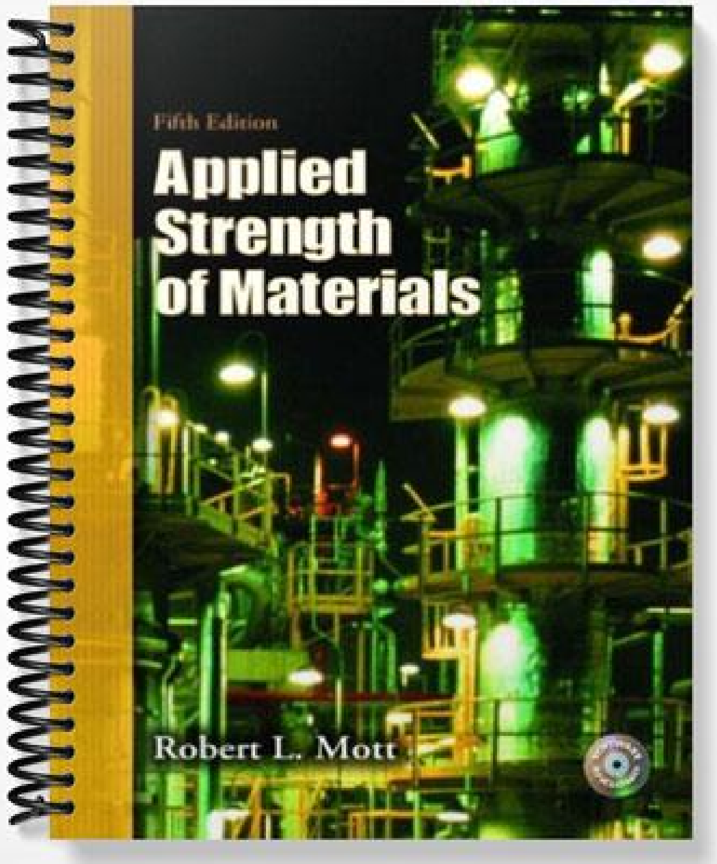
SOLUTIONS MANUAL



Instructor's Manual
to accompany

Applied Strength of Materials

Fifth Edition

Robert L. Mott

PEARSON
Prentice Hall

Upper Saddle River, New Jersey
Columbus, Ohio

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APPLIED STRENGTH OF MATERIALS
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Options for Course Organization

INTRODUCTION

Course organization is one of the most important responsibilities for an instructor. Knowledge of the specific objectives of the program or programs of which the course is a part is critical, particularly with regard to the prerequisite knowledge and skills students are expected to have when they begin the course and the outcomes expected as they relate to career paths of the students and abilities required for successful completion of following courses.

With these overarching considerations in mind, this document attempts to provide options for how to structure a course in Strength of Materials using this textbook. Variables considered include specific prerequisites for mathematics, statics, centroids and moments of inertia, physics mechanics, and materials science. Comments are then presented about each of the 13 chapters of the book.

Users of previous editions of this book will notice significant changes in the arrangement of topic coverage in this edition, in response to feedback from colleagues and users, both instructors and students.

- **Mathematics:** Students are expected, as a minimum, to have good abilities in college algebra and trigonometry. Additional skills in calculus are beneficial but not necessary. Comprehension of virtually all topics in the book and completion of almost all problems for student solution require only algebra and trigonometry. The principles of strength of materials in each chapter are developed first with logical observations of the behavior of materials when subjected to particular forces, moments, and torques with specific support conditions. Typically, those observations are presented in the introduction to each chapter in the form of ***The Big Picture*** in which students are asked to observe structures and various devices with which they are familiar and to engage in simple activities from which they can discover underlying principles. Then the primary formulas governing the mathematical representation of those behaviors are stated along with the definition of variables and statements of limitations on the use of the formulas. For most concepts, a separate section is included that presents a more complete development of the formulas, often using differential and integral calculus. This is beneficial for students who have completed such mathematics courses and for instructors who prefer this approach. However, it is not essential to include coverage of these sections and they are marked [Optional] in the following chapter overviews.

- **Statics:** It is considered essential that students have fundamental understanding of *forces, moments, vectors,* and *static equilibrium* to learn adequately the principles of strength of materials and the problem solution techniques presented in this book. An extensive review of the principles of **Statics** is included in Appendix A-27 for students needing reinforcement. Also, the study of **Physics Mechanics** is beneficial and is typically included as a prerequisite to **Statics**.
- **Centroids and Moments of Inertia of Areas:** Many courses in Statics include these topics. However, there is some advantage in delaying this coverage until these concepts are needed for application to beam analysis within the study of strength of materials. This provides just-in-time coverage that flows naturally as presented in Chapters 5, 6, and 7 in this book. When a particular course requires prerequisite knowledge of **Centroids and Moments of Inertia of Areas**, Chapter 6 can be skipped. Having the material in the book should be useful for students to review as needed.
- **Materials Science:** It is recommended that students have good knowledge and abilities related to the structure and behavior of materials commonly used for structural and mechanical applications. A prerequisite course in materials science is recommended. However, it is practical for students to succeed in the use of this book with only the knowledge of the principles presented in **Chapter 2 – Design Properties of Materials.** For those with good prerequisite knowledge, this chapter can be quickly reviewed with emphasis on properties of materials that will be needed in solution of problems in this book and a discussion of the extensive tables of such properties presented in Appendixes A-14 through A-20. Covered there are common metals, wood, and plastics. In addition, **Section 2-12 on Composites** and **Section 2-13 on Materials Selection** likely include useful information that may not have been included in other courses. Users of previous editions of this book report that the set of materials properties data in the Appendix and the coverage of composites are better than most other books in strength of materials. This provides a wider variety of materials to apply to problems and a better understanding of the differences among types of materials and their response to heat treatment or other processing variables.

POSSIBLE COURSE ORGANIZATIONS

The order of presentation of topics in this book is, in the opinion of the author, logical and would lead to a rather linear progression through the chapters in the order given. The primary options for course organization involve consideration of which topics are essential to the objectives of the specific course. Options are presented here in a chapter-by-chapter basis.

Chapter 1 – Basic Concepts of Strength of Materials

- Sections 1-1 through 1-12 should be covered completely in order to present a foundation for the study of later chapters, to present basic expectations for student performance, and to give students an overview of many of the Appendix tables related to the properties of areas and standard shapes used for structural and mechanical applications. [See Appendixes A-1 through A-13.]
- Sections 1-6 through 1-11 give the basic concepts of stress and strain for direct tension, direct compression, and direct shear.
- The emphasis is on analysis and the understanding of the ability of materials to resist external forces applied to them. This is necessary for progression into Chapter 2 on Design Properties of Materials where some additional material properties are discussed. These basic concepts are expanded upon in Chapter 3.
- Mention should also be made of Appendix A-26 Conversion Factors and Appendix A-27 Review of the Fundamentals of Statics.
- Coverage of Section 1-13 Experimental and Computational Stress Analysis is optional and may depend on the connection of this course with companion laboratory courses.

Chapter 2 – Design Properties of Materials

Refer to the discussion of **Materials Science** given above in regard to prerequisite study. Most students will benefit from at least a quick review of all parts of this chapter and the related Appendixes. Those without prerequisite knowledge of materials will need more intensive study. Some considerations for coverage are discussed next.

- Students in mechanical, manufacturing, civil and construction programs all require sound knowledge of metals and plastics.
- Most would also benefit from coverage of wood, concrete, and composites.
- Section 2-12 [Optional] on Composites may be delayed until Chapter 7 is covered and linked with Section 7-12 on the design of beams to be made from composite materials.
- The section on Materials Selection gives approaches to relating the expected performance of a structure or product to the behavior of appropriate materials. The method featured here leads to consideration of a wide variety of materials and refers to other references giving more extensive treatment of the materials selection processes. Of particular note is the reference for Dr. Michael Ashby's book, *Materials Selection in Mechanical Design*.

Chapter 3 – Direct Stress, Deformation, and Design

This chapter builds on the basic introductory treatment of direct stresses from Chapter 1 and adds significant competencies in design of load-carrying members. Design stresses are defined and related to the yield strength or ultimate strength of the materials and to the manner of loading; steady, repeated, and impact or shock. Coverage can be grouped as follows:

- The Big Picture, Activity, and Chapter Objectives

- Sections 3-2 through 3-6: Design of members under direct normal stresses, including the definition of design stress, design factor (factor of safety), and design approaches.
- Sections 3-7 through 3-11: Deformation, thermal stresses, members made from more than one material, and stress concentration factors for direct axial stresses
- Sections 3-12 and 3-13 on bearing stress, including design bearing stresses
- Section 3-14 – Design Shear Stress

Users of previous editions of this book will note that, in response to feedback from colleagues and external reviewers, a significant re-ordering of topics has been done in this new 5th edition. For example, Bearing Stresses were formerly presented in Chapter 1 and deformations and related topics were covered in a separate chapter. It was recommended that both stress and strain (with deformations) be included in one chapter for each type of stress.

