



Prof. Dr.-Ing. Dietmar Gross

received his Engineering Diploma in Applied Mechanics and his Doctor of Engineering degree at the University of Rostock. He was Research Associate at the University of Stuttgart and since 1976 he is Professor of Mechanics at the University of Darmstadt. His research interests are mainly focused on modern solid mechanics on the macro and micro scale, including advanced materials



Prof. Dr. Werner Hauger

studied Applied Mathematics and Mechanics at the University of Karlsruhe and received his Ph.D. in Theoretical and Applied Mechanics from Northwestern University in Evanston. He worked in industry for several years, was a Professor at the Helmut-Schmidt-University in Hamburg and went to the University of Darmstadt in 1978. His research interests are, among others, theory of stability, dynamic plasticity and biomechanics.



Prof. Dr.-Ing. Jörg Schröder

studied Civil Engineering, received his doctoral degree at the University of Hannover and habilitated at the University of Stuttgart. He was Professor of Mechanics at the University of Darmstadt and went to the University of Duisburg-Essen in 2001. His fields of research are theoretical and computer-oriented continuum mechanics, modeling of functional materials as well as the further development of the finite element method.



Prof. Dr.-Ing. Wolfgang A. Wall

studied Civil Engineering at Innsbruck University and received his doctoral degree from the University of Stuttgart. Since 2003 he is Professor of Mechanics at the TU München and Head of the Institute for Computational Mechanics. His research interests cover broad fields in computational mechanics, including both solid and fluid mechanics. His recent focus is on multiphysics and multiscale problems as well as computational biomechanics.



Prof. Nimal Rajapakse

studied Civil Engineering at the University of Sri Lanka and received Doctor of Engineering from the Asian Institute of Technology in 1983. He was Professor of Mechanics and Department Head at the University of Manitoba and at the University of British Columbia. He is currently Dean of Applied Sciences at Simon Fraser University in Vancouver. His research interests include mechanics of advanced materials and geomechanics.

Dietmar Gross • Werner Hauger
Jörg Schröder • Wolfgang A. Wall
Nimal Rajapakse

Engineering Mechanics 1

Statics

2nd Edition

 Springer

Prof. Dr. Dietmar Gross
TU Darmstadt
Solid Mechanics
Hochschulstr. 1
64289 Darmstadt, Germany
gross@mechanik.tu-darmstadt.de

Prof. Dr. Wolfgang A. Wall
TU München
Computational Mechanics
Boltzmannstr. 15
85747 Garching, Germany
wall@lnm.mw.tum.de

Prof. Dr. Werner Hauger
TU Darmstadt
Continuum Mechanics
Hochschulstr. 1
64289 Darmstadt, Germany

Prof. Nimal Rajapakse
Faculty of Applied Sciences
Simon Fraser University
8888 University Drive
Burnaby, V5A 1S6
Canada

Prof. Dr. Jörg Schröder
Universität Duisburg-Essen
Institute of Mechanics
Universitätsstr. 15
45141 Essen, Germany
j.schroeder@uni-due.de

ISBN 978-3-642-30318-0

e-ISBN 978-3-642-30319-7

DOI 10.1007/978-3-642-30319-7

Springer Dordrecht Heidelberg New York London

Library of Congress Control Number: 2012941504

© Springer Science+Business Media Dordrecht 2009, 2013

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Statics is the first volume of a three-volume textbook on Engineering Mechanics. Volume 2 deals with *Mechanics of Materials*; Volume 3 contains *Particle Dynamics and Rigid Body Dynamics*. The original German version of this series is the bestselling textbook on mechanics for nearly three decades and its 11th edition has already been published.

It is our intention to present to engineering students the basic concepts and principles of mechanics in the clearest and simplest form possible. A major objective of this book is to help the students to develop problem solving skills in a systematic manner.

The book developed out of many years of teaching experience gained by the authors while giving courses on engineering mechanics to students of mechanical, civil and electrical engineering. The contents of the book correspond to the topics normally covered in courses on basic engineering mechanics at universities and colleges. The theory is presented in as simple a form as the subject allows without being imprecise. This approach makes the text accessible to students from different disciplines and allows for their different educational backgrounds. Another aim of the book is to provide students as well as practising engineers with a solid foundation to help them bridge the gaps between undergraduate studies, advanced courses on mechanics and practical engineering problems.

A thorough understanding of the theory cannot be acquired by merely studying textbooks. The application of the seemingly simple theory to actual engineering problems can be mastered only if the student takes an active part in solving the numerous examples in this book. It is recommended that the reader tries to solve the problems independently without resorting to the given solutions. To demonstrate the principal way of how to apply the theory we deliberately placed no emphasis on numerical solutions and numerical results.

