The Automobile Industry in Japan and Germany-
Strategic Challenges and New Perspectives in the Age of Globalization
12th October 2004 -Tokyo

Fatigue Failures of Vehicle Components

by

Vatroslav Grubisic

Fraunhofer Institut Betriebsfestigkeit

1. **Introduction**

   Criteria for the design, classification of vehicle components and product liability requirements.

2. **Influences for the failures**

   2.1. Design and service loading

   2.2. Material and manufacturing

   2.3. Usage conditions (Assembly, Environment)

   The individual influences will be discussed on examples and the means to avoid failures presented.

3. **Conclusions**

   Requirements concerning the procedures for the design validation of vehicle components.

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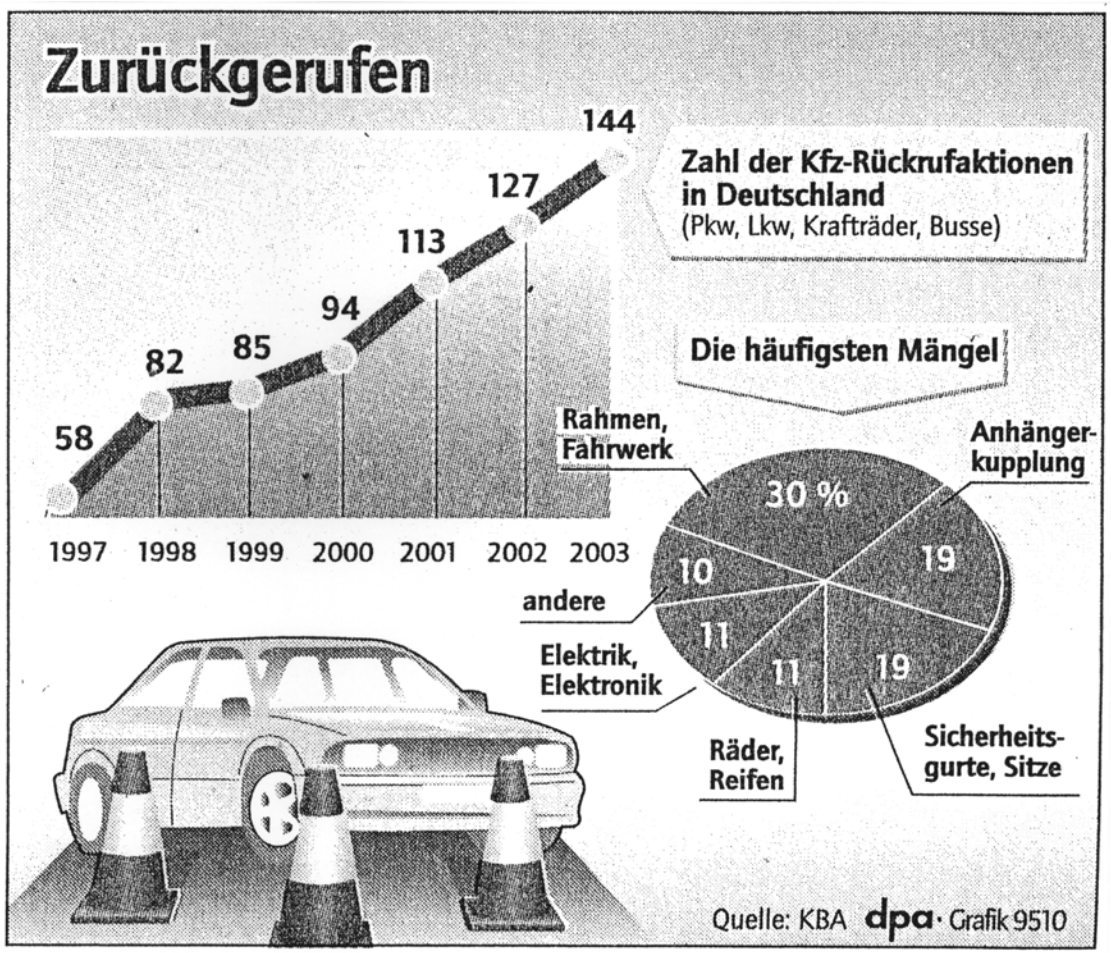
Recalls in Car Industry



Die Zahl der Pkw-Rückrufe wächst – nicht allein bei Mitsubishi. GRAFIK: DPA

Source:
German Traffic Office 2004

DIA 7329e

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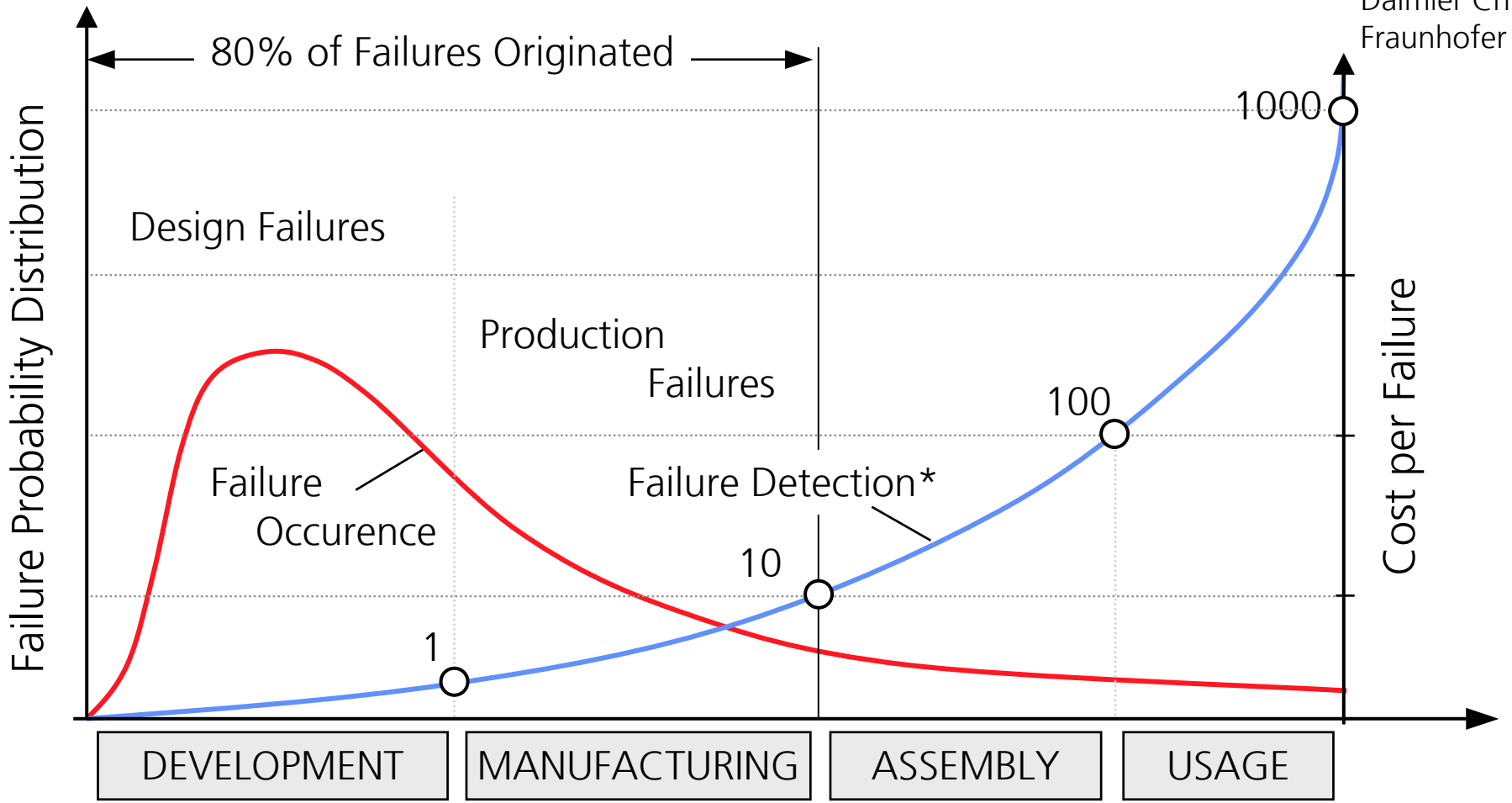
Automotive Failures-Occurence and Costs

Generalized Overview

* After study
Daimler Chrysler/
Fraunhofer Society-IPT



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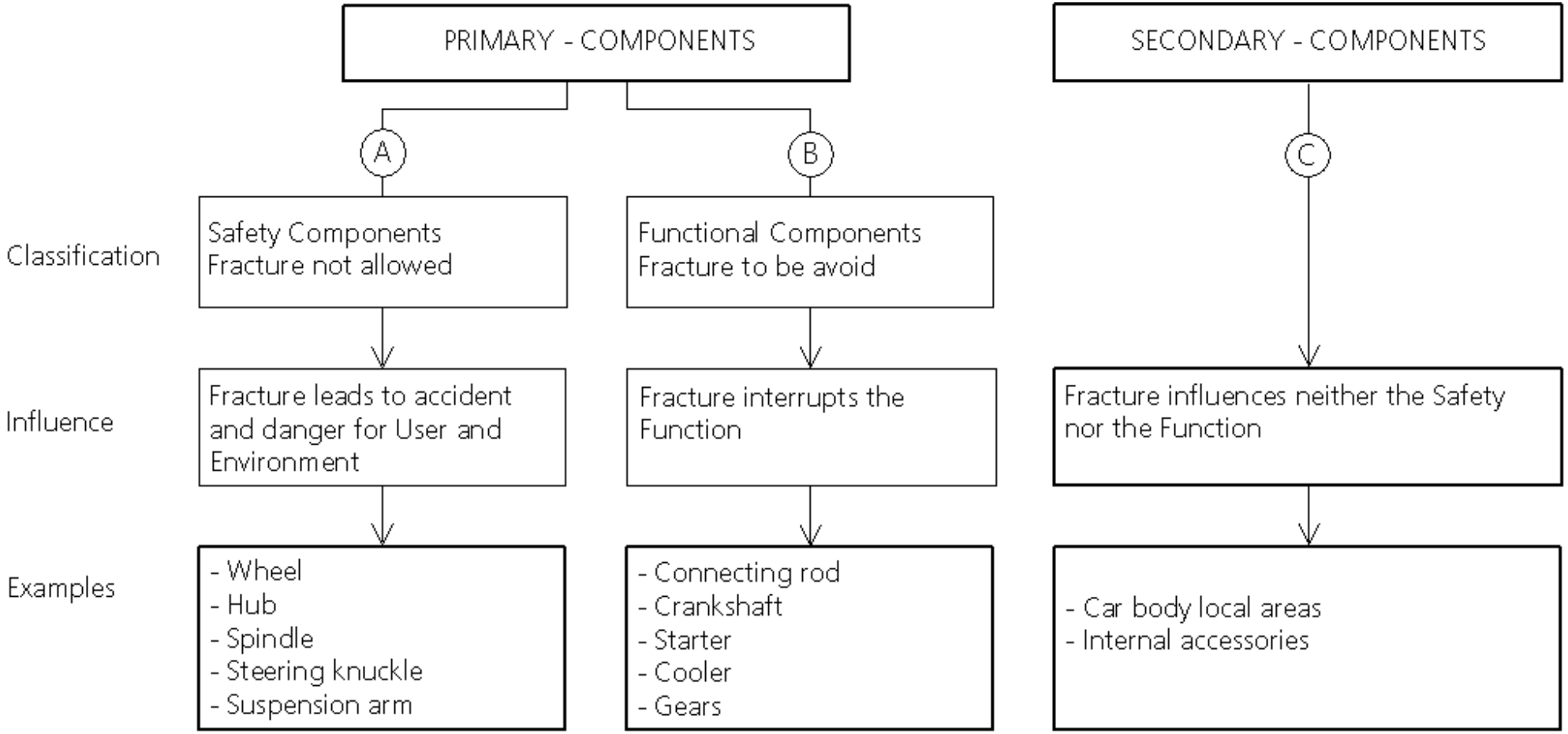
Classification of Components Concerning Reability Requirements



