Online Instructor's Manual with Solutions
to accompany

Statics and Strength of Materials
First Edition

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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 Statics and Strength of Materials using this textbook. Variables considered include specific prerequisites for mathematics, physics mechanics, and materials science. Comments are then presented about each of the 18 chapters of the book.

These comments are based on the author's experience with the book, *Applied Strength of Materials, 5th ed.*, from which this new title is adapted, his other two books, *Applied Fluid Mechanics, 6th ed.*, and *Machine Elements in Mechanical Design, 4th ed.*, feedback from colleagues and users of those books, both instructors and students, and over 40 years of teaching applied engineering mechanics.

- **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 statics and 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.

- **Physics Mechanics** is beneficial and is typically included as a prerequisite to **Statics**. Having had such a course, students can be expected to be familiar with the fundamentals of *forces, moments, vectors,* and *static equilibrium.* However, typical courses in physics mechanics are short on how these principles are applied and it is essential that they demonstrate their ability to solve applied problems from a variety of fields such as construction, mechanical design, manufacturing, aerospace, architecture, and other industrial situations to learn adequately the principles of statics and strength of materials as presented in this book. If students have not studied physics mechanics, they should be able to learn those concepts directly from the treatment in this book.
- **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 8 – 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 this chapter and Appendixes A-14 through A-20. Covered there are common metals, wood, concrete, plastics and composites. In addition, **Section 2-13 on Materials Selection** includes useful information on how to decide what basic kind of material is suitable for a given application.

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 smooth, linear progression through the chapters in the order given. Chapters 1 – 6 cover the fundamentals of Statics while Chapters 7 – 18 cover Strength of Materials. Note that the presentations of the concepts of Statics contain numerous references to how those concepts will be used in various chapters on Strength of Materials. Some instructors may choose to inter-relate basic concepts of direct stresses (tension, compression, and shear) within Chapters 1, 2, and 3 that deal with forces, moments, torques, free-body diagrams, and static equilibrium. Options exist to permit adjustments for specific course objectives.

A major variable in course planning is the amount of time devoted to the course. Many programs include separate courses in Statics and Strength of Materials, often with 3-4 credit hours in each, either in the quarter or semester system. Programs teaching both subjects in a combined course in Statics and

Strength of Materials may devote 4 to 6 semester hours or 5 to 8 quarter hours to the course. Obviously the lower numbers of credits allow fewer topics or less depth than the larger number.

Another important variable is the makeup of the group of students expected in a given class. Some programs have special courses in this subject for students in a single discipline such as construction, mechanical, manufacturing, or others. In such cases, the course can be tailored for the ways in which that particular discipline uses statics and strength of materials. Careful alignment of this course with following courses can also be accomplished. However, in many institutions offering several programs that require this course, a given class will contain students from many programs and a more general coverage is in order. The author feels that this kind of course is very desirable so students acquire more varied and well-rounded technical skills. Graduates of any program will interface with professionals and colleagues from many other fields, leading to the philosophy that guided the development of this book.

The following sections discuss the coverage in each chapter as an aid to the instructor in how to organize a course for specific objectives, time available, student preparation, and majors involved.

Chapter 1 – Basic Concepts in Statics and Strength of Materials

Students learn best when engaging concepts from a *whole-to-part* viewpoint. Building on their already-learned experiences and completing activities are important so students can relate to how newly acquired knowledge and skills are applied to a variety of applications and real-world situations. These pedagogical concepts are built into the entire book and the stage is set from the start in Chapter 1. All parts of the Chapter are critical to student success in using this book. Some topics may require only light review if students enter with strong backgrounds in physics mechanics and the U.S. and SI unit systems. Time should be spent guiding students to discovering how those already-learned concepts relate to the study of Statics and Strength of Materials.

Section 1-1 takes students through an extensive discussion of applications of Statics and Strength of Materials in a variety of applications relevant to the many fields for which this course is a part. Through photographs, group discussions, and personal quests, students identify and begin the process of analyzing how real components and systems are subjected to forces, moments, and torques and begin to visualize how stresses are created and how things are designed to avoid failure.

Sections 1-2 and 1-3 go deeper and involve students in following the *load path* from the sources of loading (gravity forces, actuation forces, wind loads, etc.) from one component to another until reaching a firm support, perhaps the earth itself.

Sections 1-4 to 1-7 establish standards for setting up problems, documenting solution procedures and details, and the manipulation of units. Special attention is given to the relationships among *mass, force,* and *weight.*

Section 1-8 is an extensive overview of standard structural shapes used in buildings, machine components, vehicular structures, manufacturing systems, and consumer products. Students should be guided through a review of the appendix tables on the geometric properties of standard shapes that are used virtually in every following chapter of the book.

Chapter 2 – Forces and Free-Body Diagrams

Picking up from the fundamentals established in Chapter 1, here students learn about how forces from nature and from human-engineered systems are represented for analysis and design. Statics concepts include components of forces (typically *x* and *y*), forces exerted on components by supports, and the all-important *free-body diagrams*. No concept can be more critical to technical analysis throughout this book. Extensive discussion is presented about building codes and bridge loading standards, primarily applicable to the civil, construction, and architectural fields.

Chapter 3 – Static Equilibrium

The principles of static equilibrium are applied to a wide variety of applications – weight distribution of a vehicle, beam reaction forces, forces on components of machinery and mechanical devices, and rotational equipment such as cranes and mechanical drives, considering only the starting conditions, forces required to hold a system stationary, and forces applied during motion with uniform velocities and rotational speeds. The concept of *mechanical advantage* is introduced in the context of lifting devices such as winches and pulley systems.

