

Ferdinand P. Beer ■ E. Russell Johnston, Jr. ■ Elliot R. Eisenberg

VECTOR MECHANICS *for* ENGINEERS

Statics

Eighth Edition

MCGRAW-HILL NOT FOR RESALE
DONATION 09ASAD9



About the Authors

As publishers of the books by Ferd Beer and Russ Johnston, we are often asked how they happened to write their books together with one of them at Lehigh and the other at the University of Connecticut.

The answer to this question is simple. Russ Johnston's first teaching appointment was in the Department of Civil Engineering and Mechanics at Lehigh University. There he met Ferd Beer, who had joined that department two years earlier and was in charge of the courses in mechanics.

Ferd was delighted to discover that the young man who had been hired chiefly to teach graduate structural engineering courses was not only willing but eager to help him reorganize the mechanics courses. Both believed that these courses should be taught from a few basic principles and that the various concepts involved would be best understood and remembered by the students if they were presented to them in a graphic way. Together they wrote lecture notes in statics and dynamics, to which they later added problems they felt would appeal to future engineers, and soon they produced the manuscript of the first edition of *Mechanics for Engineers* that was published in June 1956.

The second edition of *Mechanics for Engineers* and the first edition of *Vector Mechanics for Engineers* found Russ Johnston at Worcester Polytechnic Institute and the next editions at the University of Connecticut. In the meantime, both Ferd and Russ assumed administrative responsibilities in their departments, and both were involved in research, consulting, and supervising graduate students—Ferd in the area of stochastic processes and random vibrations and Russ in the area of elastic stability and structural analysis and design. However, their interest in improving the teaching of the basic mechanics courses had not subsided, and they both taught sections of these courses as they kept revising their texts and began writing the manuscript of the first edition of their *Mechanics of Materials* text.

Their collaboration spanned more than half a century and many successful revisions of all of their textbooks, and Ferd's and Russ's contributions to engineering education have earned them a number of honors and awards. They were presented with the Western Electric Fund Award for excellence in the instruction of engineering students by their respective regional sections of the American Society for Engineering Education, and they both received the Distinguished Educator Award from the Mechanics Division of the same society. Starting in 2001, the New Mechanics Educator Award of the Mechanics Division has been named in honor of the Beer and Johnston author team.

Ferdinand P. Beer. Born in France and educated in France and Switzerland, Ferd received an M.S. degree from the Sorbonne and an Sc.D. degree in theoretical mechanics from the University of Geneva. He came to the United States after serving in the French army during the early part of World War II and taught for four years at Williams College in the Williams-MIT joint arts and engineering program. Following his service at Williams College, Ferd joined the faculty of Lehigh University where he taught for thirty-seven years. He held several positions, including University Distinguished Professor and chairman of the Department of Mechanical Engineering and Mechanics, and in 1995 Ferd was awarded an honorary Doctor of Engineering degree by Lehigh University.

E. Russell Johnston, Jr. Born in Philadelphia, Russ holds a B.S. degree in civil engineering from the University of Delaware and an Sc.D. degree in the field of structural engineering from the Massachusetts Institute of Technology. He taught at Lehigh University and Worcester Polytechnic Institute before joining the faculty of the University of Connecticut where he held the position of chairman of the Department of Civil Engineering and taught for twenty-six years. In 1991 Russ received the Outstanding Civil Engineer Award from the Connecticut Section of the American Society of Civil Engineers.

Elliot R. Eisenberg. Elliot holds a B.S. degree in engineering and an M.E. degree, both from Cornell University. He has focused his scholarly activities on professional service and teaching, and he was recognized for this work in 1992 when the American Society of Mechanical Engineers awarded him the Ben C. Sparks Medal for his contributions to mechanical engineering and mechanical engineering technology education and for service to the American Society for Engineering Education. Elliot taught for thirty-two years, including twenty-nine years at Penn State where he was recognized with awards for both teaching and advising.

David F. Mazurek. David holds a B.S. degree in ocean engineering and an M.S. degree in civil engineering from the Florida Institute of Technology and a Ph.D. degree in civil engineering from the University of Connecticut. He was employed by the Electric Boat Division of General Dynamics Corporation and taught at Lafayette College prior to joining the U.S. Coast Guard Academy, where he has been since 1990. He has served on the American Railway Engineering and Maintenance of Way Association's Committee 15—Steel Structures for the past fourteen years. His professional interests include bridge engineering, tall towers, structural forensics, and blast-resistant design.

