SIMPLIFIED MECHANICS AND STRENGTH OF MATERIALS

Sixth Edition

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Formerly Professor of Architecture
University of Southern California
Los Angeles, California

based on the work of

THE LATE HARRY PARKER
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JOHN WILEY & SONS, INC.

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PREFACE TO THE SIXTH EDITION

Publication of this book presents the opportunity for yet another new generation of readers to pursue a study of the fundamental topics that underlie the work of design of building structures. In particular, the work here is developed in a form to ensure its accessibility to persons with limited backgrounds in engineering. That purpose and the general rationale for the book are well presented in Professor Parker's preface to the first edition, excerpts from which follow.

The fundamental materials presented here derive from two general areas of study. The first area is that of *applied mechanics*, and most principally, applications of the field of *statics*. This study deals primarily with the nature of forces and their effects when applied to objects. The second area of study is that of *strength of materials*, which deals generally with the behavior of particular forms of objects, of specific structural materials, when subjected to actions of forces. Fundamental relationships and evaluations derived from these basic fields provide the tools for investigation of structures relating to their effectiveness and safety for usage in building construction. No structural design work can be satisfactorily achieved without this investigation.

In keeping with the previously stated special purpose of this book, the work here is relatively uncomplicated and uses quite simple mathematics. A first course in algebra plus some very elementary geometry and trigonometry will suffice for the reader to follow any derivations presented here. In fact, the mathematical operations in applications to actual problem solving involve mostly only simple arithmetic and elementary algebra.

More important to the study here than mechanical mathematical operations is the conceptual visualization of the work being performed. To foster this achievement, extensive use is made of graphic images to encourage the reader to literally *see* what is going on. The ultimate extension of this approach is embodied in the first chapter, which presents the entire scope of topics in the book without mathematics. This chapter is new to this edition and is intended both to provide a comprehensive grasp of the book's scope and to condition the reader to emphasize the need for visualization preceding any analytical investigation.

Mastery of the work in this book is essentially preparatory in nature, leading to a next step that develops the topic of structural design. This step may be taken quite effectively through the use of the book that is essentially a companion to this work: *Simplified Engineering for Architects and Builders*. That book picks up the fundamental materials presented here, adds to them various pragmatic considerations for use of specific materials and systems, and engages the work of creating solutions to structural design problems.

For highly motivated readers, this book may function as a self-study reference. Its more practical application, however, is as a text for a course in which case readers will have the advantage of guidance, prodding, and counsel from a teacher. For teachers accepting such a challenge, a *Teacher's Manual* is available from the publisher.

While the work here is mostly quite theoretical in nature, some use of data and criteria derived from sources of real materials and products is necessary. Those sources consist primarily of industry organizations, and I am grateful for the permissions granted for such use. Primary sources used here include the American Concrete Institute, the American Institute for Steel Construction, and the American Forest and Paper Association.

A practical context for this theoretical work is presented through several illustrations taken from books that more thoroughly develop the topic of building construction. I am grateful to John Wiley & Sons for

permission to use these illustrations from several of its publications, both current and vintage works.

Bringing any work to actual publication requires enormous effort and contributions by highly competent and experienced people who can transform the author's raw materials into intelligible and presentable form. Through many engagements, I continue to be amazed at the level of quality and the skill of the editors and production staff at John Wiley & Sons who achieve this effort.

This work is the sixtieth publication that I have brought forth over the past 35 years, all of which were conceived and produced in my home office. None of them—first to last—would have happened there without the support, encouragement, and lately the direct assistance of my wife, Peggy. I am grateful to her for that contribution, and hope she will sustain it through the next work.

JAMES AMBROSE

2002

PREFACE TO THE FIRST EDITION

The following are excerpts from the preface to the first edition of this book, written by Professor Parker at the time of publication in 1951.

Since engineering design is based on the science of mechanics, it is impossible to overemphasize the importance of a thorough knowledge of this basic subject. Regardless of the particular field of engineering in which a student is interested, it is essential that he understand fully the fundamental principles that deal with the actions of forces on bodies and the resulting stresses.