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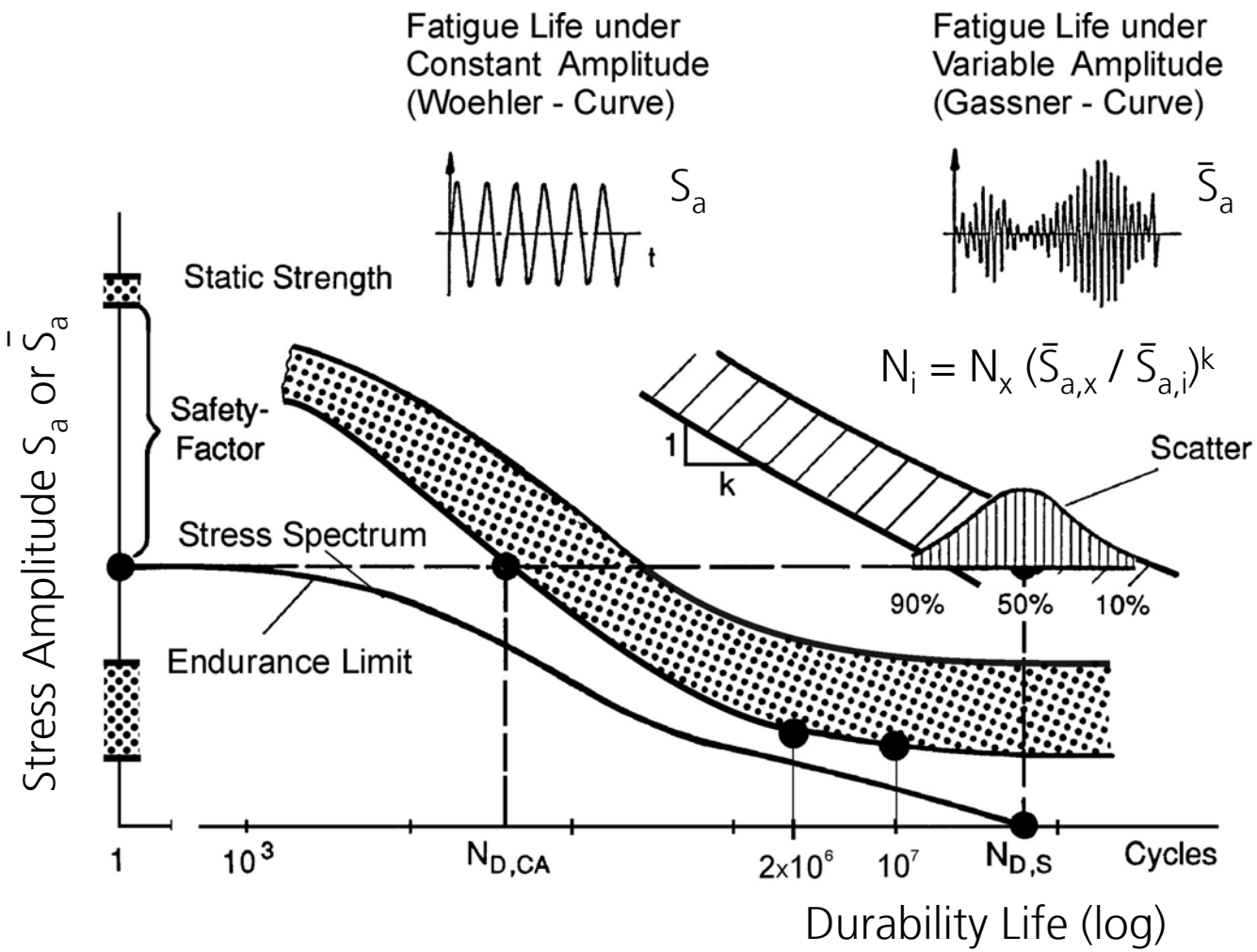
Relation between Operational Stresses and Durability Life



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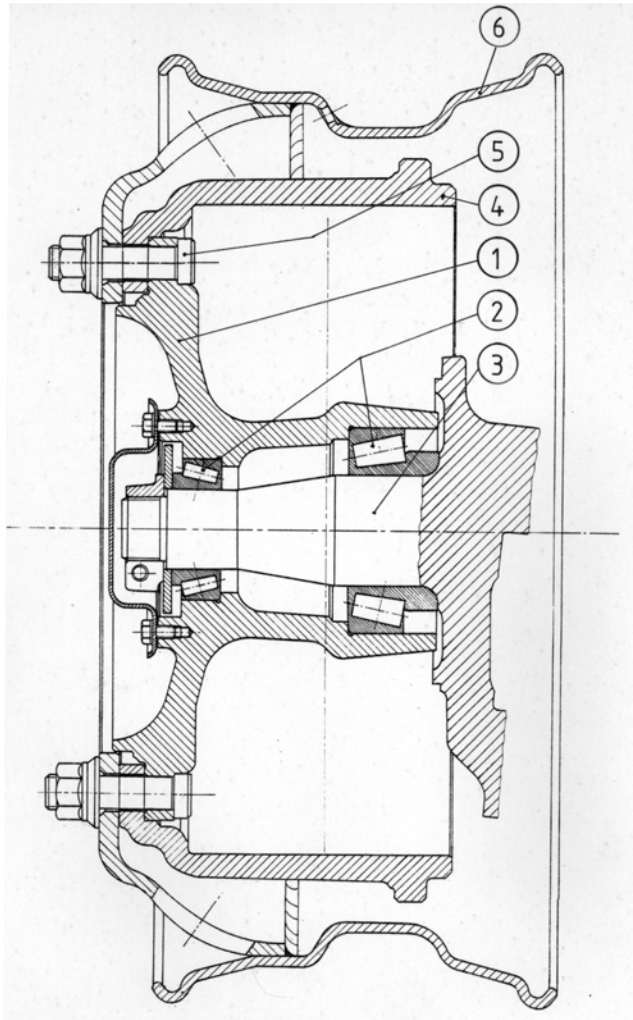
Wheel/Hub Assembly of Commercial Vehicles with Drum Brakes



1. Hub
2. Bearing
3. Spindel
4. Brake Drum
5. Bolts
6. Wheel

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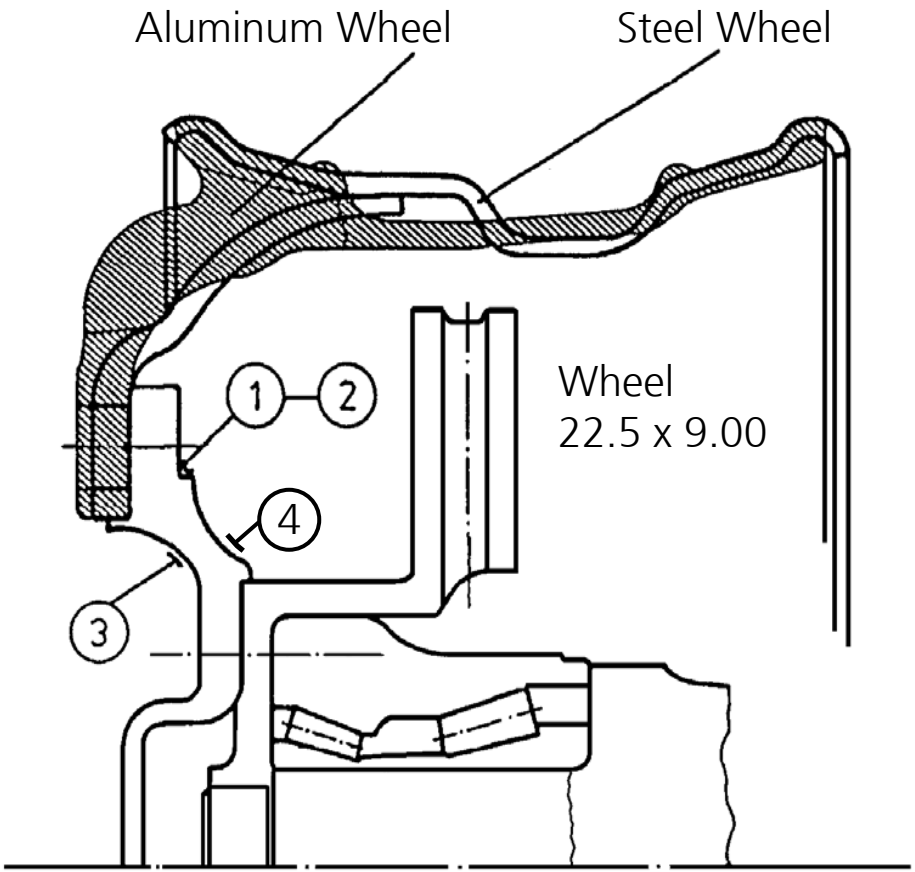
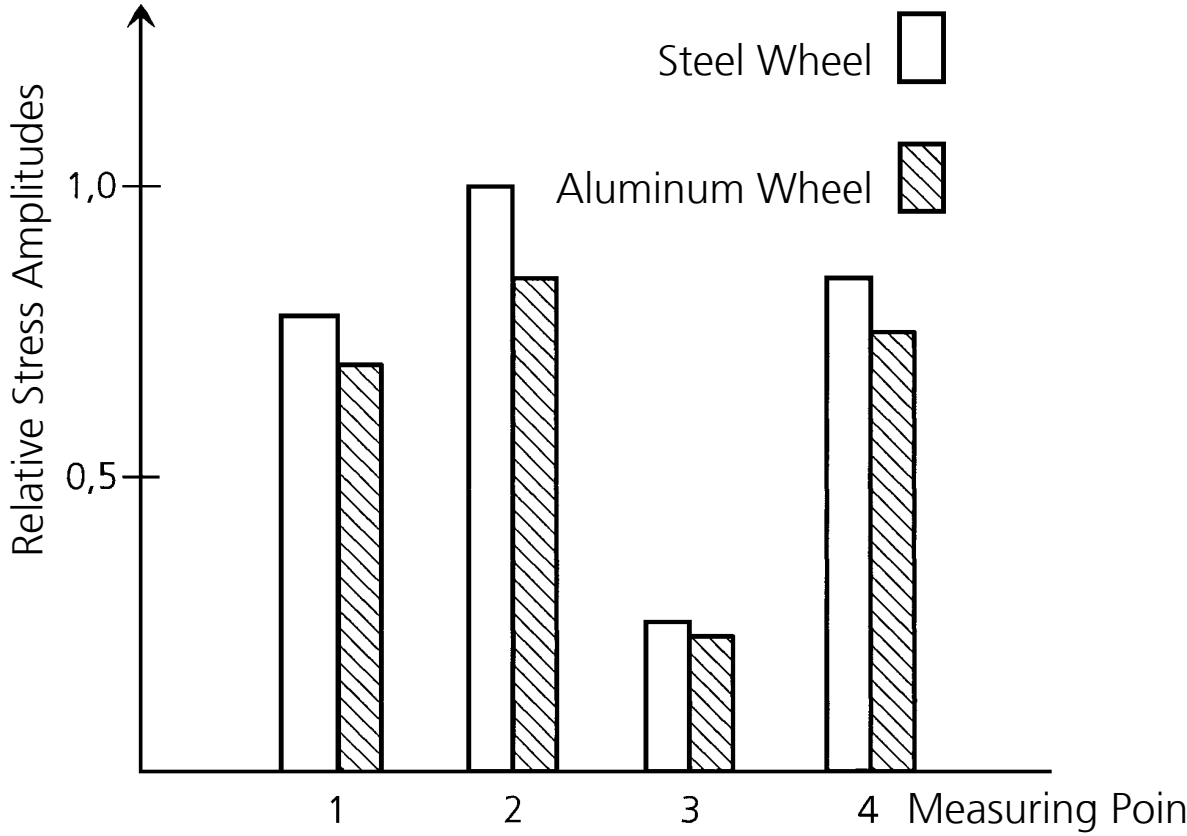
Influence of Wheel Design on Hub Stresses
Load Condition: Cornering





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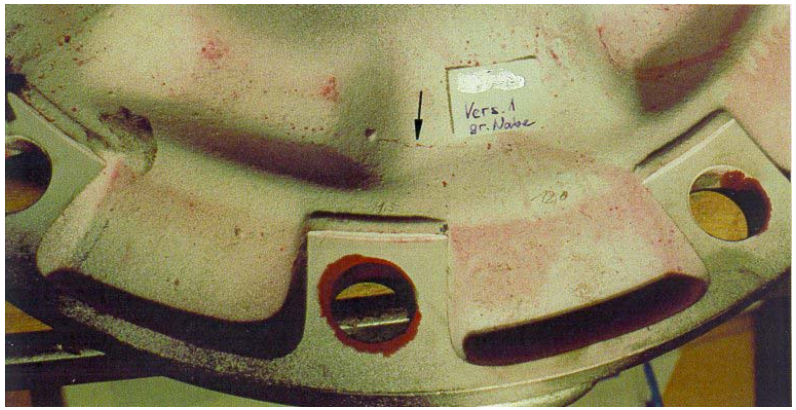
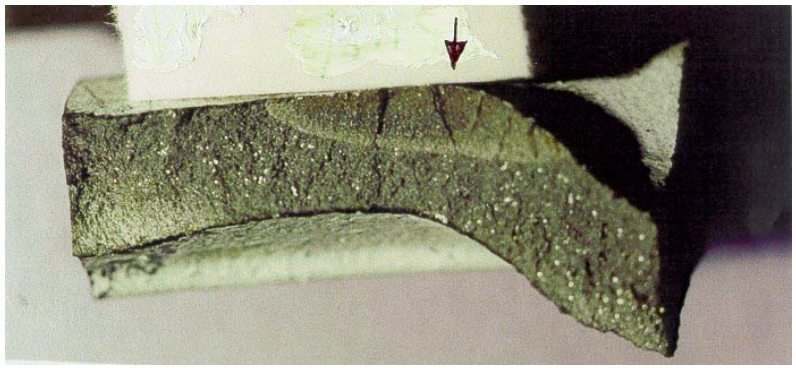
Fatigue Fractures on Trailer Hubs

Wheel: 22.5 x 11.75; Tyre: 385/65R22.5 Bridgestone; Wheel rated load: $F_{z,stat}$ = 55 kN

Fracture after ≈ 200 000 km Service usage





Fracture in Biaxial Wheel/Hub Test Facility
Load Programme „Eurocycle“
Test Life ≈ 7 000 km

