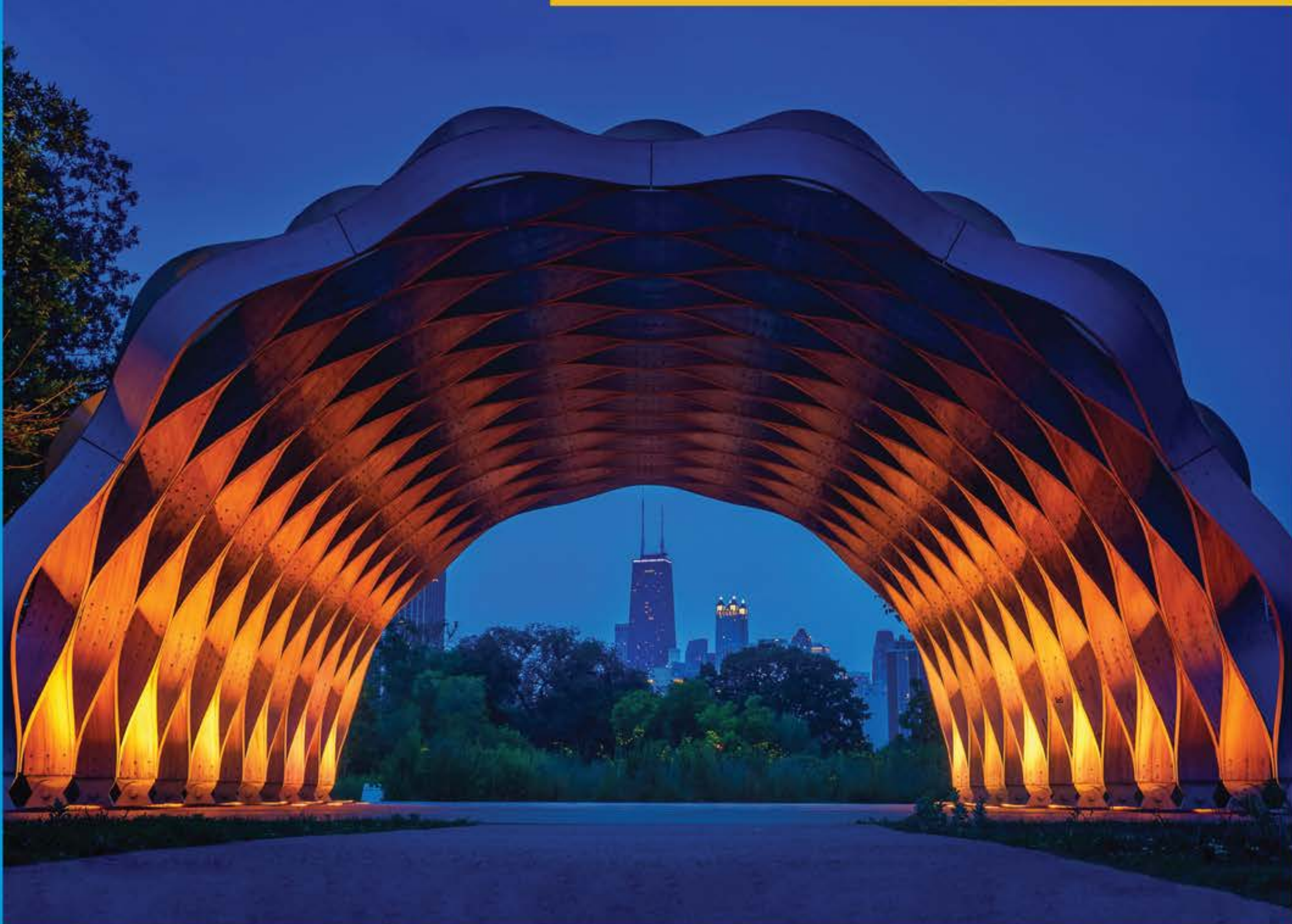
CENGAGE

Enhanced 9th Edition

MECHANICS OF MATERIALS

Barry J. Goodno | James M. Gere



CONVERSIONS BETWEEN U.S. CUSTOMARY UNITS AND SI UNITS

U.S. Customary unit		Times conversion factor		Equals SI unit	
		Accurate	Practical		
Acceleration (linear)					
foot per second squared	ft/s^2	0.3048*	0.305	meter per second squared	m/s^2
inch per second squared	$in./s^2$	0.0254*	0.0254	meter per second squared	m/s^2
Area					
square foot	ft^2	0.09290304*	0.0929	square meter	m^2
square inch	$in.^2$	645.16*	645	square millimeter	mm^2
Density (mass)					
slug per cubic foot	$slug/ft^3$	515.379	515	kilogram per cubic meter	kg/m^3
Density (weight)					
pound per cubic foot	lb/ft^3	157.087	157	newton per cubic meter	N/m^3
pound per cubic inch	$lb/in.^3$	271.447	271	kilonewton per cubic meter	kN/m^3
Energy; work					
foot-pound	ft-lb	1.35582	1.36	joule (N·m)	J
inch-pound	in.-lb	0.112985	0.113	joule	J
kilowatt-hour	kWh	3.6*	3.6	megajoule	MJ
British thermal unit	Btu	1055.06	1055	joule	J
Force					
pound	lb	4.44822	4.45	newton ($kg \cdot m/s^2$)	N
kip (1000 pounds)	k	4.44822	4.45	kilonewton	kN
Force per unit length					
pound per foot	lb/ft	14.5939	14.6	newton per meter	N/m
pound per inch	lb/in.	175.127	175	newton per meter	N/m
kip per foot	k/ft	14.5939	14.6	kilonewton per meter	kN/m
kip per inch	k/in.	175.127	175	kilonewton per meter	kN/m
Length					
foot	ft	0.3048*	0.305	meter	m
inch	in.	25.4*	25.4	millimeter	mm
mile	mi	1.609344*	1.61	kilometer	km
Mass					
slug	$lb\text{-}s^2/ft$	14.5939	14.6	kilogram	kg
Moment of a force; torque					
pound-foot	lb-ft	1.35582	1.36	newton meter	N·m
pound-inch	lb-in.	0.112985	0.113	newton meter	N·m
kip-foot	k-ft	1.35582	1.36	kilonewton meter	kN·m
kip-inch	k-in.	0.112985	0.113	kilonewton meter	kN·m

CONVERSIONS BETWEEN U.S. CUSTOMARY UNITS AND SI UNITS (Continued)

U.S. Customary unit		Times conversion factor		Equals SI unit	
		Accurate	Practical		
Moment of inertia (area)					
