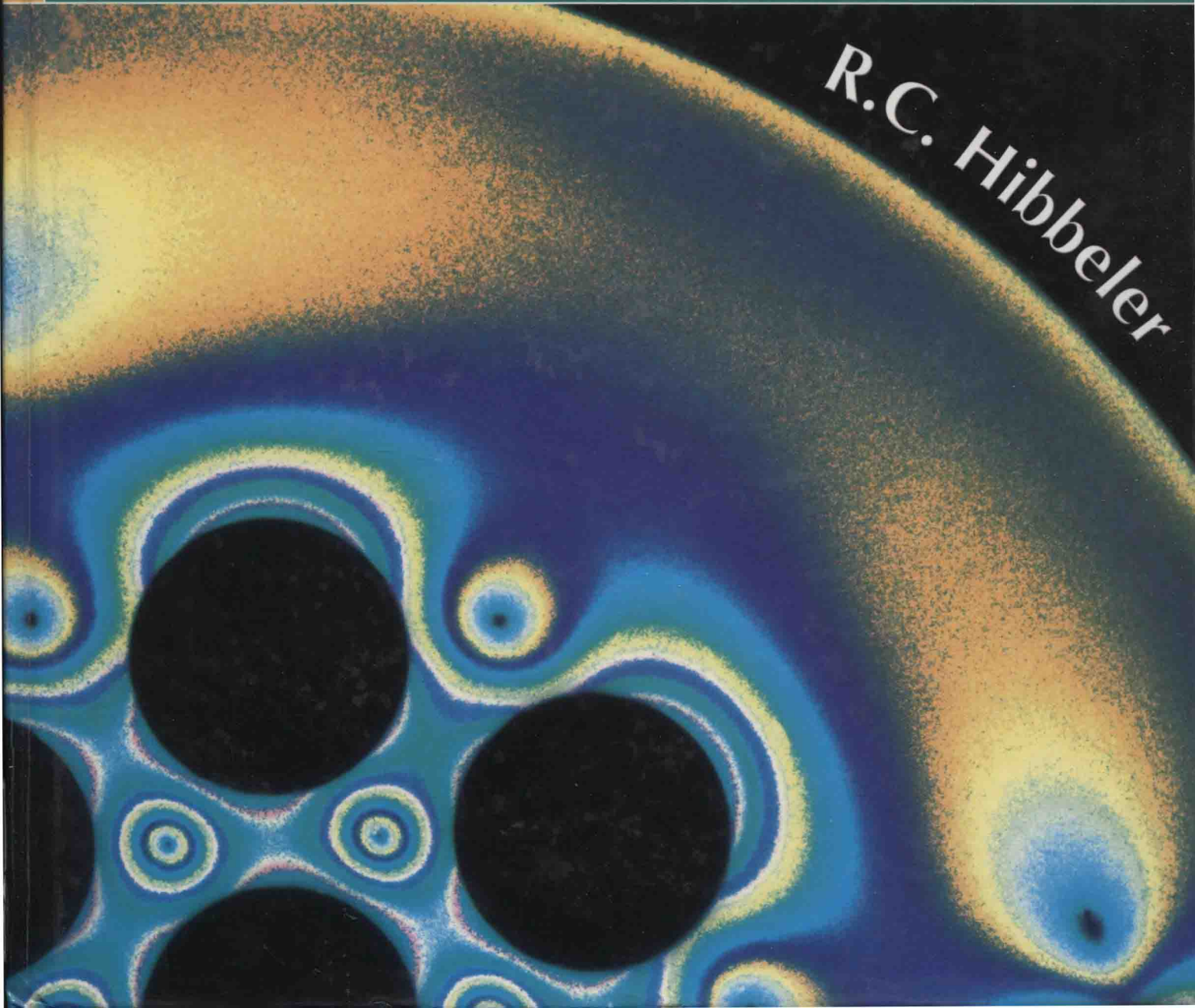


Mechanics of Materials

FIFTH EDITION

R.C. Hibbeler

A stress contour plot showing the distribution of stress in a perforated plate. The plot features several circular holes of varying sizes. The stress is represented by a color gradient from dark blue (low stress) to yellow (high stress). The highest stress concentrations are visible at the inner corners of the holes, where the color transitions from blue to yellow and then to a bright orange-red. The background of the plot is a dark blue, indicating lower stress levels in the unperforated regions.

