"十三五"江苏省高等学校重点教材
飞行器设计与工程力学品牌专业系列教材
江苏高校品牌专业建设工程资助项目

Mechanics of Materials
材料力学（双语版）

王开福 编著

科学出版社

“十三五”江苏省高等学校重点教材（编号：2016-1-117）
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内 容 简 介

This book is a bilingual textbook for mechanics of materials, written independently in English and Chinese, respectively. The main contents of the book include mechanics of materials fundamentals, axial tension and compression, torsion, bending internal forces, bending stresses, bending deformation, stress analysis and strength theories, combined loadings, stability of column, unsymmetrical bending, energy methods, impact loading, statically indeterminate structures, etc.

The book can be used as a bilingual textbook for mechanics of materials for engineering students majoring in aeronautical, mechanical, civil engineering, etc.

本书是材料力学双语教材，分别由英文和中文独立编写。本书主要内容包括材料力学基础、轴向拉伸与压缩、扭转、弯曲内力、弯曲应力、弯曲变形、应力分析与强度理论、组合载荷、压杆稳定、非对称弯曲、能量方法、冲击载荷和静不定结构等。

本书可作为航空航天工程、机械工程和土木工程等工科专业本科生的材料力学双语教材。

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Preface

"Mechanics of materials" is a required subject for engineering students majoring in aeronautical, mechanical and civil engineering, and it is usually taught during the sophomore year. This book is intended to provide these students with the theory and application of mechanics of materials, and mainly includes the analysis and design of strength, rigidity, and stability of a bar in axial tension or compression, a shaft in torsion, and a beam in bending.

The book is organized into 13 chapters and 3 appendixes. Chapter 1 introduces the fundamental concepts often used in mechanics of materials, such as internal forces, stresses, strains, etc., and the tensile and compressive properties of ductile and brittle materials subjected to axial loads. In Chapter 2 the normal and shearing stresses in a bar subjected to axial loads are analyzed, and the deformation of an axially loaded bar is also analyzed in this chapter. The normal and shearing stresses produced in a shaft in torsion, together with the angle of twist of the shaft, are discussed in Chapter 3. The shearing force and bending moment, normal and shearing stresses, and deflection and slope of a beam in pure or transverse-force bending are analyzed, respectively, in Chapters 4, 5 and 6. Chapter 7 mainly covers stress analysis, such as stress transformation, principal stress, maximum shearing stress, etc., and strength theories, including the maximum normal stress, normal strain, shearing stress and distortion energy criteria. Chapter 8 analyzes the stress of a member subjected to combined loadings, such as a bar in eccentric tension or compression, a beam in bending and tension/compression, a shaft in torsion and bending, etc. The stability of a column subjected to a centric compressive load is discussed in Chapter 9, including analysis of the critical loading and critical stress for a long or an intermediate column. The unsymmetrical pure bending, along with the unsymmetrical transverse-force bending, is covered in Chapter 10. The main energy methods including the principle of work and energy, reciprocal theorem, Castigliano's theorem, principle of virtual work, unit load method, etc., are presented in Chapter 11. Chapter 12 analyzes the vertical and horizontal impact of a member. The force method used for solving a statically indeterminate structure is presented in Chapter 13.

Kaifu WANG

Nanjing, June 2018

前　　言

“材料力学”是航空航天工程、机械工程和土木工程等工科专业本科生的必修课，通常在大二学年讲授。本书主要讲述材料力学的理论及其应用，内容包括拉压杆、扭转轴、弯曲梁的强度、刚度和稳定分析与设计等。

本书共 13 章。第 1 章介绍材料力学常用基本概念，如内力、应力和应变等，以及轴向载荷作用下塑性和脆性材料的拉压性能。第 2 章分析轴向拉压杆正应力和剪应力，同时分析轴向拉压变形。第 3 章讨论扭转轴正应力、剪应力以及扭转角。第 4～6 章分别讨论纯弯曲梁和横力弯曲梁的剪力与弯矩、正应力与剪应力、挠度与转角。第 7 章主要讨论应力分析，如应力变换、主应力和最大剪应力等，同时涉及强度理论，包括最大正应力准则、最大线应变准则、最大剪应力准则和最大畸变能准则。第 8 章分析组合载荷作用构件的应力，如偏心拉压杆、拉压弯曲梁和弯曲扭转轴等。第 9 章讨论压杆稳定，包括分析细长压杆和中长压杆的临界载荷和临界应力。第 10 章涉及非对称纯弯曲以及非对称横力弯曲。第 11 章介绍主要的能量方法，包括功能原理、互等定理、卡氏定理、虚功原理和单位载荷法等。第 12 章分析构件的垂直和水平冲击。第 13 章介绍力法，用于求解静不定结构。

