FIFTH EDITION

# Applied Strength of Materials

Robert L. Mott

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## Fifth Edition

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# APPLIED STRENGTH OF MATERIALS

# Preface

## Objectives of the Book

*Applied Strength of Materials,* Fifth Edition, provides comprehensive coverage of the important topics in strength of materials with an emphasis on applications, problem solving, and design of structural members, mechanical devices, and systems. The book is written for the student in a course called Strength of Materials, Mechanics of Materials, or Solid Mechanics in an engineering technology program at the baccalaureate or associate degree level or in an applied engineering program.

This book provides good readability for the student, appropriate coverage of the principles of strength of materials for the faculty member teaching the subject, and a problem-solving and design approach that is useful for the practicing designer or engineer. Educational programs in the mechanical, civil, construction, architectural, industrial, and manufacturing fields will find the book suitable for an introductory course in strength of materials.

## Style

This text emphasizes the *applications* of the principles of strength of materials to mechanical, manufacturing, structural, and construction problems while providing a firm understanding of those principles. At the same time, the *limitations* on the use of analysis techniques are emphasized to ensure that they are applied properly. Both analysis and design approaches are used in the book.

Units are a mixture of SI metric and U.S. Customary units, in keeping with the dual usage evident in U.S. industry and construction.

## Prerequisites

Students should be able to apply the principles of statics prior to using this book. For review, there is a summary of the main techniques of the analysis of forces and momentum in the Appendix. Several example problems are included that are similar to the statics needed to solve practice problems in this book.

While not essential, it is recommended that students have completed an introductory course in calculus. As called for by accrediting agencies, calculus is used to develop the key principles and formulas used in this book. The application of the formulas and most problem-solving and design techniques can be accomplished without the use of calculus.

## Features of the Book

**The Big Picture.** Students should see the relevance of the material they study. They should be able to visualize where devices and systems that they are familiar with depend on the principles of strength of materials. For this reason each chapter starts with a section called *The Big Picture*. Here the basic concepts developed in the chapter are identified and students are asked to think about examples from their own experience where these concepts are used. Sometimes they are asked to explore new things on their own to discover how a product works or how it can fail. They are coached to make observations about the behavior of common mechanical devices, vehicles, industrial machinery, consumer products, and structures. Educational philosophy indicates that students learn better and retain more when such methods are employed.

**Activity-Based Learning.** Activity-based learning activities are integrated into the popular Big Picture section, a successful feature in all previous editions. The activity can be used independently by the students, by the instructor as a classroom demonstration, or a combination of these approaches. These activities allow the instructor and the students to extend the Big Picture dialog into hands-on experiences that give an enhanced appreciation and greater physical feel for the phenomena involved. Activities can help students from different disciplines work together and learn from each other. The activities are generally simple and can be completed in a short amount of time with inexpensive materials and quick setups. The emphasis is on qualitative appreciation of the physical phenomena with a modest amount of measurement involved. Educational research has shown that students learn better when they are personally involved in activities as opposed to listening to lectures. Furthermore, retention of abilities learned is improved along with greater ability to transfer learning to new and different applications.

**Problem-Solving Techniques.** Students must be able to solve real problems, complete the necessary calculations, manipulate units in equations, seek appropriate data, and make good design decisions. The example problems in this book are designed to help students master these processes. In addition, students must learn to communicate the results of their work to others in the field. One important means of communication is the presentation of the problem solutions in an orderly, well-documented manner using established methods. Example problems are set off with a distinctive graphic design and type font. Readers are guided in the process of formulating an approach to problem solving that includes:

a. Statement of the objective of the problem
b. Summary of the given information
c. Definition of the analysis technique to be used
d. Detailed development of the results with all of the equations used and unit manipulations
e. At times, comments on the solution to remind the reader of the important concepts involved and to judge the appropriateness of the solution
f. At times, comments present alternate approaches or improvements to the machine element or structural member being analyzed or designed

The reader's thought process is carried beyond the requested answer into a critical review of the result. With this process, designers gain good habits of organization when solving their own problems.

**Design Approaches.** This text provides extensive information about guidelines for design of mechanical devices and structural members than in most books on this subject. The design approaches are based on another book of mine, *Machine Elements in Mechanical Design*, Fourth Edition, 2004, from Prentice Hall. Learning about design in addition to analysis increases the usefulness of the book to students and professional users. There are some students who will not go on to a following course that emphasizes design. They should get some introduction to the principles of design in the introductory course in strength of materials. For those who do proceed to a design course, they should enter that course with a higher level of capability.

**Design Properties of Materials.** Chapter 2 includes extensive information and discussion on the proper application of engineering materials of many types, both metallic and nonmetallic. There is an extensive introduction to the nature of composite materials given along with commentary throughout the book on the application of composites to various kinds of load-carrying members. Information about the advantages of composites relative to traditional structural materials such as metals, wood, concrete, and plastics are given. The reader is encouraged to seek more education and experience to learn the unique analysis and design techniques required for the proper application of composite materials. Such materials are, in fact, tailored to a specific application, and general tables of material properties are not readily available.

Chapter 2 also includes a new section on materials selection based on the landmark publication *Materials Selection in Mechanical Design,* 3rd ed., by Michael F. Ashby, published by Elsevier-Butterworth-Heinemann (2005).

**End-of-Chapter Problems.** There is an extensive set of problems for student practice at the end of each chapter. The problems are typically organized around the main topics in the chapter. In general, they are presented in a graded manner with simpler problems followed by more comprehensive problems. There are many additional problems at the end of most chapters for practice, review, and design.

