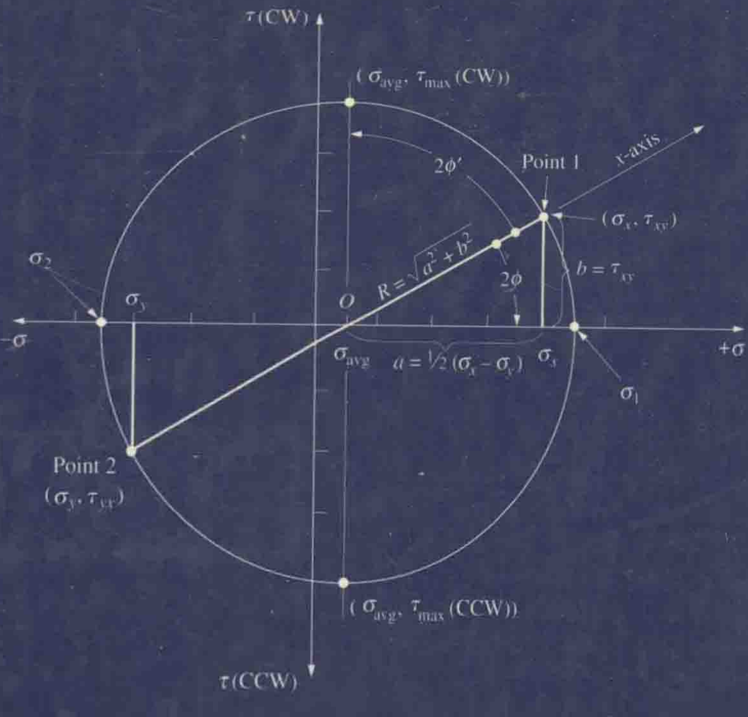
缩编国外精品教材

Applied Strength of Materials

材料力学

[美] Robert L. Mott 著　朱渝春 严　波 缩编



重庆大学出版社

Applied Strength of Materials

材料力学

Robert L. Mott　著

朱渝春　严　波　缩编

重庆大学出版社

Robert L. Mott
Applied Strength of Materials, 4th edition
ISBN: 0-13-088578-9

图书在版编目(CIP)数据

材料力学 = Applied Strength of Materials/(美)莫特(Mott, R. L.)著:朱渝春,严波缩编. —重庆:重庆大学出版社,2004,12
ISBN 7-5624-2884-0

Ⅰ.材… Ⅱ.①莫…②朱…③严… Ⅲ.材料力学—英文 Ⅳ.TB301

中国版本图书馆 CIP 数据核字(2004)第141483号

Applied Strength of Materials
材料力学 Cailiao Lixue
Robert L. Mott 著
朱渝春 严 波 缩编
出版者:重庆大学出版社
社址:重庆市沙坪坝正街174号重庆大学(A区)内
网址:http://www.cqup.com.cn
邮编:400030
电话:(023)65102378 65105781
传真:(023)65103686 65105565
出版人:张鸽盛
责任编辑:周 立
版式设计:方天瞳
责任校对:任卓惠
责任印制:秦 梅
印刷者:重庆升光电力印务有限公司印刷
发行者:全国新华书店经销
开本:787×1092 1/16 **印张**:25.25 **字数**:580千
版次:2005年1月第1版 2005年1月第1次印刷
书号:ISBN 7-5624-2884-0
印数:1—3 000
定价:38.00元

缩编说明

本书是美国新泽西州丹顿大学（University of Dayton）Robert L. Mott 教授所著教材《Applied Strength of Materials（Fourth Edition）》的缩编版。根据我国高等理工院校“材料力学”课程教学的基本要求，原教材被缩编为 14 章，内容包括：材料强度基本概念、材料特性、正应力下的构件设计、轴向变形和热应力、扭转剪应力和扭转变形、梁的剪力和弯矩、截面形心和惯性矩、弯曲应力、梁的剪应力、组合应力的特殊情形、组合应力的一般情形和摩尔圆、梁的挠度、静不定梁、柱。另有附录：优选基本尺寸、螺钉螺纹、标准木梁特性、各种工程材料及型材特性、设计应力准则、各类梁挠度公式及内力图、英制与国际单位制换算因子。