王开福

2018 年 6 月于南京

Contents

目 录

Chapter 1 Mechanics of Materials Fundamentals

In theoretical mechanics, bodies are assumed to be perfectly rigid. The deformations of bodies are important, however, as far as the resistance of the structures and machines to failure is concerned. Therefore, the bodies in mechanics of materials will no longer be assumed to be perfectly rigid as considered in theoretical mechanics.

Mechanics of materials studies the ability of structures and machines to resist failure, and mainly involves the following tasks: ① strength, i.e., the ability of members to support a specified load without experiencing excessive stresses; ② rigidity, i.e., the ability of members to support a specified load without undergoing unacceptable deformations; ③ stability, i.e., the ability of members to support a specified axial compressive load without causing a sudden lateral deflection.

Any material dealt with in mechanics of materials is assumed to be: ① continuous, i.e., the material consists of a continuous distribution of matter without voids; ② homogeneous, i.e., the material possesses the same mechanical properties at all points in the matter; ③ isotropic, i.e., the material has the same mechanical properties in all directions at any one point of the matter.

The strength and rigidity of a material depend on its abilities to support a specified load without experiencing both excessive stresses and unacceptable deformations. These abilities are inherent in the material itself and must be determined by experimental methods. One of the most important tests to determine the mechanical properties of a material is the tensile or compressive test. This test is often used to determine the stress-strain relation of the material used.

1.1 External Forces

Any external force applied to a body can be classified as either a surface force or a body force.

1. Surface Force

An external force that is applied to the surface of a body is called a surface force.

If the surface force is distributed over a finite area of the body, it is said to be a distributed load on a surface, Fig. 1.1(a). If the surface force is applied along a narrow area, this force is defined as a distributed load along a line, Fig. 1.1(b). If the area subjected to a surface force is very small, compared with the surface area of the body, then this surface force can be regarded as a concentrated load, Fig. 1.1(c).

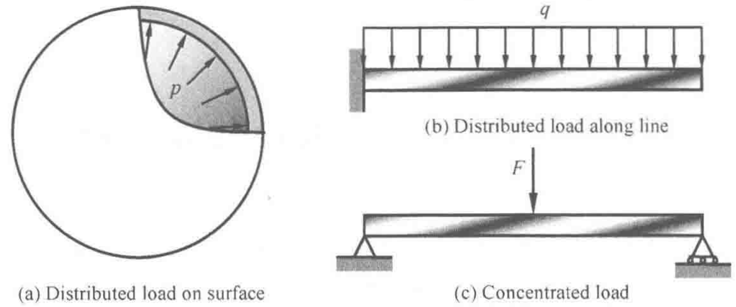

Fig. 1.1

2. Body Force

An external force that is applied to every point within a body is called a body force. A gravitational force is an excellent example of the body force since it acts upon each of the particles forming the body.

1.2 Internal Forces

When various external loads are applied to a member, the corresponding distributed internal forces will be developed at any point within the member. The distributed internal forces on any section within the member can be determined by using the method of sections.

We imagine to use a plane Π, Fig. 1.2(a), to section the member where the distributed internal forces need to be determined. For determination of the distributed internal forces on the cut plane, the portion of the member to the right of the cut plane is removed, and it is replaced by the distributed internal forces acting on the left portion, Fig. 1.2(b).

