PSAM 12

Probabilistic Safety Assessment & Management
Honolulu, Hawaii, USA

Stress-Dependent Weibull Shape Parameter Based on Field Data

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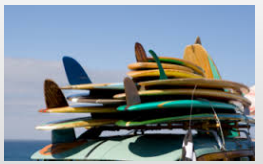
Motivation & Goal

→ One failure distribution

&

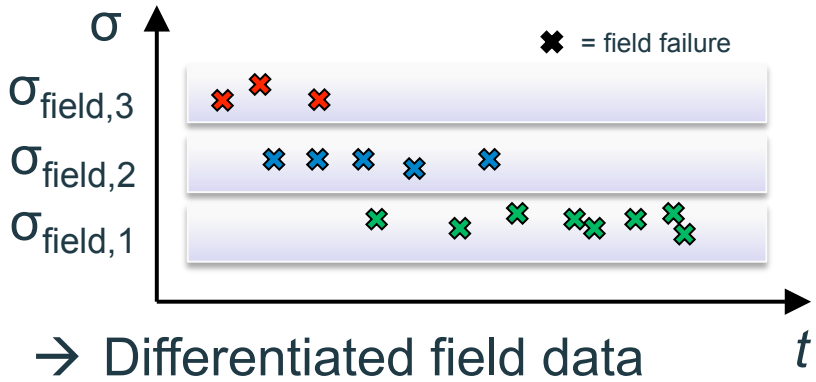
- Different customer behavior
  →different stress on product





- Stress-dependent *b*,
  →tendency: σ + *x* % → *b* = +/-?

Goal: Stress-dependent field data analysis



→ Differentiated field data

Link Weibull shape parameters to specific stress levels!

+ customer specific prediction of field reliability
+ Findings of product´s field behavior

Outline

- **Stress-Dependent Shape Parameter**
- Approach
- Applied Stress by the Customer
- Example
- Conclusion

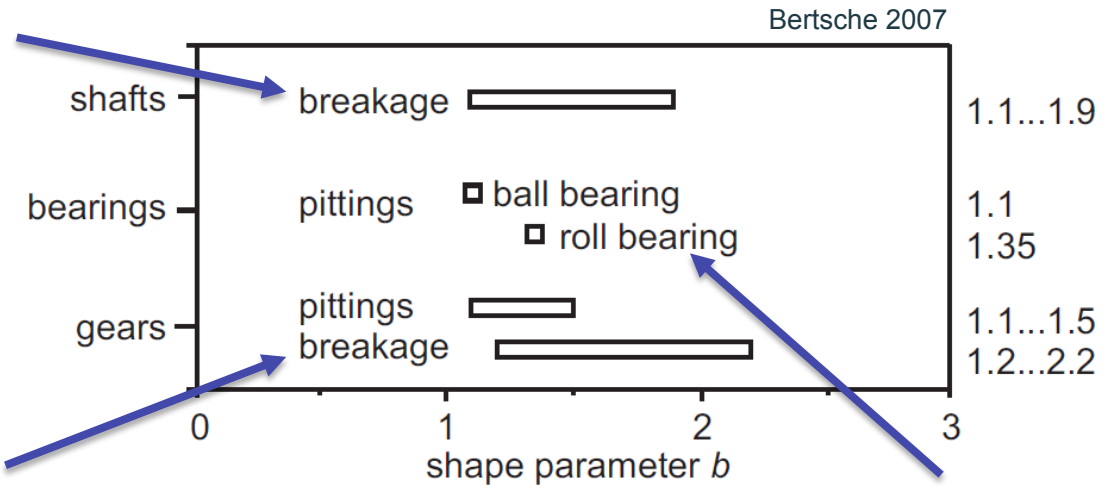
Stress-Dependent Shape Parameter (1/2)

Generally known from literature:

Meannig 1967
(*C35; fatigue*)

Nelson 2004
(*metal fatigue and roller bearing life*)