inch to fourth power	in.^{4}	416,231	416,000	millimeter to fourth power	mm^4
inch to fourth power	in.^{4}	0.416231×10^{-6}	0.416×10^{-6}	meter to fourth power	m^4
Moment of inertia (mass)					
slug foot squared	slug-ft^2	1.35582	1.36	kilogram meter squared	kg·m^2
Power					
foot-pound per second	ft-lb/s	1.35582	1.36	watt (J/s or N·m/s)	W
foot-pound per minute	ft-lb/min	0.0225970	0.0226	watt	W
horsepower (550 ft-lb/s)	hp	745.701	746	watt	W
Pressure; stress					
pound per square foot	psf	47.8803	47.9	pascal (N/m^2)	Pa
pound per square inch	psi	6894.76	6890	pascal	Pa
kip per square foot	ksf	47.8803	47.9	kilopascal	kPa
kip per square inch	ksi	6.89476	6.89	megapascal	MPa
Section modulus					
inch to third power	in.^{3}	16,387.1	16,400	millimeter to third power	mm^3
inch to third power	in.^{3}	16.3871×10^{-6}	16.4×10^{-6}	meter to third power	m^3
Velocity (linear)					
foot per second	ft/s	0.3048*	0.305	meter per second	m/s
inch per second	in./s	0.0254*	0.0254	meter per second	m/s
mile per hour	mph	0.44704*	0.447	meter per second	m/s
mile per hour	mph	1.609344*	1.61	kilometer per hour	km/h
Volume					
cubic foot	ft^3	0.0283168	0.0283	cubic meter	m^3
cubic inch	in.^{3}	16.3871×10^{-6}	16.4×10^{-6}	cubic meter	m^3
cubic inch	in.^{3}	16.3871	16.4	cubic centimeter (cc)	cm^3
gallon (231 in.^{3})	gal.	3.78541	3.79	liter	L
gallon (231 in.^{3})	gal.	0.00378541	0.00379	cubic meter	m^3

*An asterisk denotes an *exact* conversion factor

***Note:* To convert from SI units to USCS units, *divide* by the conversion factor**

Temperature Conversion Formulas

$$T(°C) = \frac{5}{9}[T(°F) - 32] = T(K) - 273.15$$

$$T(K) = \frac{5}{9}[T(°F) - 32] + 273.15 = T(°C) + 273.15$$

$$T(°F) = \frac{9}{5}T(°C) + 32 = \frac{9}{5}T(K) - 459.67$$

Mechanics of Materials

Enhanced Ninth Edition

Barry J. Goodno

Georgia Institute of Technology

James M. Gere

Professor Emeritus, Stanford University

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CONTENTS

*A star attached to a section number indicates a specialized and/or advanced topic.