Chapter 4 – Forces in Frames, Structures, and Trusses

Three major classifications of force analysis problems are presented here:

1. Pin-connected frames and mechanisms, including two-force members and multi-force members in planar configurations.
2. Trusses – while being a special case of pin-connected structures, there are several useful tools for problem analysis that are important for these important structural elements. Significant discussion is included of the wide variety of applications for trusses, not only for building structures. Race cars, performance stage equipment, sign supports, and utility system supports are pictured and described.
3. Three-dimensional frames and structures are presented as an extension of planar configurations with an emphasis on the computation of forces in members of a 3-D structure.

Chapter 5 – Friction Forces

This important topic focuses on static friction and on kinetic friction under uniform motion conditions. Analysis of the forces required to move a variety of objects against friction, the use of wedges, questions of tipping and sliding, brakes and clutches, and belt and rope friction are covered.

Chapter 6 – Centroids and Moments of Inertia of Areas

Knowledge of the procedures for computing the location of centroids and the computation of moments of inertia of areas is required for the analysis of beams and columns. Students benefit from seeing how this topic relates to standard structural shapes such as W-beams, channels, angles, and hollow structural sections. Some instructors prefer to cover completely this chapter in one continuous set of classes. Others may choose to introduce topics on a more *just-in-time* bases as outlined next.

Coverage of Sections 6-1 through 6-6 and 6-8 is essential to the understanding of concepts in Chapters 12 – 16 dealing with beams and columns and could be covered in conjunction with those topics, immediately following Chapter 11 on Shearing Forces and Bending Moments in Beams.

Section 6-12 covers *section modulus*, an important property of an area that is directly applicable to Chapter 12 on Stress Due to Bending. It may be desirable to delay the coverage of this topic to combine it with the study of beams.

In Section 6-10 presents another important property of an area, *radius of gyration,* which is used in Chapter 16 on Columns. It may be desirable to delay the coverage of this topic to combine it with the study of columns.

Coverage of the other sections of this chapter is optional as discussed next.

- Section 6-7 [Optional] uses calculus to derive the moment of inertia of an area.
- Section 6-9 [Optional] provides a useful method of analyzing shapes with all rectangular parts. The process can be implemented effectively in a spreadsheet.

Chapter 7 – Basic Concepts of Strength of Materials

- Sections 7-1 through 7-9 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 7-6 through 7-8 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 8 on Design Properties of Materials where some additional material properties are discussed. These basic concepts are expanded upon in Chapter 9.
- Reinforcement should also be made about how statics affects the study of strength of materials.
- Coverage of Section 7-9 Experimental and Computational Stress Analysis is optional and may depend on the connection of this course with companion laboratory courses.

Chapter 8 – 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, aerospace, architecture, industrial, civil and construction programs all require sound knowledge of metals and plastics.
- Most would also benefit from coverage of wood, concrete, and composites. Civil and construction majors may delve more deeply into concrete and wood.
- Section 8-13 [Optional] on Composites may be delayed until Chapter 12 is covered and linked with Section 12-13 on the design of beams to be made from composite materials.
- Section 8-14 on <u>Materials Selection</u> 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.* See Reference 4 and Internet site 31 at the end of Chapter 8.

Chapter 9 – Direct Stress, Deformation, and Design

This chapter builds on the basic introductory treatment of direct stresses from Chapter 7 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 9-3 through 9-7: Design of members under direct normal stresses, including the definition of design stress, design factor (factor of safety), and design approaches.
- Sections 9-8 through 9-12: Deformation, thermal stresses, members made from more than one material, and stress concentration factors for direct axial stresses
- Sections 9-13 and 9-14 on bearing stress, including design bearing stresses
- Section 9-15 – Design Shear Stress

Chapter 10 – Torsional Shear Stress and Torsional Deformation

Coverage of this chapter can be grouped as follows:

- Big Picture, Activity, and Objectives
- Section 10-3 on Torque, Power, and Rotational Speed: These topics should be review for many students but it has been found that careful study is required before applying them to stress analysis.
- Section 10-4 presents the fundamental torsional shear stress formula and demonstrates its application to the analysis of stresses.
- Sections 10-5, 10-6, and 10-7 [Optional] use calculus to derive the torsional shear stress formula and the equations for polar moment for solid circular bars, shafts, and 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 10-8 presents an approach to design of circular members under torsion, extending the design stress concepts from Chapter 9 to include torsional shear strength of materials.
- Section 10-9: This section provides interesting and useful comparison of the behavior of hollow circular sections and emphasizes their efficiency as compared with solid sections.
- Section 10-10: The study of stress concentrations in torsionally loaded members is essential to proper design and analysis of shafts.
- Section 10-11: The twisting of circular bars is discussed with the application of the equation for torsional deformation.
- Section 10-12 [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 11, 12, 13 and 14: 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 11 – Shearing Forces and Bending Moments in Beams

- The Big Picture, Activity, and Sections 11-1 through 11-10 are essential. Connection should be made to Section 3-2 Analysis of Static Equilibrium in Chapter 3 where methods of computing reactions on beams were presented.
- Section 11-11 [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. More complex devices and structural members can be analyzed in parts.
- Section 11-12 [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 14-8 Successive Integration Method for deflection of beams, which is, itself, optional.
- Section 11-13 [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 chapter in which 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 12 – Stress Due to Bending

- Sections 12-1 through 12-5 present the foundation material for the analysis of beams.
- Section 12-6 [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 12-7 through 12-9 cover the transitions from analysis to design of beams.
- Section 12-10 covers stress concentrations in bending situations.
- Section 12-11 is critical 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 7-12 on Preferred Shapes for Beam Cross Sections is designed to help the novice student understand better why certain shapes are preferred for beams.
- Section 12-13 [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 8-13 and it may be desirable to cover those two sections together at this point.
- ***Note: This is a 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 13 – Shearing Stresses in Beams

- Sections 13-1 through 13-5 present the fundamental concepts and the general shear formula.
- Section 13-6 [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 13-7 shows the special shear formulas applicable to rectangular, circular, hollow, and thin-webbed sections (e.g. W-beams). These formulas are frequently used.
- Section 13-8 transitions the coverage of shear in beams from analysis to design.
- Section 13-9 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. Construction and vehicular structures, and aerospace applications of shear flow are important.