Beier 2010
(*plastic; fatigue and additional wear*),
Brodbeck 1995,
Groß 1974



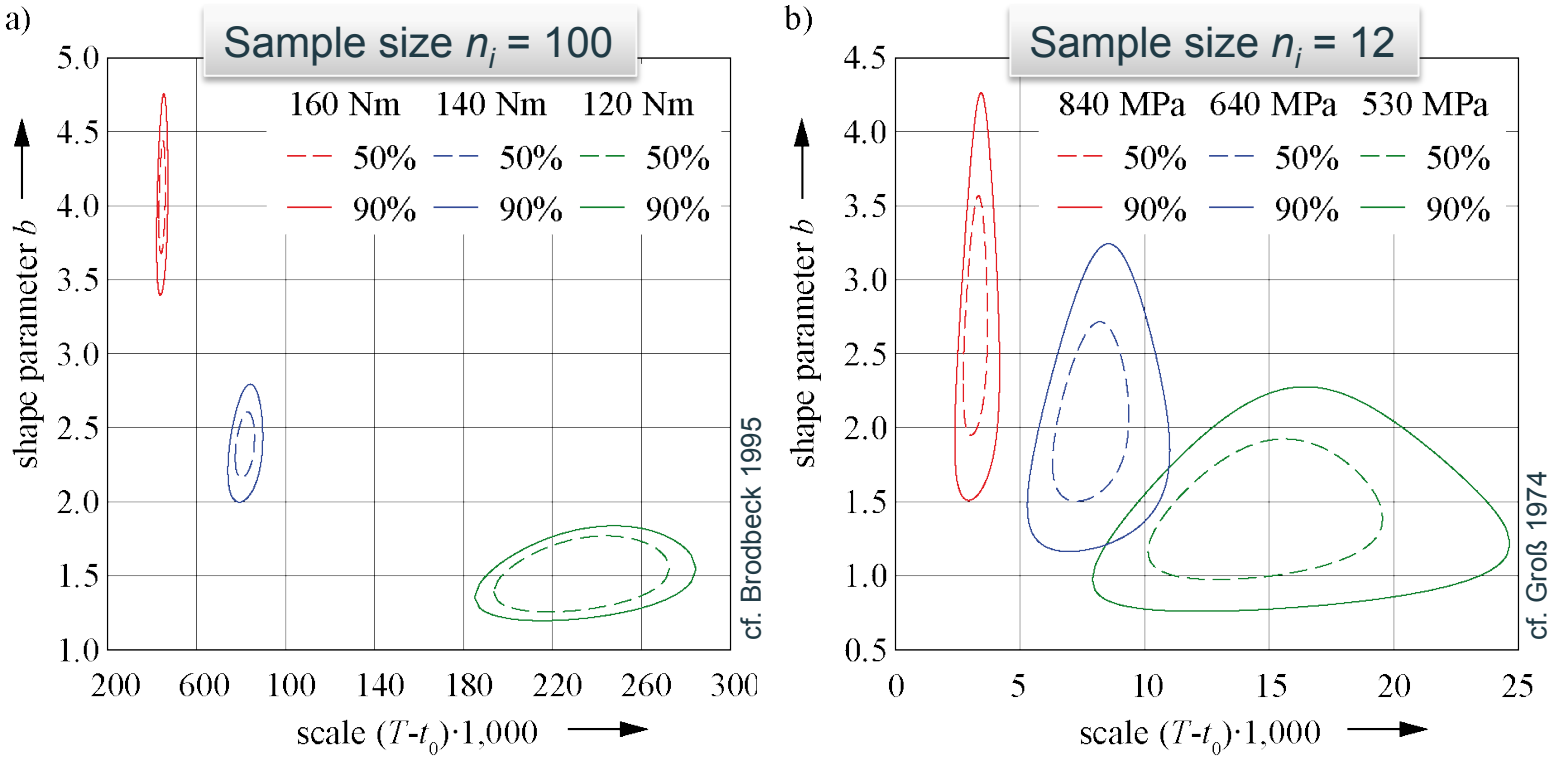
Bergling 1976
(*const. for simplification*)

higher stress → larger shape parameter *b*
lower stress → smaller shape parameter *b*

However, also a contrary dependence is observed: electrical insulations (Nelson 2004)

Stress-Dependent Shape Parameter (2/2)

Experience of historic test data of gears (fatigue crack):