Barry J. Goodno

© Barry Goodno

Barry John Goodno is Professor of Civil and Environmental Engineering at Georgia Institute of Technology. He joined the Georgia Tech faculty in 1974. He was an Evans Scholar and received a B.S. in Civil Engineering from the University of Wisconsin, Madison, Wisconsin, in 1970. He received M.S. and Ph.D. degrees in Structural Engineering from Stanford University, Stanford, California, in 1971 and 1975, respectively. He holds a professional engineering license (PE) in Georgia, is a Distinguished Member of ASCE and an Inaugural Fellow of SEI, and has held numerous leadership positions within ASCE. He is a past president of the ASCE Structural Engineering Institute (SEI) Board of Governors and is also a member of the Engineering Mechanics Institute (EMI) of ASCE. He is past-chair of the ASCE-SEI Technical Activities Division (TAD) Executive Committee, and past-chair of the ASCE-SEI Awards Committee. In 2002, Dr. Goodno received the SEI *Dennis L. Tewksbury Award* for outstanding service to ASCE-SEI. He received the departmental award for *Leadership in Use of Technology* in 2013 for his pioneering use of lecture capture technologies in undergraduate statics and mechanics of materials courses at Georgia Tech. He is a member of the Earthquake Engineering Research Institute (EERI) and has held several leadership positions within the NSF-funded Mid-America Earthquake Center (MAE), directing the MAE Memphis Test Bed Project. Dr. Goodno has carried out research, taught graduate courses and published extensively in the areas of earthquake engineering and structural dynamics during his tenure at Georgia Tech.

Dr. Goodno is an active cyclist, retired soccer coach and referee, and a retired marathon runner. Like co-author and mentor James Gere, he has completed numerous marathons including qualifying for and running the Boston Marathon in 1987.

James M. Gere

Courtesy of James and Janice Gere Family Trust

James M. Gere (1925-2008) earned his undergraduate and master's degree in Civil Engineering from the Rensselaer Polytechnic Institute in 1949 and 1951, respectively. He worked as an instructor and later as a Research Associate for Rensselaer. He was awarded one of the first NSF Fellowships, and chose to study at Stanford. He received his Ph.D. in 1954 and was offered a faculty position in Civil Engineering, beginning a 34-year career of engaging his students in challenging topics in mechanics, and structural and earthquake engineering. He served as Department Chair and Associate Dean of Engineering and in 1974 co-founded the John A. Blume Earthquake Engineering Center at Stanford. In 1980, Jim Gere also became the founding head of the Stanford Committee on Earthquake Preparedness. That same year, he was invited as one of the first foreigners to study the earthquake-devastated city of Tangshan, China. Jim retired from Stanford in 1988 but continued to be an active and most valuable member of the Stanford community.

Jim Gere was known for his outgoing manner, his cheerful personality and wonderful smile, his athleticism, and his skill as an educator in Civil Engineering. He authored nine textbooks on various engineering subjects starting in 1972 with *Mechanics of Materials*, a text that was inspired by his teacher and mentor Stephan P. Timoshenko. His other well-known textbooks, used in engineering courses around the world, include: *Theory of Elastic Stability*, co-authored with S. Timoshenko; *Matrix Analysis of Framed Structures* and *Matrix Algebra for Engineers*, both co-authored with W. Weaver; *Moment Distribution*; *Earthquake Tables: Structural and Construction Design Manual*, co-authored with H. Krawinkler; and *Terra Non Firma: Understanding and Preparing for Earthquakes*, co-authored with H. Shah.

In 1986 he hiked to the base camp of Mount Everest, saving the life of a companion on the trip. James was an active runner and completed the Boston Marathon at age 48, in a time of 3:13. James Gere will be long remembered by all who knew him as a considerate and loving man whose upbeat good humor made aspects of daily life or work easier to bear.

Mechanics of Materials is a basic engineering subject that, along with statics, must be understood by anyone concerned with the strength and physical performance of structures, whether those structures are man-made or natural. At the college level, statics is usually taught during the sophomore or junior year and is a prerequisite for the follow-on course in Mechanics of Materials. Both courses are required for most students majoring in mechanical, structural, civil, biomedical, petroleum, nuclear, aeronautical, and aerospace engineering. In addition, many students from such diverse fields as materials science, industrial engineering, architecture, and agricultural engineering also find it useful to study mechanics of materials.

Mechanics of Materials

In many university engineering programs today, both statics and mechanics of materials are taught in large sections of students from the many engineering disciplines. Instructors for the various parallel sections must cover the same material, and all of the major topics must be presented so that students are well prepared for the more advanced courses required by their specific degree programs. An essential prerequisite for success in a first course in mechanics of materials is a strong foundation in statics, which includes not only understanding fundamental concepts but also proficiency in applying the laws of static equilibrium to solutions of both two- and three-dimensional problems. This ninth edition begins with an updated section on statics in which the laws of equilibrium and an expanded list of boundary (or support) conditions are reviewed, as well as types of applied forces and internal stress resultants, all based upon and derived from a properly drawn free-body diagram. Numerous examples and end-of-chapter problems are included to help students review the analysis of plane and space trusses, shafts in torsion, beams and plane and space frames, and to reinforce basic concepts learned in the prerequisite course.