Chapter 4 – Torsional Shear Stress and Torsional Deformation

Coverage of this chapter can be groups as follows:

- Big Picture, Activity, and Objectives
- Section 4-2 on Torque, Power, and Rotational Speed: These topics should be review for most students but it has been found that careful study is required before applying them to stress analysis.
- Section 4-3 presents the fundamental torsional shear stress formula and demonstrates its application to the analysis of stresses.
- Sections 4-4 and 4-5 [Optional] use calculus to derive the torsional shear stress formula and the equations for polar moment for solid circular bars.
- Section 4-6 extends the coverage to hollow circular sections. While some calculus is used to develop equations for polar moment of inertia, the final equations are all that is required for problem solving.
- Section 4-7 presents an approach to design of circular members under torsion, extending the design stress concepts from Chapter 3 to include torsional shear strength of materials.
- Section 4-8: This section provides interesting and useful comparison of the behavior of hollow circular sections and emphasizes their efficiency as compared with solid sections.
- Section 4-9: The study of stress concentrations in torsionally loaded members is essential to proper design and analysis of shafts.
- Section 4-10: The twisting of circular bars is discussed with the application of the equation for torsional deformation.
- Section 4-11 [Optional] Torsion in noncircular sections is less frequently encountered in practice. However, it is important for students to understand that such shapes behave quite differently from circular sections.

Chapters 5 through 9: All these chapters deal with beams; members carrying loads perpendicular to their axes. Students should be advised to scan all five chapters to see the progression of topics and to observe how each chapter relates to the others.

Chapter 5 – Shearing Forces and Bending Moments in Beams

- The Big Picture, Activity, and Sections 5-1 through 5-9 are essential. On rare occasions, some programs include some of these topics in the Statics course.
- Section 5-10 [Optional] Free-Body Diagrams of Parts of Structures: Mastery of this topic gives students a better fundamental understanding of the behavior of load carrying members by visualizing the internal forces, moments, and stresses created by various external loads.
- Section 5-11 [Optional] Mathematical Analysis of Beam Diagrams: Here students apply calculus to derive equations for shearing force and bending moments from given beam loading and support conditions. This skill is required for later study of Section 9-7 Successive Integration Method for deflection of beams, which is, itself, optional.
- Section 5-12 [Optional] Continuous Beams – Theorem of Three Moments: Students should, at least, understand that the behavior of beams with three or more supports is quite different from those with only two simple supports as covered in other sections of this chapter. Extensive study of this topic, however, would be most beneficial for the civil and construction fields where such beams are frequently applied in bridges and buildings.
- ***Note: This is one place where the Beam Calculator program supplied with this book can be used effectively for analyzing complex loading patterns after students have mastered the manual process of creating shearing force and bending moment diagrams. The 'Shear' and 'Moment' selections produce complete diagrams immediately after the beam loading and support conditions are defined.***

Chapter 6 – Centroids and Moments of Inertia of Areas

This entire chapter may be skipped for those programs in which the coverage of this topic is included in a prerequisite course in Statics. However, review of the procedures for computing the location of centroids and the computation of moments of inertia of areas is typically required. This can be done by moving directly to Sections 6-5, 6-6, and 6-8 where sections commonly encountered in strength of materials are considered, especially those including standard structural shapes such as W-beams, channels, and angles.

For those programs that do not include this topic in prior courses, coverage of Sections 6-1 through 6-6 and 6-8 should be covered as a minimum. These skills are essential to the understanding of concepts in Chapters 7 – 11. Coverage of the other sections of this chapter are optional as discussed next.

- Section 6-7 [Optional] uses calculus to derive the moment of inertia of an area, I.

- Section 6-9 [Optional] provides a useful method of analyzing shapes with all rectangular parts. The process can be implemented effectively in a spreadsheet.
- Section 6-10 [Optional] Radius of Gyration is an important property of an area and is most directly applicable to Chapter 11 on Columns. It may be desirable to delay the coverage of this topic to combine it with the study of columns.
- Section 6-11 [Optional] Section Modulus is an important property of an area and is most directly applicable to Chapter 7 on Stress Due to Bending. It may be desirable to delay the coverage of this topic to combine it with the study of beams.

Chapter 7 – Stress Due to Bending

- Sections 7-1 through 7-4 present the foundation material for the analysis of beams.
- Section 7-5 [Optional] uses calculus to derive the flexure formula. It can be skipped or discussed lightly for those programs where detailed use of the calculus is not expected.
- Sections 7-6 through 7-8 cover the transitions from analysis to design of beams.
- Section 7-9 covers stress concentrations in bending situations.
- Section 7-10 is critical, at least from the standpoint that students must understand that the flexure formula applies only to symmetrical sections or when the load path passes through the flexural center (shear center) of the section. Otherwise twisting combines with the bending stress, reducing the capacity of the beam.
- Section 7-11 on Preferred Shapes for Beam Cross Sections is designed to help the novice student understand better why certain shapes are preferred for beams.
- Section 7-12 [Optional] on beams made from composites presents mostly conceptual information about the advantages of composites in bending cases and how the shape can be optimized to make best use of the special properties of composites. This section refers back to Section 2-12 and it may be desirable to cover those two sections together at this point.
- ***Note: This is one place where the Beam Calculator program supplied with this book can be used effectively for analyzing bending stress produced by complex loading patterns after students have mastered the manual process making such calculations on more simple beams. The 'Stress' selection produces the complete diagram of bending stress distribution immediately after the beam loading and support conditions are defined. Students should compare this result with the bending moment diagram.***

Chapter 8 – Shearing Stresses in Beams

- Sections 8-1 through 8-4 present the fundamental concepts and the general shear formula.
- Section 8-5 [Optional] uses calculus to derive the general shear formula. It can be skipped or discussed lightly for those programs where detailed use of the calculus is not expected.
- Section 8-6 shows the special shear formulas applicable to rectangular, circular, hollow, and thin-webbed sections (e.g. W-beams). These formulas are frequently used.
- Section 8-7 transitions the coverage of shear in beams from analysis to design.

- Section 8-8 on shear flow [Optional] is applicable to beam sections made from component shapes that are fastened, glued, or otherwise assembled where connections are subjected to shear.

Chapter 9 – Deflection of Beams

There appears to be a wide divergence of opinion about what types of beam deflection approaches to cover in a basic course in strength of materials. This book attempts to show all popular approaches and let individual instructors and program faculty members decide which is best for their programs.

Note: This is the place where the Beam Calculator program supplied with this book is most applicable. The complete deflection curve is produced immediately after the beam loading and support conditions are defined by selecting the 'Deflection' button. Comparison of the Deflection curve with the Shear, Moment, and Stress diagrams is advised.

That said, here are some factors to consider in course planning:

- Sections 9-1 through 9-4 present the basic concepts and the widely used formulas for beam deflection, using the extensive list of formulas from Appendixes A-23, A-24, and A-25.
- Section 9-5 gives students some experience in comparing the performance of several ways of supporting a given load with regard to the stresses and deflections that result. This should help the novice student gain a better 'feel' for what approaches are preferred in different applications.
- Section 9-6 extends the material in Section 9-4 to the permit use of beam deflection formulas to a much broader array of applications.
- Section 9-7 on the Successive Integration Method [Optional] provides a more analytical approach to deflection analysis. It requires the use of differential and integral calculus and should be combined with Section 5-11 Mathematical Analysis of Beam Diagrams. Mastery of these concepts would be expected for students who intend to continue their study of applied mechanics in later courses or graduate study. However, their application to typical design and analysis cases, especially those with multiple loads, is typically very cumbersome and it has become normal procedure to use commercially-available beam analysis software for such problems. ***The Beam Calculator program supplied with this book is a basic example.***
- Section 9-8 – Moment-Area Method [Optional] is preferred by some designers for applications that do not lend themselves to the use of formulas, superposition, or the successive integration approach. A notable example is the analysis of beams with varying cross sections as illustrated in this section.

Chapter 10 – Combined Stresses

The extent of coverage of the several topics in this chapter is best done by the individual instructor and/or program faculty members.

- Sections 10-1 through 10-6 give good introductory coverage of the issues presented when two or more types of stresses occur at a given point. They also tie material from previous chapters together to help students understand the distribution of stresses and the interactions involved. Combined normal stresses and combined normal and shear stresses are discussed.
- Sections 10-7 through 10-11 cover stress transformations, equations for stresses in any direction, principal stresses (maximum normal stress, maximum shear stress), and Mohr's circle.
- Section 10-12 covers the use of strain-gage rosettes to determine principal stresses and ties well with the preceding sections. It is also related to Section 1-13 – Experimental and Computational Stress Analysis, and is useful for connecting this course with companion laboratory courses.

Chapter 11 – Columns

- This chapter is a succinct, but comprehensive coverage of column analysis.
- Included are basic concepts, Euler formula for long columns, J. B. Johnson formula for short columns, and non-centrally loaded columns (crooked and eccentrically loaded).
- A Column Analysis Spreadsheet is shown that facilitates the calculations.

