

Fatigue of Structures and Materials

Jaap Schijve

Fatigue of Structures and Materials

Second Edition with CD-Rom

 Springer

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The paper “Fatigue of structure and materials in the 20th century and the state of the art” has been reprinted with kind permission from *International Journal of Fatigue*, Elsevier, vol. 25, 2003, pp. 679–702.

ISBN-13: 978-1-4020-6807-2

e-ISBN-13: 978-1-4020-6808-9

Library of Congress Control Number: 2008942484

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Preface

Fatigue of structures and materials covers a wide scope of different topics. The purpose of the present book is to explain these topics, to indicate how they can be analyzed, and how this can contribute to the designing of fatigue resistant structures and to prevent structural fatigue problems in service.

Chapter 1 gives a general survey of the topic with brief comments on the significance of the aspects involved. This serves as a kind of a program for the following chapters. The central issues in this book are predictions of fatigue properties and designing against fatigue. These objectives cannot be realized without a physical and mechanical understanding of all relevant conditions. In Chapter 2 the book starts with basic concepts of what happens in the material of a structure under cyclic loads. It illustrates the large number of variables which can affect fatigue properties and it provides the essential background knowledge for subsequent chapters. Different subjects are presented in the following main parts:

- Basic chapters on fatigue properties and predictions (Chapters 2–8)
- Load spectra and fatigue under variable-amplitude loading (Chapters 9–11)
- Fatigue tests and scatter (Chapters 12 and 13)
- Special fatigue conditions (Chapters 14–17)
- Fatigue of joints and structures (Chapters 18–20)
- Fiber-metal laminates (Chapter 21)

Each chapter presents a discussion of a specific subject. The major aspects are recapitulated in the last section of a chapter, not as a summary, but just as the most important points to remember. In spite of a qualitatively good understanding of the fatigue phenomenon in structural elements, the quantitative accuracy of the prediction of fatigue properties can still be limited. As a consequence, it is important that all relevant issues are well recognized and understood. This was one of the major reasons for writing

the present textbook. Knowledge of the fatigue mechanism in the material and how it can be affected by a large variety of practical conditions is of the utmost importance. The designer of a dynamically loaded structure should “design against fatigue”. This approach includes not only the overall concept of the structure with related safety and economic aspects, but also questions on detail design, material surface quality, and joints. At the same time, the designer should try to predict the fatigue performance of a structure, fatigue limits, fatigue lives until crack initiation and the remaining life covered by crack growth until final failure. The approach requires a profound knowledge of the various influencing factors, also because predictions on fatigue properties have their limitations and shortcomings.

The first edition of the present book was published in 2001. It has been used for university courses and several courses with participants from industry, universities, research institutes, official agencies, and teachers of technical schools. Experience has shown that the book is generally appreciated as a textbook for basic knowledge about fatigue, but also for design applications and research programs. A new feature of the present edition is the CD-rom included in this book. The first part of the CD with exercises and summaries will be useful for students and teachers, and also for self-tuition. A number of instructive case histories on fatigue problems in service is covered in the second part of the CD. The third part includes aspects of designing against fatigue and planning experimental fatigue studies. In the last part personal reflections are presented on possible research of fatigue problems in the future.

References to the literature are added to each chapter, but the number of references is much smaller than usual for a monograph. Literature sources from which results or figures have been used in this book are listed at the end of each chapter. The lists are supplemented by a small number of general references, mainly books and conference proceedings. However, research workers who want to investigate specific problems in detail should access computerized retrieval systems.

After working for more than 40 years on fatigue problems, I finally had time to write the first edition of the present book, which was published in 2001. In the present edition, written seven years later, the text of all chapters has been carefully screened and corrected, but the fundamental information is still the same. However, the chapter on “Designing against Fatigue of Structures” (Chapter 19 in the first edition) has been replaced by a completely newly written text which is Chapter 20 in the present edition.

Another difference with the first edition is the CD-rom now attached to the book, which gives the reader more opportunity to work with the material

offered and to guide and stimulate new work in this field. I trust that the present edition will be helpful for everybody engaged in fatigue of structures and materials, and also for a new generation of students.

Jaap Schijve

Delft, October 2008

Acknowledgments

For a period of 20 years I have been working in the Structures and Materials Division of the National Aerospace Laboratory NLR in Amsterdam and in the North-Eastpolder, and for another 20 years in the Structures and Materials Laboratory of the Faculty of Aerospace Engineering of the Delft University of Technology until my formal retirement. In both laboratories it was a cooperation with many people in a stimulating atmosphere. It is great to carry out investigations with colleagues and technicians who understand the essence of the fatigue experiments and microscopical examinations, too many to mention all their names. But I will make a single exception for Frans Oosterom for the indispensable assistance with microscopy and photography. It was also very stimulating to work together with many undergraduate and post-graduate students, eager to arrive at answers for unsolved questions. We shared various challenges, and at the same time a kind of a family relationship. Thanks to my successors, this continued after my retirement, first through professor Boud Voogesang, afterwards the late professor Ad Vlot who most regretfully died young, and at the moment professor Rinze Benedictus. All three were fine colleagues always available for discussion. Informal brainstorming with many people was often the elixir of new ideas and progress.