Chapter 14 – 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 14-1 through 14-5 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 14-6 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 14-7 extends the material in Section 14-4 to the permit use of beam deflection formulas to a much broader array of applications.
- Section 14-8 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 14-9 – 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 15 – 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 15-1 through 15-7 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 15-8 through 15-12 cover stress transformations, equations for stresses in any direction, principal stresses (maximum normal stress, maximum shear stress), and Mohr's circle.
- Section 15-13 covers the use of strain-gage rosettes to determine principal stresses and ties well with the preceding sections. It is also related to Section 7-9 – Experimental and Computational Stress Analysis, and is useful for connecting this course with companion laboratory courses.

Chapter 16 – 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).
- Three Column Analysis Spreadsheets are shown that facilitate the extensive calculations involved.

Chapter 17 – Pressure Vessels

- Basic concepts for thin-walled spheres and cylinders are recommended as a minimum, using Sections 17-1 through 17-5.
- Sections 17-6 through 17-8 [Optional] present extended coverage of thick-walled pressure vessels.
- Sections 17-9 and 17-10 [Optional] present additional considerations for column design.
- Section 17-11 [Optional] discusses the advantages of applying composite materials to pressure vessels. Reference to Section 8-13 should be made for basic properties of composites.

Chapter 18 – Connections

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

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Supplements Included with the Book

INTRODUCTION

Three types of supplements on a CD-ROM are included with this book:

1. A set of 21 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
3. Physical models of several objects that are depicted in the text through example problems or problems for student solution. Photographs of the models are included in the text and on the CD. In addition, the CD contains three-dimensional, solid model drawings of the models in color. These aids help students visualize the details of components and structures that appear in the book, far exceeding the effectiveness of two-dimensional drawings and sketches. Some of the models are featured in PowerPoint slides that demonstrate how the models are analyzed to determine forces or stresses and to complement the discussion in the text.

- The software packages for items 1 and 2 were created by ***Professor Jack Zecher of Indiana University - Purdue University – Indianapolis (IUPUI) in Indianapolis, Indiana.***
- The physical models and solid model drawings described in item 3 were produced by ***Professor Gary Drigel of Miami University (Ohio) in Hamilton, Middletown and Oxford Ohio.***

More detailed descriptions of the contents of the CD follow in this document.

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. Graphic icons appear in the margin of the text to signify to students and instructions where each lesson can be used to supplement the book and the instructor's presentation of the material. The lessons can be used in the classroom, in one-on-one tutoring, in review and problem-solving sessions, or by students independently.

1. ***CONCURRENT FORCE SYSTEMS*** – Presents a review of the method of determining the resultant of two or more forces acting concurrently on a component.
2. ***COMPONENTS OF FORCES*** – Methods of resolving force vectors into components, typically horizontally and vertically or some other orthogonal axes.
3. ***MOMENTS AND COUPLES*** – Development of an understanding of the definition of the moment of a force and the special case of couples.
4. ***EQUILIBRIUM & REACTION FORCES*** – Application of the principle of static equilibrium to compute unknown forces on a load-bearing component, with special attention to reaction forces at supports.
5. ***TRUSS ANALYSIS*** – Details of analyzing the forces in all members of pin-connected trusses.
6. ***FRAME ANALYSIS*** – Analysis of pin-connected frames and structures comprised of two-force members and multi-force members.
7. ***CENTROIDS*** – Methods for computing the location of the centroid of a two-dimensional shape.
8. ***FRICTION*** – Applications of the principles of frictional forces to determine their affects on other forces in a body that tends to slide over a surface.
9. ***MOMENT OF INERTIA*** – Computation of the value of moment of inertia of an area with respect to an axis of interest, typically one of the centroidal axes.
10. ***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 7-9.
11. ***DIRECT SHEAR*** – Reviews the direct shear stress equation, τ = *Force/Area in shear*, for both single shear and double shear. Relevant to Chapters 7-9.
12. ***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 7 and 9.
13. ***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 8 and 9.
14. ***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 9.

15. ***AXIAL DEFORMATION*** – Reviews the deformation of members loaded in direct tension or compression using the formula, $\delta = FL/EA$. Relevant to Chapter 9.
16. ***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 9.
17. ***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 9.
18. ***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 10.
19. ***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 6, 11. and 12.
20. ***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 13.
21. ***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 15.

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.