Chapter 12 – Pressure Vessels

- Basic concepts for thin-walled spheres and cylinders are recommended as a minimum, using Sections 12-1 through 12-4.
- Sections 12-5 through 12-7 [Optional] present extended coverage of thick-walled pressure vessels.
- Sections 12-8 and 12-9 [Optional] present additional considerations for column design.
- Section 12-9 [Optional] discusses the advantages of applying composite materials to pressure vessels. Reference to Section 2-12 should be made for basic properties of composites.

Chapter 13 – Connections

- This chapter covers bolted and riveted joints and welded connections.

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Software Included with the Book

INTRODUCTION

Two types of software on a CD-ROM are included with this book:

1. A set of 12 interactive video lessons that students can use to:
    a. Review material from the text for a given topic
    b. Observe the solution of a representative problem
    c. Complete a quiz at the end of each module to test understanding
2. A versatile beam calculator program that allows:
    a. The creation of a beam and its loading and support patterns
    b. Analysis of:
        i. Shearing force distribution
        ii. Bending moment distribution
        iii. Deflection of the beam at all points in the beam
        iv. Stress due to bending at all points in the beam

The software was created by Professor Jack Zecher of Indiana University - Purdue University – Indianapolis (IUPUI) in Indianapolis, Indiana.

ADVICE ON THE USE OF THE SOFTWARE

As with any software, students are advised to read pertinent text material and master the fundamental principles of the subject and the methods of problem solution prior to using the software.

INTERACTIVE VIDEO LESSONS

The following lessons with quizzes are included in this software:

1. ***NORMAL STRESS*** – Reviews the direct normal stress equation, σ = *Force/Area* for both tension and compression. Illustrates the calculation of direct normal stress on a member with multiple cross section sizes. Relevant to Chapters 1 – 3.
2. ***DIRECT SHEAR*** – Reviews the direct shear stress equation, τ = *Force/Area in shear*, for both single shear and double shear. Relevant to Chapters 1 – 3.
3. ***PUNCHING SHEAR*** – Reviews shearing stress that occurs in a cutting or punching situation using the direct shear stress equation, τ = *Force/Area in shear*, with emphasis on identifying the correct area in shear. Relevant to Chapters 1 and 3.
4. ***POISSON'S RATIO*** – Reviews the definition of strain and the fact that strains in both longitudinal and transverse directions are created when a load-carrying member is subjected to direct normal stress. Reviews the definition of Poisson's ratio. Relevant to Chapters 2 and 3.
5. ***STRESS CONCENTRATION*** – Reviews the concept of increased stresses occurring near sections of load-carrying members with abrupt changes in cross section. Illustrates the stress concentration factor for a member loaded in tension. Includes color graphic illustrations of stress lines around a hole and the plot of results of a finite element analysis. Relevant to Chapter 3.
6. ***AXIAL DEFORMATION*** – Reviews the deformation of members loaded in direct tension or compression using the formula, $\delta = FL/EA$. Relevant to Chapter 3.
7. ***THERMAL STRESSES*** – Reviews the property of coefficient of thermal expansion, α. Demonstrates the calculation of thermal expansion using the formula, $\delta = \alpha L(\Delta t)$ for a given change of temperature, Δt. Also demonstrates the stress created when members are restrained as temperatures change. Relevant to Chapter 3.
8. ***STATICALLY INDETERMINATE*** – Reviews the principles of axial deformation and considers the case when two or more members, possibly made from different materials, are loaded together. Relevant to Chapter 3.
9. ***TORSIONAL STRESS AND DEFORMATION*** – Reviews both the torsional shear stress equation, $\tau = Tc/J$ and the torsional deformation equation, $\theta = TL/GJ$. Illustrates calculations for a stepped shaft loaded by two torques and shows a torque diagram. Relevant to Chapter 4.
10. ***BENDING STRESS*** – Reviews the bending stress equation, $\sigma = Mc/I$, along with shearing force and bending moment diagrams. A finite element analysis animation is included illustrating how bending stresses are produced as a section of a T-beam deforms. Relevant to Chapters 5 – 7.
11. ***SHEAR IN BEAMS*** – Reviews shearing forces and stresses produced in beams along with bending. Illustrates the application of the beam shearing stress formula, $\tau = VQ/It$, using a rectangular beam made from glued laminations. Relevant to Chapter 8.

12. ***COMBINED NORMAL STRESSES*** – Reviews the case when a member is subjected to simultaneous bending and direct normal stresses. Includes a finite element model of such a member. Relevant to Chapter 10.

Notes on the quizzes: After viewing the video of any module, the student may access an interactive quiz in which a situation similar to the example shown in the video is presented with data. The student must complete the analysis on paper and enter the result. The program determines whether the entered result is correct or not and reports back. Students are permitted to enter values twice before the correct solution is shown.

BEAM CALCULATOR

This versatile software permits students to perform analyses of beams with complex loading patterns and with many combinations of support conditions. Its use, after students have mastered the principles of beam analysis by hand calculations, facilitates the evaluation of multiple alternative designs for a beam to explore relationships among variables such as:

- Types of support and their placement relative to the applied loads
- Magnitude of the loads and their placement relative to the supports
- Beam materials and cross section properties such as modulus of elasticity, moment of inertia, and shape

Many more and more complex examples can be analyzed in a given amount of time, extending learning beyond the typical problems that are assigned for practice by hand calculations.

The software uses a finite element analysis-based process that divides the beam into 50 segments. Calculations of results are made for each of the 50 points and at any applied load or support. ***If the user desires that the results for any other point be given, a concentrated load of zero value may be placed at that point.***

Features of the software include:

1. **Units** - Units of length are first selected by the user in either English (feet or inches) or Metric (meters or millimeters).
2. **Beam Properties** – Beam properties are entered by the user for:
    a. Beam length
    b. Modulus of elasticity, E, for the material of the beam
    c. Moment of inertia, I, for the cross section shape and dimensions of the beam
    d. Distance from the neutral axis of the cross section to the top of the beam
    e. Distance from the neutral axis of the cross section to the bottom of the beam
3. **Supports** – The type or types of supports and their placement are defined by the user. Up to 20 supports may be used in any combination of:
    a. Roller support providing only vertical support
    b. Pinned support providing vertical or horizontal support

        i. Note: Theoretically one roller support and one pin support should be provided for a simply supported beam to ensure equilibrium. However, this program permits only vertical concentrated or distributed loads and couples for which only vertical reactions are computed.
   c. Fixed support providing vertical and moment resistance, such as the support for a cantilever
   d. Before the analysis can proceed, the beam design must have a minimum of either:
        i. Two pinned supports
        ii. One pinned and one roller support
        iii. One fixed support
   e. The user may modify any support type or location before analysis is performed. This feature facilitates correction of entered data or the exploration of several alternative designs.
4. **Loads** – The user defines any combination of up to 20 loads by giving their placement and magnitudes. The load types available are:
   a. **Concentrated**
   b. **Distributed** – Either uniformly or uniformly varying distributed loads can be used. The user enters the placement and magnitude (force per unit length) at the start and at the end of the loading.
   c. **Couple** – This is a concentrated moment applied at any point along the beam. A counterclockwise couple is considered positive.
5. **Analyze** – After the beam is defined completely, the user selects the 'Analyze' button. If an incomplete or an excessive set of data are provided, the analysis will not be completed. The following analyses are completed:
   a. **Shear** – A complete shearing force diagram is shown under the beam design
   b. **Moment** – A complete bending moment diagram is shown under the beam design
   c. **Deflection** – A complete diagram of the shape of the deflected beam is shown
   d. **Stress** – The distribution of bending stress across the entire length of the beam is shown
   e. **Notes**:
        i. Values at any point on any diagram can be displayed by placing the cursor at the desired point.
        ii. The ESC (escape) key must be used to stop the interaction with the currently displayed diagram before switching from one type of output to another.

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This chapter builds on the basic introductory treatment of direct stresses from Chapter 1 and adds significant competencies in design of load-carrying members. Design stresses are defined and related to the yield strength or ultimate strength of the materials and to the manner of loading; steady, repeated, and impact or shock. Coverage can be grouped as follows:

- The Big Picture, Activity, and Chapter Objectives

- Sections 3-2 through 3-6: Design of members under direct normal stresses, including the definition of design stress, design factor (factor of safety), and design approaches.
- Sections 3-7 through 3-11: Deformation, thermal stresses, members made from more than one material, and stress concentration factors for direct axial stresses
- Sections 3-12 and 3-13 on bearing stress, including design bearing stresses
- Section 3-14 – Design Shear Stress

Users of previous editions of this book will note that, in response to feedback from colleagues and external reviewers, a significant re-ordering of topics has been done in this new 5th edition. For example, Bearing Stresses were formerly presented in Chapter 1 and deformations and related topics were covered in a separate chapter. It was recommended that both stress and strain (with deformations) be included in one chapter for each type of stress.

