Mc Graw Hill Education

Mechanics of Materials

Fourth Edition in SI Units

材料力学（第4版）

英文缩编版

（美）Ferdinand P. Beer 等编著
张燕 王红囡 彭丽 改编

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前　　言

近年来，国家教育部出台的一系列倡导高等院校开展双语教学、引进原版教材的政策，对于加快我国高等教育改革的步伐，培养具有国际竞争力的高水平技术人才，发挥了积极的促进作用。材料力学也引进了多个版本的英文原版教材，但由于教育体制和教学模式的差异，一时还很难直接用于我国目前的课程教学。缩编和改编是把优秀原版教材引入双语教学的桥梁。我们在开展材料力学双语教学的过程中，针对本专业的特点，尝试在国外优秀教材基础上精选其主体内容并进行适当缩编的方式，取得了较好的效果。通过几年的教学实践我们体会到，缩编的原版教材有内容贴近教学和语言原汁原味等特点，适于教学。

由 Ferdinand P. Beer 等编写的 *Mechanics of Materials*（*Fourth Edition in SI Units*）采用以应力为铺路石，以构件变形为主线的体系，符合国内教学改革的主流方向。教材结构清晰、论述严谨、图文并茂，同时还附有少量计算题目。该教材将杆件设计概念贯穿全书，广泛采用三维插图，有助于揭示力学原理、贴近工程实际以及培养学生分析问题、解决问题的能力。书中每章都分别针对基本概念和原理设置多个“Examples and Sample Problems”和“Homework Problem Sets”，每章后面还设有“Chapter Review and Summary”、“Review Problems”和“Computer Problems”，具有突出“三基”，循序渐进，由简到繁的特色。教材中一些专题性的内容是独立的，便于删减。

经过认真对比研究，我们选择了该书作为基础进行缩编。缩编后的教材保留了原版教材的特色，同时结合国内双语教学的需要适当地删减了一些内容，如去掉了塑性变形（除轴向拉伸与压缩变形以外）等国内材料力学教材都不讲授或很少讲授的内容，精选了部分例题、习题讲解和习题等。

缩编工作由上海师范大学建筑工程学院工程力学部张燕主持。其中张燕改编第 4 章、第 9 章、第 10 章和全书的习题；王红囡改编第 5～8 章和附录，并负责全书统稿工作；彭丽改编第 1～3 章内容。特别感谢赵一鸣同学为教材录入和排版所做的大量工作，以及缩编教材的倡导人王增忠副院长对于本工作给予的大力支持。查珑珑老师也对本书作出了贡献。

