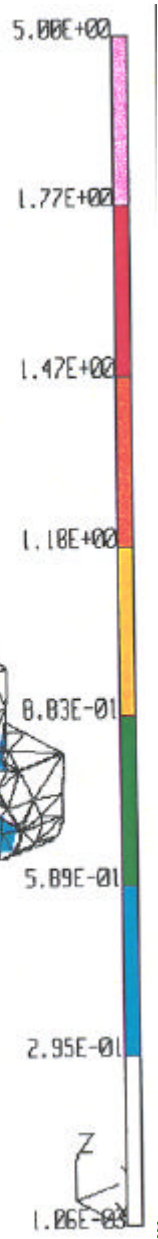
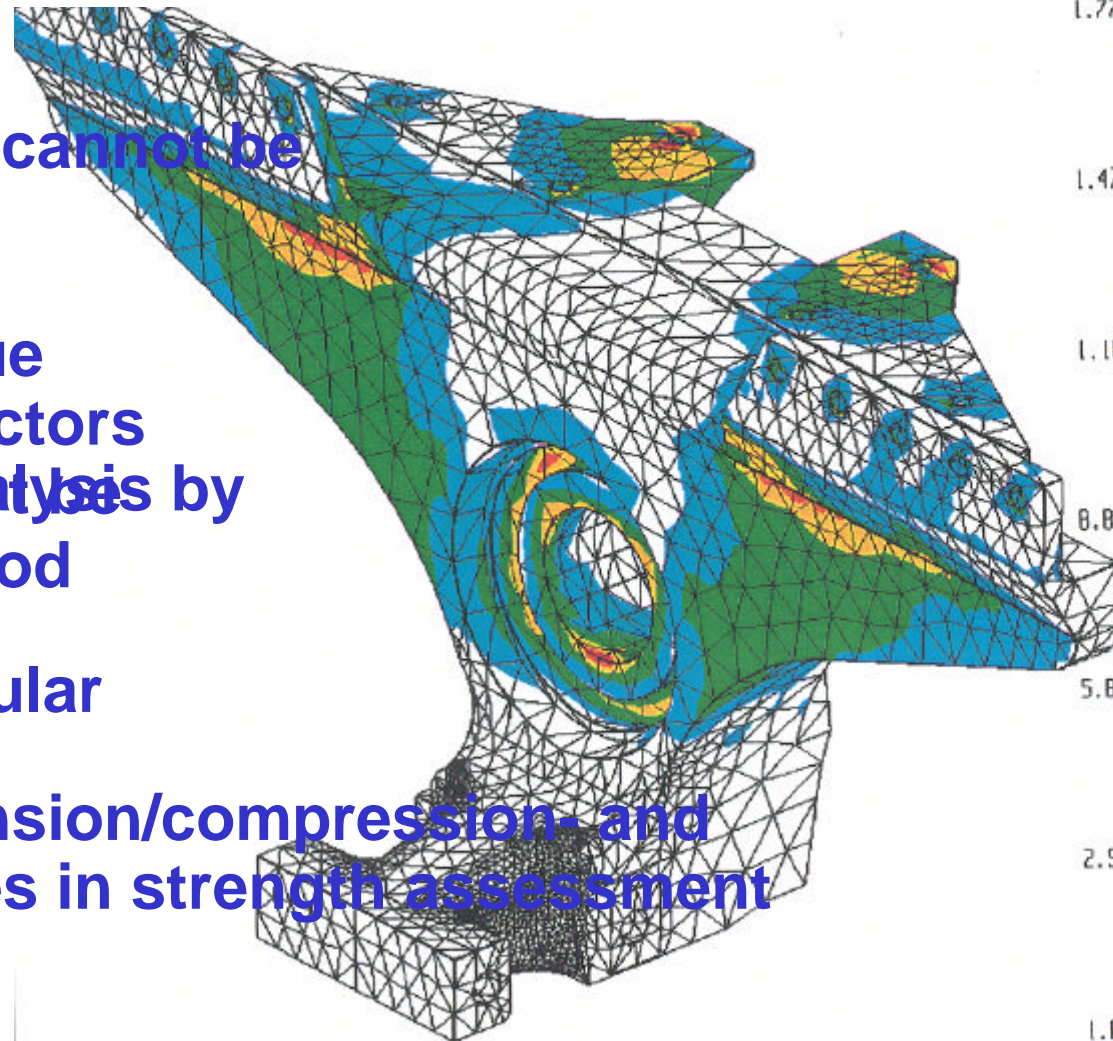
# **Synthetic S/N-Curves for Fatigue Simulation**

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Montanuniversität Leoben  
Austria**

# Problems in Strength Assessment

*of components with complex geometry and loading:*

- Nominal section cannot be defined
- Stress and fatigue concentration factors (K<sub>t</sub> and K<sub>f</sub>) cannot be defined
- Power flow irregular
- Separation of tension/compression- and bending- stresses in strength assessment not possible





# Fatigue Life Calculation

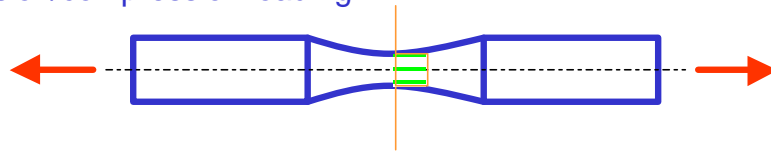
- Calculation / measurement of local stresses
- Damage accumulation according to Miner

$$D = \sum \frac{n_i}{N_i}$$

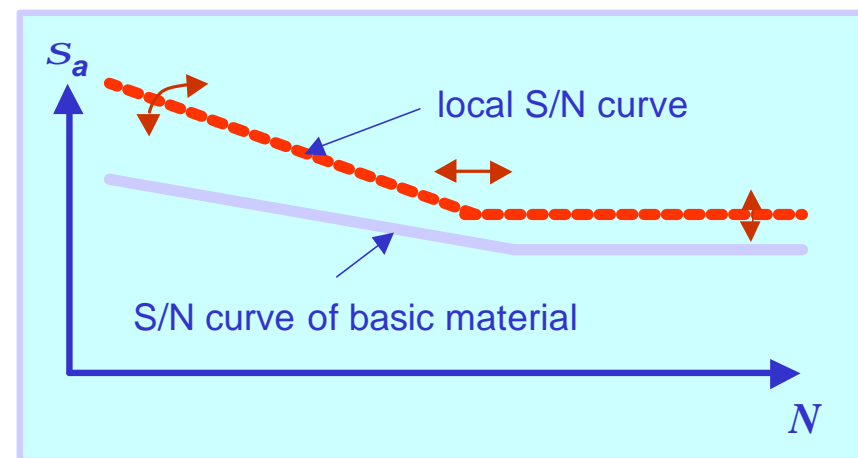
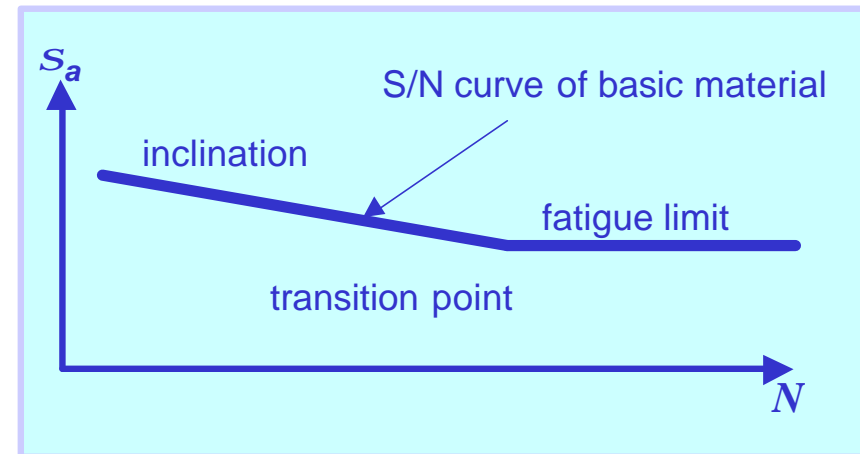
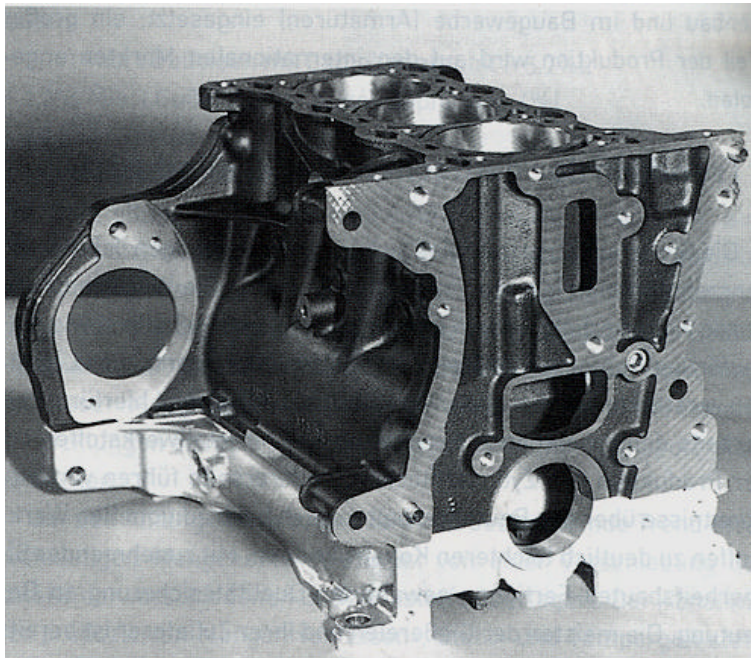
- Description of materials behavior by S/N-curve
- *S/N-curve depends on local influences !*