PHYSICAL MODELS, SOLID MODELING, AND POWERPOINT SLIDES DESCRIBING THE APPLICATION OF THE MODELS TO PROBLEM SOLVING

Educational research shows that student comprehension of new concepts is enhanced by physical models that demonstrate the details of the form and function of objects being analyzed for forces and stresses. Several objects that are depicted in the text through example problems or problems for student solution have been produced to provide additional learning aids for the study of this book, *Statics and Strength of Materials.* Photographs of most models are included in the text and on the CD. In addition, the CD contains three-dimensional, solid model drawings of the models in color. These aids help students visualize the details of components and structures that appear in the book, far exceeding the effectiveness of two-dimensional drawings and sketches. Some of the models are featured in PowerPoint slides that demonstrate how the models are analyzed to determine forces or stresses and to complement the discussion in the text. The images on the CD can be used in a classroom to augment student comprehension.

The following is a set of descriptions of the contents of this package that appears on the CD in each book.

Figure 4-6 – Crane with a pin-connected frame

The crane is a scale model built to the proportions and specifications given in Example Problem 4-2 in Section 4-2 – *Analysis of Pin-Connected Frames and Mechanisms.* The crane is comprised of:

1. A vertical post supported at its base
2. A cable extending from the top of the post to the ground at the left to support the post
3. A boom extending from the post outward to the right
4. An actuator simulating a hydraulic cylinder that can control the elevation of the boom.

As depicted in the photograph in Example Problem 4-2, the boom is horizontal. However, the actuator can be adjusted to swing the boom upward or downward through an arc. Similar cranes are the subjects of end-of-chapter problems 4-9 through 4-13.

Figure P4-31 – Truss with one pinned support and one roller support

The truss is a scale model of the truss in Problem 4-31 that carries two downward loads at two panel points on the lower chord. The model aids in the visualization of the connection of the members of the truss, the orientation of the truss members, and the difference between a roller-type support and a fully pinned support.

Figure 7-13 – Pin joint in single shear

Section 7-7 introduces the concepts of direct shear stress with pin-type joints as a primary example. The model of a pin in single shear shown in Figure 7-13 demonstrates that a single cross section of the pin is subjected to direct shearing stress. The photograph of the physical model shows very clearly how the components of the joint fit and act together.

Figure 7-14 – Pin joint in double shear

The photograph of this model shows clearly how the support frame of the joint now provides two places for support of the pin instead of the single support of Figure 7-13. Students can see that two cross sections of the pin share the applied force, doubling the area in shear. This is the classic *clevis.*

Figure 7-16 – Key-shaft-hub assembly

The model consists of a shaft on which is mounted a three-groove, stepped sheave (pulley) with a key clearly visible at the end of the shaft at the interface between the shaft and the hub of the sheave. Students can see how transmitting power and torque from the sheave to the shaft (or vice-versa) generates a shearing force on the side of the key that tends to cut the key across its cross-section. Bearing stress on the sides of the key can also be visualized. A key of similar design is analyzed in the accompanying Example Problem 7-6 in Section 7-7 on Direct Shear Stress.

Figure P7-44 – Connector assembly

In the problem section of Chapter 7, this is one of the more complex designs to be analyzed. Two hollow tubes are connected with a special connector that fits inside both tubes. A transverse pin passes through the side walls of the upper tube and through the connector. A collar on the connector bears on the top of the lower tube. The assembly is designed to transmit a compressive load from the upper tube to the lower tube. The model shows clearly the load path from the upper tube; through the transverse pin; into the upper part of the connector; through the collar to the end surface of the lower tube; and thence to the lower tube itself. Multiple possible failure modes of compressive stress, shearing stress, and bearing stress occur and are more easily visualized with the physical model and the solid model drawings.

Figure P7-50 – Bolted butt joint for Problem 7-50

Two tension members are connected end-to-end by cover plates on both sides with bolts passing through both plates and the tension members. Students can see clearly the load path from one tension member; through the first set of two bolts; to the two cover plates; back into the second bolt; and finally into the second tension member. Thus the student can better appreciate the possible failure modes of the joint: a) tension failure of the tension members across the line where the bolts pass through; b) shear of the bolts; c) bearing stress on the sides of the bolts and the holes; d) end tear-out axially behind each bolt.

This type of connection is also discussed in Chapter 18 on Connections.

Figure P9-140 – Bearing stress problem

Physical models of three designs for the legs and feet of a heavy machine base are shown and students are asked to analyze the resulting bearing stress between the feet and the floor. The designs are:

1. A hollow square tube, 1.50 inches on a side with a 0.125 inch wall thickness. The cross section of the tube contacts the floor. A very high bearing stress results.
2. A standard C3×4.1 channel is used for the legs with the cross section contacting the floor. The area is larger than the square tube so the bearing stress is moderately reduced.

3. However, the bearing stresses of both designs 1 and 2 are higher than desired. Therefore, a third design calls for a square plate to be welded to the end of the legs to provide more bearing area. A square plate with dimensions 3.5 inches on a side is made and shown to produce a significantly lower bearing stress.
4. In fact, it is judged that the allowable bearing stress on the floor is a bit higher than the value achieved with design #3. A final design is to use the square plate but with smaller dimensions to match the allowable bearing stress. It is found that a square plate 2.5 inches on a side is acceptable.

The models of the three basic designs helps students visualize what is actually happening in this problem.

Table of Contents

CHAPTER 1

Basic Concepts in Statics and Strength of Materials

Solutions to End-of Chapter Problems

SOLUTIONS – CHAPTER 1

Definitions and Unit Systems

For Problems 1-1 to 1-5, state the standard unit for the following basic quantities in both the U.S. Customary unit system and the SI metric unit system.

1-1	Length	foot (ft)	meter (m)
1-2	Time	second (s)	second (s)
1-3	Force	pound (lb)	newton (N)
1-4	Temperature	degree Fahrenheit (°F)	Kelvin (K)
1-5	Angle	degree (deg)	radian (rad)

For Problems 1-6 to 1-10, state typically-used units in the SI metric unit system other than the standard unit.