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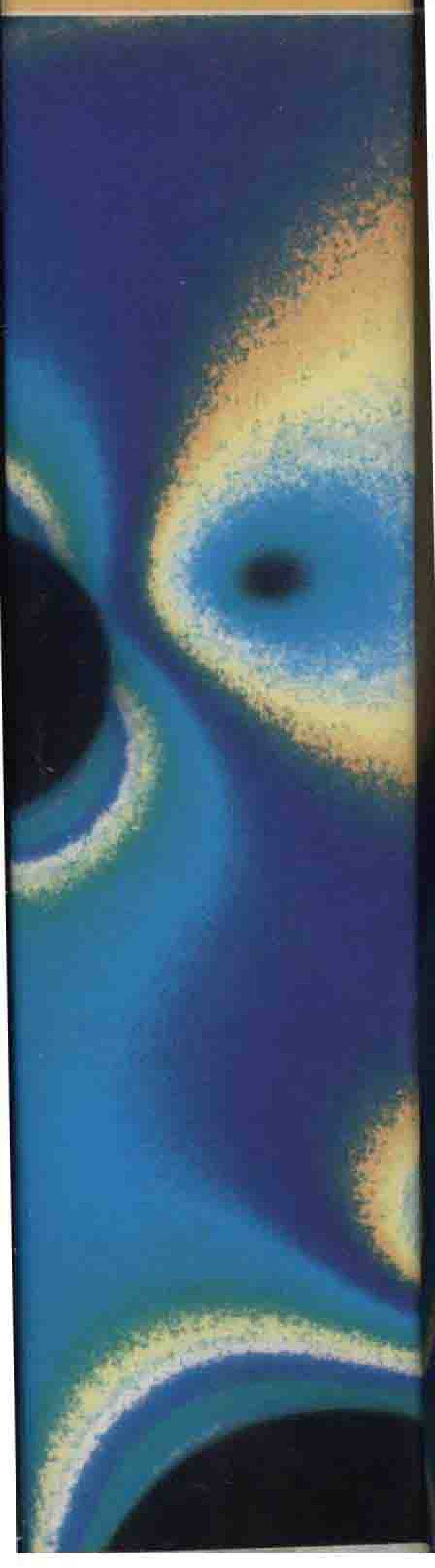
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Fundamental Equations of Mechanics of Materials

Axial Load

Normal Stress

$$\sigma = \frac{P}{A}$$

Displacement

$$\delta = \int_0^L \frac{P(x)dx}{A(x)E}$$

$$\delta = \sum \frac{PL}{AE}$$

$$\delta_T = \alpha \Delta T L$$

Torsion

Shear stress in circular shaft

$$\tau = \frac{T\rho}{J}$$

where

$$J = \frac{\pi}{2} c^4 \text{ solid cross section}$$

$$J = \frac{\pi}{2} (c_o^4 - c_i^4) \text{ tubular cross section}$$

Power

$$P = T\omega = 2\pi fT$$

Angle of twist

$$\phi = \int_0^L \frac{T(x)dx}{J(x)G}$$

$$\phi = \sum \frac{TL}{JG}$$

Average shear stress in a thin-walled tube

$$\tau_{\text{avg}} = \frac{T}{2tA_m}$$

Shear Flow

$$q = \tau_{\text{avg}} t = \frac{T}{2A_m}$$

Bending

Normal stress

$$\sigma = \frac{My}{I}$$

Unsymmetric bending

$$\sigma = -\frac{M_z y}{I_z} + \frac{M_y z}{I_y}, \quad \tan \alpha = \frac{I_z}{I_y} \tan \theta$$

Shear

Average direct shear stress

$$\tau_{\text{avg}} = \frac{V}{A}$$

Transverse shear stress

$$\tau = \frac{VQ}{It}$$

Shear flow

$$q = \tau t = \frac{VQ}{I}$$

Stress in Thin-Walled Pressure Vessel

Cylinder

$$\sigma_1 = \frac{pr}{t} \quad \sigma_2 = \frac{pr}{2t}$$

Sphere

$$\sigma_1 = \sigma_2 = \frac{pr}{2t}$$

Stress Transformation Equations

$$\sigma_{x'} = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2} \cos 2\theta + \tau_{xy} \sin 2\theta$$

$$\tau_{x'y'} = -\frac{\sigma_x - \sigma_y}{2} \sin 2\theta + \tau_{xy} \cos 2\theta$$