As a special feature the textbook offers the TM-Tools. Students may solve various problems of mechanics using these tools. They can be found at the web address <www.springer.com/engineering/grundlagen/tm-tools>.

In the second edition the text was revised and part of the notation was changed to make it compatible with the usual notation in English speaking countries. To provide the students with more material to develop their skills in solving problems, additional Supplementary Examples are supplied.

We gratefully acknowledge the support and the cooperation of the staff of Springer who were responsive to our wishes and helped to create the present layout of the books.

Darmstadt, Essen, Munich and Vancouver,
Summer 2012

D. Gross
W. Hauger
J. Schröder
W.A. Wall
N. Rajapakse

Table of Contents

Introduction	1
1 Basic Concepts	
1.1 Force	7
1.2 Characteristics and Representation of a Force	7
1.3 The Rigid Body	9
1.4 Classification of Forces, Free-Body Diagram	10
1.5 Law of Action and Reaction	13
1.6 Dimensions and Units	14
1.7 Solution of Statics Problems, Accuracy	16
1.8 Summary	18
2 Forces with a Common Point of Application	
2.1 Addition of Forces in a Plane.....	21
2.2 Decomposition of Forces in a Plane, Representation in Cartesian Coordinates	25
2.3 Equilibrium in a Plane	29
2.4 Examples of Coplanar Systems of Forces.....	30
2.5 Concurrent Systems of Forces in Space	38
2.6 Supplementary Problems	44
2.7 Summary	49
3 General Systems of Forces, Equilibrium of a Rigid Body	
3.1 General Systems of Forces in a Plane.....	53
3.1.1 Couple and Moment of a Couple	53
3.1.2 Moment of a Force	57
3.1.3 Resultant of Systems of Coplanar Forces	59
3.1.4 Equilibrium Conditions.....	62
3.2 General Systems of Forces in Space.....	71
3.2.1 The Moment Vector.....	71
3.2.2 Equilibrium Conditions.....	77
3.3 Supplementary Problems	83
3.4 Summary	88
4 Center of Gravity, Center of Mass, Centroids	
4.1 Center of Forces.....	91

VIII

4.2	Center of Gravity and Center of Mass	94
4.3	Centroid of an Area	100
4.4	Centroid of a Line	110
4.5	Supplementary Problems	112
4.6	Summary	116
5	Support Reactions	
5.1	Plane Structures	119
5.1.1	Supports	119
5.1.2	Statical Determinacy	122
5.1.3	Determination of the Support Reactions	125
5.2	Spatial Structures	127
5.3	Multi-Part Structures	130
5.3.1	Statical Determinacy	130
5.3.2	Three-Hinged Arch	136
5.3.3	Hinged Beam	139
5.3.4	Kinematical Determinacy	142
5.4	Supplementary Problems	145
5.5	Summary	150
6	Trusses	
6.1	Statically Determinate Trusses	153
6.2	Design of a Truss	155
6.3	Determination of the Internal Forces	158
6.3.1	Method of Joints	158
6.3.2	Method of Sections	163
6.4	Supplementary Problems	167
6.5	Summary	171
7	Beams, Frames, Arches	
7.1	Stress Resultants	175
7.2	Stress Resultants in Straight Beams	180
7.2.1	Beams under Concentrated Loads	180
7.2.2	Relationship between Loading and Stress Resultants	188
7.2.3	Integration and Boundary Conditions	190
7.2.4	Matching Conditions	195

7.2.5	Pointwise Construction of the Diagrams	200
7.3	Stress Resultants in Frames and Arches.....	205
7.4	Stress Resultants in Spatial Structures	211
7.5	Supplementary Problems	215
7.6	Summary	220
8	Work and Potential Energy	
8.1	Work and Potential Energy	223
8.2	Principle of Virtual Work.....	229
8.3	Equilibrium States and Forces in Nonrigid Systems.....	231
8.4	Reaction Forces and Stress Resultants.....	237
8.5	Stability of Equilibrium States.....	242
8.6	Supplementary Problems	253
8.7	Summary	258
9	Static and Kinetic Friction	
9.1	Basic Principles	261
9.2	Coulomb Theory of Friction	263
9.3	Belt Friction	273
9.4	Supplementary Problems	278
9.5	Summary	283
A	Vectors, Systems of Equations	
A.1	Vectors.....	286
A.1.1	Multiplication of a Vector by a Scalar	289
A.1.2	Addition and Subtraction of Vectors.....	289
A.1.3	Dot Product	290
A.1.4	Vector Product (Cross-Product).....	291
A.2	Systems of Linear Equations.....	293
Index	299