Many instructors like to present the basic theory of say, beam bending, and then use real world examples to motivate student interest in the subject of beam flexure, beam design, etc. In many cases, structures on campus offer easy access to beams, frames, and bolted connections that can be dissected in lecture or in homework problems, to find reactions at supports, forces and moments in members and stresses in connections. In addition, study of causes of failures in structures and components also offers the opportunity for students to begin the process of learning from actual designs and past engineering mistakes. A number of the new example problems and also the new and revised end-of-chapter problems in this ninth edition are based upon actual components or structures and are accompanied by photographs so that the student can see the real world problem alongside the simplified mechanics model and free-body diagrams used in its analysis.

An increasing number of universities are using rich media lecture (and/or classroom) capture software (such as Panopto and Tegrity) in their large undergraduate courses in mathematics, physics, and engineering. The *many new photos and enhanced graphics* in the ninth edition are designed to support this enhanced lecture mode.

Key Features

The main topics covered in this book are the analysis and design of structural members subjected to tension, compression, torsion, and bending, including the fundamental concepts mentioned above. Other important topics are the transformations of stress and strain, combined loadings and combined stress, deflections of beams, and stability of columns. Some additional specialized topics include the following: stress concentrations, dynamic and impact loadings, non-prismatic members, shear centers, bending of beams of two materials (or composite beams), bending of unsymmetric beams, maximum stresses in beams, energy based approaches for computing deflections of beams, and statically indeterminate beams.

Each chapter begins with the ***Chapter Objectives*** and a ***Chapter Outline*** highlighting the major topics covered in that chapter and closes with a ***Chapter Summary and Review*** in which the key points as well as major mathematical formulas in the chapter are listed for quick review. Each chapter also opens with a photograph of a component or structure that illustrates the key concepts discussed in the chapter.

New Features

Some of the notable features of this ninth edition, which have been added as new or updated material to meet the needs of a modern course in mechanics of materials, are:

- **Problem-Solving Approach**—All examples in the text are presented in a new Four-Step Problem-Solving Approach which is patterned after that presented by R. Serway and J. Jewett in *Principles of Physics*, 5e, Cengage Learning, 2013. This new structured format helps students refine their problem-solving skills and improve their understanding of the main concepts illustrated in the example.
- **Statics Review**—The *Statics Review* section has been enhanced in Chapter 1. Section 1.2 includes four new example problems which illustrate calculation of support reactions and internal stress resultants for truss, beam, circular shaft and plane frame structures. Thirty-four end-of-chapter problems on statics provide students with two- and three-dimensional structures to be used as practice, review, and homework assignment problems of varying difficulty.
- **Expanded Chapter Objectives and Chapter Summary and Review sections**—The *Chapter Objectives* are listed at the beginning of each chapter and the *Chapter Summary* section has been expanded to include ***key equations*** and ***figures*** presented in each chapter. These summary sections serve as a convenient review for students of key topics and equations presented in each chapter.
- **Continued emphasis on underlying fundamental concepts** such as equilibrium, constitutive, and strain-displacement/ compatibility equations in problem solutions. Example problem and end-of-chapter problem solutions have been updated to emphasize an orderly process of explicitly writing out the equilibrium, constitutive and strain-displacement/ compatibility equations before attempting a solution.

- **Expanded topic coverage**—The following topics have been updated or have received expanded coverage: stress concentrations in axially loads bars (Sec. 2.10); torsion of noncircular shafts (Sec. 3.10); stress concentrations in bending (Sec. 5.13); transformed section analysis for composite beams (Sec. 6.3); generalized flexure formula for unsymmetric beams (Sec. 6.5); and updated code provisions for buckling of steel, aluminum and timber columns (Sec. 11.9).
- **Many new example and end-of-chapter problems**—More than forty new example problems have been added to the ninth edition. In addition, there are more than 400 new and revised end-of-chapter problems out of the 1440 problems presented in the ninth edition text. The end-of-chapter problems are now grouped as **Introductory** or **Representative** and are arranged in order of increasing difficulty.
- **Centroids and Moments of Inertia review** has been moved to Appendix D to free up space for more examples and problems in earlier chapters.

Importance of Example Problems

- Examples are presented throughout the book to illustrate the theoretical concepts and show how those concepts may be used in practical situations. All examples are presented in the **Four-Step Problem-Solving Approach** format so that the basic concepts as well as the key steps in setting up and solving each problem are clearly understood. New photographs have been added showing actual engineering structures or components to reinforce the tie between theory and application. Each example begins with a clear statement of the problem and then presents a simplified analytical model and the associated free-body diagrams to aid students in understanding and applying the relevant theory in engineering analysis of the system. In most cases, the examples are worked out in symbolic terms so as to better illustrate the ideas, and then numeric values of key parameters are substituted in the final part of the analysis step. In selected examples throughout the text, graphical display of results (e.g., stresses in beams) has been added to enhance the student's understanding of the problem results.