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Fatigue Fracture on Cast Hubs for Commercial Vehicles (Nodular Iron GGG 50)

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Truck Overloaded

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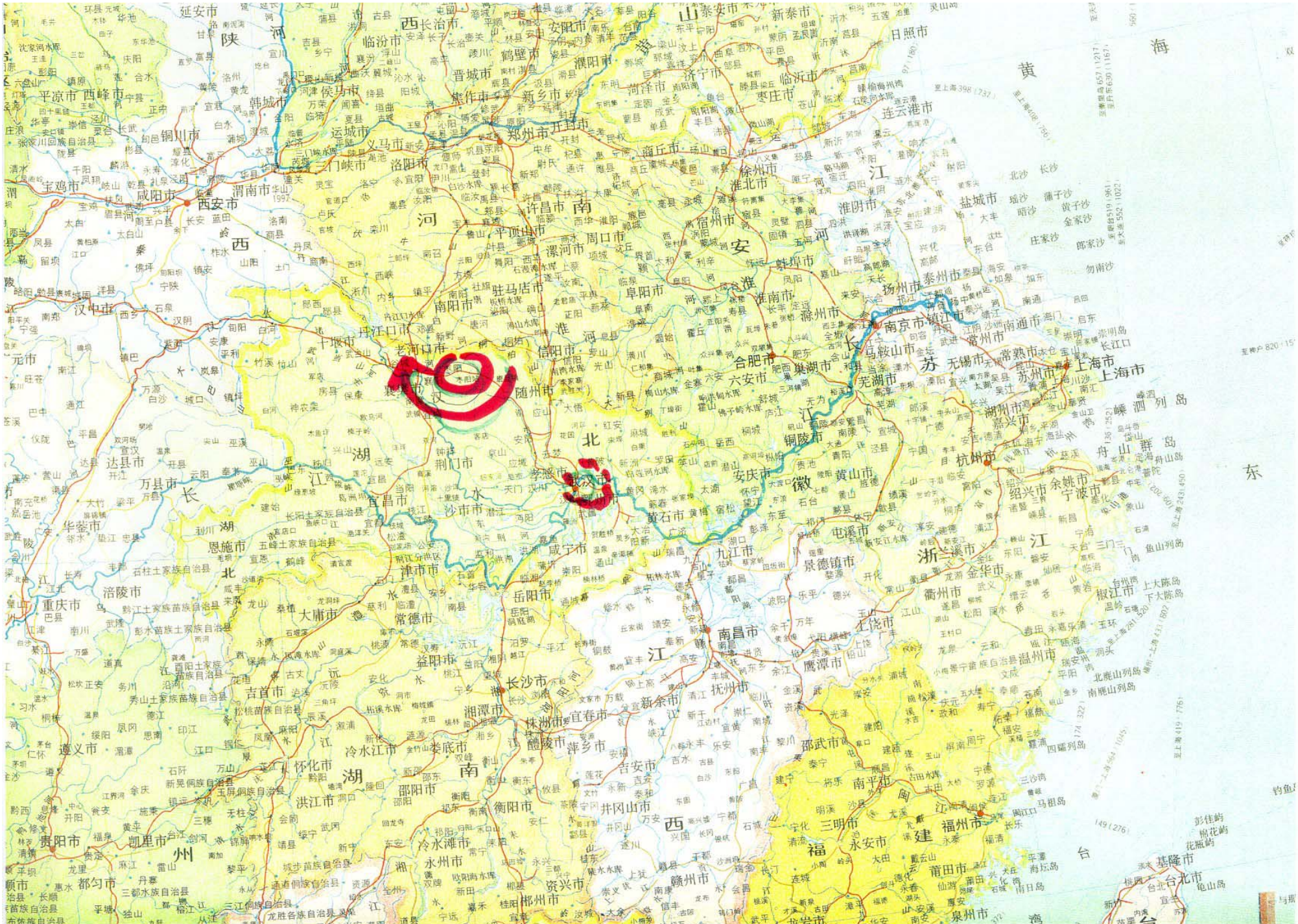
Measurements on roads in Hubei – Province (China)



Measuring Vehicle

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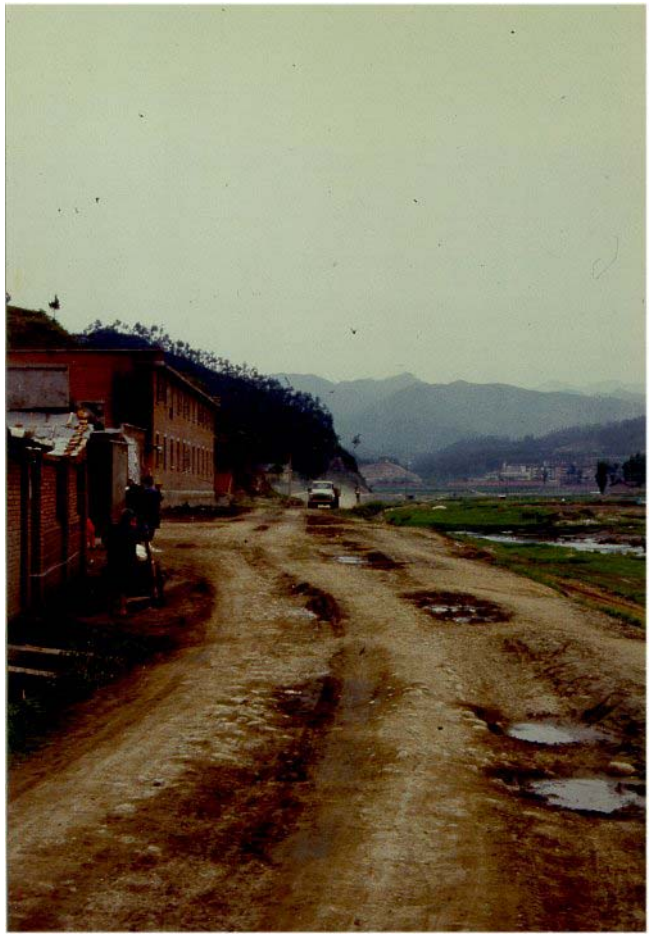
Pothole Test Track *MAO JIAN*



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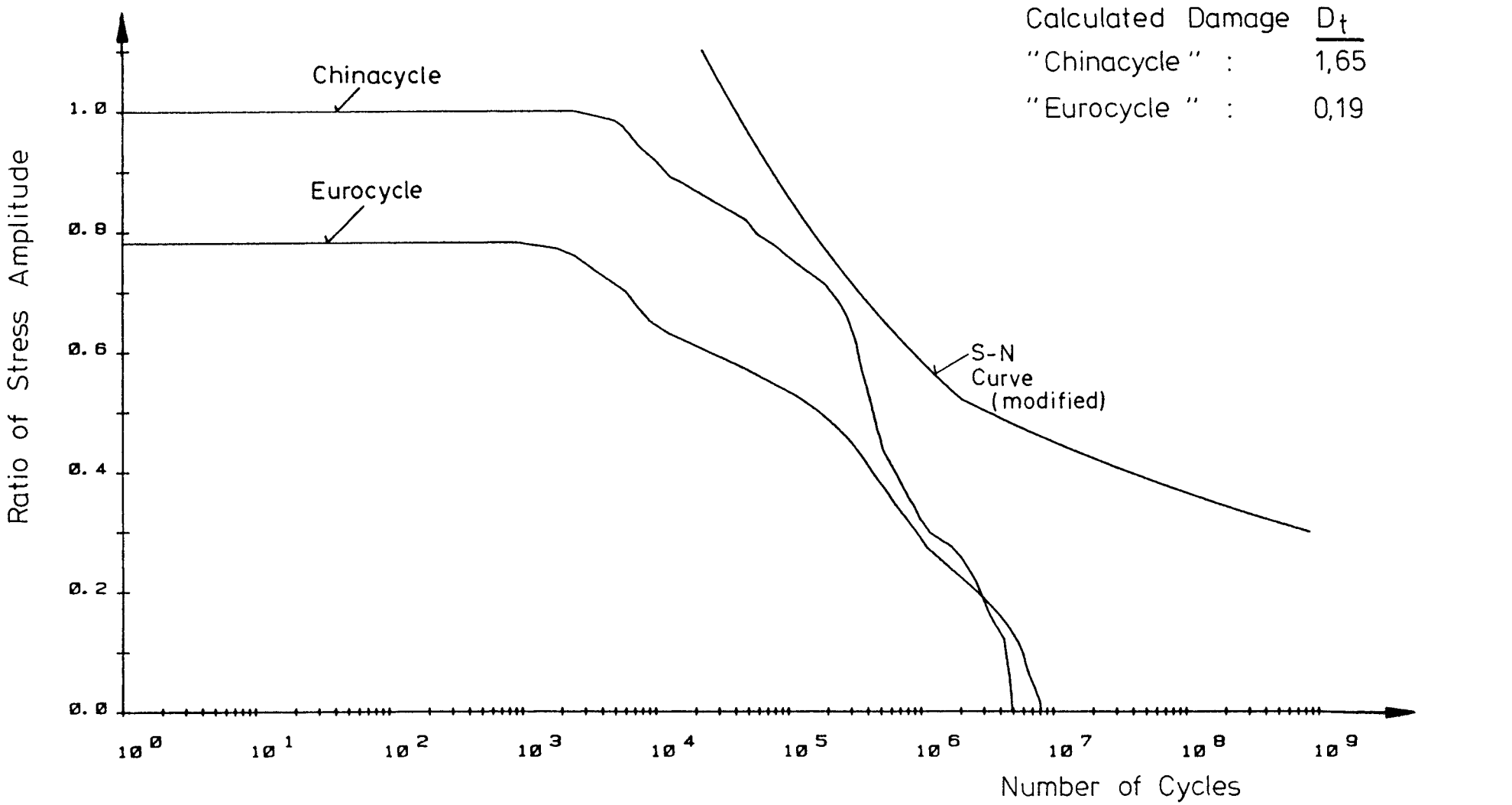
Comparison of Test Spectra (L_t = 15 000 km) Hub, Area Gage 3



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Influence of Design Spectra on Required Design Modifications

Damage Relation: $D_{China} \approx 5\, D_{Europe}$

Design Life Relation: $L_{China} \approx 1/5\, L_{Europe}$

Required Design Modifications

$$t_{China} = t_{Europe} \cdot \left(\frac{D_{China}}{D_{Europa}} \right)^{\frac{1}{k \cdot n}}$$

t – thickness

k – slope of S-N-Curve

n - ratio of Loading mode

n = 2 (pure bending)

n = 1 (pure tensile/compession)

Required thickness for China compared to Europe for the same operational life and unchanged design of the wheel hub (n = 1.8, k = 7) for hub manufactured from nodular iron:

$$\frac{t_{China}}{t_{Europe}} \approx 1.14$$

: e.g. from t_0 = 12 mm to t_{new} = 13,7 mm

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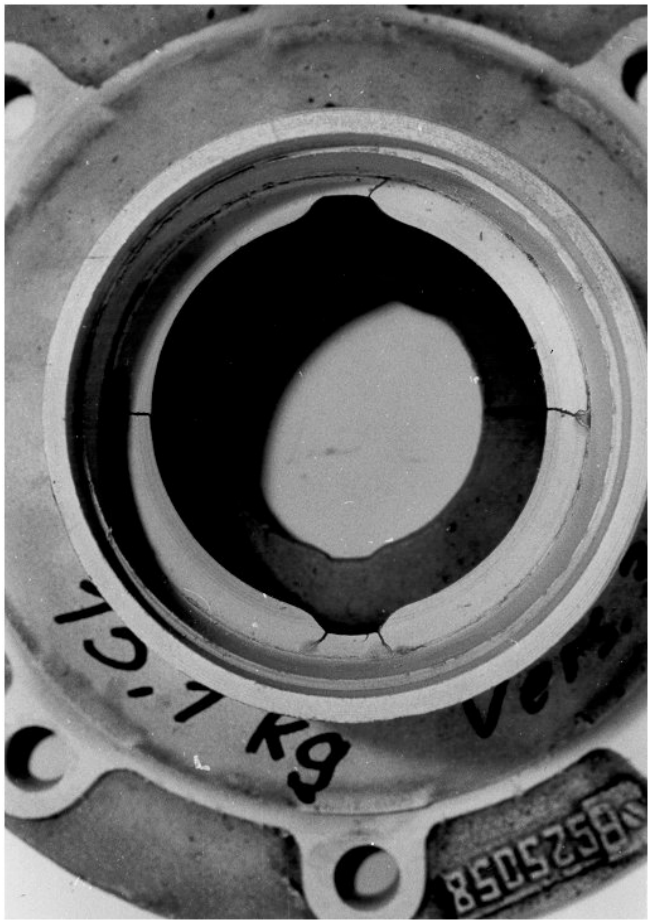
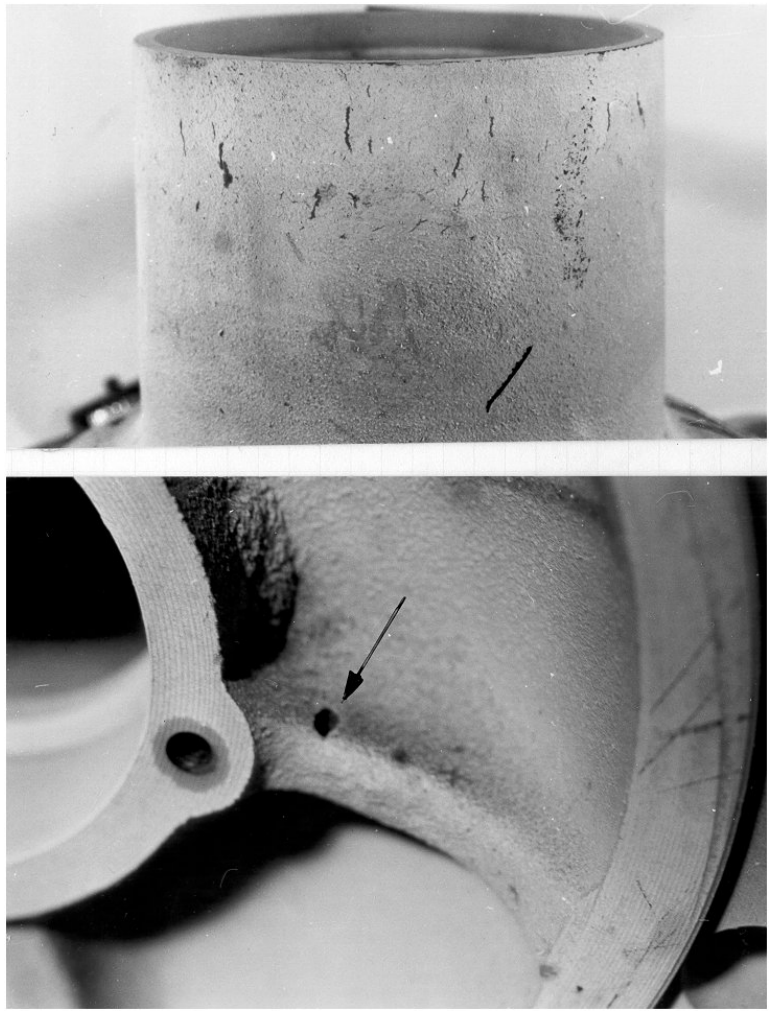
Proof Test in Biaxial Test Facility Load Program *CHINACYCLE*