缩编版《材料力学》教材较之原版教材有以下主要不同：

- 缩编版教材篇幅较小，便于学生学习，教师教学。
- 删除了“压力容器”、“连接”两章内容及其他章节中部分内容，使之尽量贴近我国材料力学课程教学大纲。
- 原教材包含大量例题和习题，但为精减篇幅作了较大删减，保留了较具特色及启发性的习题，并重新编号，给出了部分习题答案以便于使用。

此外，缩编教材还保留了原教材的下列主要特色：

- 特别强调材料力学原理在结构构件、机械和系统设计中的应用，注重提高读者解决工程实际问题的能力。
- 每章开头有内容提要，概述全章内容，并引导读者将自己的经验和试验中的发现与本章的新概念联系起来，促进知识的领会和掌握。
- 特别介绍了合成材料的工程实用知识，提供了最新的机械和结构构件设计标准和准则。
- 部分章节后面安排有计算机程序设计作业。

缩编教材中大多数内容采用国际单位制，但也有部分内容采用英制单位。为便于应用，在附录中保留了英制与国际单位制换算因子表。

需特别指出的是，缩编教材采用的是最新的美国和国际设计标准准则，与我国现行设计标准准则有差别。建议在学习及使用中予以足够的注意。

为使读者对原教材能有更全面的了解，保留了原书作者序。

使用本教材的教师，可利用书末的教学支持说明向培生教育出版集团北京办事处索取相关的教学资料和课件。

本教材不仅注意材料力学知识的阐述，更注重提高读者解决工程实际问题的能力。实用性强，语言流畅，通俗易懂，是一本材料力学课程双语教学的优秀教材，适用于力学、机械、土木、电气、动力、材料等类专业材料力学课程双语教学，还可供广大工程技术人员参考使用。

由于学识及时间有限，缩编教材仍有欠妥及疏漏之处，诚望读者不吝赐教。

朱渝春　严　波

2005 年 1 月

Table of Contents

Chapter 1 Basic Concepts in Strength of Materials

The Big Picture

Basic Concepts in Strength of Materials
Discussion Map

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

Discover

Think about products, machines, and structures that you are familiar with that contain components that must carry loads safely. For each device that you think of, write down the following information:
The basic function or purpose of the device.
The description and sketches of its primary components, particularly those that are subjected to significant forces.
The material from which each component is made. Is it a metal or plastic? What kind of metal? What kind of plastic? Is it some other material?
How is each component supported within the product, machine, or structure?
How are forces applied to the component?
What would be the consequence if the component broke?
How much deformation would cause the component to be incapable of performing its desired function?
Consider products around your home; parts of your bicycle, car, or motorcycle; buildings; toys; amusement park rides; aircraft and space vehicles; ships; manufacturing machinery; construction equipment; agricultural machinery; and others.
Discuss these products and systems with your colleagues and with your course instructor or facilitator.

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

1. In your home, the floors must be strong and stiff to support the loads due to people, furniture, and appliances. A typical floor is comprised of a series of joists that are supported on walls or beams, a subfloor on top of the joists, and the finished floor. These elements act together to provide a rigid support system. Pitched roofs employ trusses to span long distances between support walls and to provide the support for the roof sheathing and shingles while remaining fairly lightweight and using materials efficiently. Chairs and tables must be designed to support people and other materials safely and stably. Even in the refrigerator, the shelves must

be designed to support heavy milk and juice jugs while being lightweight and allowing the free movement of cooled air over the food. In the garage, you might have a step ladder, a garage door opener, a lawn mower, and shovels, all of which carry forces when they are used. What other examples can you find around the home?