Statistically proven stress-dependence of the Weibull shape parameter

Outline

- Stress-Dependent Shape Parameter
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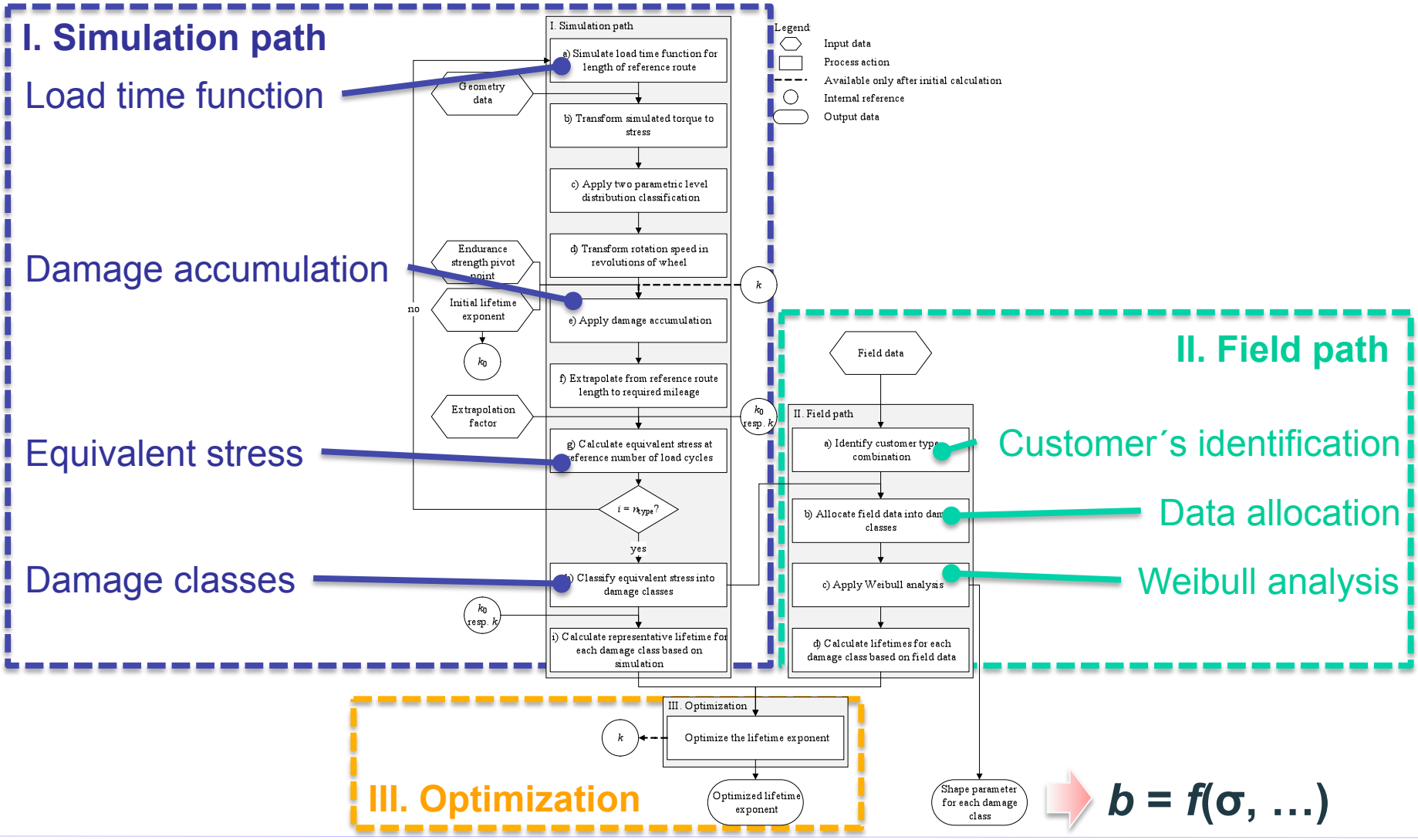
Approach