## S/N-curves

tension/compression loading

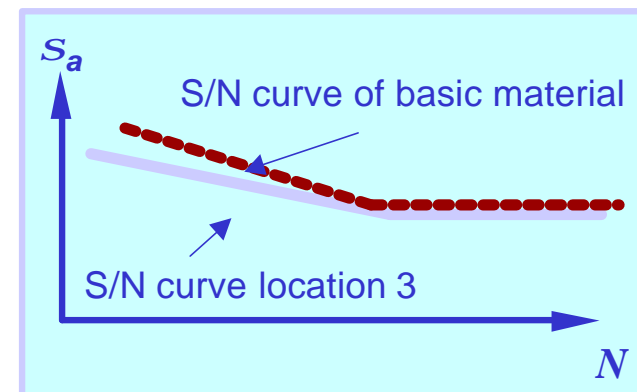
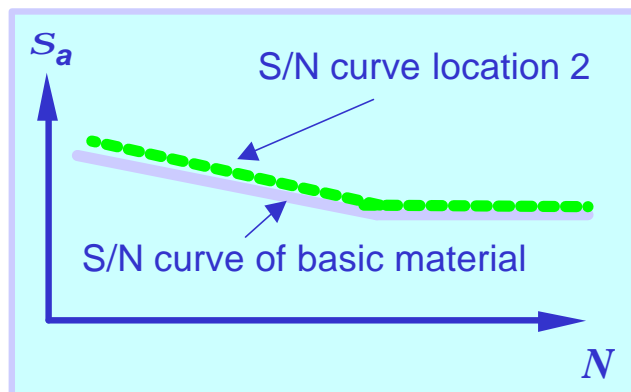
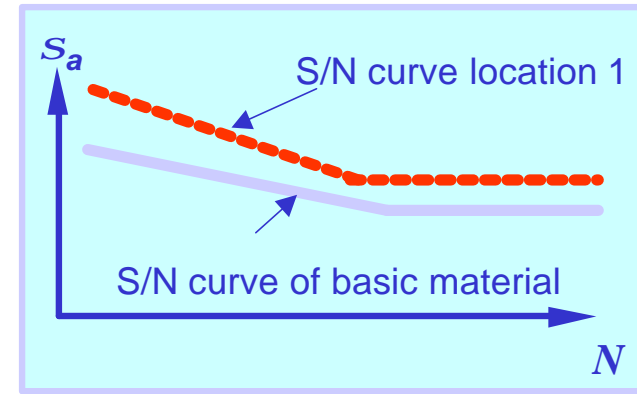
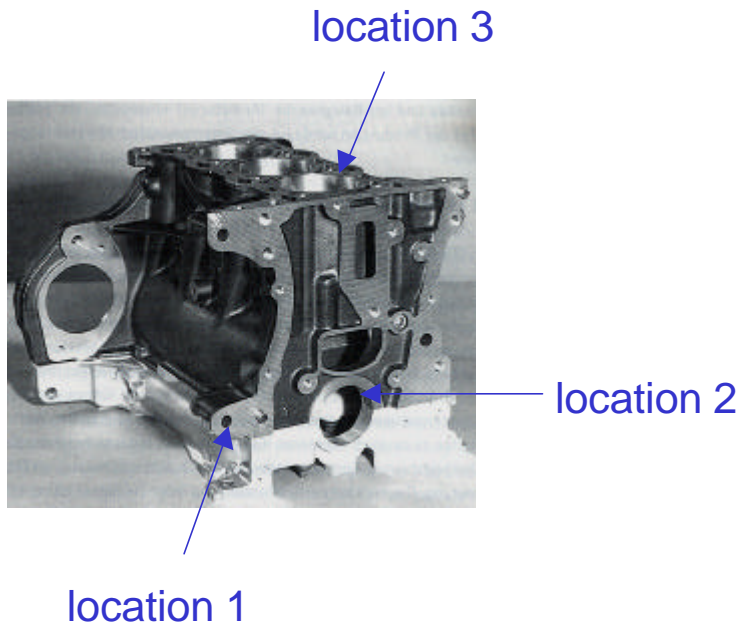


Test of specimens

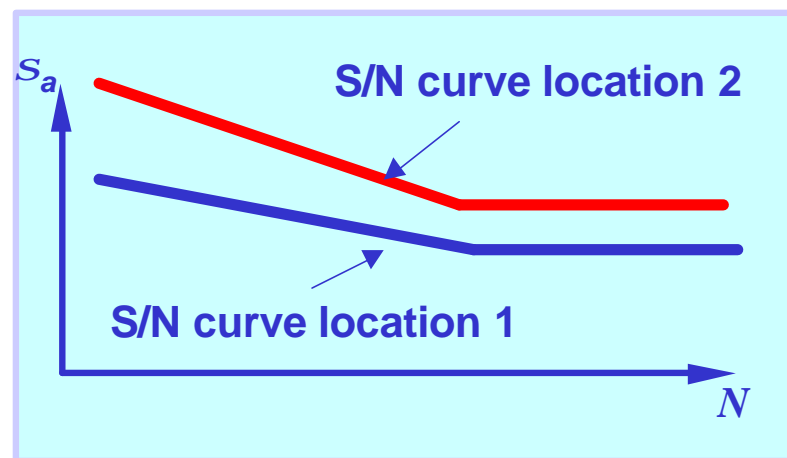
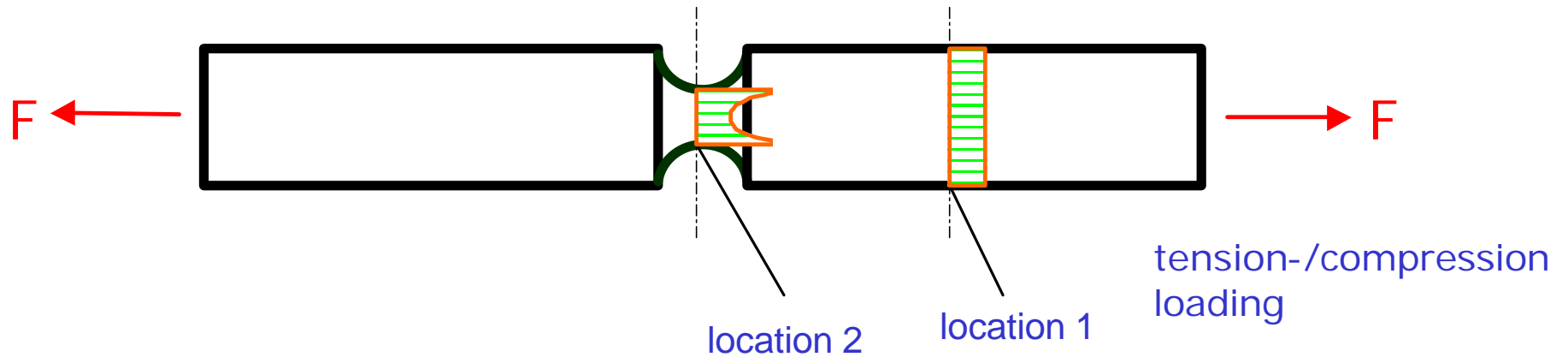




# S/N-curves



## Local S/N curve in specimen





## Why local S/N curves ?

- Basics for fatigue life calculation acc. to Miner
- Deviations of materials behavior in components compared to behavior of basic material by:
  - influences under service conditions
  - technological influences
  - loading conditions



# Development of synthetic S/N curves

## Development of synthetic S/N curves (milestones):

- **Tests & Synth. Model: Hück/Thrainer/Schütz (1981)**
- **Synth. model: Eichseder (1989)**
- **Synth. model: Mertens/Hahn (1997)**
- **Artificial Neural Network: Artymiak, Bukowski, Feliks, Narberhaus, Zenner (1999)**
- **modified synth. model**





# Analysis of local S/N curves

**Hück/Thrainer/Schütz (1981):**

**evaluation of about 600 S/N-curves**

*steel* {

- Fatigue strength:** -
- Slope:** 
$$k = \frac{12}{b_k^2 - 1 + 1/F_o^2} + 3$$
- Transition point:** 
$$\log N_D = 6,4 - \frac{2,5}{k}$$



# Analysis of local S/N curves

**Eichseder (1989):**

*steel* {

**Fatigue strength:** 
$$n = 1 + \frac{(s_{bw}/s_{zdw} - 1) j^{*v}}{(2/b)^v}$$

**Slope:** 
$$k = \frac{(k_1 - k_2)}{\left( \frac{1 + 2 \cdot c^{*1,2}}{1 + (s_{bw}/s_{zdw} - 1) \left( (c^* \cdot b/2)^v \right)} \right)^{k_3} - 1 + 1/F_o^2} + 3$$

**Transition point:** 
$$\log N_D = 6,4 - \frac{2,5}{k}$$



# Analysis of local S/N curves

## Mertens/Hahn (1989):

*steel* {

**Fatigue strength:**

für  $\alpha_k = 1$ :

$$s_w = 56N / mm^2 + 0,144.R_m + 0,309.R_{p0,2}$$

für  $\alpha_k > 1,5$ :

$$s_w = 56N / mm^2 + 0,144.R_m + 0,309.R_{p0,2}$$
$$s_{Schw} = 1,52.s_w + 33N / mm^2$$