Principal Stress

$$\tan 2\theta_p = \frac{\tau_{xy}}{(\sigma_x - \sigma_y)/2}$$

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

Maximum in-plane shear stress

$$\tan 2\theta_s = -\frac{(\sigma_x - \sigma_y)/2}{\tau_{xy}}$$

$$\tau_{\text{max}} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$\sigma_{\text{avg}} = \frac{\sigma_x + \sigma_y}{2}$$

Absolute maximum shear stress

$$\tau_{\text{abs max}} = \frac{\sigma_{\text{max}} - \sigma_{\text{min}}}{2}$$

$$\sigma_{\text{avg}} = \frac{\sigma_{\text{max}} + \sigma_{\text{min}}}{2}$$

Geometric Properties of Area Elements

Material Property Relations

Poisson's ratio

$$\nu = -\frac{\epsilon_{\text{lat}}}{\epsilon_{\text{long}}}$$

Generalized Hooke's Law

$$\epsilon_x = \frac{1}{E} [\sigma_x - \nu(\sigma_y + \sigma_z)]$$

$$\epsilon_y = \frac{1}{E} [\sigma_y - \nu(\sigma_x + \sigma_z)]$$

$$\epsilon_z = \frac{1}{E} [\sigma_z - \nu(\sigma_x + \sigma_y)]$$

$$\gamma_{xy} = \frac{1}{G} \tau_{xy}, \quad \gamma_{yz} = \frac{1}{G} \tau_{yz}, \quad \gamma_{zx} = \frac{1}{G} \tau_{zx}$$

where

$$G = \frac{E}{2(1 + \nu)}$$

Relations Between w , V , M

$$\frac{dV}{dx} = -w(x), \quad \frac{dM}{dx} = V$$

Elastic Curve

$$\frac{1}{\rho} = \frac{M}{EI}$$

$$EI \frac{d^4v}{dx^4} = -w(x)$$

$$EI \frac{d^3v}{dx^3} = V(x)$$

$$EI \frac{d^2v}{dx^2} = M(x)$$

Buckling

Critical axial load

$$P_{\text{cr}} = \frac{\pi^2 EI}{(KL)^2}$$

Critical stress

$$\sigma_{\text{cr}} = \frac{\pi^2 E}{(KL/r)^2}, \quad r = \sqrt{I/A}$$

Secant formula

$$\sigma_{\text{max}} = \frac{P}{A} \left[1 + \frac{ec}{r^2} \sec \left(\frac{L}{2r} \sqrt{\frac{P}{EA}} \right) \right]$$

Energy Methods

Conservation of energy

$$U_e = U_i$$

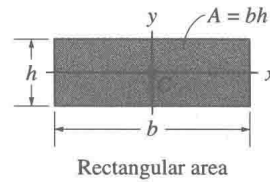
Strain energy

$$U_i = \frac{N^2 L}{2AE} \quad \text{constant axial load}$$

$$U_i = \int_0^L \frac{M^2 dx}{EI} \quad \text{bending moment}$$

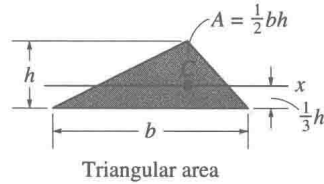
$$U_i = \int_0^L \frac{f_s V^2 dx}{2GA} \quad \text{transverse shear}$$

$$U_i = \int_0^L \frac{T^2 dx}{2GJ} \quad \text{torsional moment}$$

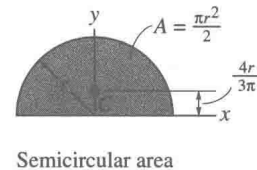
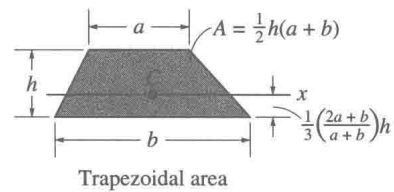