Example 1-1

FIGURE 1-6

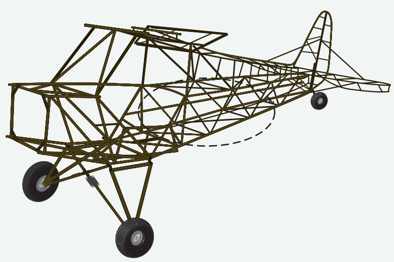
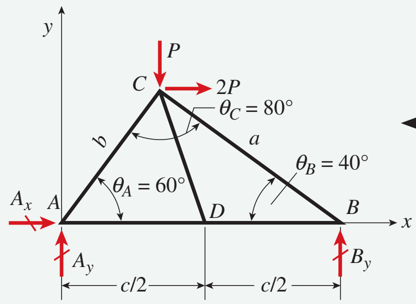


FIGURE 1-7

Free-body diagram of truss model



In many cases, the problem involves the analysis of a real physical structure, such as this truss structure (Fig. 1-6) representing part of the fuselage of a model air plane. Begin by sketching the portion of the structure of interest showing members, supports, dimensions and loadings. This ***Conceptualization*** step in the analysis often leads to a free-body diagram (Fig. 1-7).

The next step is to simplify the problem, list known data and identify all unknowns, and make necessary assumptions to create a suitable model for analysis. This is the ***Categorize*** step.

Write the governing equations, then use appropriate mathematical and computational techniques to solve the equations and obtain results, either in the form of mathematical formulas or numerical values. The ***Analysis*** step leads to support reaction and member forces in the truss.

List the major steps in your analysis procedure so that it is easy to review or check at a later time.

Solution:

The solution involves the following steps:

1. ***Conceptualize*** [*hypothesize, sketch*]: First sketch a free-body diagram of the entire truss model (Figure 1-7). Only known applied forces at C and unknown reaction forces at A and B are shown and then used in an equilibrium analysis to find the reactions.
2. ***Categorize*** [*simplify, classify*]: Overall equilibrium requires that the force components in x and y directions and the moment about the z axis must sum to zero; this leads to reaction force components A_x, A_y, and B_y. The truss is statically determinate (*unknowns*: $m + r = 5 + 3 = 8$, *knowns*: $2j = 8$) so all member forces can be obtained using the *method of joints*. . . .
3. ***Analyze*** [*evaluate; select relevant equations, carry out mathematical solution*]: First find the lengths of members AC and BC, which are needed to compute distances to lines of action of forces.

   Law of sines to find member lengths *a* and *b*: Use known angles θ_A, θ_B, and θ_C and $c = 10$ ft to find lengths a and b:

$$b = c\frac{\sin(\theta_B)}{\sin(\theta_C)} = (10\text{ ft})\frac{\sin(40°)}{\sin(80°)} = 6.527\text{ ft},$$

$$a = c\frac{\sin(\theta_A)}{\sin(\theta_C)} = (10\text{ ft})\frac{\sin(60°)}{\sin(80°)} = 8.794\text{ ft}$$

   Check that computed lengths a and b give length c by using the law of cosines:

$$c = \sqrt{(6.527\text{ ft})^2 + (8.794\text{ ft})^2 - 2(6.527\text{ ft})(8.794\text{ ft})\cos(80°)} = 10\text{ ft}$$

4. ***Finalize*** [*conclude; examine answer—does it make sense? Are units correct? How does it compare to similar problem solutions?*]: There are $2j = 8$ equilibrium equations for the simple plane truss considered above and, using the *method of joints*, these are obtained by applying $\Sigma F_x = 0$ and $\Sigma F_y = 0$ at each joint in succession. A computer solution of these simultaneous equations leads to the three reaction forces and five member forces. The *method of sections* is an efficient way to find selected member forces.

List the major steps in the ***Finalize*** step, review the solution to make sure that it is presented in a clear fashion so that it can be easily reviewed and checked by others. Are the expressions and numerical values obtained reasonable? Do they agree with your initial expectations?

Problems

In all mechanics courses, solving problems is an important part of the learning process. This textbook offers more than 1440 problems, many with multiple parts, for homework assignments and classroom discussions. The problems are placed at the end of each chapter so that they are easy to find and don't break up the presentation of the main subject matter. Also, problems are generally arranged in order of increasing difficulty, thus alerting students to the time necessary for solution. Answers to all problems are listed near the back of the book.

Considerable effort has been spent in checking and proofreading the text so as to eliminate errors. If you happen to find one, no matter how trivial, please notify me by e-mail (*bgoodno@ce.gatech.edu*). We will correct any errors in the next printing of the book.

Units

Both the International System of Units (SI) and the U.S. Customary System (USCS) are used in the examples and problems. Discussions of both systems and a table of conversion factors are given in Appendix A. For problems involving numerical solutions, odd-numbered problems are in USCS units and even-numbered problems are in SI units. This convention makes it easy to know in advance which system of units is being used in any particular problem. In addition, tables containing properties of structural-steel shapes in both USCS and SI units may be found in Appendix F so that solution of beam analysis and design examples and end-of-chapter problems can be carried out in either USCS or SI units.