Contents

Preface xii

List of Symbols xviii

1

INTRODUCTION

1

- 1.1 What Is Mechanics? 2
- 1.2 Fundamental Concepts and Principles 2
- 1.3 Systems of Units 5
- 1.4 Conversion from One System of Units to Another 10
- 1.5 Method of Problem Solution 11
- 1.6 Numerical Accuracy 13

2

STATICS OF PARTICLES

15

- 2.1 Introduction 16
- Forces in a Plane** 16
- 2.2 Force on a Particle. Resultant of Two Forces 16
- 2.3 Vectors 17
- 2.4 Addition of Vectors 18
- 2.5 Resultant of Several Concurrent Forces 20
- 2.6 Resolution of a Force into Components 21
- 2.7 Rectangular Components of a Force. Unit Vectors 27
- 2.8 Addition of Forces by Summing x and y Components 30
- 2.9 Equilibrium of a Particle 35
- 2.10 Newton's First Law of Motion 36
- 2.11 Problems Involving the Equilibrium of a Particle.
 Free-Body Diagrams 36
- Forces in Space** 45
- 2.12 Rectangular Components of a Force in Space 45
- 2.13 Force Defined by Its Magnitude and Two Points on Its
 Line of Action 48

2.14	Addition of Concurrent Forces in Space	49
2.15	Equilibrium of a Particle in Space	57
Review and Summary for Chapter 2		64
Review Problems		67
Computer Problems		69

3

RIGID BODIES: EQUIVALENT SYSTEMS OF FORCES

73

3.1	Introduction	74
3.2	External and Internal Forces	74
3.3	Principle of Transmissibility. Equivalent Forces	75
3.4	Vector Product of Two Vectors	77
3.5	Vector Products Expressed in Terms of Rectangular Components	79
3.6	Moment of a Force about a Point	81
3.7	Varignon's Theorem	83
3.8	Rectangular Components of the Moment of a Force	83
3.9	Scalar Product of Two Vectors	93
3.10	Mixed Triple Product of Three Vectors	95
3.11	Moment of a Force about a Given Axis	97
3.12	Moment of a Couple	107
3.13	Equivalent Couples	108
3.14	Addition of Couples	110
3.15	Couples Can Be Represented by Vectors	110
3.16	Resolution of a Given Force Into a Force at O and a Couple	111
3.17	Reduction of a System of Forces to One Force and One Couple	122
3.18	Equivalent Systems of Forces	123
3.19	Equipollent Systems of Vectors	124
3.20	Further Reduction of a System of Forces	124
*3.21	Reduction of a System of Forces to a Wrench	127
Review and Summary for Chapter 3		146
Review Problems		151
Computer Problems		153

4

EQUILIBRIUM OF RIGID BODIES

157

4.1	Introduction	158
4.2	Free-Body Diagram	159
Equilibrium in Two Dimensions		160
4.3	Reactions at Supports and Connections for a Two-Dimensional Structure	160
4.4	Equilibrium of a Rigid Body in Two Dimensions	162
4.5	Statically Indeterminate Reactions. Partial Constraints	164
4.6	Equilibrium of a Two-Force Body	183
4.7	Equilibrium of a Three-Force Body	184
Equilibrium in Three Dimensions		191
4.8	Equilibrium of a Rigid Body in Three Dimensions	191

- 4.9 Reactions at Supports and Connections for a
Three-Dimensional Structure 191

Review and Summary for Chapter 4 211

Review Problems 213

Computer Problems 215

5

DISTRIBUTED FORCES: CENTROIDS AND CENTERS OF GRAVITY

219

- 5.1 Introduction 220

Areas and Lines 220

- 5.2 Center of Gravity of a Two-Dimensional Body 220

- 5.3 Centroids of Areas and Lines 222

- 5.4 First Moments of Areas and Lines 223

- 5.5 Composite Plates and Wires 226

- 5.6 Determination of Centroids by Integration 236

- 5.7 Theorems of Pappus-Guldinus 238

- *5.8 Distributed Loads on Beams 248

- *5.9 Forces on Submerged Surfaces 249

Volumes 259

- 5.10 Center of Gravity of a Three-Dimensional Body.