**Slope:**

$$k_Q = -\frac{\log(2N_D)}{\log Q}$$

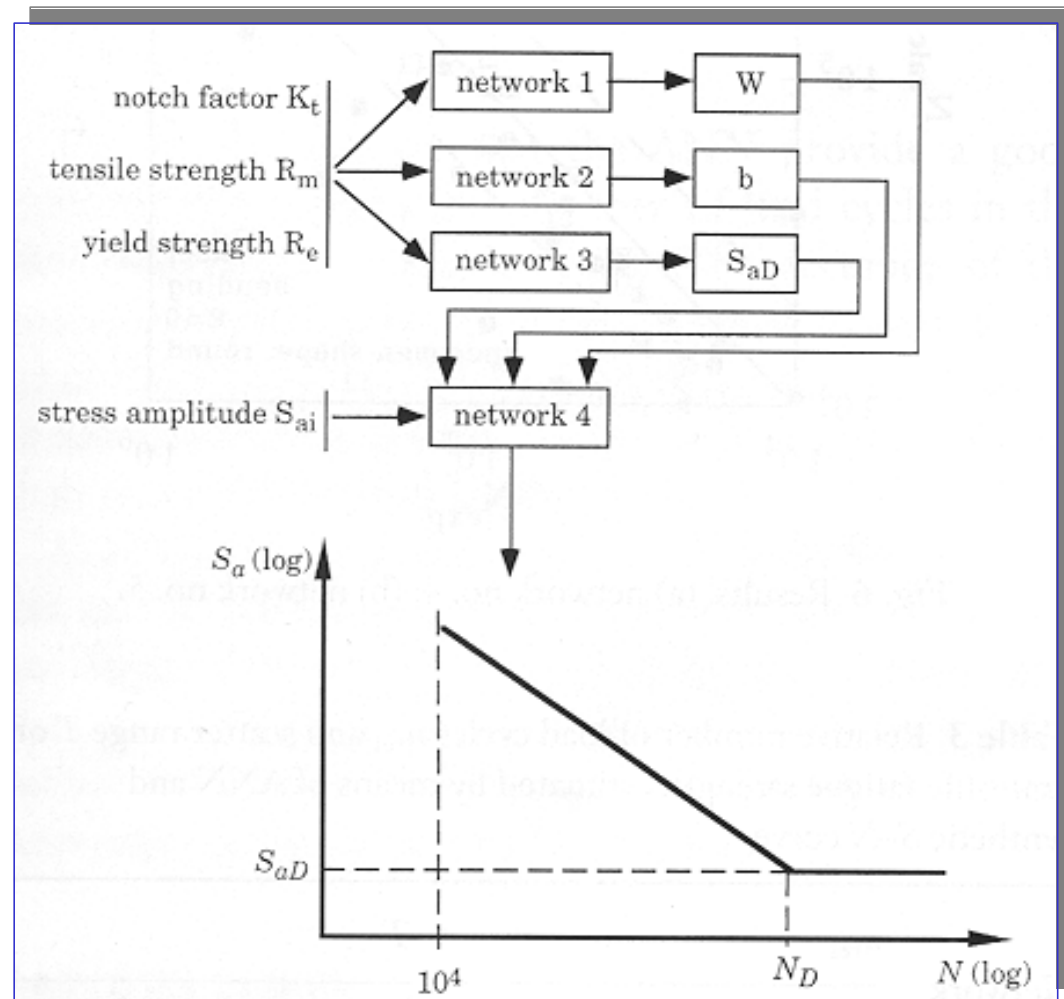
**Transition point:**

$$N_D = 10^6$$

# Analysis of local S/N curves

**Artymiak,  
Bukowski, Feliks,  
Narberhaus,  
Zenner (1999):**

**Artificial Neural  
Networks (ANN)**





# Influences on Local S/N Curves

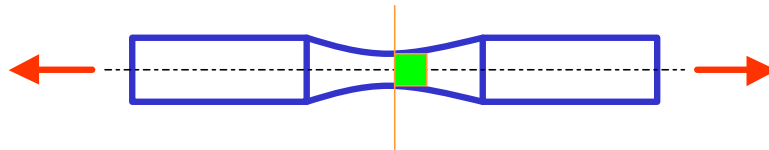
- ⇒ type of loading
- ⇒ notch sensitivity effects
- ⇒ size influence
- ⇒ mean stresses
- ⇒ residual stresses
- ⇒ technological influences
- ⇒ temperature
- ⇒ plastic deformations
- ⇒ surface quality



## Influence on S/N curve **Type of Loading**

- ⇒ type of loading
- ⇒ notch sensitivity effects
- ⇒ size influence
- ⇒ mean stresses
- ⇒ residual stresses
- ⇒ technological influences
- ⇒ temperature
- ⇒ plastic deformations
- ⇒ surface quality

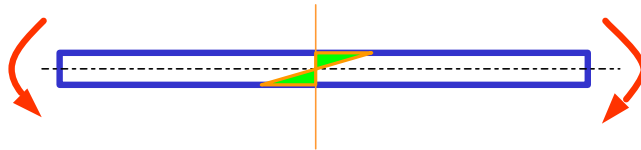
tension-/compression loading



EN-GJS-400-18  
GGG40

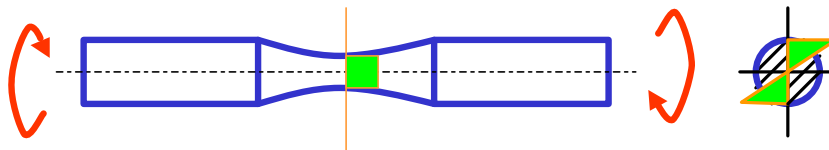
$\sigma_{aTension/Compression}$  135 N/mm<sup>2</sup>

bending loading



$\sigma_{aBending}$  185 N/mm<sup>2</sup>

torsional loading



$\tau_{aTorsion}$  120 N/mm<sup>2</sup>

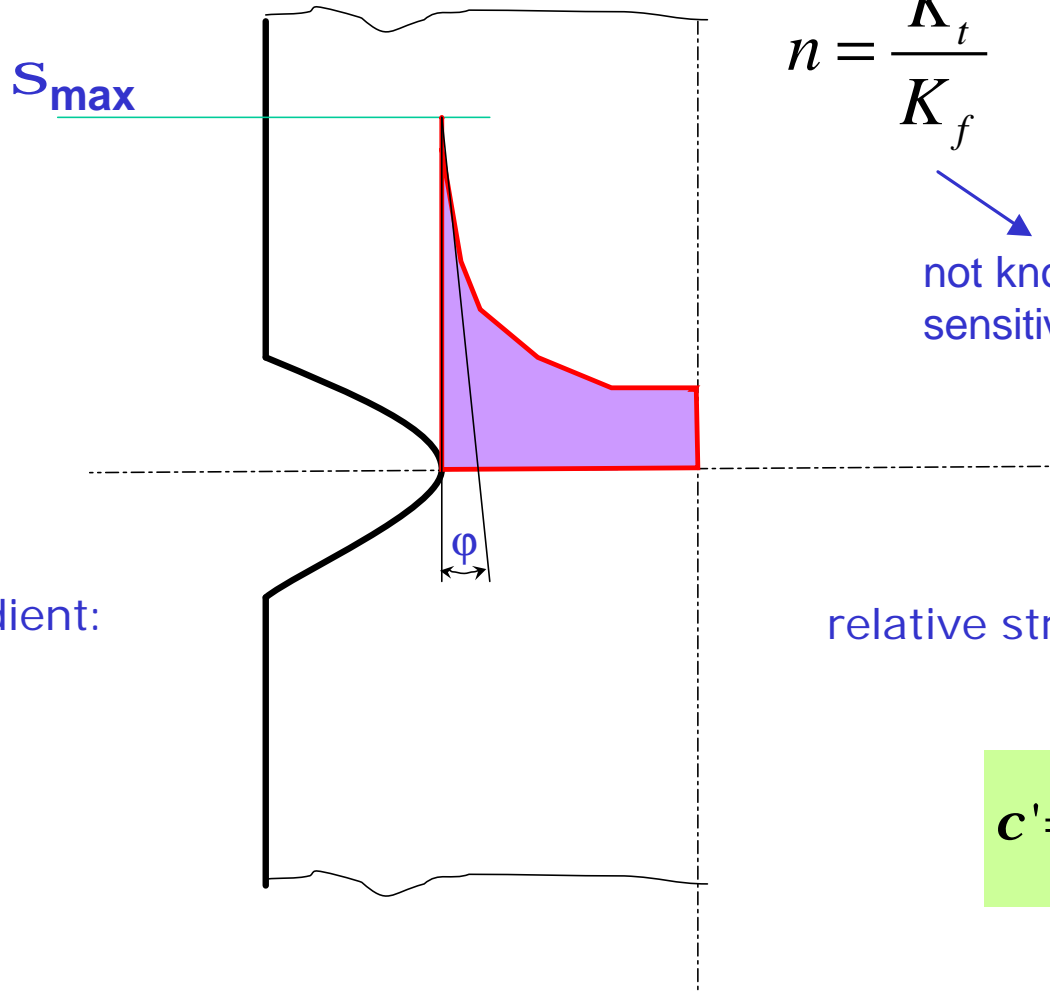
185/135=1,37



## Influence on S/N curve **Notch Sensitivity Effect**

- ⇒ type of loading
- ⇒ notch sensitivity effects
- ⇒ size influence
- ⇒ mean stresses
- ⇒ residual stresses
- ⇒ technological influences
- ⇒ temperature
- ⇒ plastic deformations
- ⇒ surface quality

$$\tan j = \frac{dS}{dx}$$



$$n = \frac{K_t}{K_f}$$

not known, therefore notch sensitivity effect unknown

stress gradient:

$$c = \frac{dS}{dx}$$

relative stress gradient:

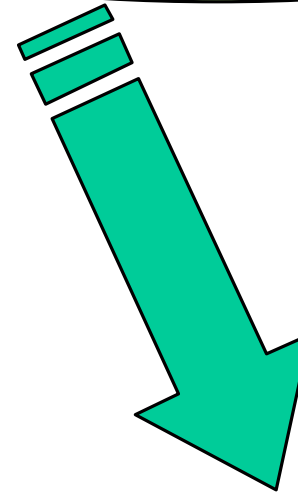
$$c' = \frac{1}{S_{\max}} \left( \frac{dS}{dx} \right)$$



## Local S/N-curves

- ⇒ type of loading
- ⇒ notch sensitivity effects
- ⇒ size influence
- ⇒ mean stresses
- ⇒ residual stresses
- ⇒ technological influences
- ⇒ temperature
- ⇒ plastic deformations
- ⇒ surface quality

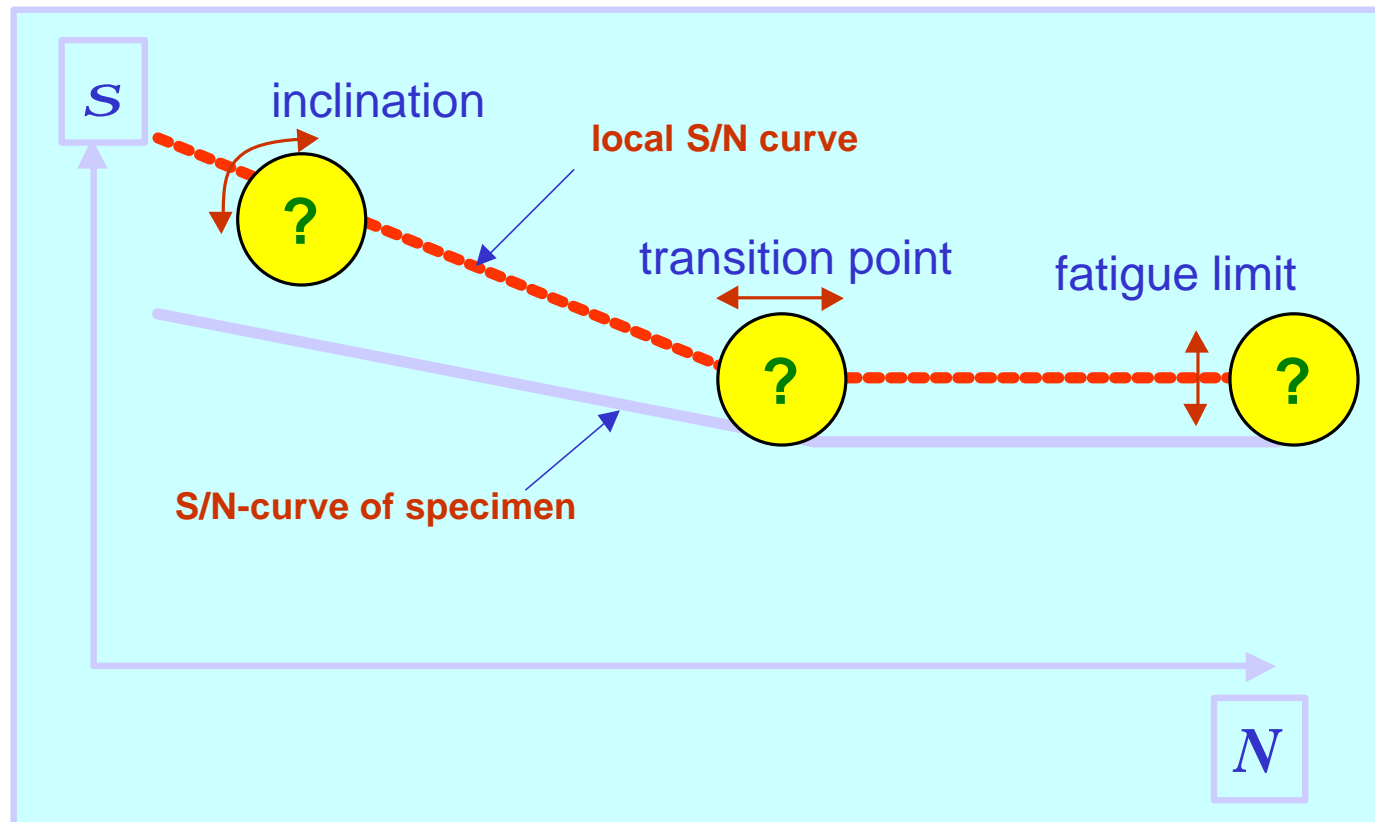
**S/N curves of basic material  
by test**



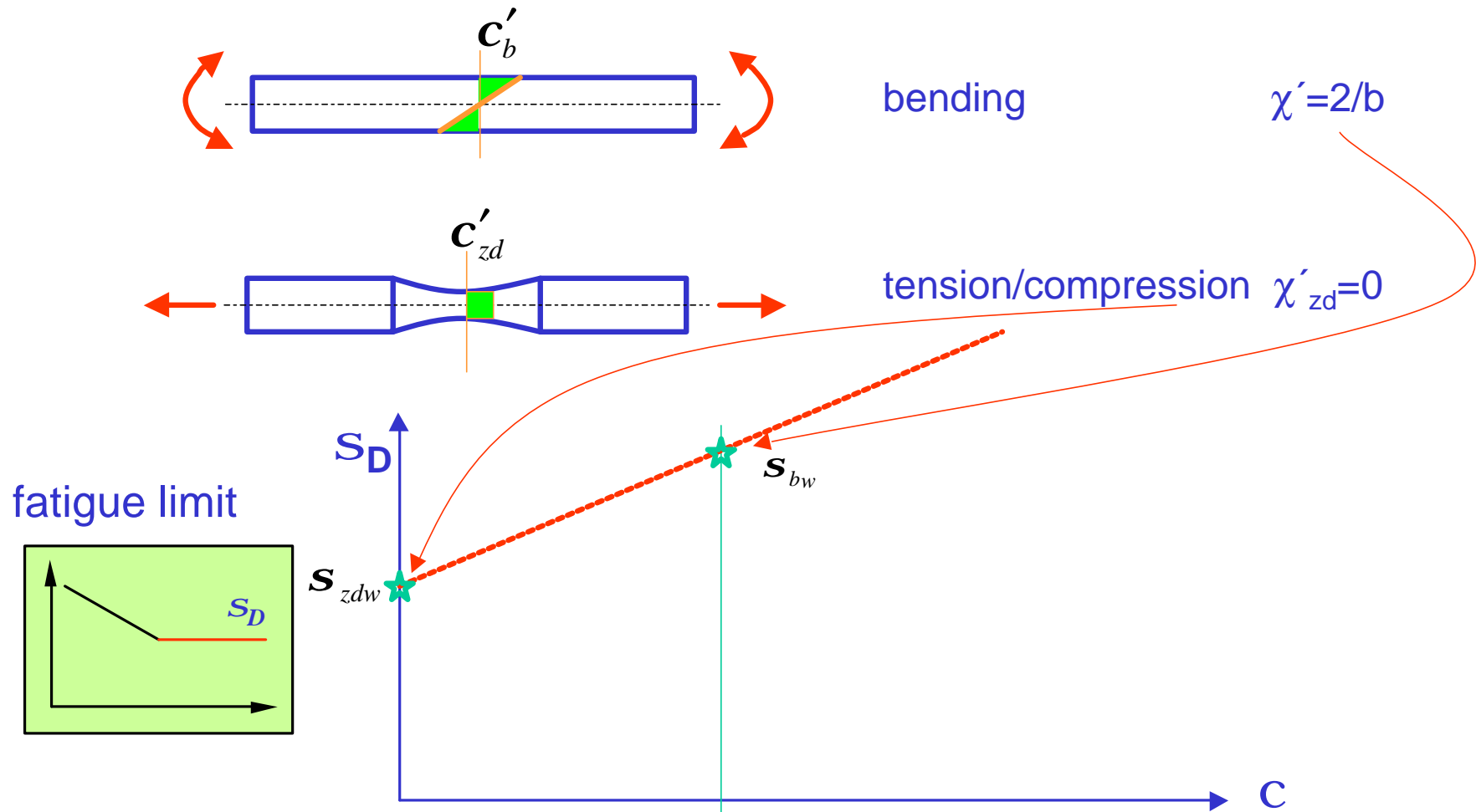
**Local S/N curves  
synthetically generated**