Supplements

Instructor Resources

An **Instructor's Solutions Manual** is available online on the Instructor's Resource Center for this book, and includes solutions to all problems from this edition with Mathcad solutions available for some problems. The Manual includes rotated stress elements for problems as well as an increased number of free body diagrams. The Solutions Manual is accessible to instructors on http://login.cengage.com. The Instructor Resource Center also contains a full set of **Lecture Note PowerPoints.**

Student Resources

FE Exam Review Problems has been updated and now appears online. This supplement contains 106 FE-type review problems and solutions, which cover all of the major topics presented in the text and are representative of those likely to appear on an FE exam. Each of the problems is presented in the FE Exam format and is intended to serve as a useful guide to the student in preparing for this important examination.

Many students take the *Fundamentals of Engineering Examination* upon graduation, the first step on their path to registration as a Professional Engineer. Most of these problems are in SI units which is the system of units used on the FE Exam itself, and require use of an engineering calculator to carry out the solution. The student must select from four available answers, only one of which is the correct answer. Go to http://login.cengage.com to find the FE Exam Review Problems and the resources below, which are available on the student website for this book:

- *Answers to the FE Exam Review Problems*
- *Detailed Solutions for Each Problem*

S.P. Timoshenko (1878–1972) and J.M. Gere (1925–2008)

Many readers of this book will recognize the name of Stephen P. Timoshenko—probably the most famous name in the field of applied mechanics. A brief biography of Timoshenko appears in the first reference in the *References and Historical Notes* section. Timoshenko is generally recognized as the world's most outstanding pioneer in applied mechanics. He contributed many new ideas and concepts and became famous for both his scholarship and his teaching. Through his numerous textbooks he made a profound change in the teaching of mechanics not only in this country but wherever mechanics is taught. Timoshenko was both teacher and mentor to James Gere and provided the motivation for the first edition of this text, authored by James M. Gere and published in 1972. The second and each subsequent edition of this book were written by James Gere over the course of his long and distinguished tenure as author, educator, and researcher at Stanford University. James Gere started as a doctoral student at Stanford in 1952 and retired from Stanford as a professor in 1988 having authored this and eight other well-known and respected text books on mechanics, and structural and earthquake engineering. He remained active at Stanford as Professor Emeritus until his death in January of 2008.

Acknowledgments

To acknowledge everyone who contributed to this book in some manner is clearly impossible, but I owe a major debt to my former Stanford teachers, especially my mentor and friend, and co-author James M. Gere.

I am grateful to my many colleagues teaching Mechanics of Materials at various institutions throughout the world who have provided feedback and constructive criticism about the text; for all those anonymous reviews, my thanks. With each new edition, their advice has resulted in significant improvements in both content and pedagogy.

My appreciation and thanks also go to the reviewers who provided specific comments for this ninth edition:

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I wish to also acknowledge my Structural Engineering and Mechanics colleagues at the Georgia Institute of Technology, many of whom provided valuable advice on various aspects of the revisions and additions leading to the current edition. It is a privilege to work with all of these educators and to learn from them in almost daily interactions and discussions about structural engineering and mechanics in the context of research and higher education. I wish to extend my thanks to my many current and former students who have helped to shape this text in its various editions. Finally, I would like to acknowledge the excellent work of Edwin Lim who suggested new problems and also carefully checked the solutions of many of the new examples and end of chapter problems.

I wish to acknowledge and thank the Global Engineering team at Cengage for their dedication to this new book:

Timothy Anderson, Product Director; MariCarmen Constable, Learning Designer; Alexander Sham, Associate Content Manager; Andrew Reddish, Product Assistant; and Rose Kernan of RPK Editorial Services, Inc.

They have skillfully guided every aspect of this text's development and production to successful completion.

I am deeply appreciative of the patience and encouragement provided by my family, especially my wife, Lana, throughout this project.

Finally, I am very pleased to continue this endeavor begun so many years ago by my mentor and friend, Jim Gere. This ninth edition text has now reached its 45th year of publication. I am committed to its continued excellence and welcome all comments and suggestions. Please feel free to provide me with your critical input at *bgoodno@ce.gatech.edu*.

Barry J. Goodno
Atlanta, Georgia

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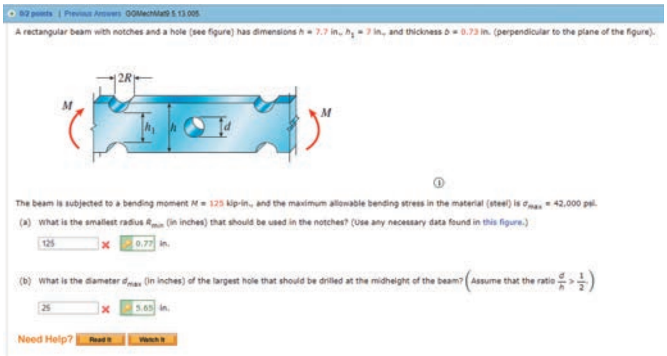
Within WebAssign, a "Read It" button at the bottom of each question links students to corresponding sections of the textbook, enabling access to the MindTap

Reader at the precise moment of learning. A "Watch It" button allows a short video to play. These videos help students understand and review the problem they need to complete, enabling support at the precise moment of learning.