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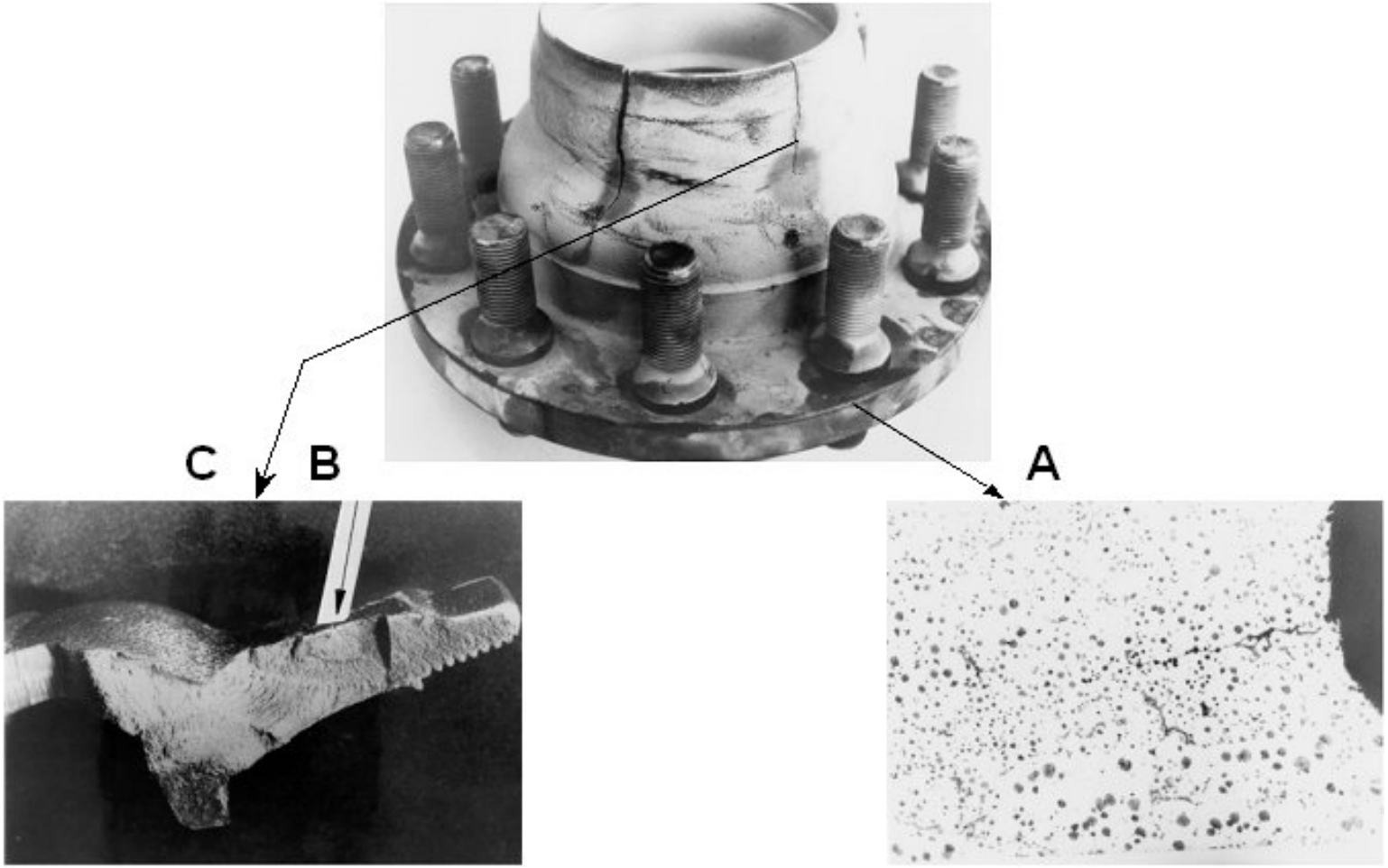
Fatigue Damage on a Cast Nodular Iron Hub for Dual Wheels



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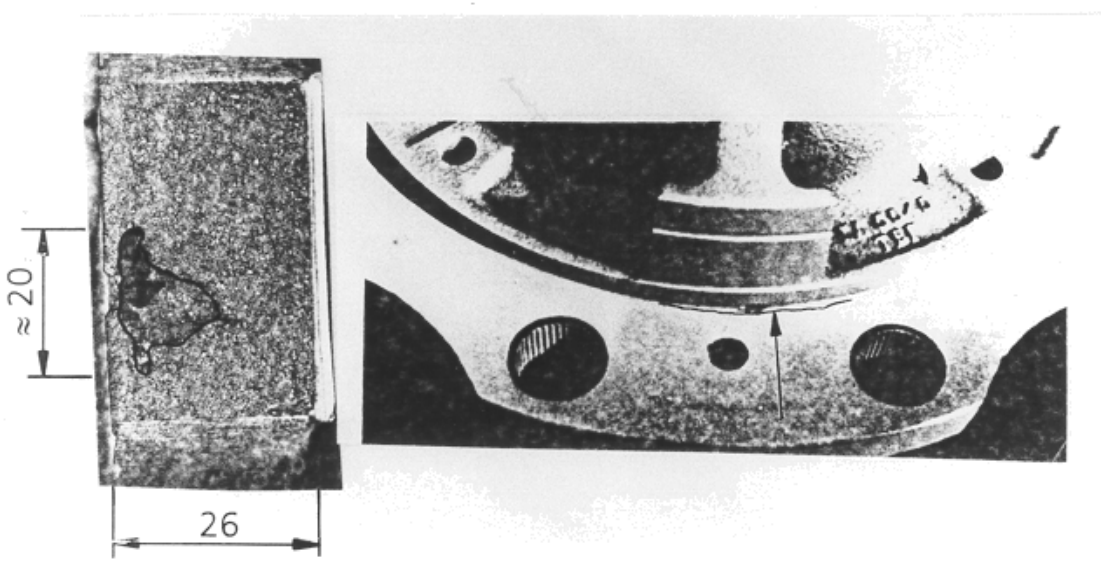
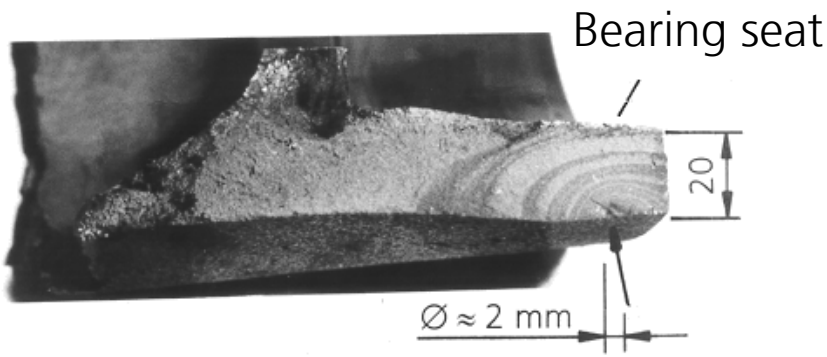
Classification of Allowable and Non-Allowable Pores in Nodular Cast Hubs (GGG 50)

b. Non-allowable flange shrinkage



c. Non-allowable outer pore in bearing seat area



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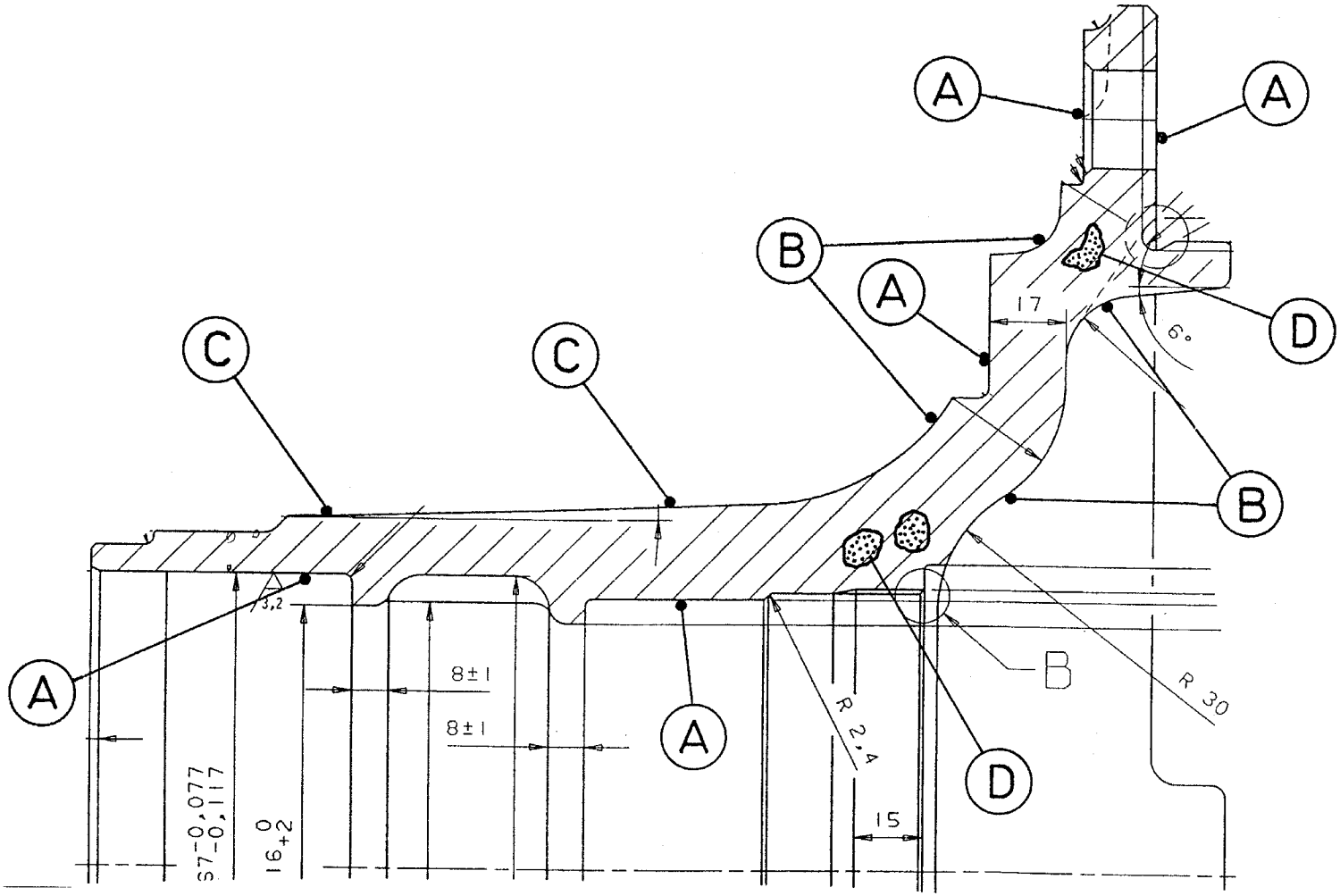
Areas of Shrinkage and Porosity on Cast Hubs for Commercial Vehicles