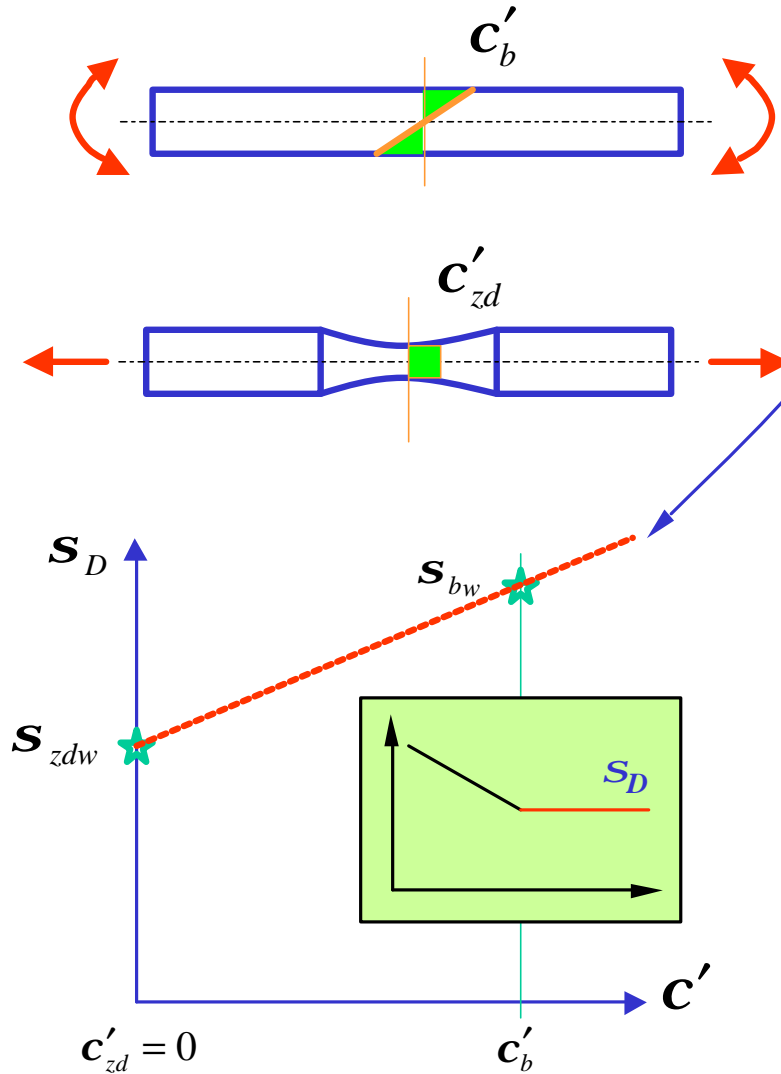
# Local S/N curves, synthetically generated



## Type of loading + notch sensitivity effect: Influence of stress gradient on fatigue limit



## Type of loading + notch sensitivity effect: Influence of stress gradient on fatigue limit



Assumption: straight line

$$S_D = S_{zdw} + \frac{S_{bw} - S_{zdw}}{c'_b - c'_{zd}} \cdot c'$$

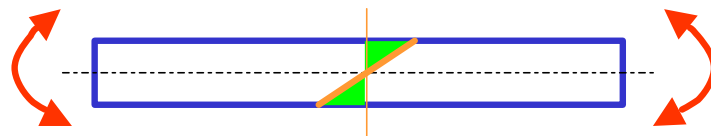
$$c'_{zd} = 0: \quad S_D = S_{zdw} + \frac{S_{bw} - S_{zdw}}{c'_b} \cdot c'$$

$$\frac{S_D}{S_{zdw}} = \frac{S_{zdw}}{S_{zdw}} + \frac{S_{bw}/S_{zdw} - 1}{c'_b} \cdot c'$$

$$S_D = S_{zdw} \left( 1 + \frac{S_{bw}/S_{zdw} - 1}{c'_b} \cdot c' \right)$$

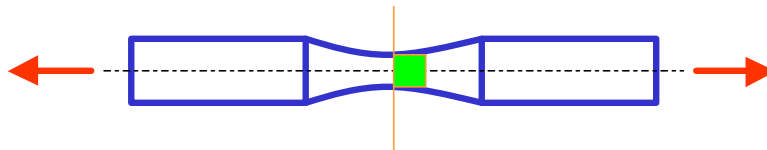


# Type of loading + notch sensitivity effect: Influence of stress gradient on fatigue limit



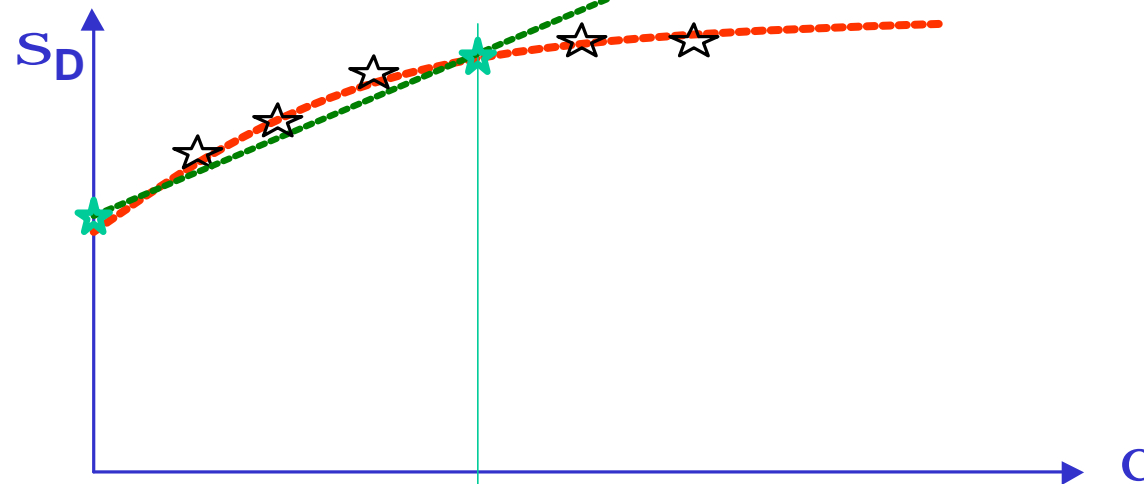
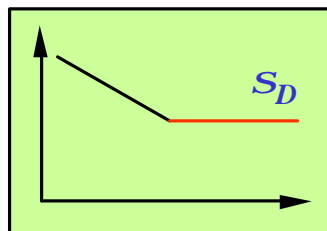
bending