Chapter 4 – Torsional Shear Stress and Torsional Deformation

Coverage of this chapter can be groups as follows:

- Big Picture, Activity, and Objectives
- Section 4-2 on Torque, Power, and Rotational Speed: These topics should be review for most students but it has been found that careful study is required before applying them to stress analysis.
- Section 4-3 presents the fundamental torsional shear stress formula and demonstrates its application to the analysis of stresses.
- Sections 4-4 and 4-5 [Optional] use calculus to derive the torsional shear stress formula and the equations for polar moment for solid circular bars.
- Section 4-6 extends the coverage to hollow circular sections. While some calculus is used to develop equations for polar moment of inertia, the final equations are all that is required for problem solving.
- Section 4-7 presents an approach to design of circular members under torsion, extending the design stress concepts from Chapter 3 to include torsional shear strength of materials.
- Section 4-8: This section provides interesting and useful comparison of the behavior of hollow circular sections and emphasizes their efficiency as compared with solid sections.
- Section 4-9: The study of stress concentrations in torsionally loaded members is essential to proper design and analysis of shafts.
- Section 4-10: The twisting of circular bars is discussed with the application of the equation for torsional deformation.
- Section 4-11 [Optional] Torsion in noncircular sections is less frequently encountered in practice. However, it is important for students to understand that such shapes behave quite differently from circular sections.

Chapters 5 through 9: All these chapters deal with beams; members carrying loads perpendicular to their axes. Students should be advised to scan all five chapters to see the progression of topics and to observe how each chapter relates to the others.

Chapter 5 – Shearing Forces and Bending Moments in Beams

- The Big Picture, Activity, and Sections 5-1 through 5-9 are essential. On rare occasions, some programs include some of these topics in the Statics course.
- Section 5-10 [Optional] Free-Body Diagrams of Parts of Structures: Mastery of this topic gives students a better fundamental understanding of the behavior of load carrying members by visualizing the internal forces, moments, and stresses created by various external loads.
- Section 5-11 [Optional] Mathematical Analysis of Beam Diagrams: Here students apply calculus to derive equations for shearing force and bending moments from given beam loading and support conditions. This skill is required for later study of Section 9-7 Successive Integration Method for deflection of beams, which is, itself, optional.
- Section 5-12 [Optional] Continuous Beams – Theorem of Three Moments: Students should, at least, understand that the behavior of beams with three or more supports is quite different from those with only two simple supports as covered in other sections of this chapter. Extensive study of this topic, however, would be most beneficial for the civil and construction fields where such beams are frequently applied in bridges and buildings.
- ***Note: This is one place where the Beam Calculator program supplied with this book can be used effectively for analyzing complex loading patterns after students have mastered the manual process of creating shearing force and bending moment diagrams. The 'Shear' and 'Moment' selections produce complete diagrams immediately after the beam loading and support conditions are defined.***

Chapter 6 – Centroids and Moments of Inertia of Areas

This entire chapter may be skipped for those programs in which the coverage of this topic is included in a prerequisite course in Statics. However, review of the procedures for computing the location of centroids and the computation of moments of inertia of areas is typically required. This can be done by moving directly to Sections 6-5, 6-6, and 6-8 where sections commonly encountered in strength of materials are considered, especially those including standard structural shapes such as W-beams, channels, and angles.

For those programs that do not include this topic in prior courses, coverage of Sections 6-1 through 6-6 and 6-8 should be covered as a minimum. These skills are essential to the understanding of concepts in Chapters 7 – 11. Coverage of the other sections of this chapter are optional as discussed next.

- Section 6-7 [Optional] uses calculus to derive the moment of inertia of an area, I.

- Section 6-9 [Optional] provides a useful method of analyzing shapes with all rectangular parts. The process can be implemented effectively in a spreadsheet.
- Section 6-10 [Optional] Radius of Gyration is an important property of an area and is most directly applicable to Chapter 11 on Columns. It may be desirable to delay the coverage of this topic to combine it with the study of columns.
- Section 6-11 [Optional] Section Modulus is an important property of an area and is most directly applicable to Chapter 7 on Stress Due to Bending. It may be desirable to delay the coverage of this topic to combine it with the study of beams.

Chapter 7 – Stress Due to Bending

- Sections 7-1 through 7-4 present the foundation material for the analysis of beams.
- Section 7-5 [Optional] uses calculus to derive the flexure formula. It can be skipped or discussed lightly for those programs where detailed use of the calculus is not expected.
- Sections 7-6 through 7-8 cover the transitions from analysis to design of beams.
- Section 7-9 covers stress concentrations in bending situations.
- Section 7-10 is critical, at least from the standpoint that students must understand that the flexure formula applies only to symmetrical sections or when the load path passes through the flexural center (shear center) of the section. Otherwise twisting combines with the bending stress, reducing the capacity of the beam.
- Section 7-11 on Preferred Shapes for Beam Cross Sections is designed to help the novice student understand better why certain shapes are preferred for beams.
- Section 7-12 [Optional] on beams made from composites presents mostly conceptual information about the advantages of composites in bending cases and how the shape can be optimized to make best use of the special properties of composites. This section refers back to Section 2-12 and it may be desirable to cover those two sections together at this point.
- ***Note: This is one place where the Beam Calculator program supplied with this book can be used effectively for analyzing bending stress produced by complex loading patterns after students have mastered the manual process making such calculations on more simple beams. The 'Stress' selection produces the complete diagram of bending stress distribution immediately after the beam loading and support conditions are defined. Students should compare this result with the bending moment diagram.***

Chapter 8 – Shearing Stresses in Beams

- Sections 8-1 through 8-4 present the fundamental concepts and the general shear formula.
- Section 8-5 [Optional] uses calculus to derive the general shear formula. It can be skipped or discussed lightly for those programs where detailed use of the calculus is not expected.
- Section 8-6 shows the special shear formulas applicable to rectangular, circular, hollow, and thin-webbed sections (e.g. W-beams). These formulas are frequently used.
- Section 8-7 transitions the coverage of shear in beams from analysis to design.

- Section 8-8 on shear flow [Optional] is applicable to beam sections made from component shapes that are fastened, glued, or otherwise assembled where connections are subjected to shear.

Chapter 9 – Deflection of Beams

There appears to be a wide divergence of opinion about what types of beam deflection approaches to cover in a basic course in strength of materials. This book attempts to show all popular approaches and let individual instructors and program faculty members decide which is best for their programs.

Note: This is the place where the Beam Calculator program supplied with this book is most applicable. The complete deflection curve is produced immediately after the beam loading and support conditions are defined by selecting the 'Deflection' button. Comparison of the Deflection curve with the Shear, Moment, and Stress diagrams is advised.

That said, here are some factors to consider in course planning:

- Sections 9-1 through 9-4 present the basic concepts and the widely used formulas for beam deflection, using the extensive list of formulas from Appendixes A-23, A-24, and A-25.
- Section 9-5 gives students some experience in comparing the performance of several ways of supporting a given load with regard to the stresses and deflections that result. This should help the novice student gain a better 'feel' for what approaches are preferred in different applications.
- Section 9-6 extends the material in Section 9-4 to the permit use of beam deflection formulas to a much broader array of applications.
- Section 9-7 on the Successive Integration Method [Optional] provides a more analytical approach to deflection analysis. It requires the use of differential and integral calculus and should be combined with Section 5-11 Mathematical Analysis of Beam Diagrams. Mastery of these concepts would be expected for students who intend to continue their study of applied mechanics in later courses or graduate study. However, their application to typical design and analysis cases, especially those with multiple loads, is typically very cumbersome and it has become normal procedure to use commercially-available beam analysis software for such problems. ***The Beam Calculator program supplied with this book is a basic example.***
- Section 9-8 – Moment-Area Method [Optional] is preferred by some designers for applications that do not lend themselves to the use of formulas, superposition, or the successive integration approach. A notable example is the analysis of beams with varying cross sections as illustrated in this section.

Chapter 10 – Combined Stresses

The extent of coverage of the several topics in this chapter is best done by the individual instructor and/or program faculty members.

- Sections 10-1 through 10-6 give good introductory coverage of the issues presented when two or more types of stresses occur at a given point. They also tie material from previous chapters together to help students understand the distribution of stresses and the interactions involved. Combined normal stresses and combined normal and shear stresses are discussed.
- Sections 10-7 through 10-11 cover stress transformations, equations for stresses in any direction, principal stresses (maximum normal stress, maximum shear stress), and Mohr's circle.
- Section 10-12 covers the use of strain-gage rosettes to determine principal stresses and ties well with the preceding sections. It is also related to Section 1-13 – Experimental and Computational Stress Analysis, and is useful for connecting this course with companion laboratory courses.

Chapter 11 – Columns

- This chapter is a succinct, but comprehensive coverage of column analysis.
- Included are basic concepts, Euler formula for long columns, J. B. Johnson formula for short columns, and non-centrally loaded columns (crooked and eccentrically loaded).
- A Column Analysis Spreadsheet is shown that facilitates the calculations.