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Allowable Shrinkage and Porosity on Highly Stressed Areas of Nodular Iron Hubs for Commercial Vehicles

	Area	Percentage of pores	Size of single pores ∅ in mm	No. of areas with pores of 1 cm² +)	Porosity according to ASTM E 155 (Cast Aluminium)
A	• Machined flange to wheel seat / brake disc • Bearing seat	0	≤ 0,1	0	0
B	• Non - machined hub radii	≤ 5	< 1	< 3	p ≈ 8
C	• Higher circumferential stress on outer bearing seat	≤ 3	< 0,5	< 1	p ≈ 4
D	• Internal areas with mainly bending stress	< 5	< 0,5 Surface distance > 5 mm	< 1 at 3 cross sections (max.)	p ≈ 0 - 4

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+) These areas of defects are allowed, if their distances along the circumference are ≥ 5 cm

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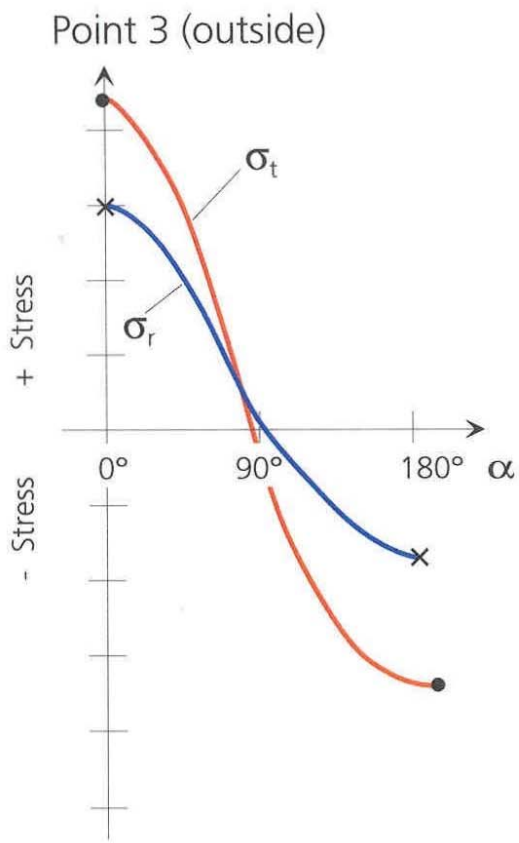
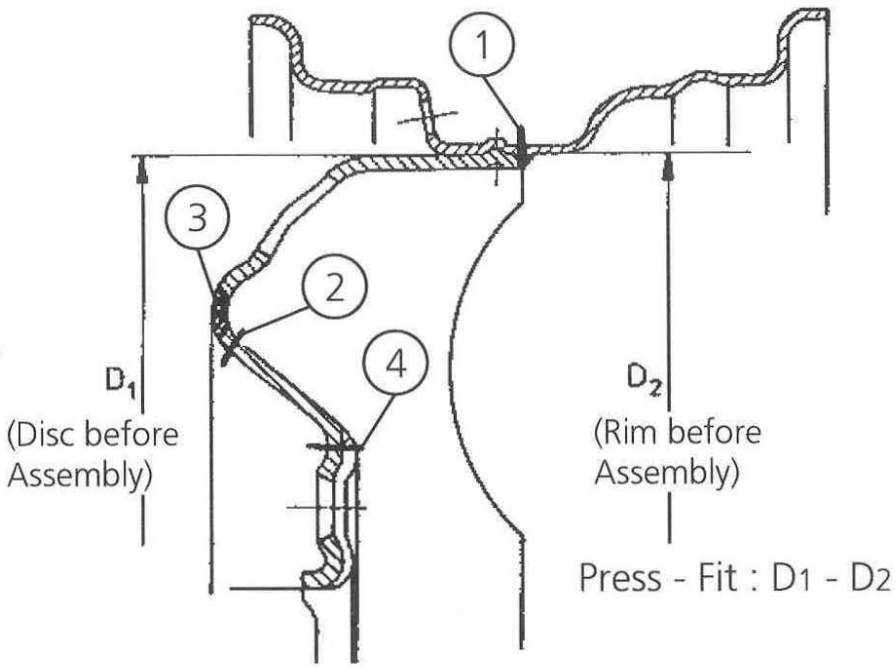
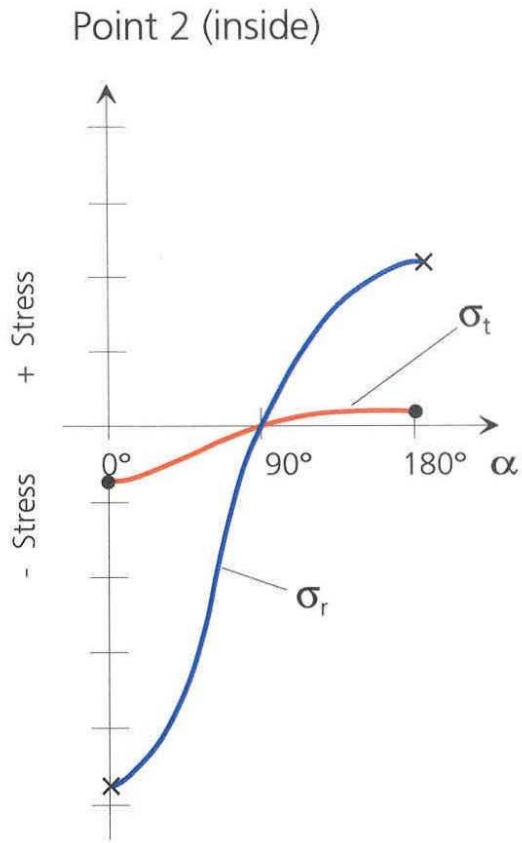
Operational Stresses (Cornering) and Fracture Modes on Steel Wheels







x σ_r = radial stress
• σ_t = tangential stress

σ_e = equivalent stress
$\sigma_{e,3} \leq 0{,}95\ \sigma_{e,2}$

α = angle of rotation
0° corresponding to load input

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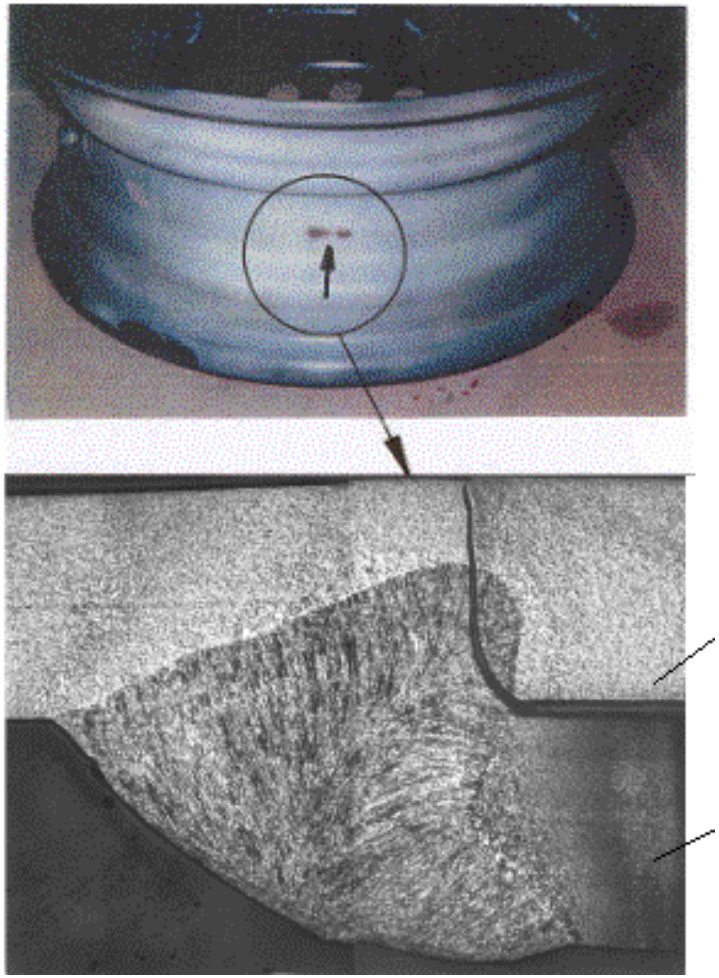
Fatigue Crack on Welding between Disc and Rim



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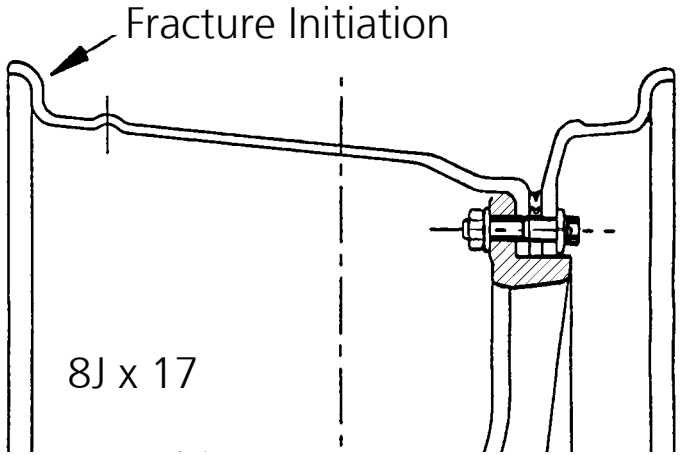
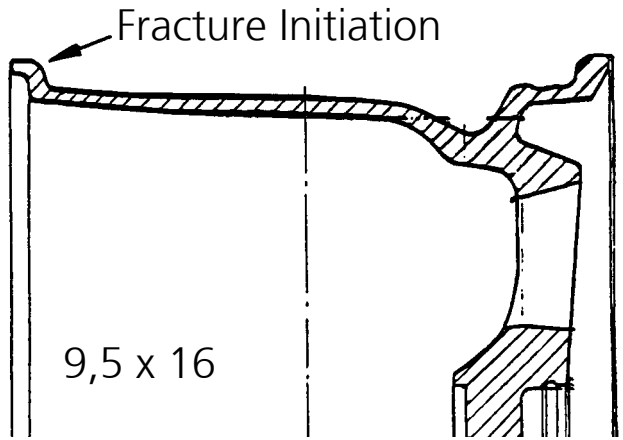
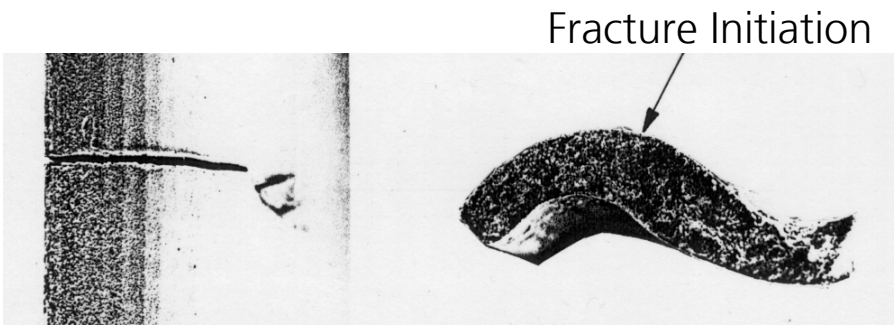
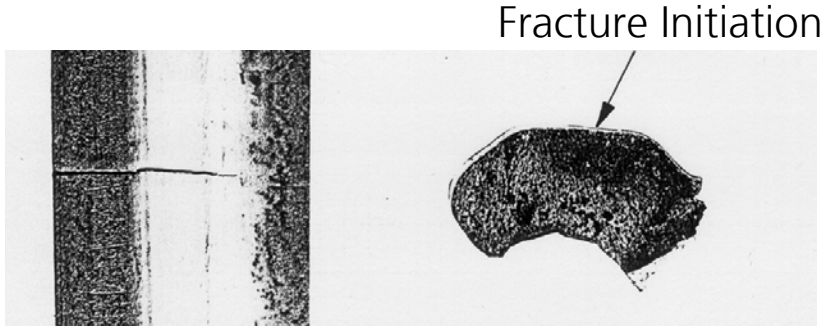
Fatigue Cracks on Wheels with Large Rims (>7 inches) and Low Profile Tyres Operational Usage 60.000 – 100.000 km

Wheels:	8J x 17;	9,5 x 16 (240 TR 415);	10,5 x 18
Tyres:	245/40 ZR 17	280/45 VR 415	295/35 ZR 18