$$\chi' = 2/b$$

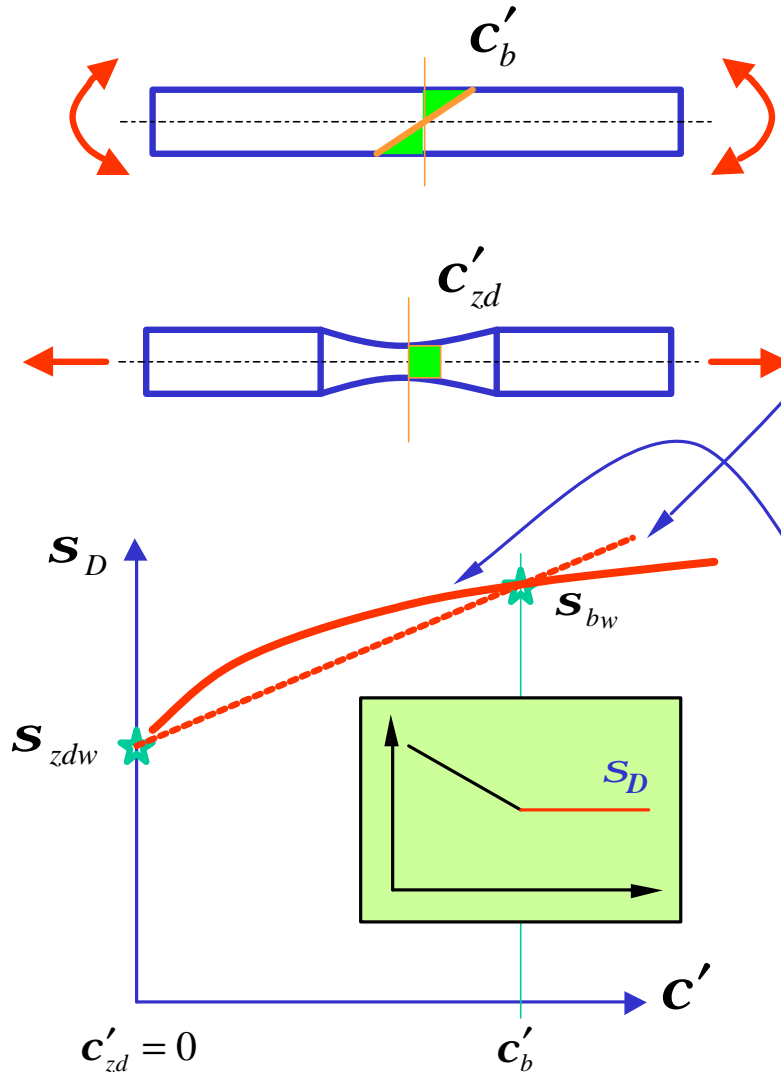


tension/compression  $\chi'_{zd} = 0$

fatigue limit



## Type of loading + notch sensitivity effect: Influence of stress gradient on fatigue limit



Assumption: straight

$$s_D = s_{zdw} + \frac{s_{bw} - s_{zdw}}{c'_b - c'_{zd}} \cdot c'$$

$$\frac{(s_D - s_{zdw})}{(s_{bw} - s_{zdw})} = \frac{c'}{(c'_b - c'_{zd})}$$

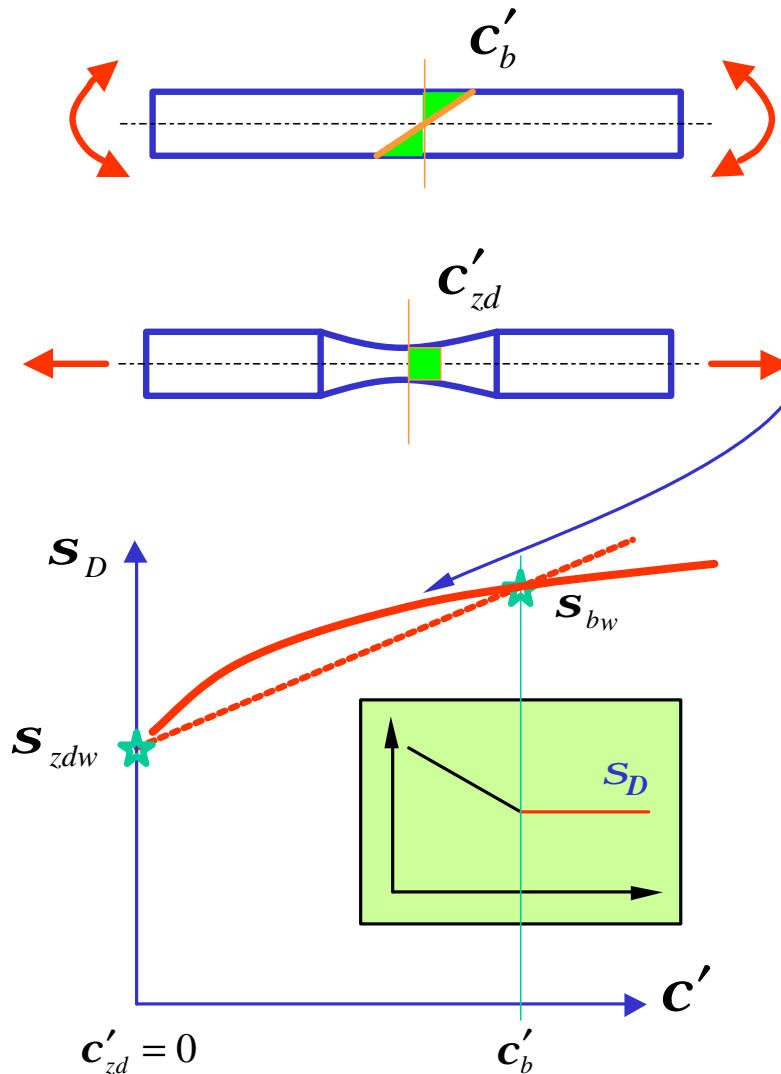
$$c'_{zd} = 0: \frac{(s_D - s_{zdw})}{(s_{bw} - s_{zdw})} = \frac{c'}{c'_b}$$

Assumption: exponential course

$$\frac{(s_D - s_{zdw})}{(s_{bw} - s_{zdw})} = \left( \frac{c'}{c'_b} \right)^{K_D}$$

$K_D$  ... Stress gradient exponent

## Type of loading + notch sensitivity effect: Influence of stress gradient on fatigue limit



exponential course:

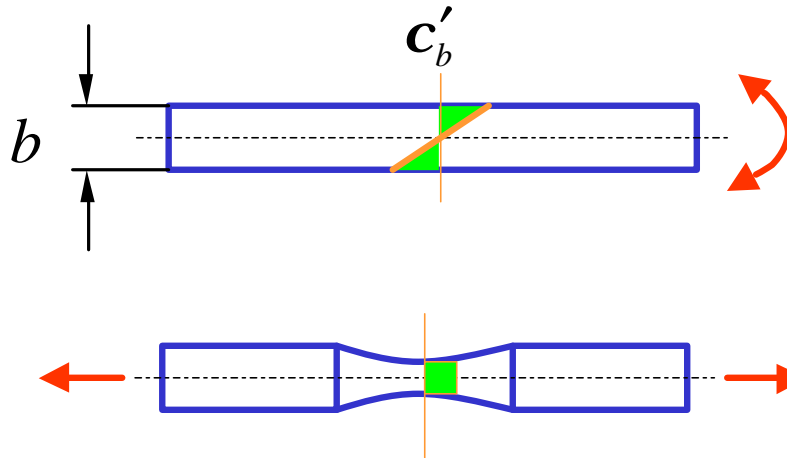
$$\frac{(S_D - S_{zdw})}{(S_{bw} - S_{zdw})} = \left( \frac{c'}{c'_b} \right)^{K_D}$$

$$S_D - S_{zdw} = \frac{S_{bw} - S_{zdw}}{c'_b{}^{K_D}} c'^{K_D}$$

$$\frac{S_D}{S_{zdw}} = \frac{S_{zdw}}{S_{zdw}} + \frac{S_{bw}/S_{zdw} - S_{zdw}/S_{zdw}}{c'_b{}^{K_D}} \cdot c'^{K_D}$$

$$S_D = S_{zdw} \left( 1 + \frac{S_{bw}/S_{zdw} - 1}{c'_b{}^{K_D}} \cdot c'^{K_D} \right) = S_{zdw} \cdot n_c$$

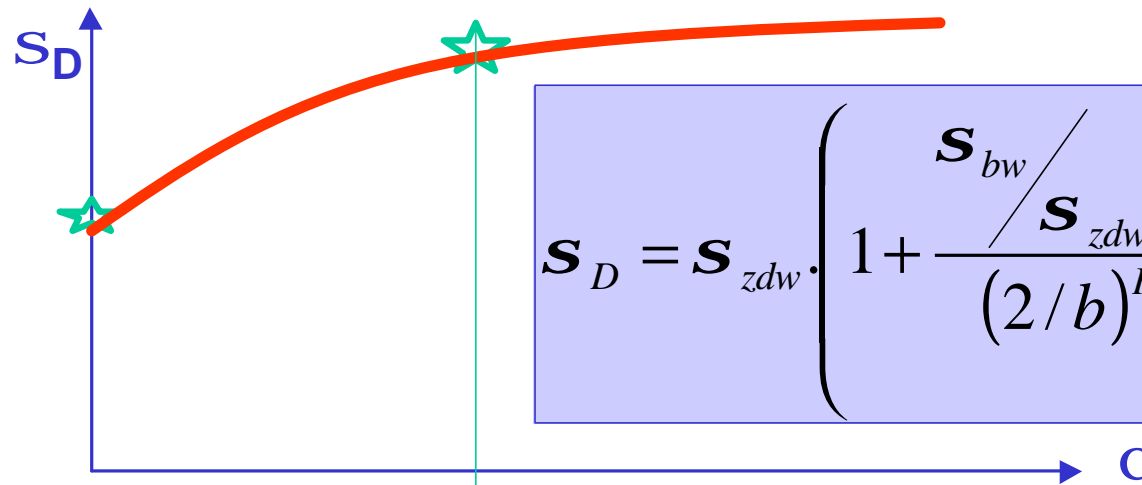
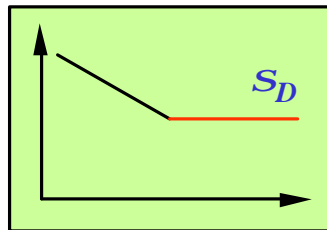
## Type of loading + notch sensitivity effect: Influence of stress gradient on fatigue limit



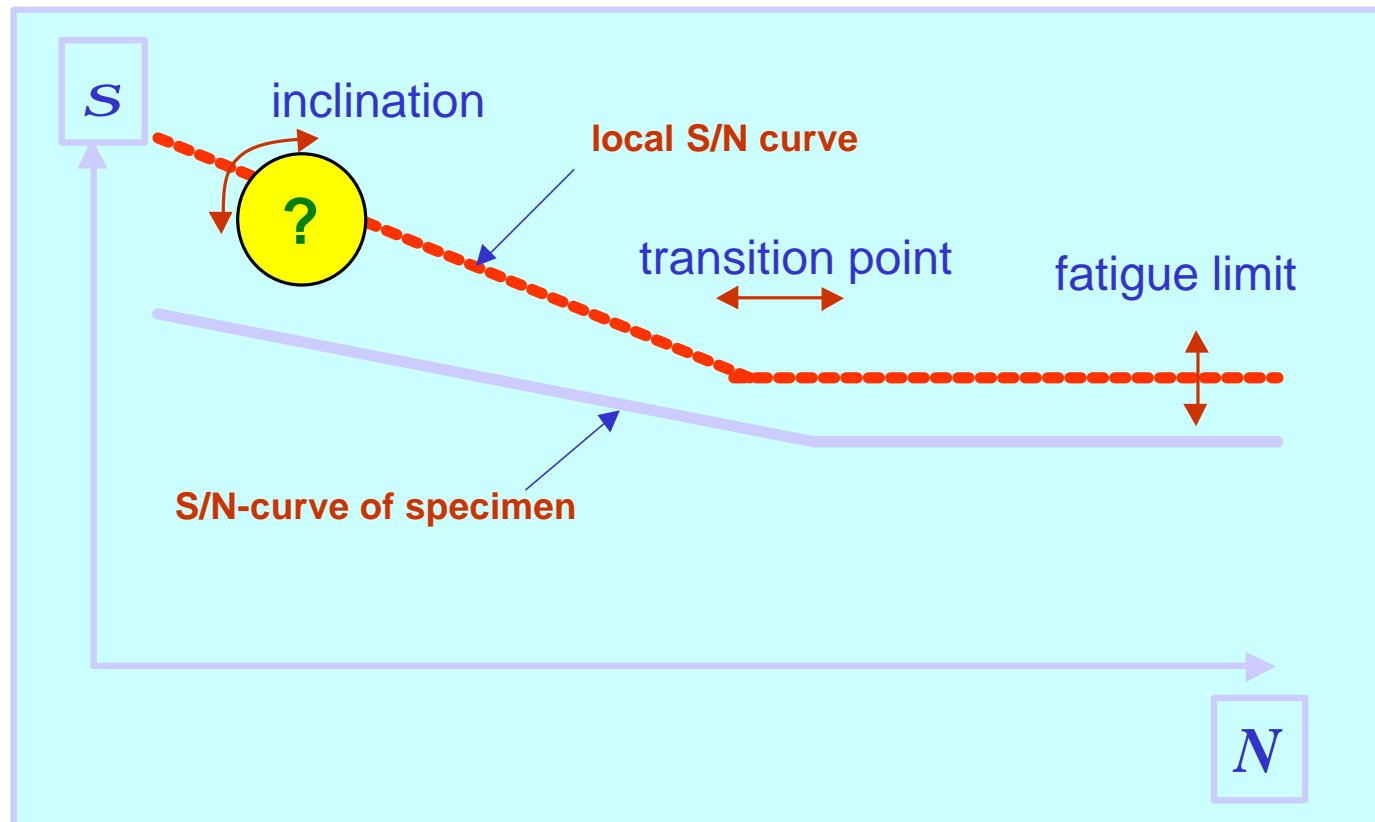
$$S_D = 1 + \frac{s_{bw}/s_{zdw} - 1}{c'_b{}^{K_D}} \cdot c'^{K_D}$$