This is an elementary treatment written for those who have had limited preparation. The best books on the subject of mechanics and strength of materials make use of physics, calculus, and trigonometry. Such books are useless for many ambitious men. Consequently, this book has been prepared for the student who has not obtained a practical appreciation of mechanics or advanced mathematics. A working knowledge of algebra and arithmetic is sufficient to enable him to comprehend the mathematics involved in this volume.

This book has been written for use as a textbook in courses in mechanics and strength of materials and for use by practical men interested in mechanics and construction. Because it is elementary, the material has been arranged so that it may be used for home study. For those who have had previous training it will serve as a refresher course in reviewing the most important of the basic principles of structural design.

One of the most important features of this book is a detailed explanation of numerous illustrative examples. In so far as possible, the examples relate to problems encountered in practice. The explanations are followed by problems to be solved by the student.

This book presents no short-cuts to a knowledge of the fundamental principles of mechanics and strength of materials. There is nothing unique in the presentation, for the discussions follow accepted present-day design procedure. It is the belief of the author, however, that a thorough understanding of the material contained herein will afford a foundation of practical information and serve as a step to further study.

HARRY PARKER

High Hollow
Southampton
Bucks County, Pennsylvania
May 1951

INTRODUCTION

The principal purpose of this book is to develop the topic of *structural investigation*, also sometimes described as *structural analysis*. To the extent possible, the focus of this study is on a consideration of the analytical study as a background for work in structural design. The work of structural investigation consists of the consideration of the tasks required of a structure and the evaluation of the responses of the structure in performing these tasks. Investigation may be performed in various ways, the principal ones being either the use of mathematical modeling or the construction of physical models.

For the designer, a major first step in any investigation is the visualization of the structure and the force actions to which it must respond. In this book, extensive use is made of graphic illustrations in order to encourage the reader to develop the habit of first clearly *seeing* what is happening, before proceeding with the essentially abstract procedures of mathematical investigation. To further emphasize the need for visualization, and the degree to which it can be carried out without any mathematical computations, the first chapter of the book presents the whole range of book topics in this manner. The reader is encouraged to read

Chapter 1 completely, and to study the many graphic illustrations. This initial study should help greatly in giving the reader a grasp for the many concepts to be presented later and for the whole body of the book's topic scope.

STRUCTURAL MECHANICS

The branch of physics called *mechanics* concerns the actions of forces on physical bodies. Most of engineering design and investigation is based on applications of the science of mechanics. *Statics* is the branch of mechanics that deals with bodies held in a state of unchanging motion by the balanced nature (called *static equilibrium*) of the forces acting on them. *Dynamics* is the branch of mechanics that concerns bodies in motion or in a process of change of shape due to actions of forces. A static condition is essentially unchanging with regard to time; a dynamic condition implies a time-dependent action and response.

When external forces act on a body, two things happen. First, internal forces that resist the actions of the external forces are set up in the body. These internal forces produce *stresses* in the material of the body. Second, the external forces produce *deformations*, or changes in shape, of the body. *Strength of materials*, or mechanics of materials, is the study of the properties of material bodies that enable them to resist the actions of external forces, of the stresses within the bodies, and of the deformations of bodies that result from external forces.

Taken together, the topics of applied mechanics and strength of materials are often given the overall designation of *structural mechanics* or *structural analysis*. This is the fundamental basis for structural investigation, which is essentially an analytical process. On the other hand, *design* is a progressive refining process in which a structure is first generally visualized; then it is investigated for required force responses and its performance is evaluated; finally—possibly after several cycles of investigation and modification—an acceptable form is derived for the structure.

UNITS OF MEASUREMENT

Early editions of this book have used U.S. units (feet, inches, pounds, etc.) for the basic presentation. In this edition, the basic work is developed with U.S. units with equivalent metric unit values in brackets [thus].

While the building industry in the United States is now in the process of changing over to the use of metric units, our decision for the presentation here is a pragmatic one. Most of the references used for this book are still developed primarily in U.S. units, and most readers educated in the United States will have acquired use of U.S units as their "first language," even if they now also use metric units.