本教材适合于机械类和土木类等专业的本科生70~90学时的材料力学双语教学,不足70学时应酌情删减。由于时间和编者的水平限制,书中难免疏误,敬请读者批评指正。

编　者

2008年5月于上海

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List of Symbols

a	Constant; distance
$\mathbf{A}, \mathbf{B}, \mathbf{C}, \ldots$	Forces; reactions
$A, B, C, \ldots$	Points
$A, \mathcal{A}$	Area
b	Distance; width
c	Constant; distance; radius
C	Centroid
$C_1, C_2, \ldots$	Constants of integration
C_P	Column stability factor
d	Distance; diameter; depth
D	Diameter
e	Distance; eccentricity; dilatation
E	Modulus of elasticity
f	Frequency; function
$\mathbf{F}$	Force
$F.S.$	Factor of safety
G	Modulus of rigidity; shear modulus
h	Distance; height
$\mathbf{H}$	Force
H, J, K	Points
$I, I_x, \ldots$	Moment of inertia
$I_{xy}, \ldots$	Product of inertia
J	Polar moment of inertia
k	Spring constant; shape factor; bulk modulus; constant
K	Stress concentration factor; torsional spring constant
l	Length; span
L	Length; span
L_e	Effective length
m	Mass
$\mathbf{M}$	Couple
$M, M_x, \ldots$	Bending moment
M_D	Bending moment, dead load (LRFD)
M_L	Bending moment, live load (LRFD)
M_U	Bending moment, ultimate load (LRFD)
n	Number; ratio of moduli of elasticity; normal direction
p	Pressure
$\mathbf{P}$	Force; concentrated load
P_D	Dead load (LRFD)
P_L	Live load (LRFD)
P_U	Ultimate load (LRFD)
q	Shearing force per unit length; shear flow
$\mathbf{Q}$	Force
Q	First moment of area
r	Radius; radius of gyration
$\mathbf{R}$	Force; reaction
R	Radius; modulus of rupture
s	Length
S	Elastic section modulus
t	Thickness; distance; tangential deviation
$\mathbf{T}$	Torque
T	Temperature
u, v	Rectangular coordinates
u	Strain-energy density
U	Strain energy; work
$\mathbf{v}$	Velocity
$\mathbf{V}$	Shearing force
V	Volume; shear
w	Width; distance; load per unit length
$\mathbf{W}, W$	Weight, load
x, y, z	Rectangular coordinates; distance; displacements; deflections
$\bar{x}, \bar{y}, \bar{z}$	Coordinates of centroid
Z	Plastic section modulus
α, β, γ	Angles
α	Coefficient of thermal expansion; influence coefficient
γ	Shearing strain; specific weight
γ_D	Load factor, dead load (LRFD)
γ_L	Load factor, live load (LRFD)
δ	Deformation; displacement
ϵ	Normal strain
θ	Angle; slope
λ	Direction cosine
ν	Poisson's ratio
ρ	Radius of curvature; distance; density
σ	Normal stress
τ	Shearing stress
ϕ	Angle; angle of twist; resistance factor
ω	Angular velocity

CHAPTER

1

Introduction—Concept of Stress

This chapter is devoted to the study of the stresses occurring in many of the elements contained in this excavator, such as two-force members, axles, bolts, and pins.

1.1. Introduction

The main objective of the study of the mechanics of materials is to provide the future engineer with the means of analyzing and designing various machines and load-bearing structures.

Both the analysis and the design of a given structure involve the determination of *stresses* and *deformations*. This first chapter is devoted to the concept of *stress*.

Section 1.2 will introduce you to the concept of *stress* in a member of a structure, and you will be shown how that stress can be determined from the *force* in the member. After a short discussion of engineering analysis and design (Sec. 1.3), you will consider successively the *normal stresses* in a member under axial loading (Sec. 1.4), the *shearing stresses* caused by the application of equal and opposite transverse forces (Sec. 1.5), and the *bearing stresses* created by bolts and pins in the members they connect (Sec. 1.6). These various concepts will be applied in Sec. 1.7 to the determination of the stresses in the members of the simple structure considered earlier in Sec. 1.3.

In Sec. 1.8, where a two-force member under axial loading is considered again, it will be observed that the stresses on an *oblique* plane include both *normal* and *shearing* stresses, while in Sec. 1.9 you will note that *six components* are required to describe the state of stress at a point in a body under the most general loading conditions.

Finally, Sec. 1.10 will be devoted to the determination from test specimens of the *ultimate strength* of a given material and to the use of a *factor of safety* in the computation of the *allowable load* for a structural component made of that material.

1.2. Stresses in the Members of a Structure

The force per unit area, or intensity of the forces distributed over a given section, is called the *stress* on that section and is denoted by the Greek letter σ (sigma). The stress in a member of cross-sectional area A subjected to an axial load **P** (Fig. 1.1) is therefore obtained by dividing the magnitude P of the load by the area A:

$$\sigma = \frac{P}{A} \tag{1.1}$$

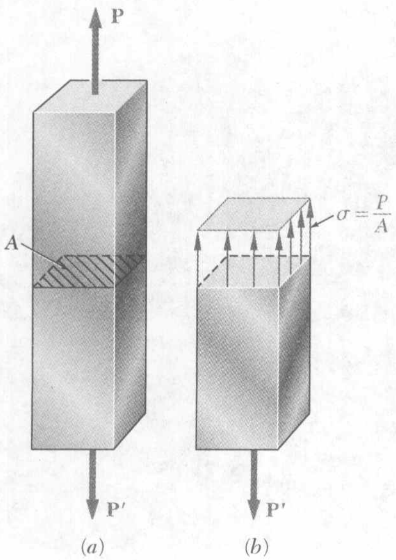

Fig. 1.1

A positive sign will be used to indicate a tensile stress (member in tension) and a negative sign to indicate a compressive stress (member in compression).

With P expressed in newtons (N) and A in square meters (m^2), the stress σ will be expressed in N/m^2. This unit is called a *pascal* (Pa). However, one finds that the pascal is an exceedingly small quantity and that, in practice, multiples of this unit must be used, namely, the kilopascal (kPa), the megapascal (MPa), and the gigapascal (GPa). We have

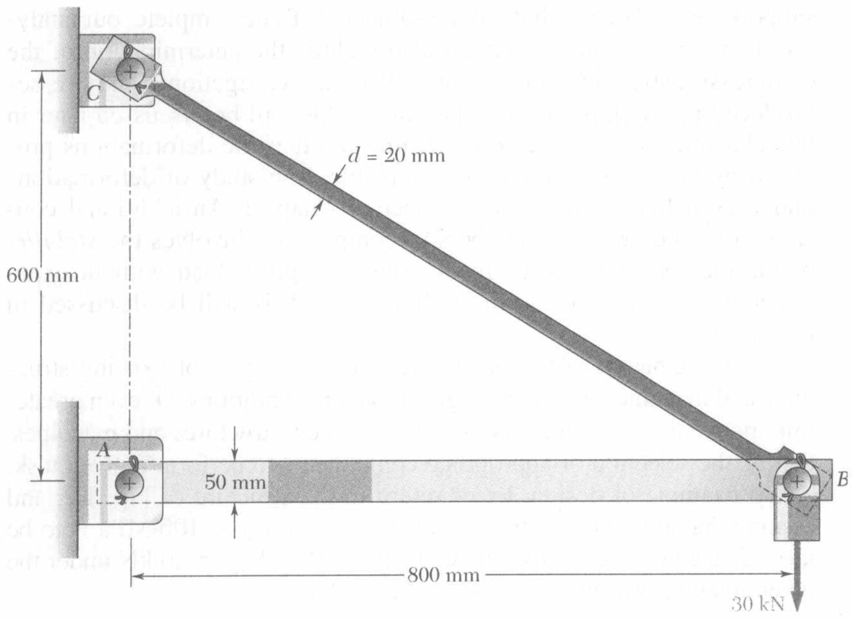

Fig. 1.2

$$1 \text{ kPa} = 10^3 \text{ Pa} = 10^3 \text{ N/m}^2$$

$$1 \text{ MPa} = 10^6 \text{ Pa} = 10^6 \text{ N/m}^2$$

$$1 \text{ GPa} = 10^9 \text{ Pa} = 10^9 \text{ N/m}^2$$

1.3. Analysis and Design

Considering the structure of Fig. 1.2, let us assume that rod BC is made of a steel with a maximum allowable stress $\sigma_{\text{all}} = 165$ MPa. Can rod BC safely support the load to which it will be subjected? The magnitude of the force F_{BC} in the rod was found earlier to be 50 kN. knowing that the diameter of the rod is 20 mm, we use Eq. (1.1) to determine the stress created in the rod by the given loading. We have

$$P = F_{BC} = +50 \text{ kN} = +50 \times 10^3 \text{ N}$$

$$A = \pi r^2 = \pi \left(\frac{20 \text{ mm}}{2}\right)^2 = \pi(10 \times 10^{-3} \text{ m})^2 = 314 \times 10^{-6} \text{ m}^2$$

$$\sigma = \frac{P}{A} = \frac{+50 \times 10^3 \text{ N}}{314 \times 10^{-6} \text{ m}^2} = +159 \times 10^6 \text{ Pa} = +159 \text{ MPa}$$