bending specimen:  $c'_b = 2/b$

Fatigue limit

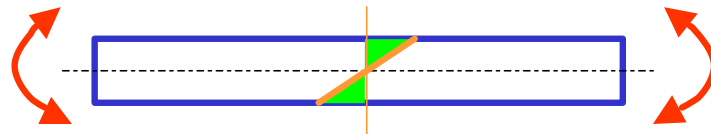


# Local S/N curves, synthetically generated



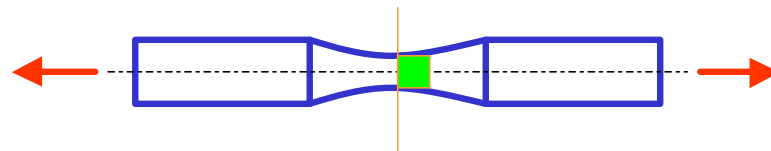


## Type of loading + notch sensitivity effect: Influence of stress gradient on inclination



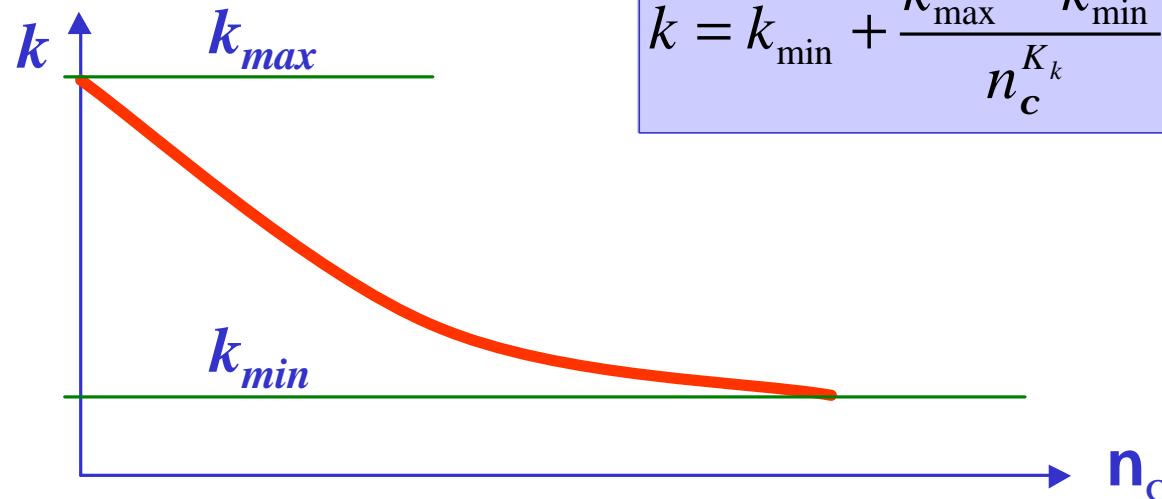
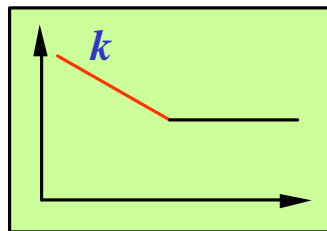
bending