Table 1 lists the standard units of measurement in the U.S. system with the abbreviations used in this work and a description of common usage in structural design work. In similar form, Table 2 gives the corresponding units in the metric system (or Système International, SI). Conversion factors to be used for shifting from one unit system to the other are given in Table 3. Direct use of the conversion factors will produce what is called a *hard conversion* of a reasonably precise form.

In the work in this book, many of the unit conversions presented are *soft conversions*, meaning one in which the converted value is rounded off to produce an approximate equivalent value of some slightly more relevant numerical significance to the unit system. Thus, a wood 2 × 4 (actually 1.5 × 3.5 inches in the U.S. system) is precisely 38.1 × 88.9 mm in the metric system. However, the metric equivalent of a "2 by 4" is more likely to be made 40 × 90 mm, close enough for most purposes in construction work.

For some of the work in this book, the units of measurement are not significant. What is required in such cases is simply to find a numerical answer. The visualization of the problem, the manipulation of the mathematical processes for the solution, and the quantification of the answer are not related to specific units—only to their relative values. In such situations, the use of dual units in the presentation is omitted in order to reduce the potential for confusion for the reader.

ACCURACY OF COMPUTATIONS

Structures for buildings are seldom produced with a high degree of dimensional precision. Exact dimensions are difficult to achieve, even for the most diligent of workers and builders. Add this to considerations for the lack of precision in predicting loads for any structure, and the significance of highly precise structural computations becomes moot. This is not to be used as an argument to justify sloppy mathematical work, overly sloppy construction, or use of vague theories of investigation of

TABLE 1 Units of Measurement: U.S. System

Name of Unit	Abbreviation	Use in Building Design
Length		
Foot	ft	Large dimensions, building plans, beam spans
Inch	in.	Small dimensions, size of member cross sections
Area		
Square feet	ft^2	Large areas
Square inches	$in.^2$	Small areas, properties of cross sections
Volume		
Cubic yards	yd^3	Large volumes, of soil or concrete (commonly called simply "yards")
Cubic feet	ft^3	Quantities of materials
Cubic inches	$in.^3$	Small volumes
Force, Mass		
Pound	lb	Specific weight, force, load
Kip	kip, k	1000 pounds
Ton	ton	2000 pounds
Pounds per foot	lb/ft, plf	Linear load (as on a beam)
Kips per foot	kips/ft, klf	Linear load (as on a beam)
Pounds per square foot	lb/ft^2, psf	Distributed load on a surface, pressure
Kips per square foot	k/ft^2, ksf	Distributed load on a surface, pressure
Pounds per cubic foot	lb/ft^3	Relative density, unit weight
Moment		
Foot-pounds	ft-lb	Rotational or bending moment
Inch-pounds	in.-lb	Rotational or bending moment
Kip-feet	kip-ft	Rotational or bending moment
Kip-inches	kip-in.	Rotational or bending moment
Stress		
Pounds per square foot	lb/ft^2, psf	Soil pressure
Pounds per square inch	$lb/in.^2$, psi	Stresses in structures
Kips per square foot	$kips/ft^2$, ksf	Soil pressure
Kips per square inch	$kips/in.^2$, ksi	Stresses in structures
Temperature		
Degree Fahrenheit	°F	Temperature

TABLE 2 Units of Measurement: SI System

Name of Unit	Abbreviation	Use in Building Design
Length		
Meter	m	Large dimensions, building plans, beam spans
Millimeter	mm	Small dimensions, size of member cross sections
Area		
Square meters	m^2	Large areas
Square millimeters	mm^2	Small areas, properties of member cross sections
Volume		
Cubic meters	m^3	Large volumes
Cubic millimeters	mm^3	Small volumes
Mass		
Kilogram	kg	Mass of material (equivalent to weight in U.S. units)
Kilograms per cubic meter	kg/m^3	Density (unit weight)
Force, Load		
Newton	N	Force or load on structure
Kilonewton	kN	1000 newtons
Moment		
Newton-meters	N-m	Rotational or bending moment
Kilonewton-meters	kN-m	Rotational or bending moment
Stress		
Pascal	Pa	Stress or pressure (1 pascal = 1 N/m^2)
Kilopascal	kPa	1000 pascals
Megapascal	MPa	1,000,000 pascals
Gigapascal	GPa	1,000,000,000 pascals
Temperature		
Degree Celsius	°C	Temperature