Chapter 12 – Pressure Vessels

- Basic concepts for thin-walled spheres and cylinders are recommended as a minimum, using Sections 12-1 through 12-4.
- Sections 12-5 through 12-7 [Optional] present extended coverage of thick-walled pressure vessels.
- Sections 12-8 and 12-9 [Optional] present additional considerations for column design.
- Section 12-9 [Optional] discusses the advantages of applying composite materials to pressure vessels. Reference to Section 2-12 should be made for basic properties of composites.

Chapter 13 – Connections

- This chapter covers bolted and riveted joints and welded connections.

APPLIED STRENGTH OF MATERIALS
5TH Ed.
by
Robert L. Mott

Software Included with the Book

INTRODUCTION

Two types of software on a CD-ROM are included with this book:

1. A set of 12 interactive video lessons that students can use to:
   a. Review material from the text for a given topic
   b. Observe the solution of a representative problem
   c. Complete a quiz at the end of each module to test understanding
2. A versatile beam calculator program that allows:
   a. The creation of a beam and its loading and support patterns
   b. Analysis of:
      i. Shearing force distribution
      ii. Bending moment distribution
      iii. Deflection of the beam at all points in the beam
      iv. Stress due to bending at all points in the beam

The software was created by Professor Jack Zecher of Indiana University - Purdue University – Indianapolis (IUPUI) in Indianapolis, Indiana.

ADVICE ON THE USE OF THE SOFTWARE

As with any software, students are advised to read pertinent text material and master the fundamental principles of the subject and the methods of problem solution prior to using the software.

INTERACTIVE VIDEO LESSONS

The following lessons with quizzes are included in this software:

1. ***NORMAL STRESS*** – Reviews the direct normal stress equation, σ = *Force/Area* for both tension and compression. Illustrates the calculation of direct normal stress on a member with multiple cross section sizes. Relevant to Chapters 1 – 3.
2. ***DIRECT SHEAR*** – Reviews the direct shear stress equation, τ = *Force/Area in shear*, for both single shear and double shear. Relevant to Chapters 1 – 3.
3. ***PUNCHING SHEAR*** – Reviews shearing stress that occurs in a cutting or punching situation using the direct shear stress equation, τ = *Force/Area in shear*, with emphasis on identifying the correct area in shear. Relevant to Chapters 1 and 3.
4. ***POISSON'S RATIO*** – Reviews the definition of strain and the fact that strains in both longitudinal and transverse directions are created when a load-carrying member is subjected to direct normal stress. Reviews the definition of Poisson's ratio. Relevant to Chapters 2 and 3.
5. ***STRESS CONCENTRATION*** – Reviews the concept of increased stresses occurring near sections of load-carrying members with abrupt changes in cross section. Illustrates the stress concentration factor for a member loaded in tension. Includes color graphic illustrations of stress lines around a hole and the plot of results of a finite element analysis. Relevant to Chapter 3.
6. ***AXIAL DEFORMATION*** – Reviews the deformation of members loaded in direct tension or compression using the formula, $\delta = FL/EA$. Relevant to Chapter 3.
7. ***THERMAL STRESSES*** – Reviews the property of coefficient of thermal expansion, α. Demonstrates the calculation of thermal expansion using the formula, $\delta = \alpha L(\Delta t)$ for a given change of temperature, Δt. Also demonstrates the stress created when members are restrained as temperatures change. Relevant to Chapter 3.
8. ***STATICALLY INDETERMINATE*** – Reviews the principles of axial deformation and considers the case when two or more members, possibly made from different materials, are loaded together. Relevant to Chapter 3.
9. ***TORSIONAL STRESS AND DEFORMATION*** – Reviews both the torsional shear stress equation, $\tau = Tc/J$ and the torsional deformation equation, $\theta = TL/GJ$. Illustrates calculations for a stepped shaft loaded by two torques and shows a torque diagram. Relevant to Chapter 4.
10. ***BENDING STRESS*** – Reviews the bending stress equation, $\sigma = Mc/I$, along with shearing force and bending moment diagrams. A finite element analysis animation is included illustrating how bending stresses are produced as a section of a T-beam deforms. Relevant to Chapters 5 – 7.
11. ***SHEAR IN BEAMS*** – Reviews shearing forces and stresses produced in beams along with bending. Illustrates the application of the beam shearing stress formula, $\tau = VQ/It$, using a rectangular beam made from glued laminations. Relevant to Chapter 8.

12. ***COMBINED NORMAL STRESSES*** – Reviews the case when a member is subjected to simultaneous bending and direct normal stresses. Includes a finite element model of such a member. Relevant to Chapter 10.

Notes on the quizzes: After viewing the video of any module, the student may access an interactive quiz in which a situation similar to the example shown in the video is presented with data. The student must complete the analysis on paper and enter the result. The program determines whether the entered result is correct or not and reports back. Students are permitted to enter values twice before the correct solution is shown.

BEAM CALCULATOR

This versatile software permits students to perform analyses of beams with complex loading patterns and with many combinations of support conditions. Its use, after students have mastered the principles of beam analysis by hand calculations, facilitates the evaluation of multiple alternative designs for a beam to explore relationships among variables such as:

- Types of support and their placement relative to the applied loads
- Magnitude of the loads and their placement relative to the supports
- Beam materials and cross section properties such as modulus of elasticity, moment of inertia, and shape

Many more and more complex examples can be analyzed in a given amount of time, extending learning beyond the typical problems that are assigned for practice by hand calculations.

The software uses a finite element analysis-based process that divides the beam into 50 segments. Calculations of results are made for each of the 50 points and at any applied load or support. ***If the user desires that the results for any other point be given, a concentrated load of zero value may be placed at that point.***

Features of the software include:

1. **Units** - Units of length are first selected by the user in either English (feet or inches) or Metric (meters or millimeters).
2. **Beam Properties** – Beam properties are entered by the user for:
   a. Beam length
   b. Modulus of elasticity, *E*, for the material of the beam
   c. Moment of inertia, *I*, for the cross section shape and dimensions of the beam
   d. Distance from the neutral axis of the cross section to the top of the beam
   e. Distance from the neutral axis of the cross section to the bottom of the beam
3. **Supports** – The type or types of supports and their placement are defined by the user. Up to 20 supports may be used in any combination of:
   a. Roller support providing only vertical support
   b. Pinned support providing vertical or horizontal support

        i. Note: Theoretically one roller support and one pin support should be provided for a simply supported beam to ensure equilibrium. However, this program permits only vertical concentrated or distributed loads and couples for which only vertical reactions are computed.
    c. Fixed support providing vertical and moment resistance, such as the support for a cantilever
    d. Before the analysis can proceed, the beam design must have a minimum of either:
        i. Two pinned supports
        ii. One pinned and one roller support
        iii. One fixed support
    e. The user may modify any support type or location before analysis is performed. This feature facilitates correction of entered data or the exploration of several alternative designs.

4. **Loads** – The user defines any combination of up to 20 loads by giving their placement and magnitudes. The load types available are:
    a. **Concentrated**
    b. **Distributed** – Either uniformly or uniformly varying distributed loads can be used. The user enters the placement and magnitude (force per unit length) at the start and at the end of the loading.
    c. **Couple** – This is a concentrated moment applied at any point along the beam. A counterclockwise couple is considered positive.
5. **Analyze** – After the beam is defined completely, the user selects the 'Analyze' button. If an incomplete or an excessive set of data are provided, the analysis will not be completed. The following analyses are completed:
    a. **Shear** – A complete shearing force diagram is shown under the beam design
    b. **Moment** – A complete bending moment diagram is shown under the beam design
    c. **Deflection** – A complete diagram of the shape of the deflected beam is shown
    d. **Stress** – The distribution of bending stress across the entire length of the beam is shown
    e. **Notes**:
        i. Values at any point on any diagram can be displayed by placing the cursor at the desired point.
        ii. The ESC (escape) key must be used to stop the interaction with the currently displayed diagram before switching from one type of output to another.

CHAPTER 1 Basic Concepts in Strength of Materials

1-1 TO **1-15** ANSWERS IN TEXT.