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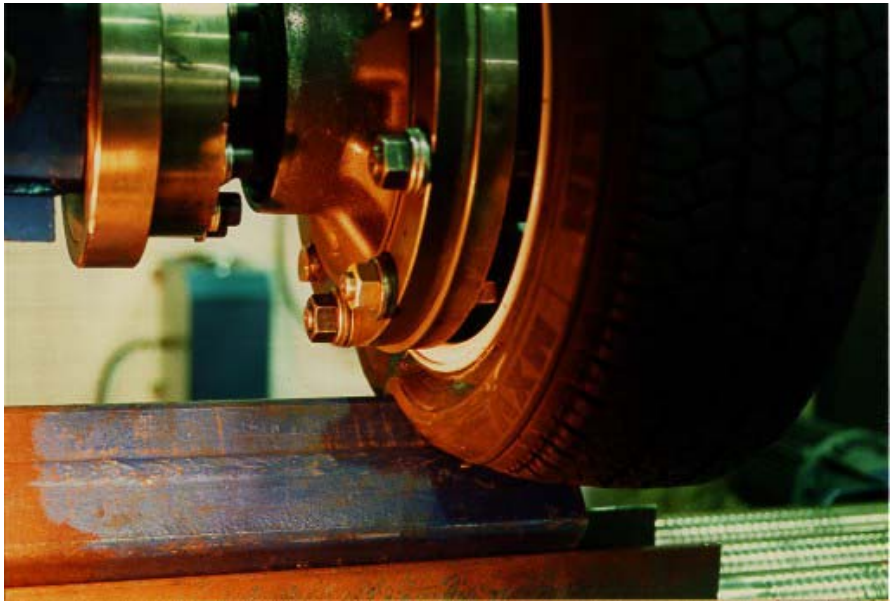
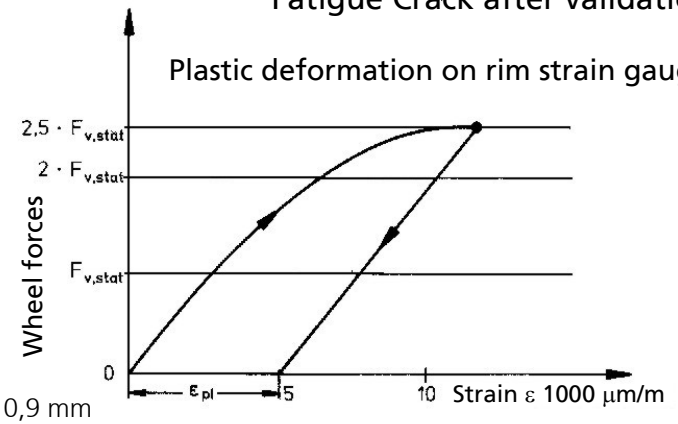
Procedure for Pre-Loading of Wheels for Durability Approval



Fatigue Crack after validation test

Static Pre-Loading:
Vertical Force: $F_v = 2{,}5 \cdot F_{v,stat}$
Tyre pressure: $p_l = 0{,}6 \cdot p_{l,n}$
Half tyre width (inside section)
Obstacle radius r = 12 cm



Plastic deformation: ΔD = 0,9 mm

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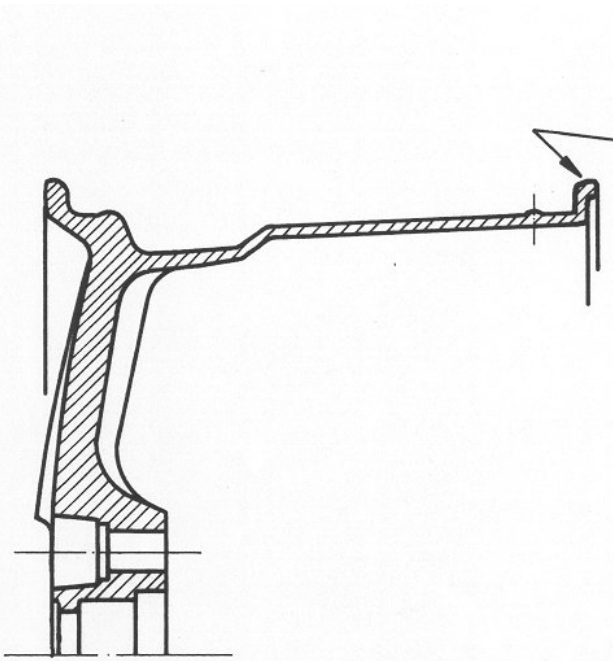
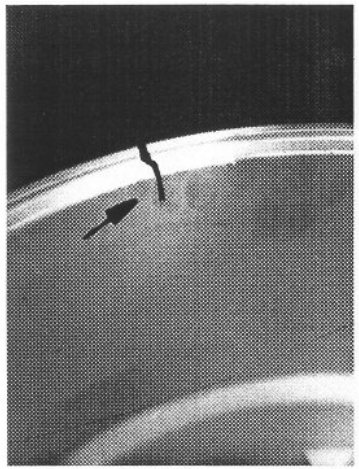
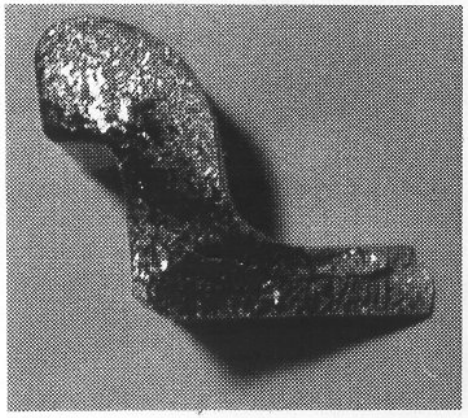
Fatigue Cracks at Durability Approval on Wheels after Pre-Loading



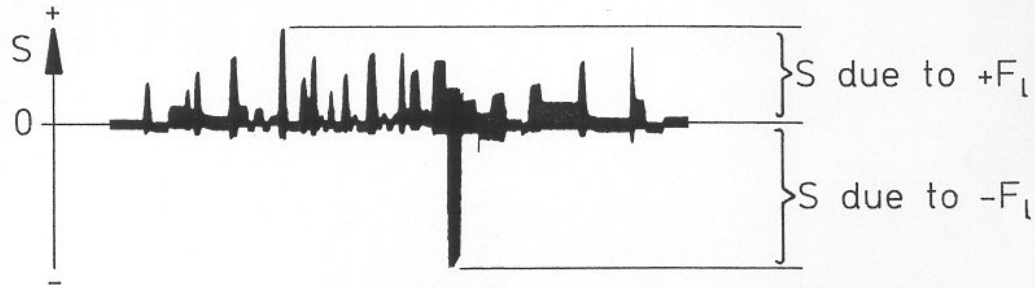
Wheel Design : $10^1/_2$ Jx18
Tyre : 295/35 ZR18

Fatigue Cracks
on Rim Flange





Stress-
Time-History



DIA 7297e_2

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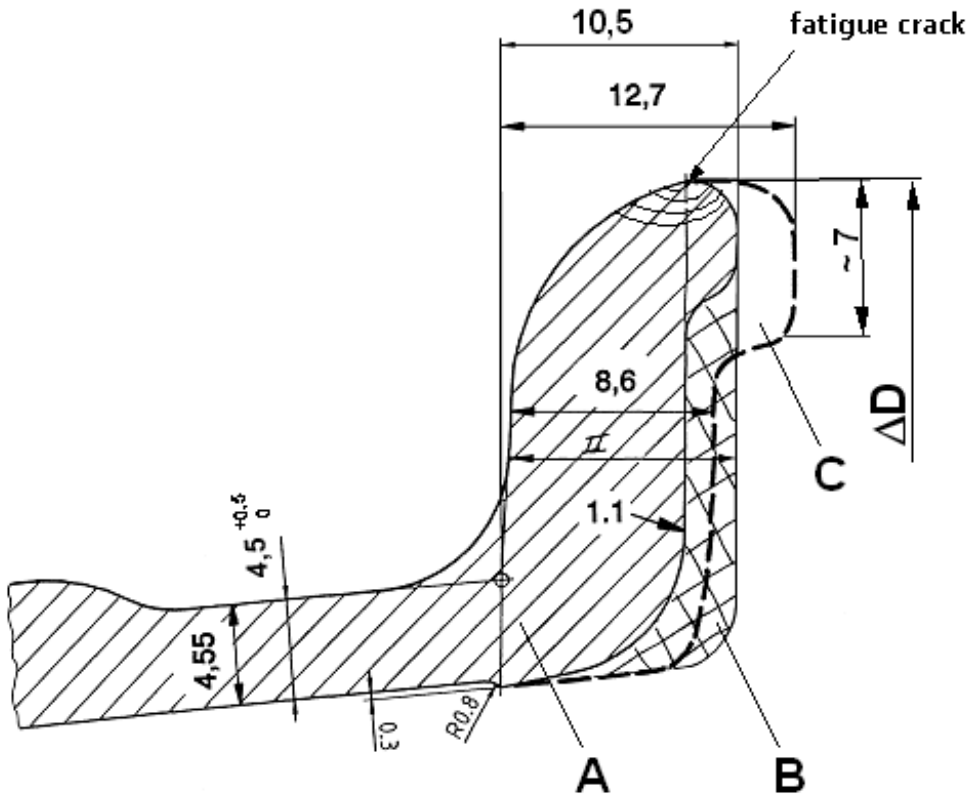
Influence of the Rim Design on Plastic Deformation and Durability

Design	Weight [kg]	Plastic * Deformation ΔD [mm]	Durability Test Life [km]
A	10.9	- 0.85	cracks at 4 979 ≈0.5
B	11	-0.55	cracks at 10 141 ≈1.0
C	11.35	-0.35	without cracks 14 920 >1.5



* After Preloading: $F_v = 2.5 \cdot F_{z,stat}$; $p_I = 0.6 \cdot p_{I,n}$

DIA 7299e

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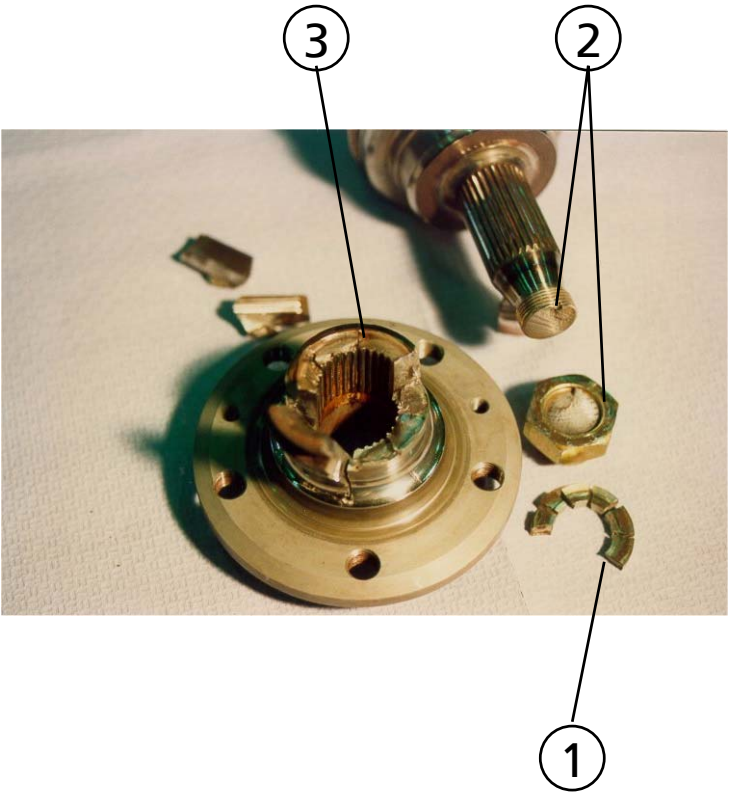
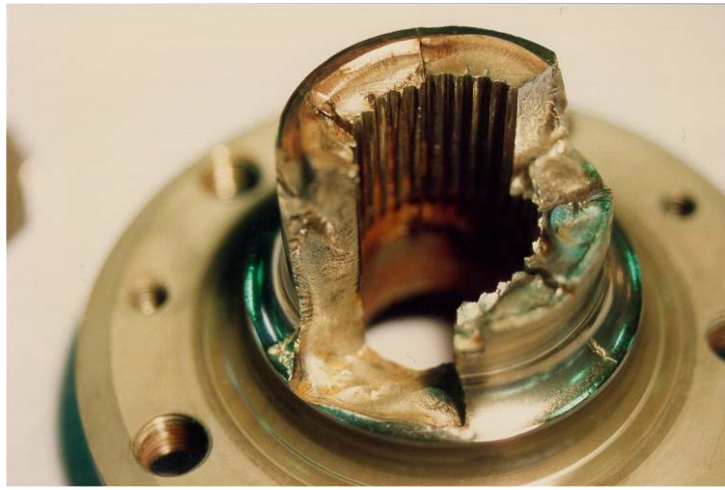
Fracture of Washer (1), Hub (3) and Drive Shaft (2)