**Extensive Appendix.** To complement the use of design approaches, the Appendix provides additional information on material properties, geometry of common areas and commercially available structural shapes, stress concentration factors, formulas for beam deflection, conversion factors, and many others. This allows for a wider variety of problems in the book and for creating tests and projects. It adds to the realism of the book and gives the student practice in looking for the necessary information to solve a problem or to complete a design.

This edition includes a significant amount of additional Appendix data in SI metric units. All commercially available section property data for structural shapes include separate tables of SI data in addition to the formerly included U.S. Customary unit data. The SI data are taken from the latest versions of publications by the American Institute of Steel Construction (AISC). The SI data tables and the U.S. data tables are coordinated so students and instructors can quickly compare the designations and specific data from the two systems. Problems stated in SI metric data should be solved using the SI property data; instructors can develop their own quiz and exam problems completely in the SI system.

An entirely new table has been added on property data for mechanical tubing to supplement the standard pipe data from AISC and to offer designers of mechanical devices or manufacturing applications a wider variety of sizes of hollow circular sections, particularly on the smaller part of the size spectrum.

## Adjustments to Format from Previous Edition

Users of previous editions of this book will find a significant amount of reordering of the coverage of some topics. Guided by intensive feedback from users, the revised arrangement is more streamlined. Some highlights of these changes are:

- Chapter 1, Basic Concepts in Strength of Materials, has been reduced in size to focus on the most cogent introductory material. Several sections on material properties, stress, and strain were relocated into Chapters 2 and 3.
- The coverage of deformation due to axial stresses has been integrated into Chapter 3 on Direct Stresses instead of being in a separate chapter.
- All topics on combined stresses have been consolidated into a single chapter (Chapter 10).
- The discussions of continuous beams and the theorem of three moments have been included with the chapter on Shearing Forces and Bending Moments in Beams (Chapter 5). Other topics related to statically indeterminate beams have been integrated into Chapter 9, Deflection of Beams.
- The introduction of the area property of section modulus has been included in the chapter on Centroids and Moments of Inertia of Areas (Chapter 6). This topic is expanded upon in Chapter 7, Stress Due to Bending.

**Enhanced Visual Attractiveness.** The addition of a second color makes the book more visually appealing; illustrations, graphs, and tables are easier to use and interpret. Many illustrations have been improved by the addition of three-dimensional graphics, greater realism, and more effective use of shading as well as the introduction of color.

## Acknowledgments

I appreciate the feedback provided by both students and instructors who have used the earlier editions of this book. I am also grateful to my colleagues at the University of Dayton. I would like to thank the participants of a focus group that provided input for the revision of this book: Janice Chambers, Portland Community College; Janak Dave, University of Cincinnati; David Dvorak, University of Maine; Frank Gourley, West Virginia University Institute of Technology; and Jack Zecher, Indiana University–Purdue University at Indianapolis (IUPUI). I would also like to thank the reviewers of this edition: Joana Finegan, Central Michigan University; Robert Michael, Pennsylvania State University, Erie; and Thomas Roberts, Milwaukee Area Technical College for their helpful suggestions for improvement. I hope this edition has implemented those suggestions in a manner consistent with the overall approach of the book.

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# Contents

NOTE: Every effort has been made to provide accurate and current Internet information in this book. However, the Internet and information posted on it are constantly changing, and it is inevitable that some of the Internet addresses listed in this textbook will change.

# 1

# Basic Concepts in Strength of Materials

**The Big Picture**

## Basic Concepts in Strength of Materials

### Discussion Map

- ☐ Products, machines, and structures must be designed to be safe and to provide satisfactory performance during the intended use.
- ☐ Safety is paramount. The load-carrying components must not fracture during use.
- ☐ Excessive deformation is another form of failure.
- ☐ Buckling, occurring when the shape of a load-carrying member becomes unstable, must be avoided.
- ☐ You will learn about the basic nature of stresses and strains in this course.
- ☐ You will be able to recognize several types of stresses created by different loading and support situations.
- ☐ You will analyze situations where more than one kind of stress is experienced by a load-carrying member at the same time.
- ☐ Design requires that you determine the shape and size of a load-carrying member and specify the material from which it is to be made.
- ☐ You will learn how to design safe load-carrying components of machines and structures.

***Discover***

*Think about products, machines, and structures that you are familiar with that contain components that must carry loads safely. For each device that you think of, write down the following information:*

*The basic function or purpose of the device.*

*The description and sketches of its primary components, particularly those that are subjected to significant forces.*

*The material from which each component is made. Is it a metal or plastic? What kind of metal? What kind of plastic? Is it some other material?*

*How is each component supported within the product, machine, or structure?*

*How are forces applied to the component?*

*What would be the consequence if the component broke?*

*How much deformation would cause the component to be incapable of performing its desired function?*

*Consider products around your home; parts of your bicycle, car, or motorcycle; buildings; toys; amusement park rides; aircraft and space vehicles; ships; manufacturing machinery; construction equipment; agricultural machinery; and others.*

*Discuss these products and systems with your colleagues and with your course instructor or facilitator.*

Here are some examples of mechanical and structural systems and how they relate to the material you will study in this book.

1. In your home, the floors must be strong and stiff to support the loads due to people, furniture, and appliances [Figure 1–1(a)]. A typical floor is comprised of a series of joists that are supported on walls or beams, a subfloor on top of the joists, and the finished floor. These elements act together to provide a rigid support system. Pitched roofs employ trusses to span long distances between support walls and to provide the support for the roof sheathing and shingles while remaining fairly lightweight and using materials efficiently. Chairs and tables must be designed to support people and other materials safely and stably. Even in the refrigerator, the shelves must be designed to support heavy milk and juice jugs while being lightweight and allowing the free movement of cooled air over the food. In the garage, you might have a stepladder, a garage door opener, a lawn mower, and shovels, all of which carry forces when they are used. What other examples can you find around the home?