TABLE 3 Factors for Conversion of Units

To convert from U.S. Units to SI Units, Multiply by:	U.S. Unit	SI Unit	To convert from SI Units to U.S. Units, Multiply by:
25.4	in.	mm	0.03937
0.3048	ft	m	3.281
645.2	$in.^2$	mm^2	1.550×10^{-3}
16.39×10^3	$in.^3$	mm^3	61.02×10^{-6}
416.2×10^3	$in.^4$	mm^4	2.403×10^{-6}
0.09290	ft^2	m^2	10.76
0.02832	ft^3	m^3	35.31
0.4536	lb (mass)	kg	2.205
4.448	lb (force)	N	0.2248
4.448	kip (force)	kN	0.2248
1.356	ft-lb (moment)	N-m	0.7376
1.356	kip-ft (moment)	kN-m	0.7376
16.0185	lb/ft^3 (density)	kg/m^3	0.06243
14.59	lb/ft (load)	N/m	0.06853
14.59	kip/ft (load)	kN/m	0.06853
6.895	psi (stress)	kPa	0.1450
6.895	ksi (stress)	MPa	0.1450
0.04788	psf (load or pressure)	kPa	20.93
47.88	ksf (load or pressure)	kPa	0.02093
$0.566 \times (^oF - 32)$	^oF	^oC	$(1.8 \times {}^oC) + 32$

Source: Adapted from data in the *Manual of Steel Construction*, 8th edition, with permission of the publishers, American Institute of Steel Construction. This table is a sample from an extensive set of tables in the reference document.

behaviors. Nevertheless, it makes a case for not being highly concerned with any numbers beyond about the second digit.

While most professional design work these days is likely to be done with computer support, most of the work illustrated here is quite simple and was actually performed with a hand calculator (the eight-digit, scientific type is adequate). Rounding off of these primitive computations is done with no apologies.

With the use of the computer, accuracy of computational work is a somewhat different matter. Still, it is the designer (a person) who makes judgements based on the computations, and who knows how good the input to the computer was, and what the real significance of the degree of accuracy of an answer is.

SYMBOLS

The following shorthand symbols are frequently used.

Symbol	Reading
$>$	is greater than
$<$	is less than
$\geq$	is equal to or greater than
$\leq$	is equal to or less than
6'	6 feet
6"	6 inches
Σ	the sum of
ΔL	change in L

NOMENCLATURE

Notation used in this book complies generally with that used in the building design field. A general attempt has been made to conform to usage in the 1997 edition of the *Uniform Building Code*, UBC for short (Ref. 1). The following list includes all of the notation used in this book that is general and is related to the topic of the book. Specialized notation is used by various groups, especially as related to individual materials: wood, steel, masonry, concrete, and so on. The reader is referred to basic references for notation in special fields. Some of this notation is explained in later parts of this book.

Building codes, including the UBC, use special notation that is usually carefully defined by the code, and the reader is referred to the source for interpretation of these definitions. When used in demonstrations of computations, such notation is explained in the text of this book.

A_g = gross (total) area of a section, defined by the outer dimensions
A_n = net area
C = compressive force

E = modulus of elasticity (general)

F = (1) force; (2) a specified limit for stress

I = moment of inertia

L = length (usually of a span)

M = bending moment

P = concentrated load

S = section modulus

T = tension force

W = (1) total gravity load; (2) weight, or dead load of an object; (3) total wind load force; (4) total of a uniformly distributed load or pressure due to gravity

a = unit area

e = (1) total dimensional change of length of an object, caused by stress or thermal change; (2) eccentricity of a nonaxial load, from point of application of the load to the centroid of the section

f = computed direct stress

h = effective height (usually meaning unbraced height) of a wall or column

l = length, usually of a span

s = spacing, center to center

v = computed shear stress

1

STRUCTURES: PURPOSE AND FUNCTION

This book deals with the behavior of structures; in particular, with structures for buildings. The behavior referred to is that which occurs when the structures respond to various force actions produced by natural and usage-generated effects. Investigation of structural behaviors has the direct purpose of supporting an informed design of the structures and an assurance as to the safety of the construction with regard to the building occupants.