Centroid of a Volume 259

- 5.11 Composite Bodies 262

- 5.12 Determination of Centroids of Volumes by Integration 262

Review and Summary for Chapter 5 274

Review Problems 278

Computer Problems 281

6

ANALYSIS OF STRUCTURES

284

- 6.1 Introduction 285

Trusses 286

- 6.2 Definition of a Truss 286

- 6.3 Simple Trusses 288

- 6.4 Analysis of Trusses by the Method of Joints 289

- *6.5 Joints under Special Loading Conditions 291

- *6.6 Space Trusses 293

- 6.7 Analysis of Trusses by the Method of Sections 303

- *6.8 Trusses Made of Several Simple Trusses 304

Frames and Machines 315

- 6.9 Structures Containing Multiforce Members 315

- 6.10 Analysis of a Frame 315

- 6.11 Frames Which Cease to Be Rigid When Detached
from Their Supports 316

- 6.12 Machines 331

Review and Summary for Chapter 6 343

Review Problems 346

Computer Problems 349

7 FORCES IN BEAMS AND CABLES 353

*7.1	Introduction	354
*7.2	Internal Forces in Members	354
	Beams	361
*7.3	Various Types of Loading and Support	361
*7.4	Shear and Bending Moment in a Beam	362
*7.5	Shear and Bending-Moment Diagrams	364
*7.6	Relations among Load, Shear, and Bending Moment	372
	Cables	383
*7.7	Cables with Concentrated Loads	383
*7.8	Cables with Distributed Loads	384
*7.9	Parabolic Cable	385
*7.10	Catenary	394
	Review and Summary for Chapter 7	402
	Review Problems	405
	Computer Problems	408

8 FRICTION 411

8.1	Introduction	412
8.2	The Laws of Dry Friction. Coefficients of Friction	412
8.3	Angles of Friction	415
8.4	Problems Involving Dry Friction	416
8.5	Wedges	431
8.6	Square-Threaded Screws	431
*8.7	Journal Bearings. Axle Friction	440
*8.8	Thrust Bearings. Disk Friction	442
*8.9	Wheel Friction. Rolling Resistance	443
*8.10	Belt Friction	450
	Review and Summary for Chapter 8	461
	Review Problems	464
	Computer Problems	467

9 DISTRIBUTED FORCES: MOMENTS OF INERTIA 471

9.1	Introduction	472
	Moments of Inertia of Areas	473
9.2	Second Moment, or Moment of Inertia, of an Area	473
9.3	Determination of the Moment of Inertia of an Area by Integration	474
9.4	Polar Moment of Inertia	475
9.5	Radius of Gyration of an Area	476
9.6	Parallel-Axis Theorem	483
9.7	Moments of Inertia of Composite Areas	484
*9.8	Product of Inertia	497
*9.9	Principal Axes and Principal Moments of Inertia	498

*9.10	Mohr's Circle for Moments and Products of Inertia	506
	Moments of Inertia of Masses	512
9.11	Moment of Inertia of a Mass	512
9.12	Parallel-Axis Theorem	514
9.13	Moments of Inertia of Thin Plates	515
9.14	Determination of the Moment of Inertia of a Three-Dimensional Body by Integration	516
9.15	Moments of Inertia of Composite Bodies	516
*9.16	Moment of Inertia of a Body with Respect to an Arbitrary Axis through <i>O</i> . Mass Products of Inertia	531
*9.17	Ellipsoid of Inertia. Principal Axes of Inertia	532
*9.18	Determination of the Principal Axes and Principal Moments of Inertia of a Body of Arbitrary Shape	534
	Review and Summary for Chapter 9	545
	Review Problems	551
	Computer Problems	554

10

METHOD OF VIRTUAL WORK

557

*10.1	Introduction	558
*10.2	Work of a Force	558
*10.3	Principle of Virtual Work	561
*10.4	Applications of the Principle of Virtual Work	562
*10.5	Real Machines. Mechanical Efficiency	564
*10.6	Work of a Force during a Finite Displacement	578
*10.7	Potential Energy	580
*10.8	Potential Energy and Equilibrium	581
*10.9	Stability of Equilibrium	582

	Review and Summary for Chapter 10	592
	Review Problems	595
	Computer Problems	597

Appendix

FUNDAMENTALS OF ENGINEERING EXAMINATION

601

Photo Credits	603
Index	605
Answers to Problems	611