- **Four-Step Active Examples**

Throughout this title, selected examples guide students through a four-step process needed to master concepts. Worked-out solutions are included for these examples.

- **My Class Insights**

WebAssign's built-in study feature shows performance across course topics so that students can quickly identify which concepts they have mastered and which areas they may need to spend more time on.

- **Ask Your Teacher**

This powerful feature enables students to contact their instructor with questions about a specific assignment or problem they are working on.

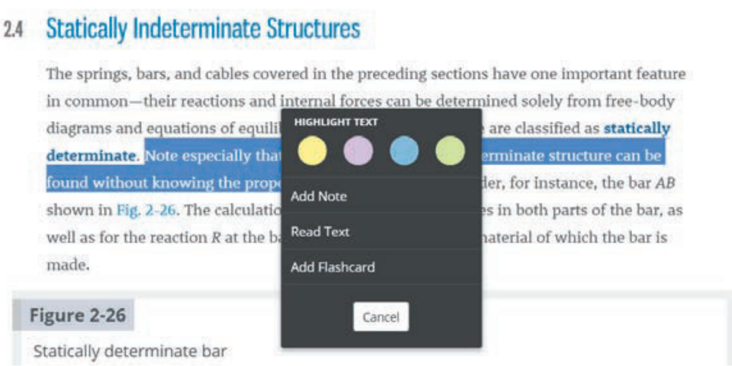
MindTap Reader

Available via WebAssign and our digital subscription service, Cengage Unlimited, **MindTap Reader** is Cengage's next-generation eBook for engineering students.

The MindTap Reader provides more than just text learning for the student. It offers a variety of tools to help our future engineers learn chapter concepts in a way that resonates with their workflow and learning styles.

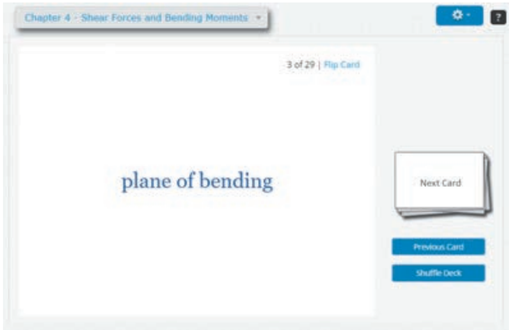
- **Personalize their experience**

Within the MindTap Reader, students can highlight key concepts, add notes, and bookmark pages. These are collected in My Notes, ensuring they will have their own study guide when it comes time to study for exams.



- **Flexibility at their fingertips**

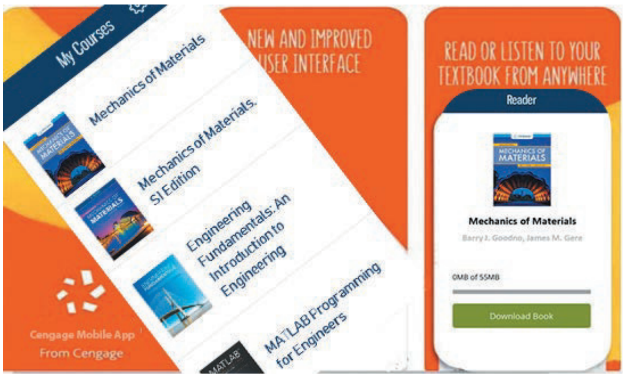
With access to the book's internal glossary, students can personalize their study experience by creating and collating their own custom flashcards. The ReadSpeaker feature reads text aloud to students, so they can learn on the go—wherever they are.



The Cengage Mobile App

Available on iOS and Android smartphones, the Cengage Mobile App provides convenience. Students can access their entire textbook anyplace and anytime. They can take notes, highlight important passages, and have their text read aloud whether they are online or off.

To download the mobile app, visit https://www.cengage.com/mobile-app.



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A	area
A_f, A_w	area of flange; area of web
a, b, c	dimensions, distances
C	centroid, compressive force, constant of integration
c	distance from neutral axis to outer surface of a beam
D	diameter
d	diameter, dimension, distance
E	modulus of elasticity
E_r, E_t	reduced modulus of elasticity; tangent modulus of elasticity
e	eccentricity, dimension, distance, unit volume change (dilatation)
F	force
f	shear flow, shape factor for plastic bending, flexibility, frequency (Hz)
f_T	torsional flexibility of a bar
G	modulus of elasticity in shear
g	acceleration of gravity
H	height, distance, horizontal force or reaction, horsepower
h	height, dimensions
I	moment of inertia (or second moment) of a plane area
I_x, I_y, I_z	moments of inertia with respect to x, y, and z axes
I_{x1}, I_{y1}	moments of inertia with respect to x_1 and y_1 axes (rotated axes)
I_{xy}	product of inertia with respect to xy axes
I_{x1y1}	product of inertia with respect to x_1y_1 axes (rotated axes)
I_P	polar moment of inertia
I_1, I_2	principal moments of inertia
J	torsion constant
K	stress-concentration factor, bulk modulus of elasticity, effective length factor for a column
k	spring constant, stiffness, symbol for $\sqrt{P/EI}$
k_T	torsional stiffness of a bar
L	length, distance
L_E	effective length of a column
ln, log	natural logarithm (base e); common logarithm (base 10)
M	bending moment, couple, mass
M_P, M_Y	plastic moment for a beam; yield moment for a beam
m	moment per unit length, mass per unit length
N	axial force