With respect to preparing the manuscript for the first edition of this book, I want to acknowledge the unselfish help of Dr. Scott Fawaz, who did the work for his doctoral thesis in Delft. He read every chapter and suggested various improvements and corrections. The same was done by the late professor Hans Overbeeke of the Technical University of Eindhoven. Significant support was given by Harry van Lipzig, my first student in Delft, and now responsible for various post-academic courses on fatigue of structures.

For the second edition of this textbook I want to express my appreciation to Dr. René Alderliesten (Delft University) and Professor Malgorzata Skorupa (University of Mining and Metallurgy, Krakow) for useful comments on specific chapters of the book.

Publishing the book was a joint effort between the author and Springer Science+Business Media. I gratefully acknowledge the pleasant and effective cooperation with Mrs Nathalie Jacobs and Anneke Pot, who were concerned with getting the book printed, and Mrs. Jolanda Karada who arranged the typesetting of the book and figures, and suggested text improvements. It was really a great help.

Last but not least, without Janine, my love for uncountable years, this book would not exist. In addition of creating the circumstances which allowed me to write the book, her comments and questions about my work were meaningful.

Jaap Schijve
Delft, October 2008

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Symbols, Acronyms and Units

Symbols

a	crack length, or semi-crack length, or depth of part through crack
a_0	initial crack length
a, b	semi-axes of ellipse
a_f	final crack length
c	(semi) crack length of surface crack
C	constant in Paris equation
D	diameter Also: damage parameter
da/dN	crack growth rate
dU/da	strain energy release rate
E	Young's modulus
G	shear modulus
k	slope factor in Basquin relation, or irregularity factor of random load
K	stress intensity factor
ΔK	$= K_{\max} - K_{\min}$
ΔK_{th}	threshold ΔK (Figure 8.6)
K_{op}	K at S_{op}
ΔK_{eff}	$= K_{\max} - K_{\text{op}}$
K_f	fatigue strength reduction factor
K_{Ic}	fracture toughness
K_t	stress concentration factor
l	crack length from edge of notch
m	exponent in Paris equation
M	bending moment
M_t	torsion moment
n	number of cycles
N	fatigue life until failure
P	load
$p(x)$	probability density function
$P(x)$	distribution function
r	root radius of notch Also: polar coordinate
r_p	plastic zone size
R	stress ratio $= S_{\min}/S_{\max}$

S	nominally applied (gross) stress
S_1, S_2	biaxial stresses
S_a	stress amplitude
S_f	fatigue limit
S_{f1}	fatigue limit, unnotched specimen
S_{fk}	fatigue limit, notched specimen
S_m	mean stress
S_N	fatigue strength at fatigue life N
S_{op}	crack opening stress
S_{res}	residual stress
S_U	tensile strength of a material
$S_{0.2}$	yield strength of a material
ΔS	$= S_{max} - S_{min}$
ΔS_{eff}	$= S_{max} - S_{op}$
t	thickness Also: time
T	temperature
u, v, w	displacements in x, y, z direction
W	width
β	geometry factor in $K = \beta S \sqrt{\pi a}$
γ	surface roughness reduction factor
ε	strain
θ	polar coordinate
λ	biaxiality ratio (S_1/S_2)
ν	Poisson ratio
ρ	tip radius of notch
σ	local stress in material
$\sigma_{\log N}$	standard deviation of $\log N$
σ_a	stress amplitude
σ_m	mean stress
$\sigma_{nominal}$	nominal stress in net section
σ_{peak}	peak stress at notch
σ_{res}	residual stress
τ	shear stress
ϕ	location angle in ellipse (Figure 5.16)
ω	circular frequency in radian per second

Acronyms

CA	constant-amplitude
CCT	centered cracked tension (specimen)
COD	crack opening displacement
CT	compact tension (specimen)
M(T)	centered cracked tension (specimen)
OL	overload

PD	potential drop
VA	variable-amplitude
UL	underload

Units and conversion factors

1 meter (m) = 10^3 millimeters (mm) = 10^6 microns (μm)

1 inch = 25.4 mm, 1 mm = 0.04 inch

Stress: 1 MPa = 10^6 Pascal (1 Pascal = 1 Newton/m²)

1 ksi = 6.90 MPa, 1 MPa = 0.145 ksi

Stress intensity factor: 1 MPa $\sqrt{\text{m}}$ = 0.910 ksi $\sqrt{\text{in}}$, 1 ksi $\sqrt{\text{in}}$ = 1.099 MPa $\sqrt{\text{m}}$

1 kc = 1000 cycles