2. Your bicycle has a frame to which the forks, crank, and wheels are attached. The seat support and handlebars also connect to the frame. Pedals take the forces from your feet and cause a torque to be applied to the crank that in turn drives the chain through sprockets, eventually driving the real wheel. The gear shift and brake actuation linkages have numerous levers, links, and pins that transmit the forces from your hands to do important tasks. The wheels and their axles must be designed to be strong and stiff and to resist repeated force applications.
3. An automobile contains hundreds of mechanical parts that support, latch, and move critical systems. Starting by opening the door, you engage the door latch mechanism. When you close the door, the latch re-engages, keeping the door safely closed. You insert the key and turn the ignition causing the starter to turn the engine until it starts and runs on its own. Inside the engine, the crank, connecting rods, pistons, and valve mechanisms operate in synchronism to provide power to the transmission and then to the drive shaft that delivers power to the wheels. As the car rolls down the road, its suspension elements, shock absorbers, struts, and brakes manage the motion of the chassis and isolate disturbing vibrations from the passenger compartment. Inside the car you may switch on the windshield wipers, adjust your seat position, or open a window. All of these devices must be designed to be safe, strong, stiff, and easy to operate.
4. Take a look at a construction site. A bulldozer or grader is leveling out the land, requiring large forces to be transmitted through its linkages and hydraulic actuators. Cranes lift beams, columns, roof trusses, and other construction materials to elevated floors. Notice the design of the building elements. Backhoes and front-end loaders dig trenches and lift the dirt into dump trucks. Look at their mechanisms. The dump truck itself has a heavy-duty hydraulic cylinder to lift its bed for discharging the load.
5. Aircraft and the space shuttle have efficient structures called monocoque or stressed-skin designs. Many of the loads are carried through the skin of the craft, supported by frames internal to the fuselage and wings. Control of the craft depends on flaps, ailerons, and rudders, all of which must be actuated by hydraulic systems and linkages. The landing gear must take tremendous loads during take-off and touch-down while being able to be stowed neatly inside the body of the craft. In the passenger compartments, floors, seats, seat belt anchors, door hardware, storage bins, racks, and service trays must be designed to be strong, safe, and lightweight.

These are but a few of the many examples of situations where you may use the skills from strength of materials in your career.

This book is organized to present basic stress analysis first, considering direct tension, direct compression, and direct shear. Torsional shear stresses and stresses in beams follow. In each case, you will learn the fundamental principles governing these kinds of stress, how to analyze real load-carrying members for their ability to withstand such stress, and to design the members themselves. Deformations under loads are covered along with the stress analysis.

You will then learn about combined stresses, statically indeterminate beams, columns, pressure vessels, and connections.

Numerous example problems are given in each chapter to demonstrate the approach to solving real analysis and design problems. You should develop a high level of skill in setting up such problems and documenting your solution procedure so that others may understand and evaluate your work.

1-1 OBJECTIVE OF THIS BOOK—TO ENSURE SAFETY

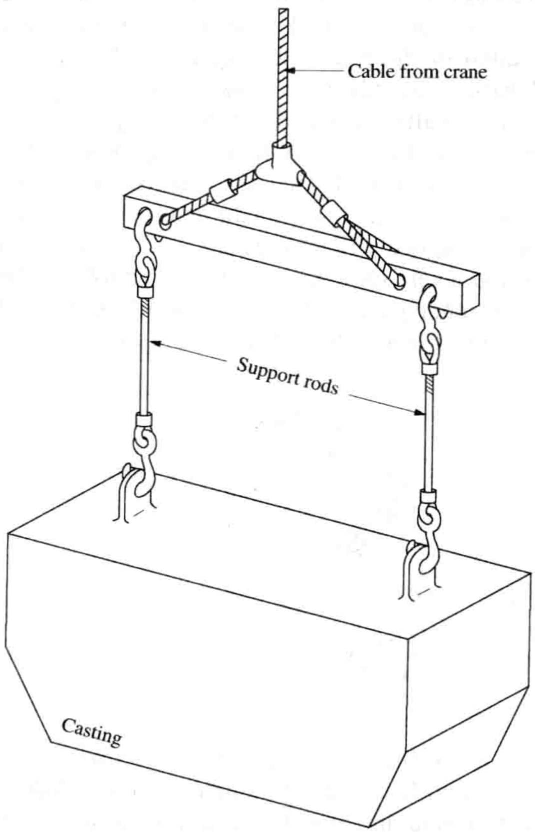
It is essential that any product, machine, or structure be safe and stable under the loads exerted on it during any foreseeable use. The analysis and design of such devices or structures to ensure safety is the primary objective of this book.