1-16 $W = m \cdot g = 1800\ kg \cdot 9.81\ m/s^2 = 17658\ kg\,m/s^2 = 17.7 \times 10^3\ N$

$W = 17.7\ kN$

1-17 TOTAL WT. $= mg = 4000\ kg \cdot 9.81\ m/s^2 = 39.24\ kN$

EACH FRONT WHEEL: $F_F = (\frac{1}{2})(0.40)(39.24\ kN) = 7.85\ kN$

EACH REAR WHEEL: $F_R = (\frac{1}{2})(0.60)(39.24\ kN) = 11.77\ kN$

1-18 LOADING = TOTAL FORCE/AREA

TOTAL FORCE $= 6800\ kg \cdot 9.81\ m/s^2 = 66.7\ kN$

AREA $= (5.0\ m)(3.5\ m) = 17.5\ m^2$

LOADING $= 66.7\ kN / 17.5\ m^2 = 3.81\ kN/m^2 = 3.81\ kPa$

1-19 FORCE = WT $= m \cdot g = 25\ kg \cdot 9.81\ m/s^2 = 245\ N$

K = SPRING SCALE $= 4500\ N/m = F/\Delta L$

$\Delta L = \frac{F}{K} = \frac{245\ N}{4500\ N/m} = 0.0545\ m = 54.5 \times 10^{-3}\ m = 54.5\ mm$

1-22 $W = 17.7\ kN = 17700\ N \times 0.2248\ LB/N = 3980\ LB$

1-23 $F_F = 7.85\ kN = 7850\ N \times 0.2248\ LB/N = 1765\ LB$

$F_R = 11.77\ kN = 11770\ N \times 0.2248\ LB/N = 2646\ LB$

1-24 LOADING $= 3.81\ kPa = 3.81 \times 10^3 \frac{N}{m^2} \times \frac{0.2248\ LB}{N} \times \frac{1\ m^2}{(3.28\ ft)^2} = 79.6 \frac{LB}{FT^2}$

1-25 $F = 245\ N \cdot 0.2248\ LB/N = 55.1\ LB$

$K = 4500 \frac{N}{m} \times \frac{0.2248\ LB}{N} \times \frac{1\ m}{39.37\ in} = 25.7\ LB/IN$

$\Delta L = \frac{F}{K} = \frac{55.1\ LB}{25.7\ LB/IN} = 2.14\ IN$

1-26 $m = \frac{w}{g} = \frac{2750\ LB}{32.2\ FT/S^2} = 85.4\ \frac{LB\cdot S^2}{FT} = \underline{85.4\ SLUGS}$

1-27 $m = \frac{w}{g} = \frac{12800\ LB}{32.2\ FT/S^2} = 398\ \frac{LB\cdot S^2}{FT} = \underline{398\ SLUGS}$

1-29 $p = 1200\ psi \times 6.895\ kPa/psi = \underline{8274\ kPa}$

1-30 $\sigma = 21600\ psi \times 6.895\ kPa/psi = 149{,}000\ kPa = \underline{149\ MPa}$

1-31 $S_u = 14000\ psi \times 6.895\ kPa/psi = 96{,}500\ kPa = \underline{96.5\ MPa}$

$S_u = 76000\ psi \times 6.895\ kPa/psi = 524000\ kPa = \underline{524\ MPa}$

1-32 $n = 1750\ \frac{REV}{MIN} \times \frac{2\pi\ RAD}{REV} \times \frac{1\ MIN}{60\ S} = \underline{183\ RAD/S}$

1-33 $A = 14.1\ in^2 \times \frac{(25.4\ mm)^2}{IN^2} = \underline{9097\ mm^2}$

1-34 $y = 0.08\ IN \times 25.4\ mm/IN = \underline{2.03\ mm}$

1-35 DIMENSIONS: $18\ IN \times 25.4\ mm/IN = 457\ mm$

$12\ IN \times 25.4\ mm/IN = 305\ mm$

$AREA = (18\ IN)^2 = \underline{324\ IN^2}$

$AREA = (457\ mm)^2 = \underline{209 \times 10^5\ mm^2}$

VOLUME = V = AREA × HEIGHT

$V = 324\ IN^2 \times 12\ IN = \underline{3888\ IN^3}$

$V = (1.5\ FT)^2 \times 1.0\ FT = \underline{2.25\ FT^3}$

$V = (209 \times 10^3\ mm^2) \times 305\ mm = \underline{6.37 \times 10^7\ mm^3}$

$V = (0.457\ m)^2 \times 0.305\ m = 0.0637\ m^3 = \underline{6.37 \times 10^{-2}\ m^3}$

1-36 $A = \pi D^2/4 = \pi(0.505\ IN)^2/4 = \underline{0.200\ IN^2}$

$A = 0.200\ IN^2 \times \frac{(25.4\ mm)^2}{IN^2} = \underline{129\ mm^2}$

1-37 $\sigma = \frac{P}{A} = \frac{3200\ N}{\pi D^2/4} = \frac{3200\ N}{\pi(10\ mm)^2/4} = 40.7\ N/mm^2 = \underline{40.7\ MPa}$

1-38 $\sigma = \frac{P}{A} = \frac{20 \times 10^3\ N}{(10)(30)\ mm^2} = 66.7\ N/mm^2 = \underline{66.7\ MPa}$

1-39 $\sigma = \frac{P}{A} = \frac{860\ LB}{(0.40\ IN)^2} = \underline{5375\ psi}$

1-40 $\sigma = \frac{P}{A} = \frac{1850\ LB}{\pi(0.375\ IN)^2/4} = \underline{16750\ psi.}$

1-41 LOAD ON SHELF $= W = mg = 1840\,kg \cdot 9.81\,m/s^2 = 18050\,N$

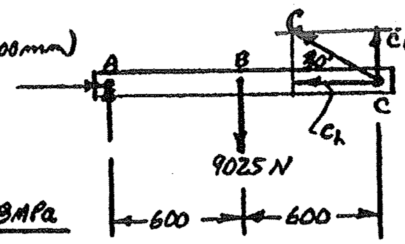
$W/2 = 9025\,N$ ON EACH SIDE

$\Sigma M_A = 0 = (9025\,N)(600\,mm) - C_V(1200\,mm)$

$C_V = 4512\,N$

$C = C_V/\sin 30° = 9025\,N$

$\sigma = \frac{P}{A} = \frac{C}{A} = \frac{9025\,N}{\pi(12\,mm)^2/4} = \underline{79.8\,MPa}$



1-42 $\sigma = \frac{P}{A} = \frac{70000\,LB}{\pi(8\,IN)^2/4} = \underline{1393\,psi}$

1-43 $\sigma = \frac{P}{A} = \frac{29500\,LB/3}{(3.5\,IN)^2} = \underline{803\,psi}$

1-44 $\sigma = \frac{P}{A} = \frac{3500\,N}{(8.0\,mm)^2} = \underline{54.7\,MPa}$

1-45 $w = mg = 4200\,kg \cdot 9.81\,m/s^2 = 41.2\,kN$

$AB_X = AB \sin 35°$

$AB_Y = AB \cos 35°$

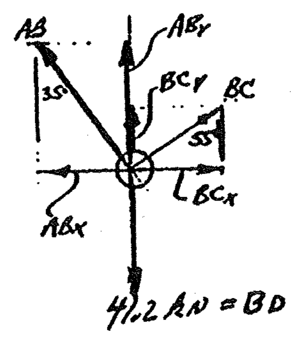
$BC_X = BC \sin 55°$

$BC_Y = BC \cos 55°$

$\Sigma F_X = 0 = AB_X - BC_X$

$0 = AB \sin 35° - BC \sin 55°$

$AB = BC \cdot \frac{\sin 55°}{\sin 35°} = 1.428\,BC$



$\Sigma F_V = 0 = AB_Y + BC_Y - 41.2\,kN = AB\cos 35° + BC\cos 55° - 41.2\,kN$

$0 = (1.428\,BC)\cos 35° + BC\cos 55° - 41.2\,kN$

$41.2\,kN = BC[1.170 + 0.574] = 1.743\,BC$

$BC = 41.2\,kN/1.743 = 23.63\,kN$

$AB = 1.428\,BC = 33.75\,kN$

STRESS IN ROD AB: $\sigma_{AB} = \frac{AB}{A} = \frac{33.75 \times 10^3\,N}{\pi(20\,mm)^2/4} = \underline{107.4\,MPa}$

STRESS IN ROD BC: $\sigma_{BC} = \frac{BC}{A} = \frac{23.63 \times 10^3\,N}{\pi(20\,mm)^2/4} = \underline{75.2\,MPa}$

STRESS IN ROD BD: $\sigma_{BD} = \frac{BD}{A} = \frac{41.2 \times 10^3\,N}{\pi(20\,mm)^2/4} = \underline{131.1\,MPa}$

1-46 $F = 0.01097\, m R n^2 = (0.01097)(0.40)(0.60)(3000)^2\ N$

$F = 23695\ N$

$A = \pi(16\ mm)^2/4 = 201\ mm^2$

$\sigma = \frac{F}{A} = \frac{23695N}{201\ mm^2} = \underline{118\ MPa}$

1-47 $A = (30\ mm)^2 = 900\ mm^2$

FOR AB: $F_{AB} = (110 - 40 + 80)kN = 150\ kN$

$\sigma_{AB} = \frac{F_{AB}}{A} = \frac{150 \times 10^3 N}{900\ mm^2} = \underline{167\ MPa}$ TENSION

FOR BC: $F_{BC} = 110 - 40 = 70\ kN$

$\sigma_{BC} = \frac{F_{BC}}{A} = \frac{70 \times 10^3 N}{900\ mm^2} = \underline{77.8\ MPa}$ TENSION

FOR CD: $F_{CD} = 110\ kN$

$\sigma_{CD} = \frac{F_{CD}}{A} = \frac{110 \times 10^3 N}{900\ mm^2} = \underline{122\ MPa}$ TENSION

1-48 AREAS: A-C ; $A_1 = \pi(25)^2/4 = 491\ mm^2$

C-D ; $A_2 = \pi(16)^2/4 = 201\ mm^2$

FOR AB: $F_{AB} = -9.65 - 12.32 + 4.45 = -17.52\ kN$

$\sigma_{AB} = \frac{F_{AB}}{A_1} = \frac{-17.52 \times 10^3 N}{491\ mm^2} = \underline{-35.7\ MPa}$ COMPR.