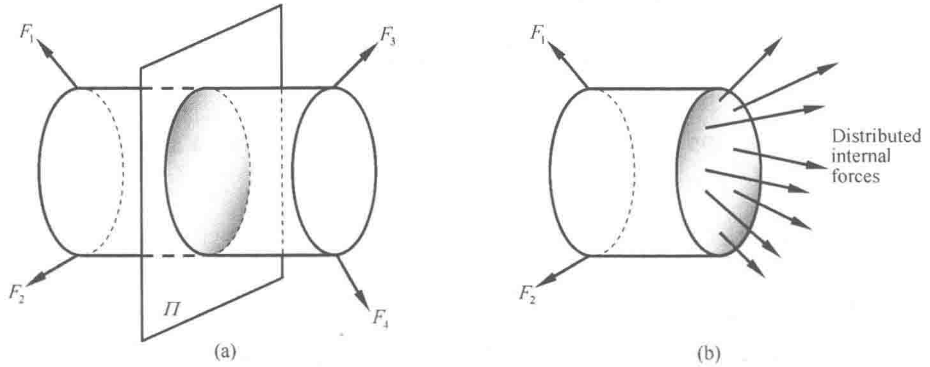

Fig. 1.2

For equilibrium of the remaining portion of the member, the distributed internal forces can be determined by using the equations of static equilibrium. Although the exact distribution of internal forces may be unknown, we can use the equations of static equilibrium to relate the applied external loads to the resultant force $\boldsymbol{R}$ and resultant couple $\boldsymbol{M}_O$ about point O on the cut plane, which are caused by the distributed internal forces, Fig. 1.3(a).

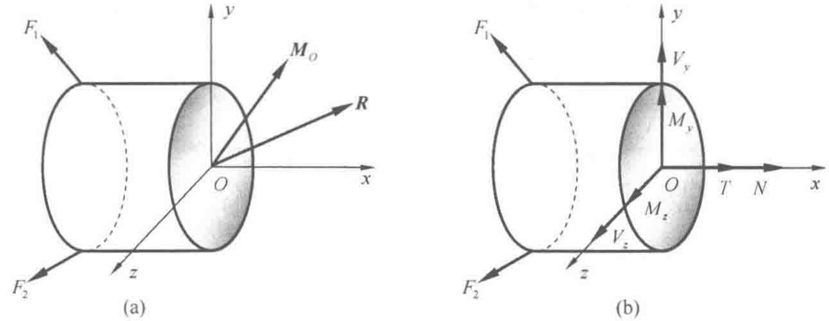

Fig. 1.3

Generally speaking, the resultant force $\boldsymbol{R}$ and resultant couple $\boldsymbol{M}_O$ have arbitrary directions, neither perpendicular nor parallel to the cut plane. However, we can resolve the resultant force and couple into six components, respectively along the x, y, and z axes, Fig. 1.3(b).

(1) Axial force. The normal component, along the x direction, of the resultant force is called the axial force (normal force), N. It is developed when the external loads tend to pull or push the two segments of the member.

(2) Shearing force. The tangential components, respectively along the y and z directions, of the resultant force are regarded as the shearing forces, denoted by V_y and V_z, which are developed when the external loads tend to cause the two segments of the member to slide over one another.

(3) Torsional moment. The normal component, rotating about the x axis, of the resultant couple is called the torsional moment (twisting moment, or torque), T, and developed when the external loads tend to twist one segment of the member with respect to the other.

(4) Bending moment. The tangential components of the resultant couple tend to bend the member about the y and z axes, respectively. These two components, M_y and M_z, rotating about the y and z axes respectively, are called the bending moments.

1.3 Stresses

The distributed internal forces are developed at any point within the member subjected to external loads. To define the stress at a given point P of the section, Fig. 1.4(a), we consider a small area ΔA containing P and assume that the resultant force is $\Delta \boldsymbol{F}$ on the area ΔA. In general, the force $\Delta \boldsymbol{F}$ has a unique direction at a given point on the section and can be resolved into three components ΔN, ΔV_y and ΔV_z respectively along the x, y, and z axes, Fig. 1.4(b). ΔN is the normal component perpendicular to the area ΔA, ΔV_y and ΔV_z are the two tangential components within the area ΔA.

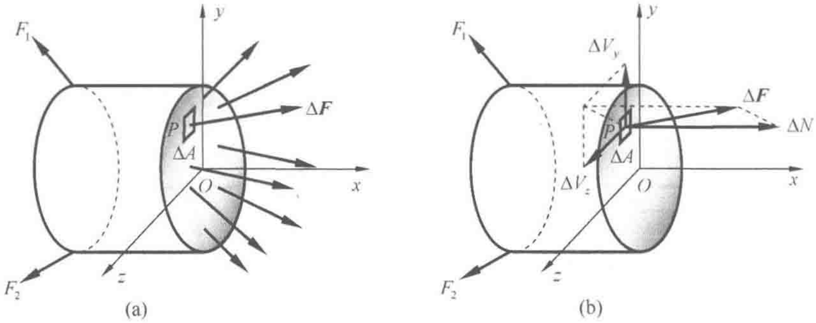

Fig. 1.4

1. Normal Stress

The intensity of the normal force, the normal force per unit area, acting normal to the area is defined as the normal stress, denoted by σ. The normal stress at the given point P on the section of the member, Fig. 1.5, can be expressed as

$$\sigma_x = \lim_{\Delta A \to 0} \frac{\Delta N}{\Delta A} \tag{1.1}$$

where σ_x is perpendicular to the section and the subscript represents the outward normal of the section and the direction of the normal stress. A positive sign is usually used to indicate a tensile stress and a negative sign to indicate a compressive stress. From SI units, with ΔN expressed in N and ΔA in m^2, the normal stress σ_x is expressed in Pascal (Pa).