Failure of a component of a structure can occur in several ways:

1. The material of the component could fracture completely.
2. The material may deform excessively under load so that the component is no longer suitable for its purpose.
3. The structure could become unstable and buckle, and thus be unable to carry the intended loads.

Examples of these failure modes should help you to understand the importance of your learning the principles of applied strength of materials as presented in this book.

FIGURE 1-1 Two rods supporting a heavy casting.



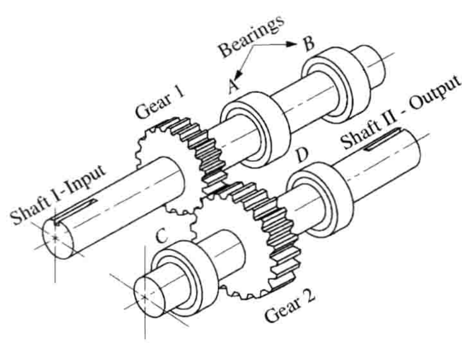
Preventing Failure by Fracture. Figure 1-1 shows two rods carrying a heavy casting. Imagine that you are the person responsible for designing the rods. Certainly you would want to ensure that the rods were sufficiently strong so they will not break and allow the casting to fall, possibly causing great damage or injury to people. As the designer of the rods, what information would you need? What design decisions must you make? Here is a partial list.

1. What is the weight and physical size of the casting?
2. Where is its center of gravity? This is important so you can decide where to place the points of attachment of the rods to the casting.
3. How will the rods be attached to the casting and to the support system at the top?
4. Of what material will the rods be made? What is its strength?
5. What will be the shape and size of the cross section of the rods?
6. How will the load of the casting be initially applied to the rods: slowly, with shock or impact, or with a jerking motion?
7. Will the rods be used for many cycles of loading during their expected life?

Knowing these factors will permit you to design the rods to be safe; that is, so they will not break under the anticipated service conditions. This will be discussed in more detail in Chapters 1 and 3.

Preventing Excessive Deformation. Gears are used in mechanical drives to transmit power in such familiar systems as the transmission of a truck, the drive for a conveyor belt, or the spindle of a machine tool. For proper operation of the gears, it is essential that they are properly aligned so the teeth of the driving gear will mesh smoothly with those of the mating gear. Figure 1-2 shows two shafts carrying gears in mesh. The shafts are supported in bearings that are in turn mounted rigidly in the housing of the transmission. When the gears are transmitting power, forces are developed that tend to push them apart. These forces are resisted by the shafts so that they are loaded as shown in Figure 1-3. The action of the forces perpendicular to the shafts tends to cause them to bend, which would cause the gear teeth to become misaligned. Therefore, the shafts must be designed to keep deflections at the gears to a small, acceptable level. Of course, the shafts must also be designed to be safe under the applied loads. In this type of loading, the shafts are considered to be *beams*. Chapters 8 and 12 discuss the principles of the design of beams for strength and deflection.

FIGURE 1-2 Two shafts carrying gears in mesh.



Stability and Buckling. A structure may collapse because one of its critical support members is unable to hold its shape under applied loads, even though the material does not fail by fracturing. An example is a long, slender post or column subjected to a downward, compressive load. At a certain critical load, the column will *buckle*. That is, it will suddenly bend or bow out, losing its preferred straight shape. When this happens, if the load remains applied, the column will totally collapse.

Figure 1-4 shows a sketch of such a column that is relatively long with a thin rectangular cross section. You can demonstrate the buckling of this type of column using a simple ruler or meter stick. To prevent buckling, you must be able to specify an appropriate material, shape, and size for the cross section of a compression member of a given length so it will remain straight under the expected loads. Chapter 14 presents the analysis and design of columns.

In summary, design and analysis, using the principles of strength of materials, are required to ensure that a component is safe with regard to *strength*, *rigidity* and *stability*. It is the objective of this book to help you gain the ability to design and analyze load-carrying components of structures and machines that will be safe and suitable for their intended functions.