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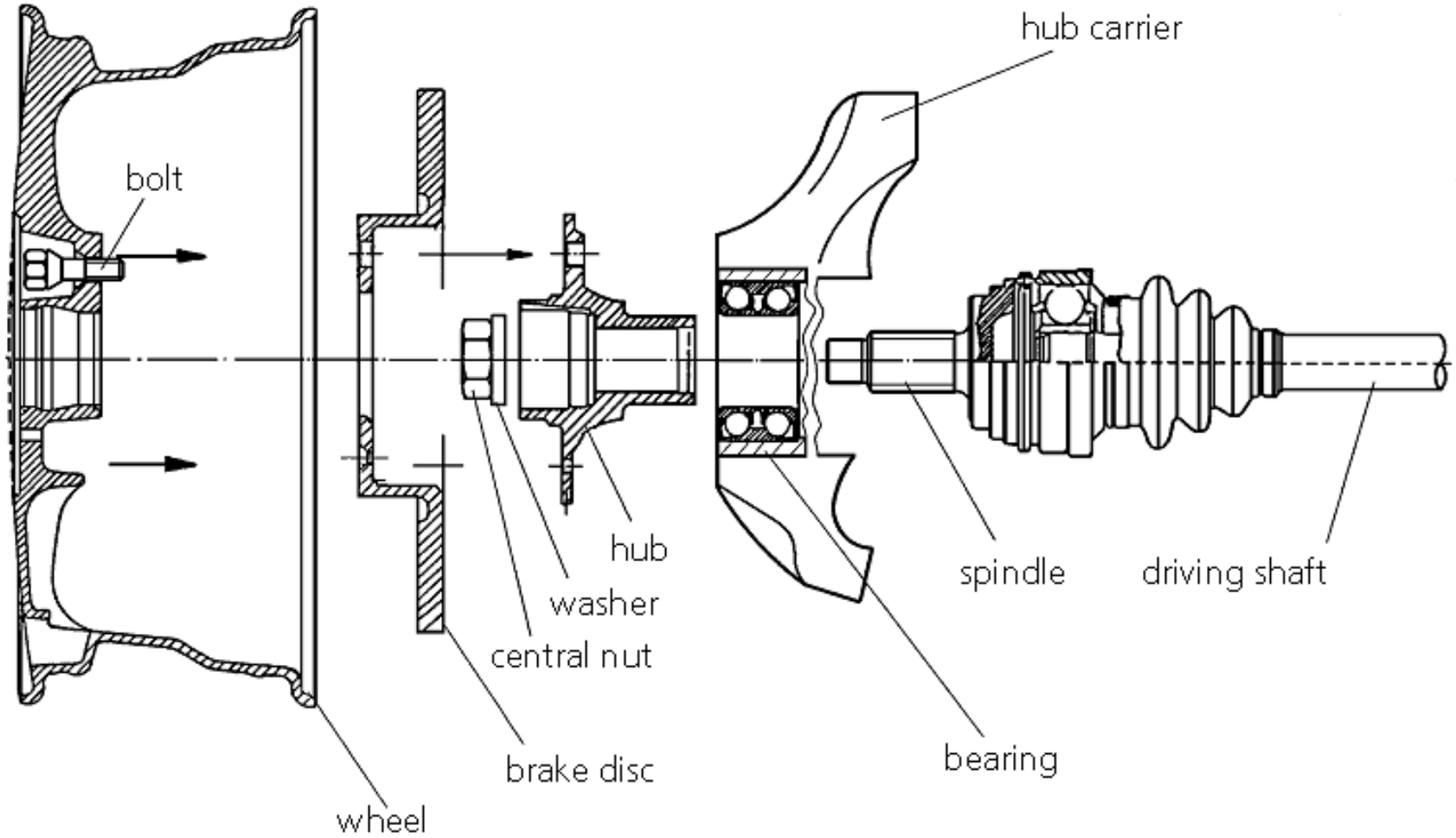
Assembly of Drive Wheel



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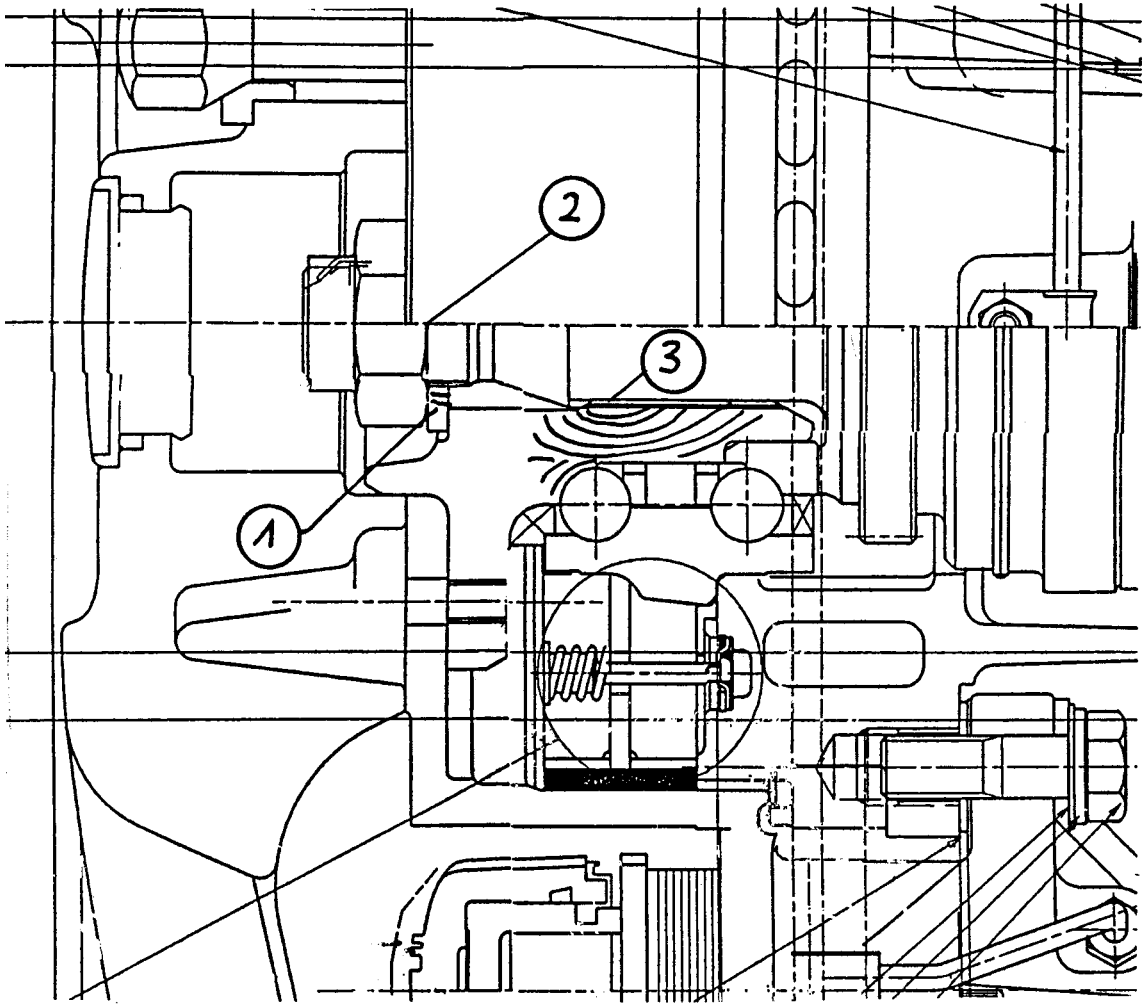
Fatigue Failure of Drive Wheel Assembly



1 **Washer**

2 **Spindle End**

3 **Hub**

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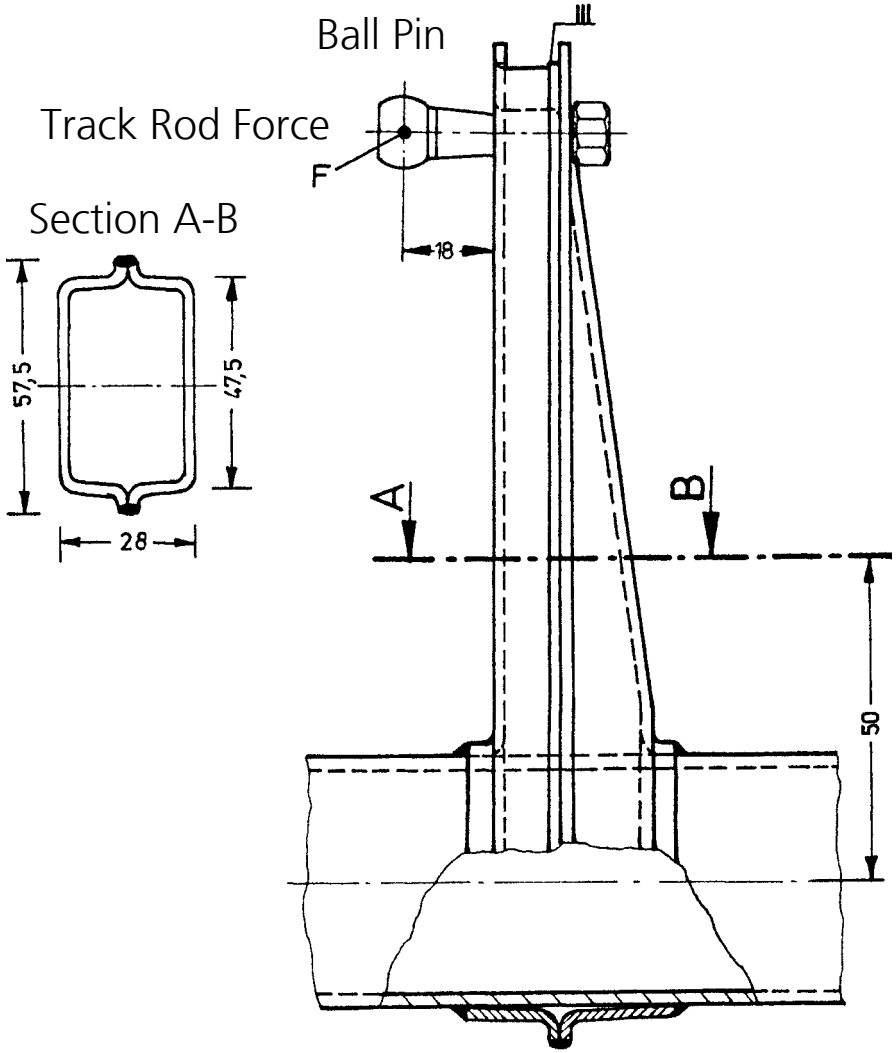
Steering-Knuckle Arm



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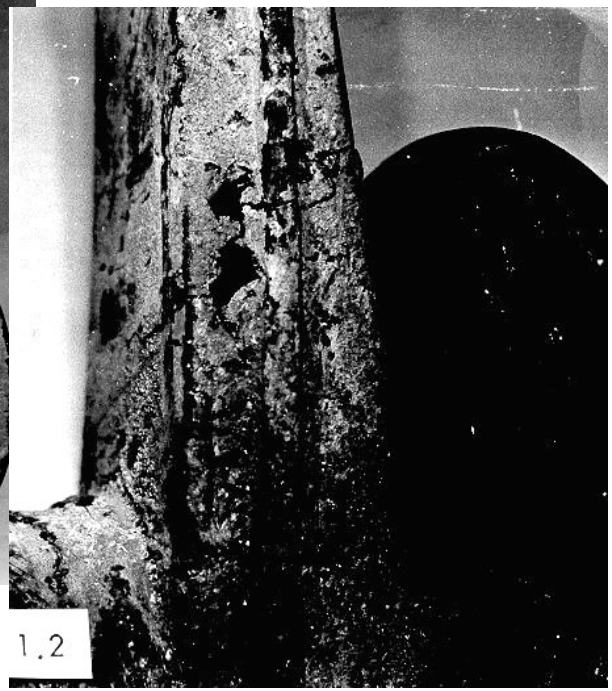
Typical Cracks on Steering-Knuckle Arms



rust out

corroded

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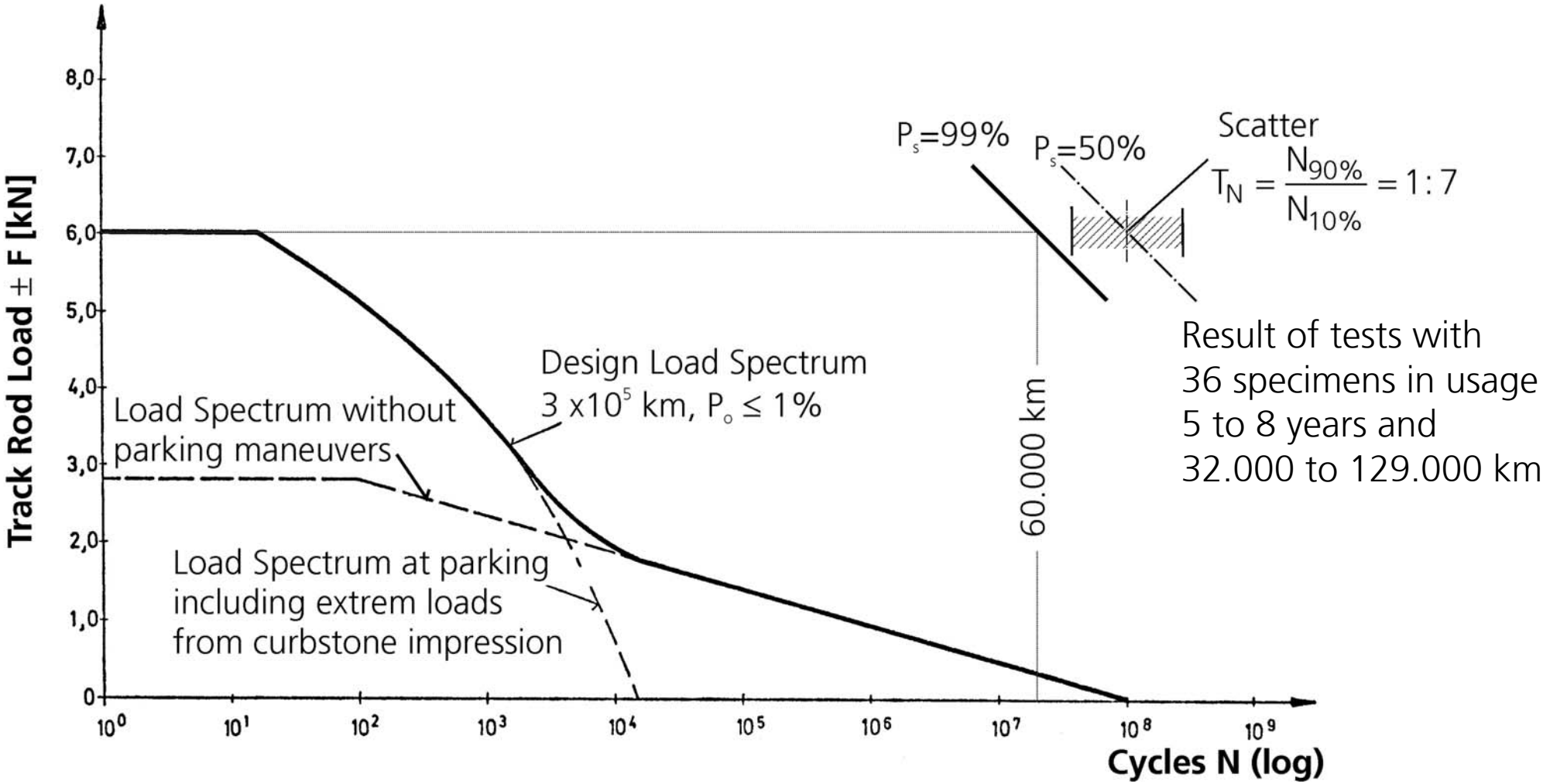
Design Load Spectrum and Test Results with corroded Steering-Knuckle Arms