1-6	Length	millimeter, kilometer
1-7	Time	minute (min), hour (h)
1-8	Force	$kg{\cdot}m/s^2$
1-9	Temperature	degree Celsius (°C)
1-10	Angle	degree (deg)

For Problems 1-11 to 1-15, state typically-used units in the U.S. Customary unit system other than the standard unit.

1-11	Length	inch (in), yard (yd), mile (mi)
1-12	Time	minute (min), hour (h)
1-13	Force	kip (K), [K = 1000 lb]
1-14	Temperature	degree Celsius (°C), degree Rankine (°R)
1-15	Angle	radian (rad)

For Problems 1-16 to 1-25, express the given computed numerical values with standard prefixes and proper units in the SI metric unit system, giving three computed digits of accuracy.

1-16 2.49×10^{-3} m or 2.49 mm

1-17 45.2×10^{3} m or 45.2 km

1-18 74.5×10^{3} m or 74.5 km

1-19 48.0×10^{-3} m or 48.0 mm

1-20 2.52×10^{3} N or 2.52 kN

1-21 338×10^3 N or 338 kN

1-22 75.2×10^3 N or 75.2 kN

1-23 5.33×10^3 N or 5.33 kN

1-24 6.43×10^6 N or 6.43 MN

1-25 29.8×10^6 N or 29.8 MN

1-26 Mass refers to the amount of substance in a body.

1-27 kilogram (kg) or $N \cdot s^2/m$

1-28 slug or $lb \cdot s^2/ft$

1-29 Weight is the force of gravitational pull on a body.

1-30 newton (N) or $kg \cdot m/s^2$

1-31 pound (lb), kip (K) [kip = 1000 lb]

1-32 Density is the amount of mass per unit volume of a material.

1-33 kg/m^3

1-34 $slugs/ft^3$

1-35 Specific weight is the amount of weight per unit volume of a material.

1-36 N/m^3

1-37 lb/ft^3

1-38 Pressure is the amount of force applied to a given unit of area.

1-39 N/m^2, Pa, kPa, MPa

1-40 lb/in^2, psi, lb/ft^2, psf, K/in^2, ksi, K/ft^2, ksf

1-41 $W = m \cdot g = 1800 \text{ kg} \cdot 9.81 \text{ m/s}^2 = 17\,658 \text{ kg} \cdot \text{m/s}^2 = 17.7 \times 10^3 \text{ N} = \underline{17.7 \text{ kN}}$

1-42 Total weight $= m \cdot g = 4000 \text{ kg} \cdot 9.81 \text{ m/s}^2 = 39.24 \times 10^3 \text{ kg} \cdot \text{m/s}^2 = 39.24 \text{ kN}$

Each front wheel: $F_F = (1/2)(0.40)(39.24 \text{ kN}) = \underline{7.85 \text{ kN}}$

Each rear wheel: $F_R = (1/2)(0.60)(39.24 \text{ kN}) = \underline{11.77 \text{ kN}}$

1-43 Loading = Total force/Area

Total force $= F = m \cdot g = 6800 \text{ kg} \cdot 9.81 \text{ m/s}^2 = 66.708 \times 10^3 \text{ kg} \cdot \text{m/s}^2 = 66.7 \text{ kN}$

Area $= A = (5.0 \text{ m})(3.5 \text{ m}) = 17.5 \text{ m}^2$

Loading $= F/A = 66.7 \text{ kN}/17.5 \text{ m}^2 = 3.81 \text{ kN/m}^2 = \underline{3.81 \text{ kPa}}$

1-44 Force = Weight $= m \cdot g = 25 \text{ kg} \cdot 9.81 \text{ m/s}^2 = 245.25 \text{ kg} \cdot \text{m/s}^2 = 245.25 \text{ N}$

k = Spring scale $= F/\Delta L = 4500$ N/m

$\Delta L = F/k = (245.25 \text{ N})/(4500 \text{ N/m}) = 0.0545 \text{ m} = 54.5 \times 10^{-3} \text{ m} = \underline{54.5 \text{ mm}}$

1-45 to 1-46 Variable solutions – Example data used for following results

1-45 Length = 262 mm; width = 209 mm; thickness = 33 mm

1-46 Assume the person weighs 165 lb. W = (165 lb)(4.448 N/lb) = 734 N

mass = W/g = 734N/(9.81 m/s^2) = 74.8 N·m/s^2 = 74.8 kg

1-47 W = (17 658 N)(0.2248 lb/N) = 3970 lb

1-48 F_F = 7.848 kN = (7848 N)(0.2248 lb/N) = 1764 lb

F_R = 11.772 kN = (11 722 N)(0.2248 lb/N) = 2646 lb

1-49 Loading = F/A = 66.708 kN/17.5 m^2 = (3.8119 kN/m^2) = 3.8119×10^3 N/m^2

Loading = (3.8119×10^3 Pa)[(1 lb/ft^2)/(47.88 Pa)] = 79.6 lb/ft^2

1-50 Force = F = (245.25 N)(0.2248 lb/N) = 55.132 lb

k = Spring scale = $F/\Delta L$ = (4500 N/m)(0.2248 lb/N)(1m)/(39.37 in) = 25.695 lb/in

$\Delta L = F/k$ = (55.132 lb)/(25.695 lb/in) = 2.15 in

1-51 mass = W/g = (2750 lb)/(32.2 ft/s^2) = 85.4 lb·s^2/ft = 85.4 slugs

1-52 mass = W/g = (12 800 lb)/(32.2 ft/s^2) = 397.5 lb·s^2/ft = 398 slugs

1-53 Variable solution: Assume the person weighs 165 lb.