FOR BC: $F_{BC} = -9.65 - 12.32 = -21.97\ kN$

$\sigma_{BC} = \frac{F_{BC}}{A_1} = \frac{-21.97 \times 10^3 N}{491\ mm^2} = \underline{-44.7\ MPa}$ COMPR.

FOR CD: $F_{CD} = -9.65\ kN$

$\sigma_{CD} = \frac{F_{CD}}{A_2} = \frac{-9.65 \times 10^3 N}{201\ mm^2} = \underline{-48.0\ MPa}$ COMPR.

1-49 $A = \pi[(1.90)^2 - (1.61)^2]/4 = 0.799\ in^2$ ($1\frac{1}{2}$ IN PIPE - APP. A-12)

FOR BC: $\sigma_{BC} = \frac{F_{BC}}{A} = \frac{2500\ LB}{0.799\ in^2} = \underline{3129\ PSI}$ TENSION

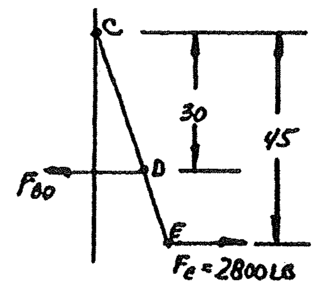
FOR AB: $F_{AB} = 2500 + 2(8000 \cos 30°) = 16356\ LB$

$\sigma_{AB} = \frac{F_{AB}}{A} = \frac{16356\ LB}{0.799\ in^2} = \underline{20471\ PSI}$ TENSION

1-50 $\Sigma M_C = 0 = 2800(45) - F_{BD}(30)$

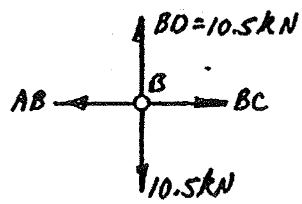
$F_{BD} = 4200 \text{ LB}$

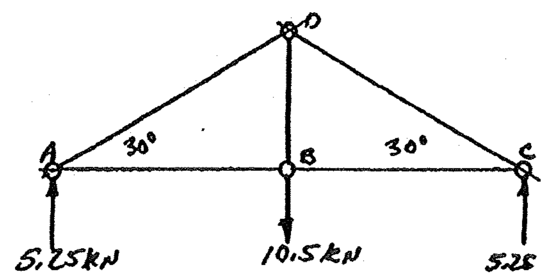
$\sigma_{BD} = \dfrac{F_{BD}}{A} = \dfrac{4200 \text{ LB}}{(2.0)(0.65) \text{ IN}^2} = 3231 \text{ psi}$ TENSION



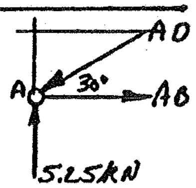
1-51

JOINT B





JOINT A



$AD \sin 30° = 5.25 \text{ kN}$

$AD = 10.5 \text{ kN} = CD$

$AB = AD \cos 30° = 9.09 \text{ kN} = BC$

STRESSES:

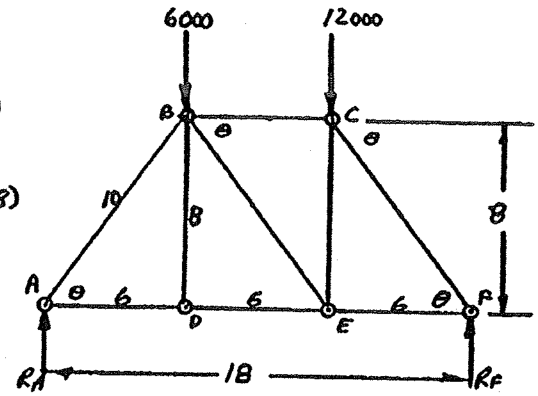
AB, BC: $\sigma_{AB} = \sigma_{BC} = \dfrac{9.09 \times 10^3 \text{ N}}{(12)(30) \text{ mm}^2} = 25.3 \text{ MPa}$ TENSION

BD: $\sigma_{BD} = \dfrac{10.5 \times 10^3 \text{ N}}{(2)(10)(30) \text{ mm}^2} = 17.5 \text{ MPa}$ TENSION

AD, CD: $A = (30)^2 - (20)^2 = 500 \text{ mm}^2$

$\sigma_{AD} = \sigma_{CD} = \dfrac{-10.5 \times 10^3 \text{ N}}{500 \text{ mm}^2} = -21.0 \text{ MPa}$ COMPRESSION

1-52

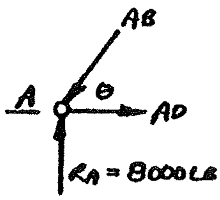


$\Sigma M_A = 0 = 6000(6) + 12000(12) - R_F(18)$

$R_F = 10000$ LB

$\Sigma M_F = 0 = 12000(6) + 6000(12) - R_A(18)$

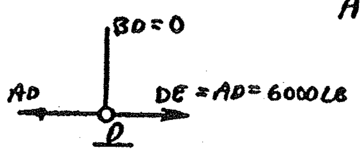
$R_A = 8000$ LB

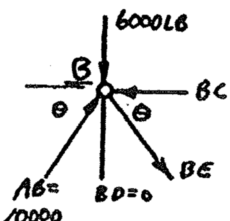


$R_A = AB \sin\theta = AB(0.8)$

$AB = R_A/0.8 = 8000/0.8 = 10000$ LB COMP.

$AD = AB \cos\theta = 10000(0.6) = 6000$ LB TENS.



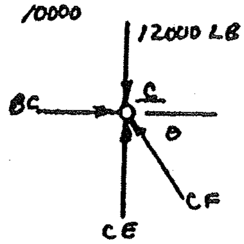


$BE \sin\theta + 6000 - AB \sin\theta = 0$

$BE = \dfrac{AB \sin\theta - 6000}{\sin\theta} = \dfrac{10000(0.8) - 6000}{0.8} = 2500$ LB TENS.

$BC = AB \cos\theta + BE \cos\theta = 10000(0.6) + 2500(0.6) =$

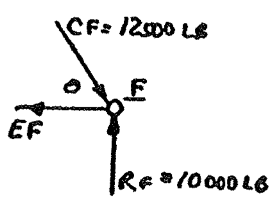
$BC = 7500$ LB COMP.



$BC = CF \cos\theta$

$CF = BC/\cos\theta = 7500/0.6 = 12500$ LB COMP.

$CE = 12000 - CF \sin\theta = 12000 - 12500(0.8) = 2000$ LB C



$EF = CF \cos\theta = 12500(0.6) = 7500$ LB TENS.

AREAS OF MEMBERS: (APP. A5, A6)

AD, DE, EF — $2(0.484) = 0.968\ IN^2$

BD, BE, CE — $0.484\ IN^2$

AB, BC, CF — $2(1.21) = 2.42\ IN^2$

NOTE: COMPRESSION MEMBERS MUST BE CHECKED FOR COLUMN BUCKLING

STRESSES:

$\sigma_{AD} = \sigma_{DE} = 6000/0.968 = +6198$ psi

$\sigma_{EF} = 7500/0.968 = +7748$ psi

$\sigma_{BD} = 0$

$\sigma_{BE} = 2500/0.484 = +5165$ psi

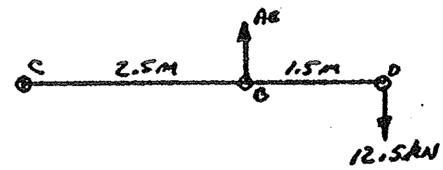
$\sigma_{CE} = -2000/0.484 = -4132$ psi

$\sigma_{AB} = -10000/2.42 = -4132$ psi

$\sigma_{BC} = -7500/2.42 = -3099$ psi

$\sigma_{CF} = -12500/2.42 = -5165$ psi

1-53



$\Sigma M_C = 0 = (2.5)(4.0) - AB(2.5)$

$AB = 20\ kN$

$\sigma = \dfrac{20 \times 10^3 N}{(20)^2 mm^2} = \underline{50\ MPa}$

1-54 $A = \pi(0.505)^2/4 = 0.200\ in^2$

$\sigma = F/A = 12600\ LB / 0.200\ in^2 = \underline{63\,000\ psi}$

1-55 $A = (2.65)(1.40) + 2[(1.40)(0.5)(\tfrac{1}{2})] = 4.41\ in^2$

$\sigma = F/A = (52000\ LB / 4.41\ in^2) = \underline{11\,791\ psi}$

1-56 $A = (80)(40) - (60)(15) + \pi(40)^2/4 = 3557\ mm^2$

$\sigma = F/A = 640 \times 10^3 N / 3557\ mm^2 = \underline{180\ MPa}$

1-57 DIRECT SHEAR – SINGLE SHEAR

$A_s = [\pi(12.0)^2/4]\ mm^2 = 113\ mm^2$

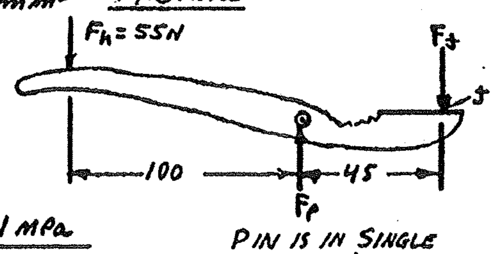
$\tau = F/A_s = 16.5 \times 10^3 N / 113\ mm^2 = \underline{146\ MPa}$