Result of tests with
36 specimens in usage
5 to 8 years and
32.000 to 129.000 km

DIA 7339e

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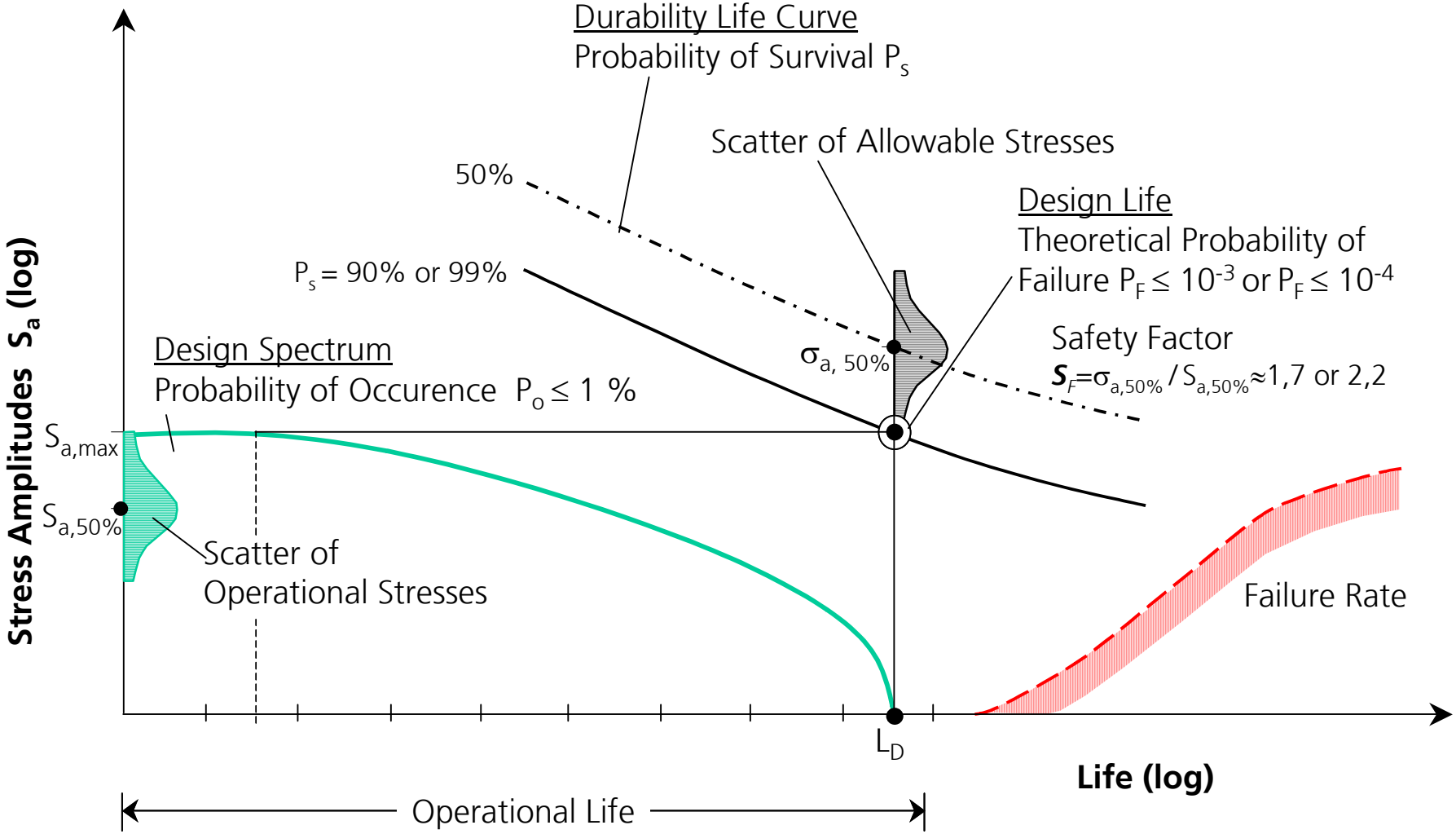
Reliability Requirements for Safety Components



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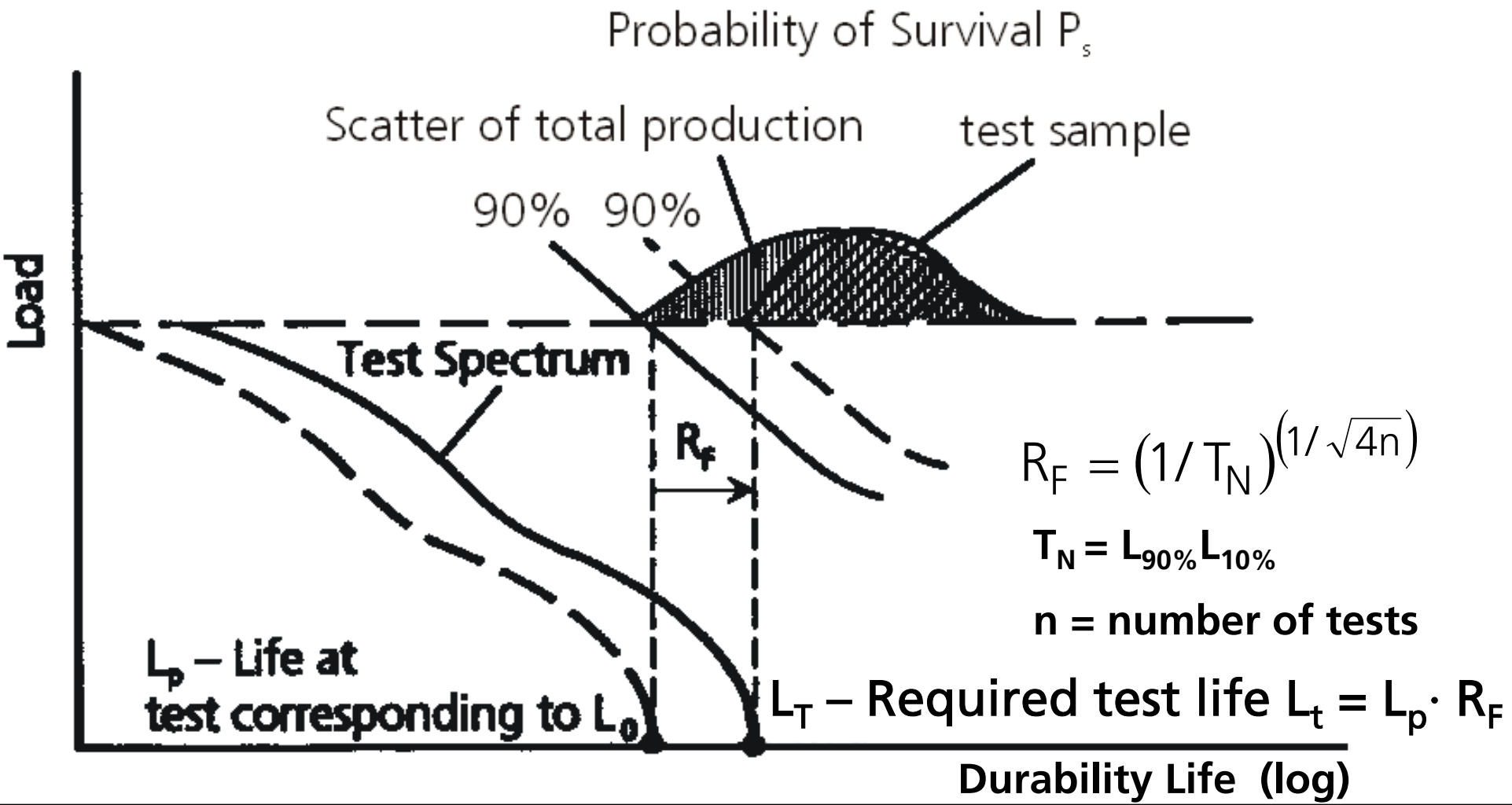
Realibility Requirements at Durability Life Approval



$$R_F = (1/T_N)^{(1/\sqrt{4n})}$$

$T_N = L_{90\%} L_{10\%}$

n = number of tests

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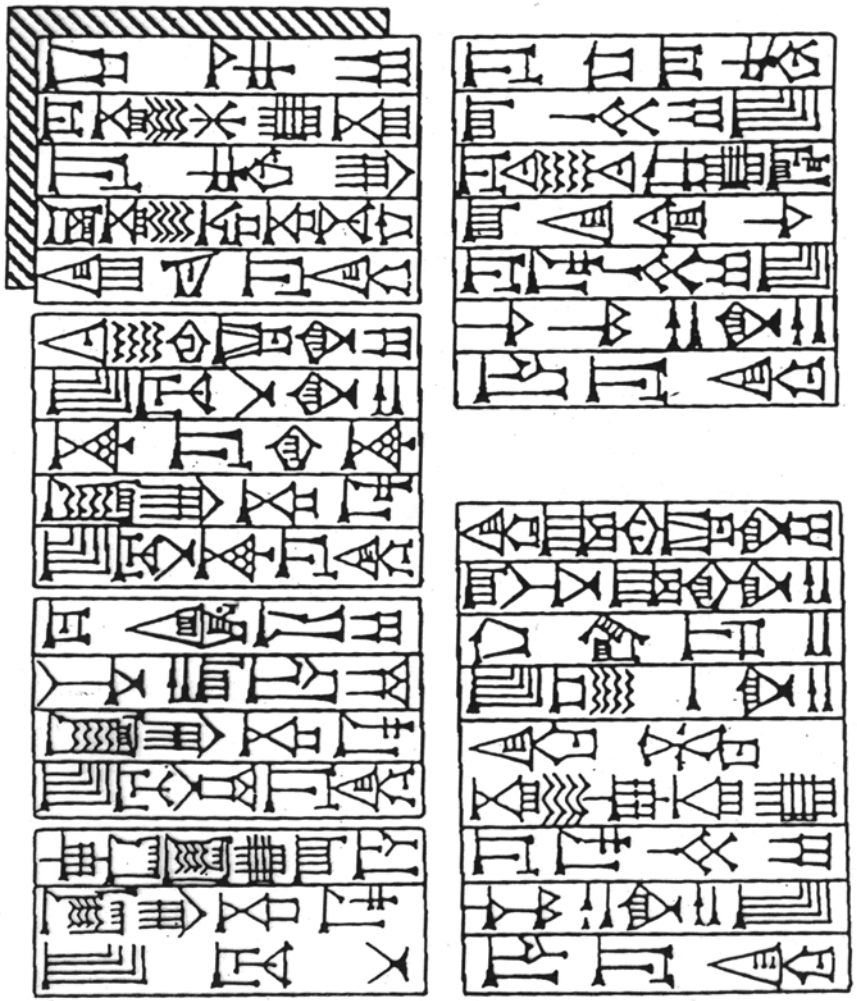
CODEX HAMMURABI (18 Century b.C.)



- If the wall of a house tumbles down, the house builder must repair it with a stronger wall on his own cost.

- If the house collapses because it is not properly built and his owner is killed, the house builder will be killed, too.

DIA 7296e

Fraunhofer LBF Institut Betriebsfestigkeit

In every development a certain amount of risk reamains. If we try to eliminate risks completely, it would be a totally unrealistic goal. But we have to take into account in the approach we apply to determine the operational strength and durability, whether or not a safety item is under consideration and to what degree the function of vehicle is influenced by possible failure. For such cases the procedures we apply have to **guarantee the whole functionability under operational usage and we are responsible for the methods we apply to prove it.**

Fraunhofer Institut Betriebsfestigkeit