I. Simulation path
Load time function
Damage accumulation
Equivalent stress
Damage classes
I. Simulation path
a) Simulate load time function for length of reference route
Geometry data
b) Transform simulated torque to stress
c) Apply two parametric level distribution classification
d) Transform rotation speed in revolutions of wheel
Endurance strength pivot point
Initial lifetime exponent
k
no
e) Apply damage accumulation
k0
f) Extrapolate from reference route length to required mileage
Extrapolation factor
k0 resp. k
g) Calculate equivalent stress at reference number of load cycles
t = ntype?
yes
h) Classify equivalent stress into damage classes
k0 resp. k
i) Calculate representative lifetime for each damage class based on simulation
Legend
Input data
Process action
Available only after initial calculation
Internal reference
Output data
II. Field path
Field data
II. Field path
a) Identify customer type combination
b) Allocate field data into damage classes
c) Apply Weibull analysis
d) Calculate lifetimes for each damage class based on field data
Customer´s identification
Data allocation
Weibull analysis
III. Optimization
k
Optimize the lifetime exponent
Optimized lifetime exponent
III. Optimization
Shape parameter for each damage class
b = f(σ, …)

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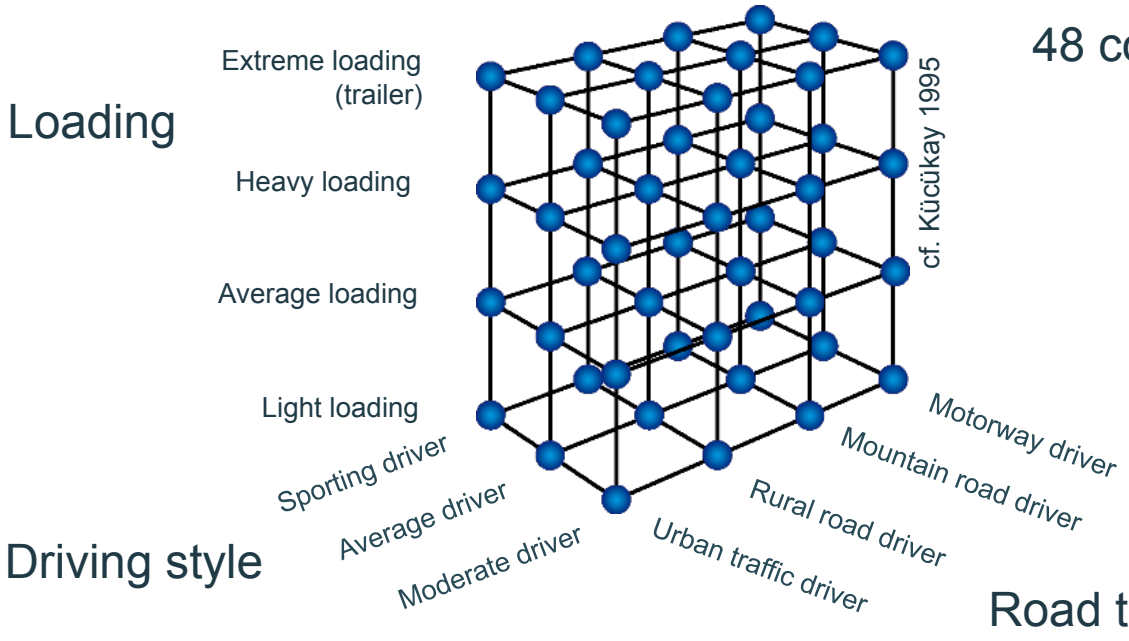
Applied Stress by the Customer (1/4)

Required Input:

- Failure information (product, mode, lifetime / mileage, etc.)
- Information about customer behavior

Customer Behavior´s Influence on Stress:



48 combinations of customer types
(→ type *i* with *i* = 1…48)

Up to 48 different stresses

Applied Stress by the Customer (2/4)

Identification of the Customer Type Combination of Interest:

1. **Representative mapping of all customers**
2. Single customer´s assessment

From statistical database [%]

Road type					Loading					Driving style			
Urban traffic driver	93	7	0	0	Light loading	94	6	0	0	Sporting driver	46	54	0
Rural road driver	4	92	0	4	Average loading	0	100	0	0	Average driver	6	86	8
Mountain road driver	10	50	30	10	Heavy loading	0	20	80	0	Moderate driver	5	10	85
Motorway driver	5	5	0	90	Extreme loading (trailer)	0	10	80	10				

cf. Müller-Kose 2002

e.g.: percentage amount p_c = motorway driver, a = urban traffic, statistics = 5 %

c … customer type
a … characteristic attribute

Applied Stress by the Customer (3/4)