Structural behaviors may be simple or complex. This quality may derive from the nature of the loads on the structure—from simple gravity to the dynamic effects of earthquakes. It may also derive from the nature of the structure itself. For example, the simple structure shown in Figure 1.1 has basic elements that yield to quite elementary investigation for behavior. This book provides a starting point for the most elementary investigations of structures. It can be the beginning of a long course of study for persons interested in the investigation and design of highly complex structures.

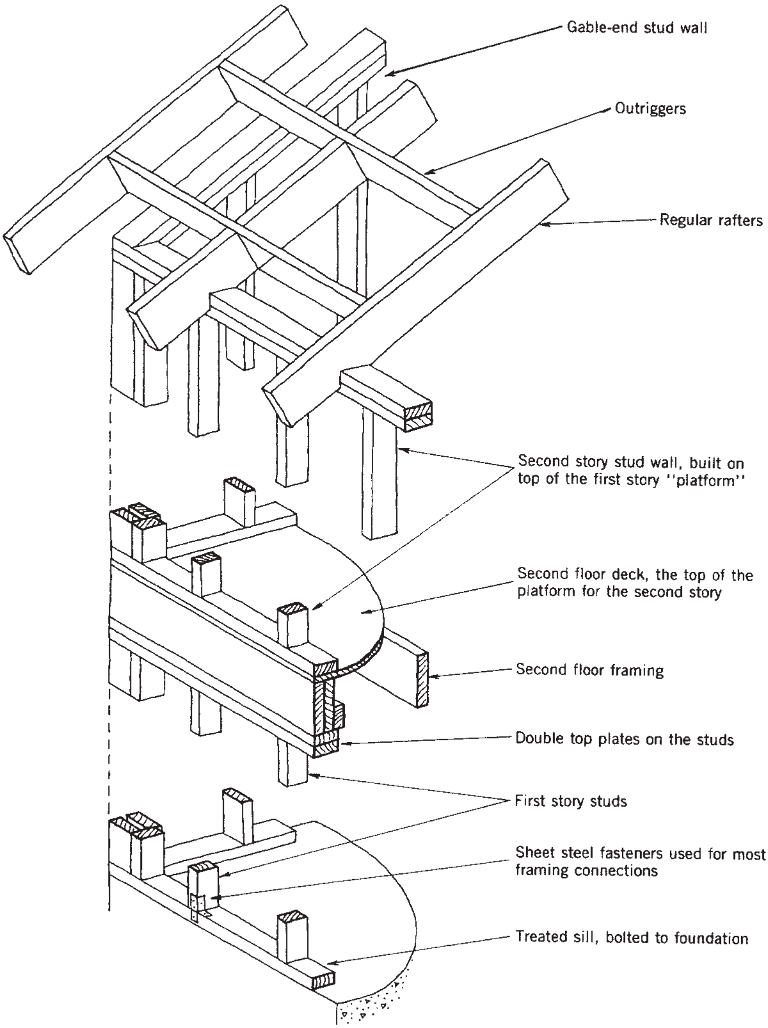

Figure 1.1 An All-American classic structure: the light wood frame, achieved almost entirely with "2 ×" dimension lumber. Wall studs serve as columns to support horizontal members in the time-honored post and beam system with its roots in antiquity. While systems of much greater sophistication have been developed, this is still the single most widely used structure in the United States today.

Consider the problems of the structure that derive from its performance of various load resisting functions. The basic issues to be dealt with are:

The load sources and their effects.

What the structure accomplishes in terms of its performance as a supporting, spanning, or bracing element.

What happens to the structure internally as it performs its various tasks.

What is involved in determining the necessary structural elements and systems for specific structural tasks.

We begin this study with a consideration of the loads that affect building structures.

1.1 LOADS

Used in its general sense, the term *load* refers to any effect that results in a need for some resistive response on the part of the structure. There are many different sources for loads, and many ways in which they can be classified. The principal kinds and sources of loads on building structures are the following.

Gravity

Source: The weight of the structure and of other parts of the construction; the weight of building occupants and contents; the weight of snow, ice, or water on the roof.