mass = W/g = (165 lb)/(32.2 ft/s^2) = 5.12 lb·s^2/ft = 5.12 slugs

1-54 pressure = 1200 psi = (1200 lb/in^2)(6895 Pa)/(1 lb/in^2) = 8.274×10^6 Pa = 8.27 MPa

1-55 stress = (21 600 psi)(6895 Pa)/(psi) = 1.489×10^8 Pa = 148.9×10^6 Pa = 149 MPa

1-56 Ultimate strength = s_u

$s_{u\text{-}min}$ = (14 000 psi)(6895 Pa)/(psi) = 9.653×10^7 Pa = 96.53×10^6 Pa = 96.5 MPa

$s_{u\text{-}max}$ = (76 000 psi)(6895 Pa)/(psi) = 5.240×10^8 Pa = 524.0×10^6 Pa = 524 MPa

1-57 n = 1750 rev/min × 2π rad/rev × 1 min/60 s = 183 rad/s

1-58 A = 14.1 in^2 × 645.2 mm^2/in^2 = 9097 mm^2

1-59 y = 0.080 in × 25.4 mm/in = 2.03 mm

1-60 Dimensions: 18.0 in × 25.4 mm/in = 457 mm

12 in × 25.4 mm/in = 305 mm

Area = (18.0 in)^2 = 324 in^2; Area = (457 mm)^2 = 209×10^5 mm^2

Volume = Area × height; $V = A \times h$

U.S.: $V = A \times h$ = (324 in^2)(12.0 in) = 3888 in^3; V = 3888 in^3 × 1 ft^3/1728 in^3 = 2.25 ft^3

SI: $V = A \times h$ = (209×10^5_ mm^2)(305 mm) = 6.37×10^7 mm^3

SI: $V = A \times h$ = (0.457 m)^2 × (0.305 m) = 6.37×10^{-2} m^3 = 0.0637 m^3

1-61 Area = $\pi D^2/4$ = π(0.505 in)^2/4 = 0.200 in^2; A = 0.200 in^2 × (645.2 mm^2/in^2) = 129 mm^2

Moments, Torques, and Couples

Consider Problems 1-62 and 1-63 to be a set, using Figure P1-62.

1-62 $M = F{\cdot}d = (935\text{ N})(850\text{ mm}) = 794\ 750\text{ N}{\cdot}\text{mm}\ (1.0\text{ m}/1000\text{ mm}) = \underline{795\text{ N}{\cdot}\text{m CW}}$

1-63 $M = F{\cdot}d = (935\text{ N})(850\text{ mm}) = 794\ 750\text{ N}{\cdot}\text{mm}\ (1.0\text{ m}/1000\text{ mm}) = \underline{795\text{ N}{\cdot}\text{m CCW}}$

Consider Problems 1-64 and 1-65 to be a set, using Figure P1-64.

1-64 $M_1 = F_1 \cdot a = (3.0\text{ kN})(0.5\text{ m}) = \underline{1.5\text{ kN}{\cdot}\text{m CCW}}$

$M_2 = F_2 \cdot b = (4.0\text{ kN})(0.6\text{ m}) = \underline{2.4\text{ kN}{\cdot}\text{m CW}}$

$M_3 = F_3 \cdot c = (5.0\text{ kN})(0.8\text{ m}) = \underline{4.0\text{ kN}{\cdot}\text{m CCW}}$

1-65 $\Sigma M_A = M_1 + M_2 + M_3 = \underset{\text{(CCW)}}{1.5\text{ kN}{\cdot}\text{m}} - \underset{\text{(CW)}}{2.4\text{ kN}{\cdot}\text{m}} + \underset{\text{(CCW)}}{4.0\text{ kN}{\cdot}\text{m}} = \underline{3.1\text{ kN}{\cdot}\text{m CCW}}$

1-66 $M = F{\cdot}d$; $d = (D/2) + 15.0\text{ in} = (18.0\text{ in}/2) + 15.0\text{ in} = 24.0\text{ in}$

$M = (180\text{ lb})(24.0\text{ in}) = \underline{4320\text{ lb}{\cdot}\text{in CW}}$

Consider Problems 1-67 and 1-68 to be a set using Figure P1-67.

1-67 Traffic light: $M_{TL} = W \cdot d = (1120\text{ N})(3.74\text{ m}) = (4189\text{ N}{\cdot}\text{m})(1.0\text{ kN}/1000\text{ N})$

$M_{TL} = \underline{4.189\text{ kN}{\cdot}\text{m CCW}}$

1-68 Arm supporting traffic light: $M_{Arm} = W \cdot d$

W = Specific Wt. × Volume = $\gamma \times V$; $\gamma = 75.3\text{ kN/m}^3$ [From Table 1-6]

$V = A \times L$; $A = 3601\text{ mm}^3$ [From Appendix A-12(SI)]; $L = 4.85\text{ m}$; $d = L/2 = 2.425\text{ m}$

$V = (3601\text{ mm}^2)(4.85\text{ m})(1.0\text{ m}/1000\text{ mm})^2 = 0.0175\text{ m}^3$

$W = \gamma \times V = (75.3\text{ kN/m}^3)(0.0175\text{ m}^3) = \underline{1.315\text{ kN}}$

$M_{Arm} = W \cdot d = (1.315\text{ kN})(2.425\text{ m}) = \underline{3.189\text{ kN}{\cdot}\text{m CCW}}$

1-69 $M_{total} = M_{TL} + M_{Arm} = 4.189\text{ kN}{\cdot}\text{m CCW} + 3.189\text{ kN}{\cdot}\text{m CCW} = \underline{7.378\text{ kN}{\cdot}\text{m CCW}}$

Consider Problems 1-70 to 1-72 to be a set using Figure P1-70.