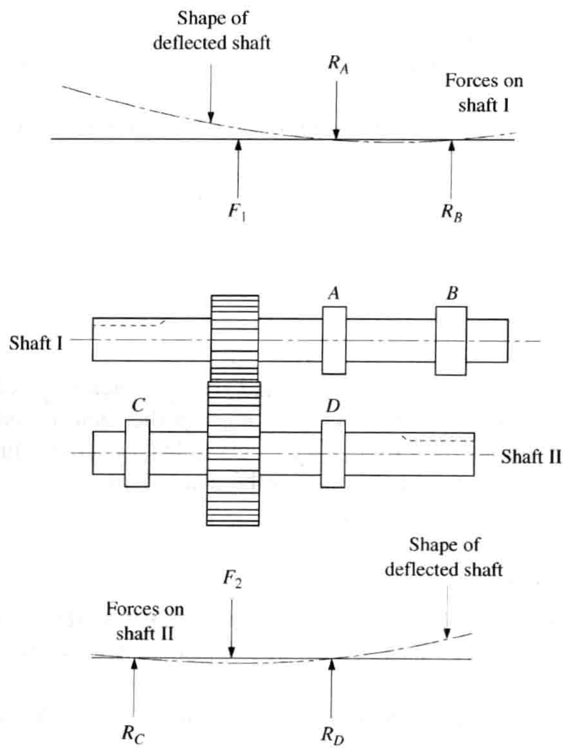


FIGURE 1-3 Forces on shafts I and II of Figure 1-2 with resulting deflection of shafts.

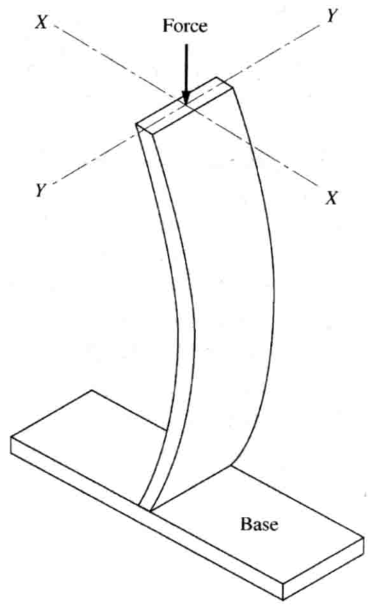


FIGURE 1-4 A slender column in compression, illustrating elastic instability or buckling.

1-2 OBJECTIVES OF THIS CHAPTER

In this chapter we present the basic concepts in strength of materials that will be expanded on in later chapters. After completing this chapter, you should be able to:

1. Use correct units for the quantities encountered in the study of strength of materials in both the SI metric unit system and the U. S. Customary unit system.

2. Use the terms *mass* and *weight* correctly and be able to compute the value of one when the value of the other is given.
3. Define *stress*.
4. Define *direct normal stress* and compute the value of this type of stress for both tension and compression loading.
5. Define *direct shear stress* and compute its value.
6. Identify conditions in which a load-carrying member is in *single shear* or *double shear*.
7. Draw *stress elements* showing the normal and shear stresses acting at a point in a load-carrying member.
8. Define *bearing stress* and compute its value.
9. Define *normal strain* and *shearing strain*.
10. Define *Poisson's ratio* and give its value for typical materials used in mechanical and structural design.
11. Recognize standard structural shapes and standard screw threads and use data concerning them.
12. Define *modulus of elasticity in tension*.
13. Define *modulus of elasticity in shear*.
14. Understand the responsibilities of designers.

1-3 PROBLEM-SOLVING PROCEDURE

The study of strength of materials and the practice of stress analysis and design inherently require problem solving. It is important for you to establish good habits of organization in the method used to solve problems and for reporting them in a clear attractive format. This will help you communicate your solution to others and when you need to refer back to a previously solved problem.