Identification of the Customer Type Combination of Interest:

1. Representative mapping of all customers
2. **Single customer´s assessment**

From statistical database [%]

Road type					Loading					Driver											
Urban traffic driver	93	7	0	0	Light loading	94	6	0	0	Mr Smith	50	25	5	20	50	20	10	20	40	40	20
Rural road driver	4	92	0	4	Average loading	0	100	0	0	Average driver	6	86	8								
Mountain road driver	10	50	30	10	Heavy loading	0	20	80	0	Moderate driver	5	10	85								
Motorway driver	5	5	0	90	Extreme loading (trailer)	0	10														

From single customer [%]

cf. Müller-Kose 2002

Sum of square error Φ

e.g.: percentage amount p_c = motorway driver, a = urban traffic, statistics = 5 %

c … customer type
a … characteristic attribute

Applied Stress by the Customer (4/4)

Identification of the Customer Type Combination of Interest:

$$\sum_{a=1}^{n_a} \left(p_{c,a,\text{statistics}} - p_{c,a,\text{customer}}\right)^2 = \Phi_c$$

c … customer type
a … characteristic attribute

Customer [%]

Driver	Urban traffic	Rural road	Mountain road	Motorway
Mr Smith	50	25	5	20

Statistics [%]

Road type	Urban traffic	Rural road	Mountain road	Motorway
Urban traffic driver	93	7	0	0
Rural road driver	4	92	0	4
Mountain road driver	10	50	30	10
Motorway driver	5	5	0	90

Mr Smith

Road type	Urban traffic	Rural road	Mountain road	Motorway	Φ_c
Urban traffic driver	0,185	0,032	0,003	0,040	0,260
Rural road driver	0,212	0,449	0,003	0,026	0,689
Mountain road driver	0,160	0,063	0,063	0,010	0,295
Motorway driver	0,203	0,040	0,003	0,490	0,735

$$\min\left(\phi_{\text{road type}}\right) \wedge \min\left(\phi_{\text{loading}}\right) \wedge \min\left(\phi_{\text{driving style}}\right)$$ → **Combination of Interest**

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Example (1/2)