1-70 Balcony: a) $W = 480$ lb; Moment arm = (0.65)(80 in) = 52 in

$M = F{\cdot}d = (480\text{ lb})(52\text{ in}) = (24\ 960\text{ lb}{\cdot}\text{in})(1\text{ ft}/12\text{ in}) = \underline{2080\text{ lb}{\cdot}\text{ft CW}}$

1-71 People on deck: W_{Total} = (180 lb/person) (4 people) = 720 lb

Consider total weight applied at very end of deck; $d = 80$ in

$M = F{\cdot}d = (720\text{ lb})(80\text{ in}) = (57\ 600\text{ lb}{\cdot}\text{in})(1\text{ ft}/12\text{ in}) = \underline{4800\text{ lb}{\cdot}\text{ft CW}}$

1-72 Multiple answers possible: Examples of other loads – Furniture, snow, more people

Consider Problems 1-73 to 1-75 to be a set, using Figure P1-73.

1-73 $M_{A1} = F_1 \cdot a = (100 \text{ lb})(12 \text{ in}) = \underline{(1200 \text{ lb·in}) \text{ CW}}$

$M_{A2} = F_2 \cdot b = (60 \text{ lb})(8 \text{ in}) = \underline{(480 \text{ lb·in}) \text{ CCW}}$

1-74 Net moment $= M_{A1} + M_{A2} = \underset{\text{(CW)}}{1200 \text{ lb·in}} - \underset{\text{(CCW)}}{480 \text{ lb·in}} = 720 \text{ lb·in CW}$

1-75 For balanced moments, $M_{A1} = M_{A2} = 1200$ lb·in

$M_{A2} = F_2 \cdot b = 1200$ lb·in; Then $\underline{F_2} = (1200 \text{ lb·in})/b = (1200 \text{ lb·in})/(8 \text{ in}) \underline{= 150 \text{ lb upward}}$

Consider Problems 1-76 to 1-78 as a set using Figure 1-5.

1-76 $T = F \cdot d = (145 \text{ N})(220 \text{ mm})(1.0 \text{ m})/(1000 \text{ mm}) = \underline{31.9 \text{ N·m CW viewed from top}}$

1-77 a) Moving force to the top of the socket results in the moment arm being zero. Therefore,

$T = F \cdot d = (145 \text{ N})(0) = 0$

b) The force F causes a moment with respect to the bolt head of:

$M = F \cdot d = (145 \text{ N})(300 \text{ mm})(1.0 \text{ m})/(1000 \text{ mm}) = \underline{43.5 \text{ N·m CW } x\text{-}z \text{ plane}}$

1-78 a) The two forces constitute a couple.

$T = F \cdot d = (145 \text{ N})(220 \text{ mm})(1.0 \text{ m})/(1000 \text{ mm}) = \underline{31.9 \text{ N·m CW viewed from top}}$

b) The two forces of equal magnitude and opposite directions balance in the x-y plane. Therefore there is zero net force acting on the drive socket (pure torque). Then $\underline{M = 0.}$

1-79 The two forces constitute a couple. $T = F \cdot d = (12.6 \text{ lb})(15.0 \text{ in}) = \underline{189 \text{ lb·in CW}}$

Consider Problems 1-80 to 1-83 to be a set using Figure P1-1(b). Some of the data are shared among the four problems.

1-80 $T = F \cdot d = (360 \text{ N})(205 \text{ mm})(1.0 \text{ m})/(1000 \text{ mm}) = \underline{73.8 \text{ N·m CW}}$

1-81 Torque from Problem 1-80 applied to the sprocket. Find chain tension.

$T = F_c \cdot R = \underline{73.8 \text{ N·m CW}}$; F_c= Chain tension;

R = Radius of sprocket $= D/2 = (230 \text{ mm})/2 = (115 \text{ mm})(1.0 \text{ m})/(1000 \text{ mm}) = 0.115$ m

Then $\underline{F_c =} T/R = (73.8 \text{ N·m})/(0.115 \text{ m}) = \underline{642 \text{ N}}$

1-82 Torque on rear sprocket:

From Problem 1-81, $F_c = 642$ N tension; pulls to right on rear sprocket.

Torque on rear sprocket $= T = F_c \cdot R = (642 \text{ N})(D/2)$

$T = (642 \text{ N})(110 \text{ mm}/2)(1.0 \text{ m})/(1000 \text{ mm}) = 35.3 \text{ N·m CW}$

1-83 Braking torque on front wheel: $D = 660$ mm; $R = D/2 = 330$ mm. $F_B = 790$ N

$T = (790 \text{ N})(330 \text{ mm})(1.0 \text{ m})/(1000 \text{ mm}) = 261 \text{ N·m CCW}$ (Opposes motion)

Consider Problems 1-84 and 1-85 to be a set.