Since the value obtained for σ is smaller than the value σ_{all} of the allowable stress in the steel used, we conclude that rod BC can safely support the load to which it will be subjected. To be complete, our analysis of the given structure should also include the determination of the compressive stress in boom AB, as well as an investigation of the stresses produced in the pins and their bearings. This will be discussed later in this chapter. We should also determine whether the deformations produced by the given loading are acceptable. The study of deformations under axial loads will be the subject of Chap. 2. An additional consideration, required for members in compression involves the *stability* of the member, i.e., its ability to support a given load without experiencing a sudden change in configuration. This will be discussed in Chap. 10.

The engineer's role is not limited to the analysis of existing structures and machines subjected to given loading conditions. Of even greater importance to the engineer is the *design* of new structures and machines, that is, the selection of appropriate components to perform a given task. As an example of design, let us return to the structure of Fig. 1.2, and assume that aluminum with an allowable stress $\sigma_{\text{all}} = 100$ MPa is to be used. Since the force in rod BC will still be $P = F_{BC} = 50$ kN under the given loading, we must have, from Eq. (1.1),

$$\sigma_{\text{all}} = \frac{P}{A} \qquad A = \frac{P}{\sigma_{\text{all}}} = \frac{50 \times 10^3 \text{ N}}{100 \times 10^6 \text{ Pa}} = 500 \times 10^{-6} \text{ m}^2$$

and, since $A = \pi r^2$,

$$r = \sqrt{\frac{A}{\pi}} = \sqrt{\frac{500 \times 10^{-6} \text{ m}^2}{\pi}} = 12.62 \times 10^{-3} \text{ m} = 12.62 \text{ mm}$$

$$d = 2r = 25.2 \text{ mm}$$

We conclude that an aluminum rod 26 mm or more in diameter will be adequate.

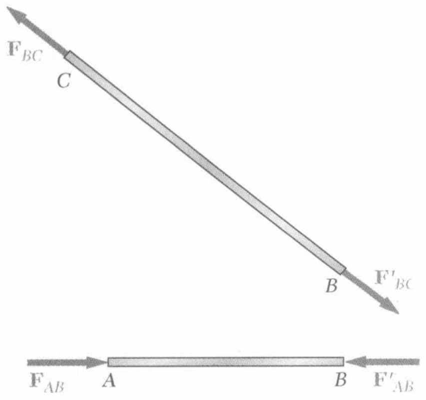

Fig. 1.3

1.4. Axial Loading; Normal Stress

As we have already indicated, rod BC of the example considered in the preceding section is a two-force member and, therefore, the forces $\mathbf{F}_{BC}$ and $\mathbf{F}'_{BC}$ acting on its ends B and C (Fig. 1.3) are directed along the axis of the rod. We say that the rod is under *axial loading*. An actual example of structural members under axial loading is provided by the members of the bridge truss shown in Fig. 1.4.

Returning to rod BC of Fig. 1.3, we recall that the section we passed through the rod to determine the internal force in the rod and the corresponding stress was perpendicular to the axis of the rod; the internal force was therefore normal to the plane of the section (Fig. 1.5) and the corresponding stress is described as a *normal stress*. Thus, formula (1.1) gives us the *normal stress in a member under axial loading*:

$$\sigma = \frac{P}{A} \tag{1.1}$$

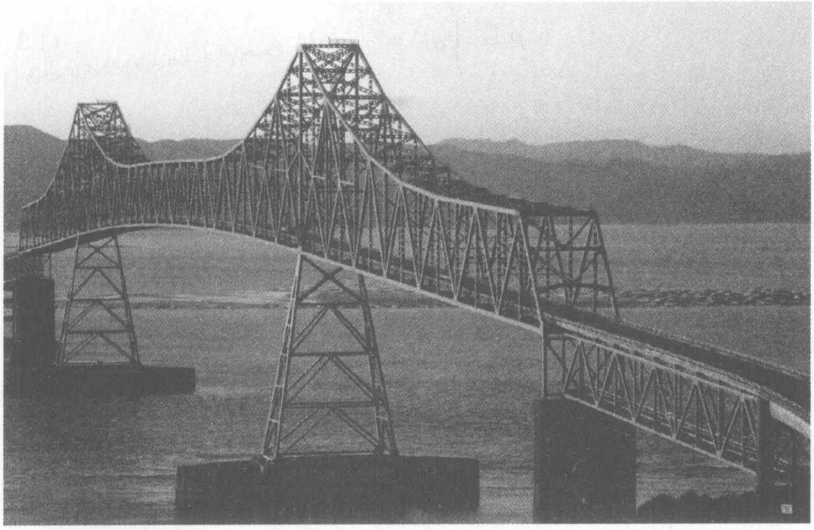

Fig. 1.4 This bridge truss consists of two-force members that may be in tension or in compression.

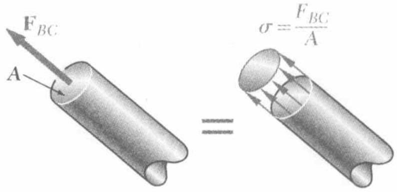

Fig. 1.5

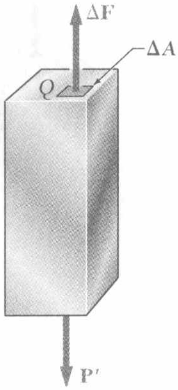

Fig. 1.6

We should also note that, in formula (1.1), σ is obtained by dividing the magnitude P of the resultant of the internal forces distributed over the cross section by the area A of the cross section; it represents, therefore, the *average value* of the stress over the cross section, rather than the stress at a specific point of the cross section.

To define the stress at a given point Q of the cross section, we should consider a small area ΔA (Fig. 1.6). Dividing the magnitude of $\Delta \mathbf{F}$ by ΔA, we obtain the average value of the stress over ΔA. Letting ΔA approach zero, we obtain the stress at point Q:

$$\sigma = \lim_{\Delta A \to 0} \frac{\Delta F}{\Delta A} \tag{1.2}$$

In general, the value obtained for the stress σ at a given point Q of the section is different from the value of the average stress given by formula (1.1), and σ is found to vary across the section. In a slender rod subjected to equal and opposite concentrated loads $\mathbf{P}$ and $\mathbf{P}'$ (Fig. 1.7a), this variation is small in a section away from the points of application of the concentrated loads (Fig. 1.7c), but it is quite noticeable in the neighborhood of these points (Fig. 1.7b and d).

It follows from Eq. (1.2) that the magnitude of the resultant of the distributed internal forces is

$$\int dF = \int_A \sigma \, dA$$

But the conditions of equilibrium of each of the portions of rod shown in Fig. 1.7 require that this magnitude be equal to the magnitude P of the concentrated loads. We have, therefore,

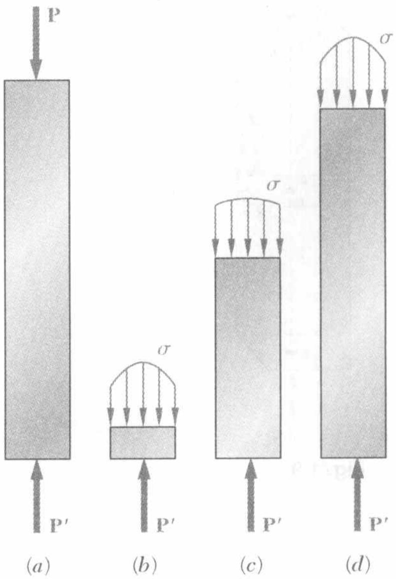

Fig. 1.7