1-58 $\Sigma F_y = 0 = 55(145) - F_p(45)$

$F_p = 177\ N$

$A_s = \pi(3.0)^2/4 = 7.07\ mm^2$

$\tau = F_p/A_s = 177\ N / 7.07\ mm^2 = \underline{25.1\ MPa}$



1-59 FROM PROB 1-46: F = 23695 N

$A_s = 2[\pi(10)^2/4] = 157\ mm^2$ DOUBLE SHEAR

$\tau = F/A_s = 23695\ N / 157\ mm^2 = \underline{151\ MPa}$

1-60 $A_s = (3.0)(3.5) = 10.5\ in^2$

$\tau = F/A_s = (1800\ lb)/(10.5\ in^2) = \underline{171\ psi}$

1-61 $A_s = [2(35) + \pi(8)](5.0) = 475.7\ mm^2$

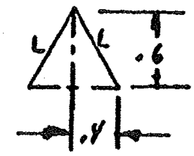
$\tau = F/A_s = 38.6\times10^3\ N / 475.7\ mm^2 = \underline{81.1\ MPa}$

1-62 $L = \sqrt{.4^2 + .6^2} = 0.721\ in.$

$A_s = [2(1.60) + \pi(0.8)/2 + 2(0.721)]\ 0.194$

$A_s = 1.144\ in^2$

$\tau = F/A_s = 45000\ lb/1.144\ in^2 = \underline{39324\ psi}$

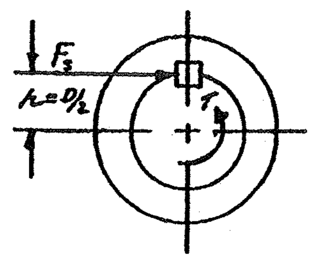


1-63 $T = F_s \cdot R$

$F_s = T/R = \dfrac{95\ N\cdot m}{35\ mm/2} \cdot \dfrac{10^3\ mm}{m} = 5429\ N$

$A_s = b\cdot L = (10)(22) = 220\ mm^2$

$\tau = F_s/A_s = 5429\ N/220\ mm^2 = \underline{24.7\ MPa}$



1-64 $F_s = T/R = 8000\ lb\cdot in/1.0\ in = 8000\ lb$

$A_s = b\cdot L = (0.50)(2.25) = 1.125\ in^2$

$\tau = F_s/A_s = 8000\ lb/1.125\ in^2 = \underline{7111\ psi}$

1-65 PIN DOUBLE SHEAR; $A_s = 2[\pi(0.5)^2/4] = 0.393\ in^2$

$\tau = F/A_s = 20\,000\ lb/0.393\ in^2 = \underline{50\,930\ psi}$

COLLAR SHEAR COLLAR FROM CONNECTOR BODY

$A_s = \pi d\, t = \pi(0.875)(0.1875) = 0.5154\ in^2$

$\tau = F/A_s = 20000\ lb/0.5154\ in^2 = \underline{38\,800\ psi}$

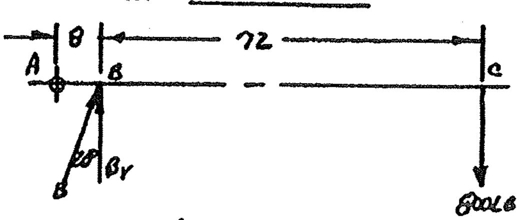
1-66 $\Sigma M_A = 0 = 800(80) - B_y(8)$

$B_y = 8000\ lb$

$B = B_y/\cos 20° = 8513\ lb$

$A_s = 2(\pi(0.375)^2/4) = 0.221\ in^2$

$\tau = B/A_s = 8513\ lb/0.221\ in^2 = \underline{38\,540\ psi}$



1-67 $A_s = (40)(12) = 480\ mm^2$

$\tau = F/A_s = 88\times10^3\ N/480\ mm^2 = \underline{183\ MPa}$

1-68 $A_s = (40)(120) = 4800\ mm^2$

$\tau = F/A_s = 88.2\times10^3\ N / 4800\ mm^2 = \underline{18.4\ MPa}$

1-69 $A_s = \pi D t = \pi(12)(8) = 301.6\ mm^2$

$\tau = F/A_s = 22.3 \times 10^3 N / 301.6\ mm^2 = \underline{73.9\ MPa}$

1-70 $A_s = 2[\pi(12)^2/4] = 226.2\ mm^2$ TWO RIVETS – SINGLE SHEAR

$\tau = F/A_s = 10.2 \times 10^3 N / 226.2\ mm^2 = \underline{45.1\ MPa}$

1-71 $A_s = 4[\pi(12)^2/4] = 452.4\ mm^2$ TWO RIVETS – DOUBLE SHEAR

$\tau = F/A_s = 10.2 \times 10^3 N / 452.4\ mm^2 = \underline{22.55\ MPa}$

CHAPTER 2 Design Properties of Materials

ONLY THOSE PROBLEMS REQUIRING NUMERICAL DATA ARE SHOWN.

2-14 S_u = 90ksi (621 MPa); S_y = 60 ksi (414 MPa); 25% ELONG.
BECAUSE % ELONGATION >5%, IT IS DUCTILE. (APP. A-14)

2-15 1020 HR: 36 % ELONGATION – GREATER DUCTILITY
1040 HR: 25 % ELONGATION (APP. A-14)

2-16 AISI 1141 OQT 700: HIGH SULFUR ALLOY STEEL WITH 0.41% CARBON, QUENCHED IN OIL, TEMPERED AT 700°F. (APP. A-14)

2-17 YES. S_y = 172 ksi @ OQT 700, S_y = 129 ksi @ OQT 900
BY INTERPOLATION $S_y \approx 150$ ksi @ OQT 800. (APP. A-14)

2-18 $E = 30 \times 10^6$ psi (207 GPa) FOR ALL CARBON AND ALLOY STEELS. (APP. A-14)

2-19 WT = DENSITY × VOLUME = $(0.283\ LB/in^3)(1.0)(4.0)(14.5)\,in^3 = \underline{16.4\ LB}$
(APP. A-14) VALUE OF LB_m = VALUE OF LB FORCE (WT.)

2-20 VOLUME = AREA × LENGTH = $\frac{\pi}{4}(50)^2 \times 250 = 4.909 \times 10^5\ mm^3$
STEEL BAR
$$MASS = \frac{7680\ kg}{m^3} \times \frac{4.909 \times 10^5\ mm^3}{1} \times \frac{1\ m^3}{(10^3\ mm)^3} = 3.77\ kg$$
(APP. A-14)
$$WT = m \cdot g = 3.77\ kg \cdot 9.81\ m/s^2 = 36.98\ kg \cdot m/s^2 = \underline{36.98\ N}$$

2-21 MAGNESIUM WOULD BECAUSE IT HAS A LOWER E.
E_{MAG} = 45 GPa ; E_{Ti} = 114 GPa ; Ti IS STIFFER. (APP. A-15)

2-23 ALLOY OF ALUMINUM WITH SILICON AND MAGNESIUM.
HEAT TREATED TO T6 TEMPER.

2-24 (APP. A-18)

	S_u	S_y	E	DENSITY
6061-O	18 ksi	8 ksi	10×10^6 psi	0.10 LB/in^3
6061-T4	35 ksi	21 ksi	"	"
6061-T6	45 ksi	40 ksi	"	"

2-29 S_{ut} = 40ksi ; S_{uc} = 140 ksi (APP. A-17)

2-31 BENDING σ_d = 1450 psi; TENSION σ_d = 850 psi; COMP. 1000 psi PARALLEL TO GRAIN, 385 psi PERPENDICULAR TO GRAIN; SHEAR τ_d = 95 psi (APP. A-19)

2-32 2000 TO 7000 psi (SECTION 2-10)