$$I_x = \frac{1}{12} bh^3$$

$$I_y = \frac{1}{12} hb^3$$

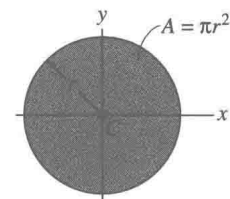


$$I_x = \frac{1}{36} bh^3$$



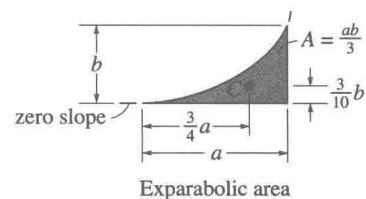
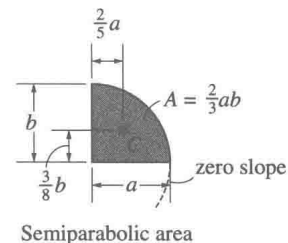
$$I_x = \frac{1}{8} \pi r^4$$

$$I_y = \frac{1}{8} \pi r^4$$



$$I_x = \frac{1}{4} \pi r^4$$

$$I_y = \frac{1}{4} \pi r^4$$



MECHANICS OF MATERIALS

PREFACE

This book is intended to provide the student with a clear and thorough presentation of both the theory and application of the fundamental principles of mechanics of materials. Understanding is based on the explanation of the physical behavior of materials under load and then modeling this behavior to develop the theory. Emphasis is placed on the importance of satisfying equilibrium, compatibility of deformation, and material behavior requirements.

Unique Features

The following is a list of some of the more important features of the text.

- *Summaries.* The “procedure for analysis” and “important points,” sections provide a guide for problem solving and a summary of the concepts.

- *Photographs.* Many photographs are used throughout the book to explain how the principles of mechanics of materials apply to real-world situations. In some sections they show how materials deform or fail under load in order to provide a conceptual understanding of the terms and concepts.

- *Problems.* The problems provide a balance between easy, medium, and difficult applications. In addition, some problems require solution by computer. Extra care has been taken in the presentation and solution of the problems, and all the problem sets have been reviewed and the solutions checked and rechecked to ensure both their clarity and numerical accuracy.

Contents

The subject matter is organized into 14 chapters. Chapter 1 begins with a review of the important concepts of statics, followed by a formal definition of both normal and shear stress, and a discussion of normal stress in axially loaded members and average shear stress caused by direct shear. In Chapter 2 normal and shear strain are defined, and in Chapter 3 a discussion of some of the important mechanical properties of materials is given.

Separate treatments of axial load, torsion, and bending are presented in Chapters 4, 5, and 6, respectively. In each of these chapters, both linear-elastic and plastic behavior of the material are considered. Also, topics related to stress concentrations and residual stress are included. Transverse shear is discussed in Chapter 7, along with a discussion of thin-walled tubes, shear flow, and the shear center. Chapter 8 provides a partial review of the material covered in the previous chapters, in which the state of stress resulting from combined loadings is discussed. In Chapter 9 the concepts for transforming multiaxial states of stress are presented. In a similar manner, Chapter 10 discusses the methods for strain transformation, including the application of various theories of failure. Chapter 11 provides a means for a further summary and review of previous material by covering design applications of beams and shafts. In Chapter 12 various methods for computing deflections of beams and shafts are covered. Also included is a discussion for finding the reactions on these members if they are statically indeterminate. Chapter 13 provides a discussion of column buckling, and lastly, in Chapter 14 the problem of impact and the application of various energy methods for computing deflections are considered.

Sections of the book that contain more advanced material are indicated by a star (*). Time permitting, some of these topics may be included in the course. Furthermore, this material provides a suitable reference for basic principles when it is covered in other courses, and it can be used as a basis for assigning special projects.

Alternative Method of Coverage. Some instructors prefer to cover stress and strain transformations *first*, before discussing specific applications of axial load, torsion, bending, and shear. One possible method for doing this would be first to cover stress and its transformation, Chapter 1 and Chapter 9, followed by strain and its transformation, Chapter 2 and the first part of Chapter 10. The discussion and example problems in these later chapters have been styled so that this is possible. Also, the problem sets have been subdivided so that this material can be covered without prior knowledge of the intervening chapters. Chapters 3 through 8 can then be covered with no loss in continuity.