1-84 Torque developed by force on one blade: $T_b = F_b \cdot R$; $F_b = 135$ N

R = Radius of turbine = $D/2$ = (1420 mm)/2 = (710 mm)(1.0 m)/(1000 mm) = 0.710 m

$\underline{T_b} = F_b \cdot R$ = (135 N)(0.710 m) = <u>95.85 N·m CW (assumed direction)</u>

1-85 Total torque on turbine:

$\underline{T_{total}} = T_b \times$ No. of blades = (95.85 N·m/blade)(56 blades) = <u>5368 N·m CW</u>

1-86 Vise: a) Torque on screw: $T_1 = F \cdot d$ = (60 lb)(4.25 in) = <u>255 lb·in CW</u>

b) Couple: $T_2 = F \cdot d$ = (60 lb)(4.25 in) = <u>255 lb·in CW</u>

c) Moment on right jaw:

$M = F_j \cdot h$ = (120 lb)(3.50 in) = <u>420 lb·in CW</u>

CHAPTER 2

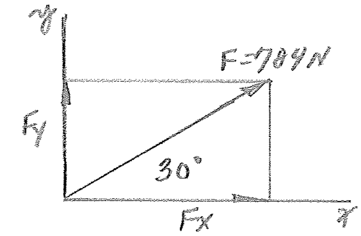
Forces and Free-Body Diagrams

Solutions to End-of Chapter Problems

SOLUTIONS – CHAPTER 2 – FORCES AND FREE-BODY DIAGRAMS

Components of Forces

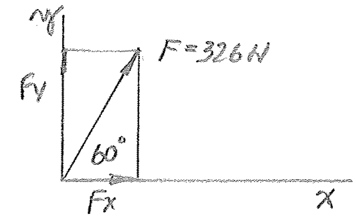
2-29 Given $F = 784$ N @ 30° above x-axis.



$F_x = F \cos 30° = (784 \text{ N}) \cos 30° = 679 \text{ N} \rightarrow$

$F_y = F \sin 30° = (784 \text{ N}) \sin 30° = 392 \text{ N} \uparrow$

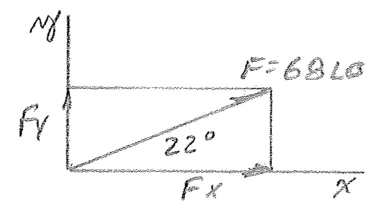
2-30 Given $F = 326$ N @ 60° above x-axis.



$F_x = F \cos 60° = (326 \text{ N}) \cos 60° = 163 \text{ N} \rightarrow$

$F_y = F \sin 60° = (326 \text{ N}) \sin 60° = 282 \text{ N} \uparrow$

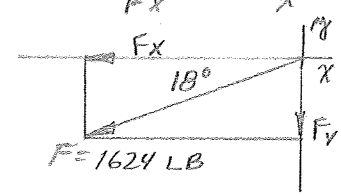
2-31 Given $F = 68$ lb @ 22° above x-axis.



$F_x = F \cos 22° = (68 \text{ lb}) \cos 22° = 63.0 \text{ lb} \rightarrow$

$F_y = F \sin 22° = (68 \text{ lb}) \sin 22° = 25.5 \text{ lb} \uparrow$

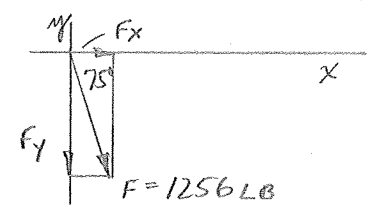
2-32 Given $F = 1624$ lb @ 18° below negative x-axis.



$F_x = -F \cos 18° = -(1624 \text{ lb}) \cos 18° = -1545 \text{ lb} \leftarrow$

$F_y = -F \sin 18° = -(1624 \text{ lb}) \sin 18° = -501.8 \text{ lb} \downarrow$

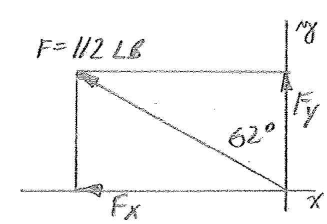
2-33 Given $F = 1256$ lb @ 75° below x-axis.



$F_x = F \cos 75° = (1256 \text{ lb}) \cos 75° = 325 \text{ lb} \rightarrow$

$F_y = -F \sin 75° = -(1256 \text{ lb}) \sin 75° = -1213 \text{ lb} \downarrow$

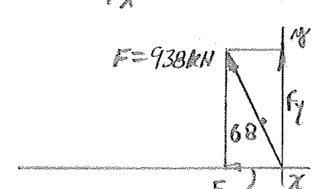
2-34 Given $F = 112$ lb @ 62° to left of y-axis.



$F_x = -F \sin 62° = -(112 \text{ lb}) \sin 62° = -98.9 \text{ lb} \leftarrow$

$F_y = F \cos 62° = (112 \text{ lb}) \cos 62° = 52.6 \text{ lb} \uparrow$

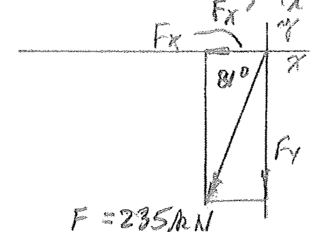
2-35 Given $F = 938$ kN @ 68° above the negative x-axis.



$F_x = -F \cos 68° = -(938 \text{ kN}) \cos 68° = -351 \text{ kN} \leftarrow$

$F_y = F \sin 68° = (938 \text{ kN}) \sin 68° = 870 \text{ kN} \uparrow$

2-36 Given $F = 235$ kN @ 81° below the negative x-axis.



$F_x = -F \cos 81° = -(235 \text{ kN}) \cos 81° = -36.8 \text{ kN} \leftarrow$

$F_y = -F \sin 81° = -(235 \text{ kN}) \sin 81° = 232 \text{ kN} \downarrow$