2. Shearing Stress

The intensity of the tangential force, the tangential force per unit area, acting tangent to the area is called the shearing stress, denoted by τ. The two shearing stress components at the given point P on the section of the member, Fig. 1.6, can be written, respectively, as

$$\tau_{xy} = \lim_{\Delta A \to 0} \frac{\Delta V_y}{\Delta A}, \qquad \tau_{xz} = \lim_{\Delta A \to 0} \frac{\Delta V_z}{\Delta A} \tag{1.2}$$

where τ_{xy} and τ_{xz} lie in the section. Two subscripts are used for the shearing stress components: the first represents the direction of the outward normal line of the section; and the second indicates the direction of the shearing stress. In SI units, the shearing stresses τ_{xy} and τ_{xz} are also measured in Pa.

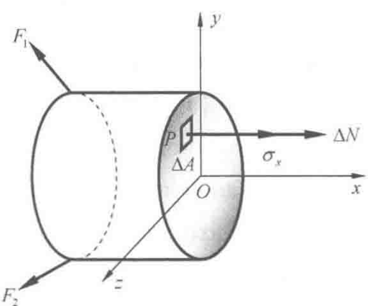

Fig. 1.5

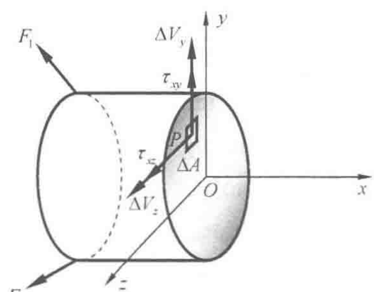

Fig. 1.6

In order to show how shearing stresses develop, we will consider a member subjected to two transverse forces of magnitude F, Fig. 1.7(a).

Sectioning the member at CC' between the points of application of the two forces, and considering the equilibrium of the left portion, Fig. 1.7(b), we conclude that distributed internal forces must exist in the cross section. The resultant of these distributed internal forces is called direct shearing force, denoted by V. Dividing the direct shearing force V in the cross section by the area A of the cross section, we obtain the direct shearing stress in the section. Denoting the direct shearing stress by the letter τ, we have

$$\tau = \frac{V}{A} \tag{1.3}$$

We should note that the value obtained is an average value of the shearing stress over the entire section.

Direct shearing stresses are commonly found in bolts, pins, and rivets used to connect various structural members and machine components. Consider the two plates, which are connected by a bolt, Fig. 1.8(a). If the plates are subjected to two tension forces of magnitude F, a direct shearing stress will develop in the section of bolt corresponding to the contacting surface of the plates. Drawing the diagram of the bolt located below the contacting surface, Fig. 1.8(b), we conclude that the direct shearing stress τ in the section is equal to V/A.

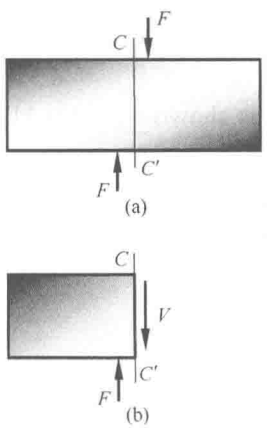

Fig. 1.7

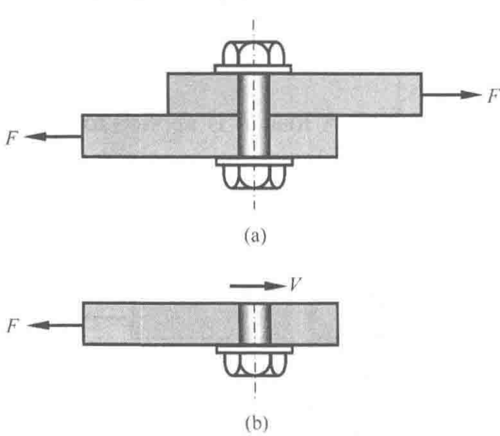

Fig. 1.8

Example 1.1 A load F is applied to a steel rod supported as shown in Fig. 1.9(a) by a plate into which a 15 mm diameter hole has been drilled. Knowing that the shearing stress must not exceed 120 MPa in the steel, determine the largest load F_{max} which may be applied to the rod.