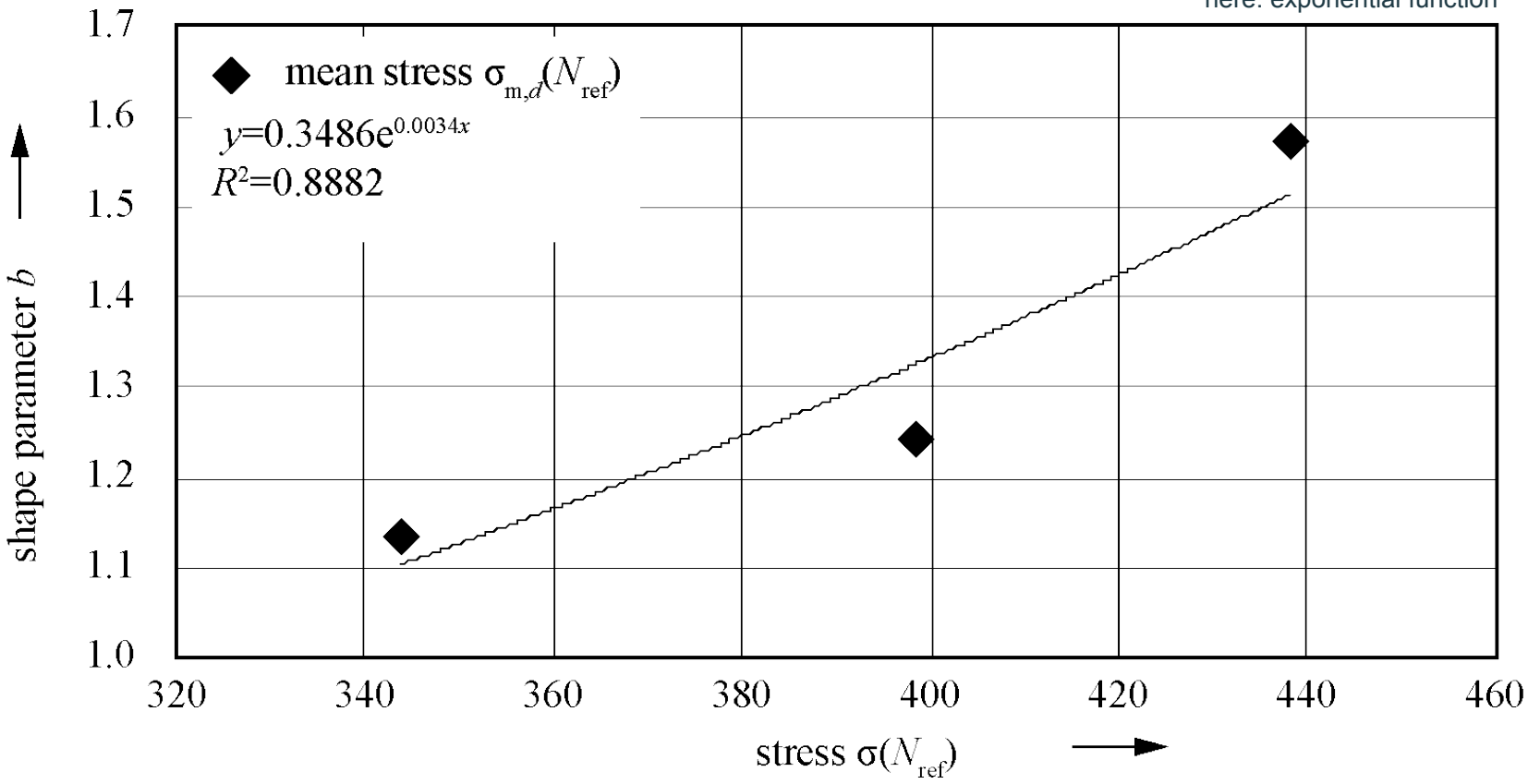
Synthetic example:

Assumed input data

	k_0	5	Initially assumed							
	k	4.884	After optimization (step III.)							
	σ_D	400								
	N_D	5.0E+07							N_{ref}	5.0E+07
			stress class 1		stress class 2					
step	type i	w_i	$\sigma_{i,1}$	$r_{i,1}$	$\sigma_{i,2}$	$r_{i,2}$	$D_{i,w}$	EF_i	D_i	$\sigma_i(N_{ref})$
I. e)-g)	1	8,000	420	300,000	500	250,000	0.022	25	0.562	355.5
	2	10,500	450	300,000	480	300,000	0.025	19	0.482	344.4
	3	10,000	420	300,000	450	350,000	0.020	20	0.401	331.8
	4	5,000	420	350,000	500	325,000	0.028	40	1.129	410.0
	5	5,500	450	350,000	480	300,000	0.027	36	0.984	398.7
	6	7,500	450	350,000	500	325,000	0.032	27	0.847	386.7
	7	6,000	500	300,000	550	400,000	0.056	33	1.858	454.1
	8	7,000	450	350,000	550	350,000	0.046	29	1.303	422.3
I. h)	n_d	3								
	d	1	2	3						
	$\sigma_{UL,d}$	372.5	413.3							
	$\sigma_{m,d}$	343.9	398.5	438.2						
I. i)	d_{ave}		2							
	$B_{50,d,sim}$	417,218	200,000	127,770						
II. c)	T_d	589,363	264,408	150,324	Estimated based on assumed field data					
	b_d	1.135	1.243	1.573						
II. d)	$B_{50,d,field}$	426,718	196,887	119,079						
III.	Φ	2.1E+08			Least square estimation					

Example (2/2)

here: exponential function



Weibull shape parameter as a funtion of stress

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Conclusion

- Approach enables stress-dependent analysis
  - Allocation of customer behavior to damage classes
  - Identification of “Customer Type Combination of Interest”
- More realistic reliability prediction for field applications

Thank you for your attention.

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