The example problems in this book require the following procedure:

a. The original statement of the problem is given.
b. Restate the primary objective of the problem.
c. Give a summary of the pertinent information and data. This is useful to help you decide what is known and what is to be found. It also serves as a convenient place to find data when needed later in the problem solution.
d. Write a general statement of the analysis technique to be used to solve the problem. State any assumptions here also.
e. Complete a detailed development of the results with all of the equations used, the insertion of the values for pertinent data, and the manipulation of units for the results. Conversion factors may be required to produce the final result in appropriate units.
f. Calculate the value of all expected results. In this book, we typically report results with three computed digits of precision and appropriate units. A greater precision is carried through the problem and rounding is done at the end. We consider all given data to be exact.
g. Comment on the solution to clarify details and to critically review the problem. Is the result reasonable? Are there alternative analysis techniques that could have been used? Are there additional analyses that would be desirable to ensure a more robust solution? If it is a design problem, specify a convenient size for key dimensions, a standard shape for the load-carrying member, or a suitable material from which to make the member.

1-4 BASIC UNIT SYSTEMS

Computations required in the application of strength of materials involve the manipulation of several sets of units in equations. For numerical accuracy it is of great importance to ensure that consistent units are used in the equations. Throughout this book units will be carried with the applicable numbers.

Because of the present transition in the United States from the traditional U. S. Customary units to metric units, both are used in this book. It is expected that persons entering or continuing an industrial career within the next several years will be faced with having to be familiar with both systems. On the one hand, many new products such as automobiles and business machines are being built using metric dimensions. Thus components and manufacturing equipment will be specified in those units. However, the transition is not being made uniformly in all areas. Designers will continue to deal with such items as structural steel, aluminum, and wood whose properties and dimensions are given in English units in standard references. Also, designers, sales and service people, and those in manufacturing must work with equipment that has already been installed and that was made to U. S. Customary system dimensions. Therefore, it seems logical that persons now working in industry should be capable of working and thinking in both systems.

The formal name for the U. S. Customary unit system is the English Gravitational Unit System (EGU). The metric system, which has been adopted internationally, is called by the French name Systéme International d'Unités, the International System of Units, abbreviated SI in this book.

In most cases, the problems in this book are worked either in the U. S. Customary unit system or the SI system rather than mixing units. In problems for which data are given in both unit systems, it is most desirable to change all data to the same system before completing the problem solution. Appendix A-24 gives conversion factors for use in performing conversions.

TABLE 1-1 Basic quantities in the SI metric unit system.

Quantity	SI unit	Other metric units
Length	meter(m)	millimeter(mm)
Time	second(s)	minute(min), hour(h)
Force	newton(N)	$kg \cdot m/s^2$
Mass	kilogram(kg)	$N \cdot s^2/m$
Temperature	kelvin(K)	degrees Celsius(℃)
Angle	radian(rad)	degree(deg)

TABLE 1-2 Basic quantities in the U. S. Customary unit system.

Quantity	U. S. Customary unit	Other U. S. units
Length	foot(ft)	inch(in)
Time	second(s)	minute(min), hour(h)
Force	pound(lb)	kip*
Mass	slug	$lb \cdot s^2/ft$
Temperature	degrees Fahrenheit(°F)	
Angle	degree(deg)	radian(rad)

*1.0 kip = 1000 pounds. The name is derived from the term *kilopound*.

The basic quantities for any unit system are length, time, force, mass, temperature, and angle.

Table 1-1 lists the units for these quantities in the SI unit system, and Table 1-2 lists the quantities in the U. S. Customary unit system.

Prefixes for SI Units. In the SI system, prefixes should be used to indicate orders of magnitude, thus eliminating digits and providing a convenient substitute for writing powers of 10, as generally preferred for computation. Prefixes representing steps of 1000 are recommended. Those usually encountered in strength of materials are listed in Table 1-3. Table 1-4 shows how computed results should be converted to the use of the standard prefixes for units.

TABLE 1-3 Prefixes for SI units.

Prefix	SI symbol	Factor
giga	G	$10^9 = 1000000000$
mega	M	$10^6 = 1000000$
kilo	k	$10^3 = 1000$
milli	m	$10^{-3} = 0.001$
micro	μ	$10^{-6} = 0.000001$

p 10^{-12}

TABLE 1-4 Proper method of reporting computed quantities.