$$\chi' = 2/b$$



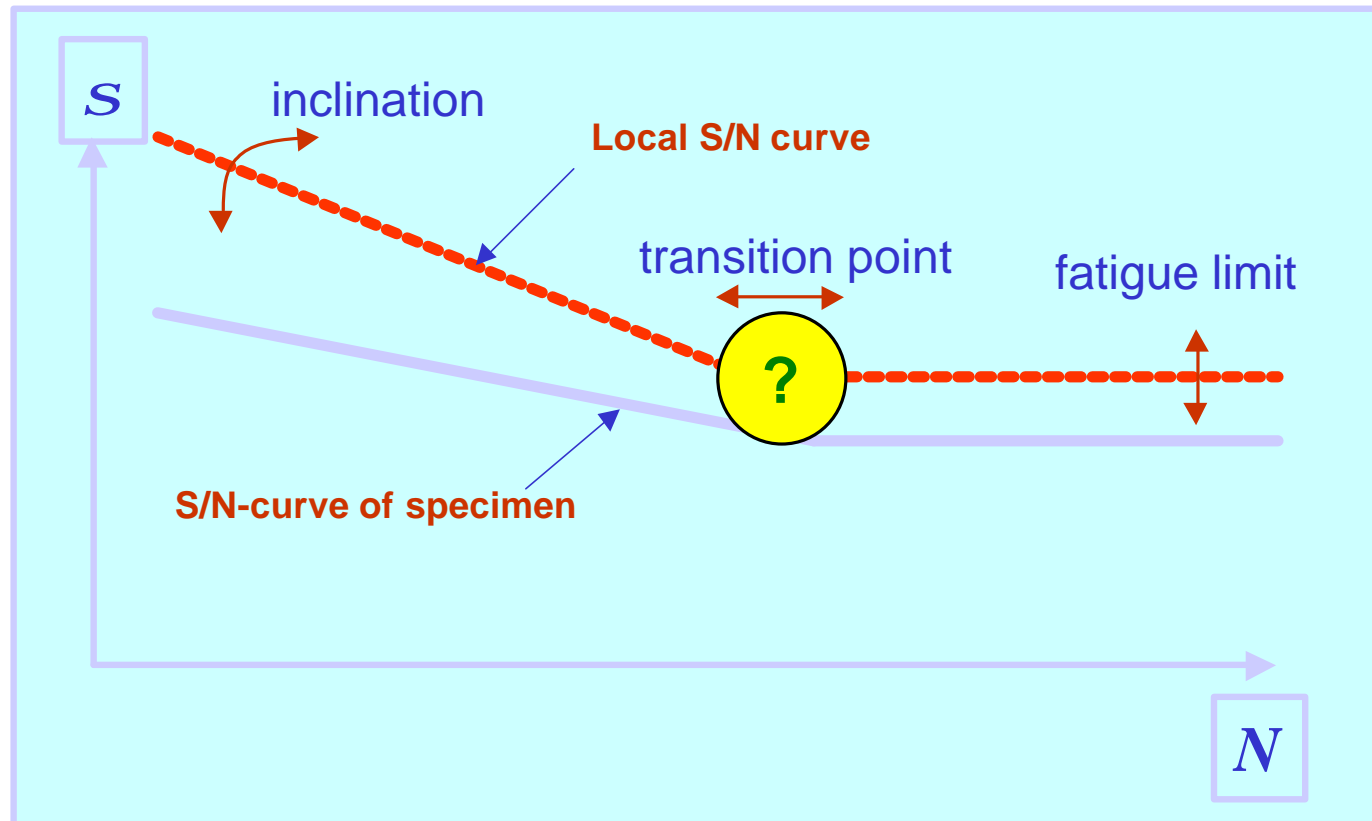
tension/compression  $\chi'_{zd} = 0$

Inclination  
 of S/N-curve

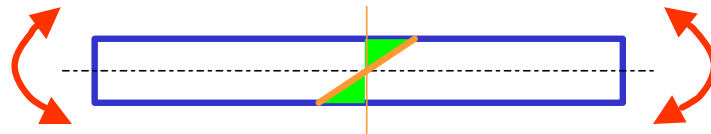


$$k = k_{\min} + \frac{k_{\max} - k_{\min}}{n_c^{K_k}}$$

# Local S/N curves, synthetically generated

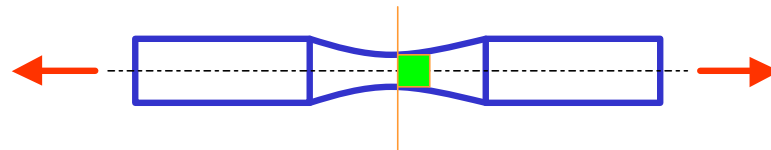


## Type of loading + notch sensitivity effect: Influence of stress gradient on transition point



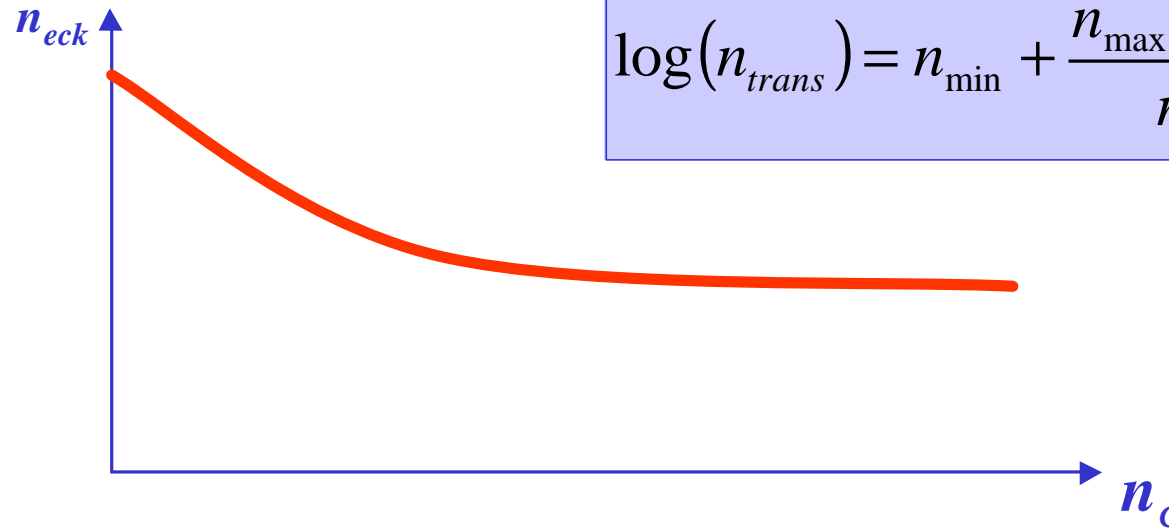
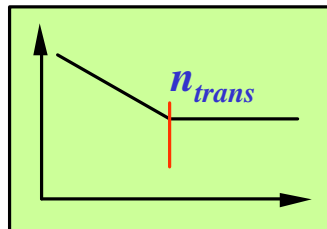
bending

$$\chi' = 2/b$$



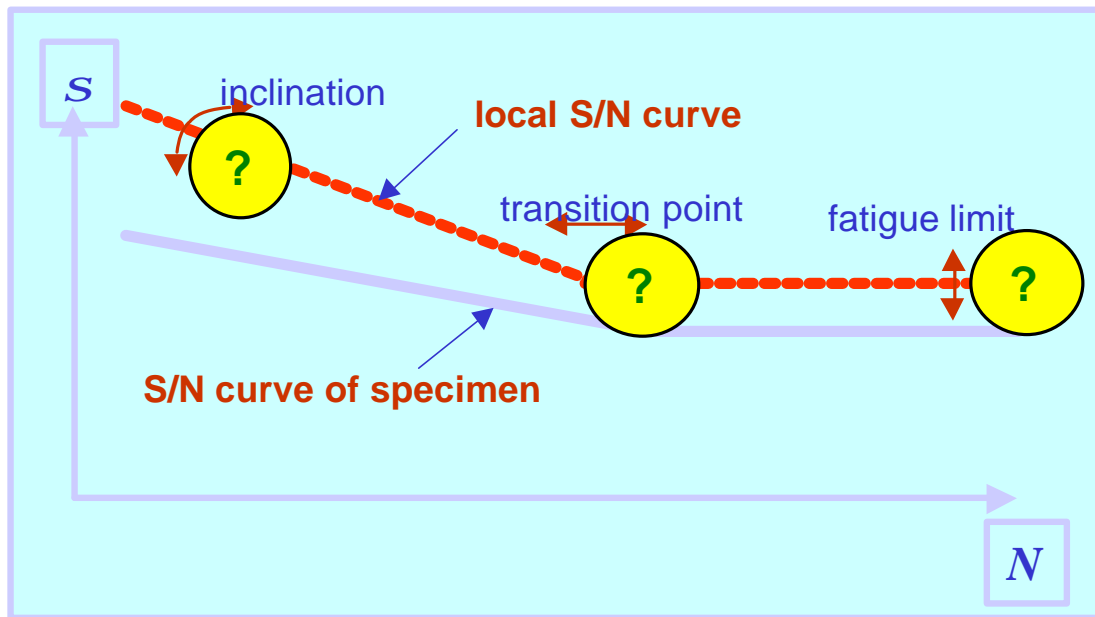
tension/compression  $\chi'_{zd} = 0$

Transition point



$$\log(n_{trans}) = n_{min} + \frac{n_{max} - n_{min}}{n_c^{K_n}}$$

## Synthetic S/N-curve, modified (1999)



$$S_D = S_{zdw} \cdot \left( 1 + \frac{S_{bw} / S_{zdw} - 1}{(2/b)^{K_D}} \cdot c'^{K_D} \right)$$

$$k = k_{\min} + \frac{k_{\max} - k_{\min}}{n_c^{K_k}}$$

$$\log(n_{trans}) = n_{\min} + \frac{n_{\max} - n_{\min}}{n_c^{K_n}}$$

Description of S/N curve:

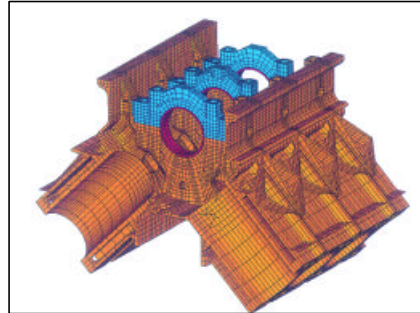
Basic material, without notch:  $S_D, n_{eck}, k$

Parameters of local S/N curve:  $K_D, k_{\max}, k_{\min}, K_k, n_{\max}, n_{\min}, K_n$

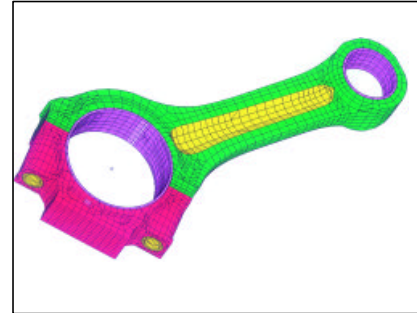
## Application of Concept: *FEMFAT*

### Fatigue Analysis of Engine Components:

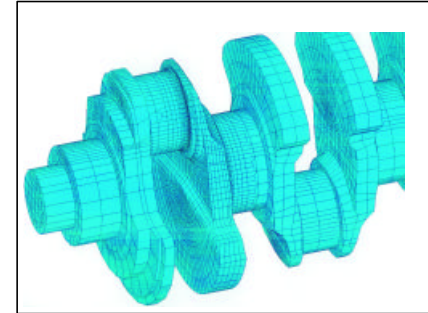
Engine block



Con - rod



Crankshaft



### Basic Loads

Bolt pre-stress  
 Overlap  
 Manufacturing stress

} *constant*

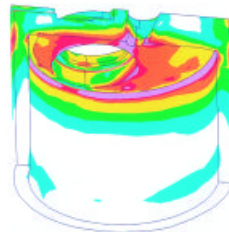
Thermal load

*constant or variable*

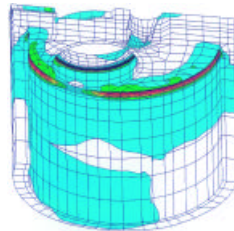
Combustion pressure  
 Injection forces  
 Mass forces

} *variable*

Thermal stress



Combustion stress



### Operation Modes

Constant max. power

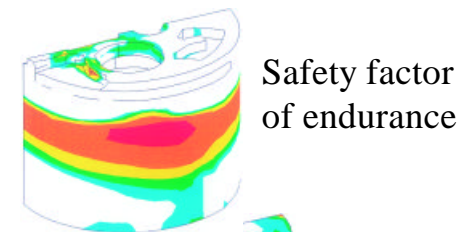
↳ High cycle fatigue  
*FEMFAT BASIC*

Thermal cycling

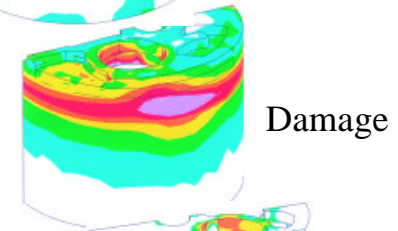
↳ Low cycle fatigue  
*FEMFAT HEAT*

Mixed operation

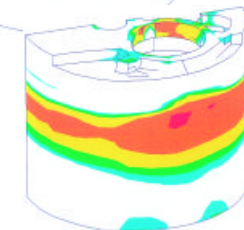
↳ Multiaxial fatigue  
*FEMFAT MAX*



Safety factor of endurance



Damage



Damage



# Summary

- Synthetic S/N-curves are necessary for automatic assessment of stresses (Finite Element results)
- Presented model of S/N-curve successfully applied in daily use
- Tests necessary to determine the influences of parameters, like
  - ⇒ temperature
  - ⇒ residual stresses
  - ⇒ notch sensitivity