n	factor of safety, integer, revolutions per minute (rpm)
O	origin of coordinates
O'	center of curvature
P	force, concentrated load, power
P_{allow}	allowable load (or working load)
P_{cr}	critical load for a column
P_P	plastic load for a structure
P_r, P_t	reduced-modulus load for a column; tangent-modulus load for a column
P_Y	yield load for a structure
p	pressure (force per unit area)
Q	force, concentrated load, first moment of a plane area
q	intensity of distributed load (force per unit distance)
R	reaction, radius
r	radius, radius of gyration ($r = \sqrt{I/A}$)
S	section modulus of the cross section of a beam, shear center
s	distance, distance along a curve
T	tensile force, twisting couple or torque, temperature
T_P, T_Y	plastic torque; yield torque
t	thickness, time, intensity of torque (torque per unit distance)
t_{f}, t_{w}	thickness of flange; thickness of web
U	strain energy
u	strain-energy density (strain energy per unit volume)
u_r, u_t	modulus of resistance; modulus of toughness
V	shear force, volume, vertical force or reaction
v	deflection of a beam, velocity
v', v'', etc.	dv/dx, d^2v/dx^2, etc.
W	force, weight, work
w	load per unit of area (force per unit area)
x, y, z	rectangular axes (origin at point O)
x_c, y_c, z_c	rectangular axes (origin at centroid C)
$\overline{x}$, $\overline{y}$, $\overline{z}$	coordinates of centroid
Z	plastic modulus of the cross section of a beam
α	angle, coefficient of thermal expansion, nondimensional ratio
β	angle, nondimensional ratio, spring constant, stiffness
β_R	rotational stiffness of a spring
γ	shear strain, weight density (weight per unit volume)
γ_{xy}, γ_{yz}, γ_{zx}	shear strains in xy, yz, and zx planes
γ_{x1y1}	shear strain with respect to x_1y_1 axes (rotated axes)
γ_θ	shear strain for inclined axes
δ	deflection of a beam, displacement, elongation of a bar or spring

ΔT	temperature differential
δ_P, δ_Y	plastic displacement; yield displacement
ε	normal strain
$\varepsilon_x, \varepsilon_y, \varepsilon_z$	normal strains in x, y, and z directions
$\varepsilon_{x1}, \varepsilon_{y1}$	normal strains in x_1 and y_1 directions (rotated axes)
ε_θ	normal strain for inclined axes
$\varepsilon_1, \varepsilon_2, \varepsilon_3$	principal normal strains
ε'	lateral strain in uniaxial stress
ε_T	thermal strain
ε_Y	yield strain
θ	angle, angle of rotation of beam axis, rate of twist of a bar in torsion (angle of twist per unit length)
θ_p	angle to a principal plane or to a principal axis
θ_s	angle to a plane of maximum shear stress
κ	curvature ($\kappa = 1/\rho$)
λ	distance, curvature shortening
ν	Poisson's ratio
ρ	radius, radius of curvature ($\rho = 1/\kappa$), radial distance in polar coordinates, mass density (mass per unit volume)
σ	normal stress
$\sigma_x, \sigma_y, \sigma_z$	normal stresses on planes perpendicular to x, y, and z axes
σ_{x1}, σ_{y1}	normal stresses on planes perpendicular to x_1y_1 axes (rotated axes)
σ_θ	normal stress on an inclined plane
$\sigma_1, \sigma_2, \sigma_3$	principal normal stresses
σ_{allow}	allowable stress (or working stress)
σ_{cr}	critical stress for a column ($\sigma_{\text{cr}} = P_{\text{cr}}/A$)
σ_{pl}	proportional-limit stress
σ_r	residual stress
σ_T	thermal stress
σ_U, σ_Y	ultimate stress; yield stress
τ	shear stress
$\tau_{xy}, \tau_{yz}, \tau_{zx}$	shear stresses on planes perpendicular to the x, y, and z axes and acting parallel to the y, z, and x axes
τ_{x1y1}	shear stress on a plane perpendicular to the x_1 axis and acting parallel to the y_1 axis (rotated axes)
τ_θ	shear stress on an inclined plane
τ_{allow}	allowable stress (or working stress) in shear
τ_U, τ_Y	ultimate stress in shear; yield stress in shear
ϕ	angle, angle of twist of a bar in torsion
ψ	angle, angle of rotation
ω	angular velocity, angular frequency ($\omega = 2\pi f$)