Computation: By determination of the volume, density, and type of dispersion of items.

Application: Vertically downward and constant in magnitude.

Wind

Source: Moving air.

Computation: From anticipated wind velocities established by local weather history.

Application: As pressure perpendicular to exterior surfaces or as shearing drag parallel to exterior surfaces. Primarily considered as a horizontal force from any compass point, but also with a vertical component on sloping surfaces and vertical uplift on flat roofs.

Earthquake (Seismic Shock)

Source: Vibration of the ground as a result of a subterranean shock.

Computation: By prediction of the probability of occurrence based on local history of seismic activity.

Application: Back-and-forth, up-and-down movement of the ground on which a building sits, resulting in forces induced by the inertial effect of the building's weight.

Blast

Source: Explosion of bomb, projectile, or volatile materials.

Computation: As pressure, depending on the magnitude of the explosion and its proximity to the structure.

Application: Slamming force on surfaces surrounding the explosion.

Hydraulic Pressure

Source: Principally from groundwater levels above the bottom of the basement floor.

Computation: As fluid pressure proportional to the depth below the water top surface.

Application: As horizontal pressure on basement walls and upward pressure on basement floors.

Thermal Change

Source: Temperature changes in the building materials caused by fluctuations of outdoor temperature.

Computation: From weather histories, coefficient of expansion of materials, and amount of exposure of the individual parts of the construction.

Application: Forces exerted when parts are restrained from expanding or contracting; distortions of building if connected parts differ in temperature or have significantly different coefficients of expansion.

Shrinkage

Natural volume reduction occurs in concrete, in the mortar joints of masonry, in green wood, and in wet clay soils. These can induce forces in a manner similar to thermal change.

Vibration

In addition to earthquake effects, vibration of the structure may be caused by heavy machinery, moving vehicles, or high intensity sounds. These may not be a critical force issue, but can be a major concern for sensation by occupants.

Internal Actions

Forces may be generated within a structure by settlement of supports, slippage or loosening of connections, or by shape changes due to sag, warping, shrinkage, and so on.

Handling

Forces may be exerted on elements of the structure during production, transportation, erection, storage, and so on. These may not be evident when considering only the normal use of the building, but must be considered for the life of the structure.

1.2 SPECIAL CONSIDERATIONS FOR LOADS

In addition to identifying load sources, it is necessary to classify loads in various ways. The following are some such classifications.

Live and Dead Loads

For design, a distinction is made between so-called *live* and *dead* loads. A dead load is essentially a permanent load, such as the weight of the structure itself and the weight of other permanent elements of the building construction supported by the structure. A live load is technically anything that is not permanently applied as a force on the structure. However, the specific term "live load" is typically used in building codes to refer to the assumed design loads in the form of dispersed load on the roof and floor surfaces that derive from the building location and its usage.

Static versus Dynamic Forces

This distinction has to do essentially with the time-dependent character of the force. Thus, the weight of the structure produces a static effect, unless the structure is suddenly moved or stopped from moving, at which time a dynamic effect occurs due to the inertia or momentum of the mass of the structure (see Figure 1.2*a*). The more sudden the stop or start, the greater the dynamic effect.

Other dynamic effects are caused by ocean waves, earthquakes, blasts, sonic booms, vibration of heavy machinery, and the bouncing effect of people walking or of moving vehicles. Dynamic effects are different in nature from static effects. A light steel-framed building, for instance, may be very strong in resisting static forces, but a dynamic force may cause large distortions or vibrations, resulting in cracking of plaster, breaking of window glass, loosening of structural connections, and so on. A heavy masonry structure, although possibly not as strong as the steel frame for static load, has considerable stiffness and dead weight, and may thus absorb the energy of the dynamic force without perceptible movement.

In the example just cited, the effect of the force on the function of the structure was described. This may be distinct from any potential damaging effect on the structure. The steel frame is flexible and may respond with a degree of movement that is objectionable. However, from a structural point of view it is probably more resistive to dynamic force than the masonry structure. Steel is strong in tension and tends to dissipate some of the dynamic force through movement, similar to a boxer rolling with