Computed result	Reported result
0.00548 m	5.48×10^{-3} m, or 5.48 mm
12750 N	12.75×10^3 N, or 12.75 kN
34500 kg	34.5×10^3 kg, or 34.5 Mg (megagrams)

1-5 RELATIONSHIP AMONG MASS, FORCE, AND WEIGHT

Force and mass are separate and distinct quantities. Weight is a special kind of force.

Mass refers to the amount of the substance in a body.

Force is a push or pull effort exerted on a body either by an external source or by gravity.

Weight is the force of gravitational pull on a body.

Mass, force, and weight are related by Newton's law:

$$\text{force} = \text{mass} \times \text{acceleration}$$

We often use the symbols F for force, m for mass, and a for acceleration. Then,

$$F = m \times a \quad \text{or} \quad m = F/a$$

When the pull of gravity is involved in the calculation of the weight of a mass, a takes the value of g, the acceleration due to gravity. Then, using W for weight,

⇨ Weight-Mass Relationship

$$W = m \times g \quad \text{or} \quad m = W/g \tag{1-1}$$

We will use the following values for g:

SI units: $g = 9.81\ \text{m/s}^2$ U. S. units: $g = 32.2\ \text{ft/s}^2$

Units for Mass, Force, and Weight. Tables 1-1 and 1-2 show the preferred units and some other convenient units for mass and force in both the SI and U. S. unit systems. The units for force are also used as the units for weight.

The newton (N) in the SI unit system is named in honor of Sir Isaac Newton and it represents the amount of force required to give a mass of 1.0 kg an acceleration of 1.0 m/s^2. Equivalent units for the newton can be derived as follows using Newton's law with units only:

$$F = m \times a = \text{kg}\cdot\text{m/s}^2 = \text{newton}$$

In the U. S. Customary unit system, the unit for force is defined to be the pound, while the unit of mass (slug) is derived from Newton's law as follows:

$$m = \frac{F}{a} = \frac{\text{lb}}{\text{ft/s}^2} = \frac{\text{lb}\cdot\text{s}^2}{\text{ft}} = \text{slug}$$

The conversion of weight and mass is illustrated in the following example problems.

Example Problem 1-1 (SI system)

A hoist lifts 425 kg of concrete. Compute the weight of the concrete that is the force exerted on the hoist by the concrete.

Solution Objective: Compute the weight of a mass of concrete.

Given: $m = 425$ kg

Analysis: $W = m \times g$; $g = 9.81\ \text{m/s}^2$

Results: $W = 425\ \text{kg} \times 9.81\ \text{m/s}^2 = 4170\ \text{kg}\cdot\text{m/s}^2 = 4170\ \text{N}$

Comment: Thus 425 kg of concrete weighs 4170 N.

Example Problem 1-2 (U. S. system)

A hopper of coal weighs 8500 lb. Determine its mass.

Solution Objective: Compute the mass of a hopper of coal.

Given: $W = 8500$ lb

Analysis: $m = W/g$; $g = 32.2\ \text{ft/s}^2$

Results: $m = 8500\ \text{lb}/32.2\ \text{ft/s}^2 = 264\ \text{lb}\cdot\text{s}^2/\text{ft} = 264$ slugs

Comment: Thus 8500 lb of coal has a mass of 264 slugs.

Density and Specific Weight. To characterize the mass or weight of a material relative to its volume, we use the terms *density* and *specific weight*, defined as follows:

Density is the amount of mass per unit volume of a material.
Specific weight is the amount of weight per unit volume of a material.

We will use the Greek letter ρ (rho) as the symbol for density. For specific weight we will use γ (gamma).

The units for density and specific weight are summarized in Table 1-5. Other conventions are sometimes used, often leading to confusion. For example, in the United States, density is occasionally expressed in lb/ft^3 or lb/in^3. Two interpretations are used for this. One is that the term implies *weight density* with the same meaning as specific weight. Another is that the quantity *lb* is meant to be *pound mass* rather than *pound weight*, and the two have equal numerical values when g is the standard value.