Solution The shearing plane is a cylindrical surface, Fig. 1.9(b), and its shearing area is equal to $A = \pi dt$. Since the maximum shearing stress $\tau_{max} = 120$ MPa, then the largest load F_{max} can, from Eq. (1.3), be obtained by

$$F_{max} = \tau_{max} A = 56.5 \text{ kN}$$

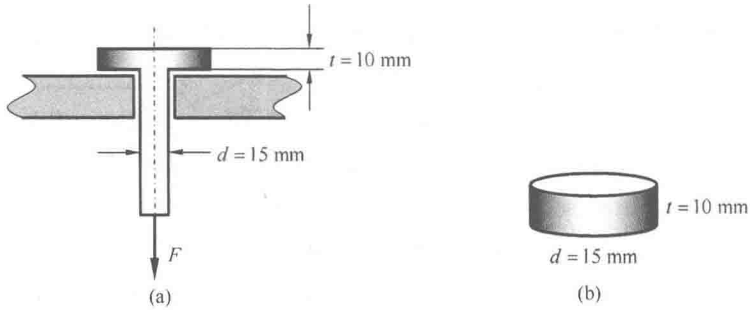

Fig. 1.9

3. Bearing Stress

Bolts, pins, and rivets create stresses on the bearing surface of the members they connect. Consider two plates connected by a bolt, Fig. 1.10(a). The bolt exerts on the upper plate a force F_{bs}, Fig. 1.10(b), equal and opposite to the force F'_{bs} exerted by the upper plate on the bolt, Fig. 1.10(c). The force F_{bs} exerted by the bolt represents the resultant of distributed forces on the inside surface of a half-cylinder.

Since the distribution of forces on the contacting surface of the members is quite complicated, the average value of the stress, obtained by dividing the resultant F_{bs} by the projected area A_{bs} of the bolt on the plate section, is regarded as the bearing stress σ_{bs}. Since this projected area A_{bs} is equal to td, where t is the plate thickness and d is the diameter of the bolt, we have

$$\sigma_{bs} = \frac{F_{bs}}{A_{bs}} = \frac{F_{bs}}{td} \tag{1.4}$$

Example 1.2 A load F is applied to a steel rod supported as shown in Fig. 1.11(a) by a plate into which a 15 mm diameter hole has been drilled. Knowing that the bearing stress of the steel must not exceed 150 MPa, determine the largest load F_{max} which may be applied to the rod.

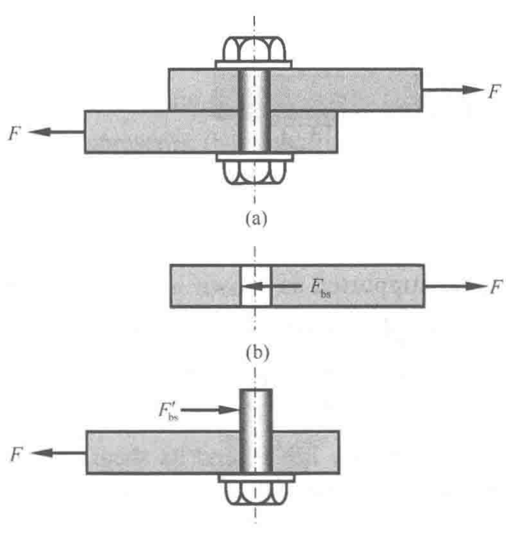

Fig. 1.10

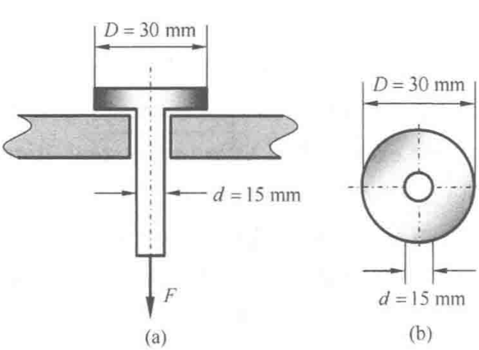

Fig. 1.11