Special Features

Organization and Approach. In order to aid both the instructor and the student, the contents of each chapter are organized into well-defined sections. Selected groups of sections contain an explanation of specific topics, followed by illustrative example problems and a set of homework problems. The topics within each section are often placed in subgroups denoted by boldface titles. The purpose of this is to present a structured method for introducing each new definition or concept and to make the book convenient

for later reference and review. Furthermore, important terms in the chapter have been highlighted in boldface to provide a convenient means for review.

Chapter Contents. Each chapter begins with a photo to illustrate a broad range application of the material within the chapter. The “chapter objectives” are then provided to give a general overview of the material that will be covered.

Procedures for Analysis. Found in many sections of the book, this unique feature provides the student with a logical and orderly method to follow when applying the theory. The example problems are then solved using this outlined method in order to clarify its numerical application. It is to be understood, however, that once the relevant principles have been mastered and enough confidence and judgment have been acquired, the student can then develop his or her own procedures for solving problems.

Important Points. This feature provides a review or summary of the most important concepts in a section and highlights the most significant points that should be realized when applying the theory to solve problems.

Conceptual Understanding. Through the use of photographs placed throughout the book, examples of the theory are provided in order to illustrate some of its more important conceptual features and instill the physical meaning of many of the terms used in the equations.

Example Problems. All the example problems are presented in a concise manner and in a style that is easy to understand. New examples have been added throughout the text, and some from the previous edition have been shortened.

Homework Problems. Numerous problems in the book depict realistic situations encountered in engineering practice. It is hoped that this realism will both stimulate the student’s interest in the subject and provide a means for developing the skill to reduce any such problem from its physical description to a model or symbolic representation to which the principles may be applied.

Throughout the book there is an approximate balance of problems using either SI or FPS units. Furthermore, in any set, an attempt has been made to arrange the problems in order of increasing difficulty. The answers to all but every fourth problem are listed in the back of the book. To alert the user to a problem without a reported answer, an asterisk (*) is placed before the problem number. Answers are reported to three significant figures, even though the data for material properties may be known with less accuracy. Although this might appear to be poor practice, it is done simply to be consistent and to allow the student a better chance to validate his or her solution. All the problems and their solutions have been independently checked for accuracy. A solid square (■) is used to identify problems that require a numerical analysis or computer application.

Appendices. The appendices of the book provide a source for review and a listing of tabular data. Appendix A provides information on the centroid and the moment of inertia of an area. Appendices B and C list tabular data for structural shapes, and the deflection and slopes of various types of beams and shafts. Appendix D, which is titled “Review for the Fundamentals of Engineering Exam,” contains typical problems, along with their partial solutions, that are commonly used on *FE exams*. These problems may also be used for review and practice in preparing for class examinations.

Accuracy Checking. The edition has undergone rigorous accuracy checking and proofing of pages. Besides the author’s review of all art pieces and pages, Karim Nohra of the University of South Florida and Scott Hendricks of Virginia Polytechnic Institute rechecked the page proofs twice, and together reviewed the entire Solutions Manual.

Supplements. Several instructor’s supplements are available with this text. An instructor’s solutions manual was prepared and typeset by the author. It has been completely checked for accuracy. In addition, an Instructor’s Resource CD is available containing PowerPoint slides and pdf files of text art, as well as PowerPoint slides of text examples.

Acknowledgments

Over the years, this text has been shaped by the suggestions and comments of many of my colleagues in the teaching profession. Their encouragement and willingness to provide constructive criticism are very much appreciated and it is hoped that they will accept this anonymous recognition.

A note of thanks is given to our reviewers: Patrick Kwon of Michigan State University, Cliff Lissenden of Penn State University, Dahsin Liu of Michigan State University, Ting-Wen Wu of the University of Kentucky, Javad Hashemi of Texas Tech University, and Assimina Pelegri of Rutgers—The State University of New Jersey. A particular note of thanks is given to Karim Nohra of the University of South Florida and Scott Hendricks of Virginia Polytechnic Institute, who rigorously checked both the text and the Solutions Manual. I would also like to thank all my students who have used the previous edition and have made comments to improve its contents. Lastly, I should like to acknowledge the assistance of my wife, Cornelia (Conny), during the time it has taken to prepare the manuscript for publication.

I would greatly appreciate hearing from you if at any time you have any comments or suggestions regarding the contents of this edition.

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