理工科核心课程双语规划教材

材料力学

Mechanics of Materials

王开福　编著

中国科学技术大学出版社

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内容简介

本书是材料力学双语教材，系统论述了材料力学的基本概念、基础理论、计算方法和工程应用。全书由13章正文和4个附录组成，正文内容包括应力与应变(Stresses and Strains)、材料的机械性能(Mechanical Properties of Materials)、杆的轴向拉伸与压缩(Axial Tension and Compression of Bars)、轴的扭转(Torsion of Shafts)、梁的剪力与弯矩(Shearing Force and Bending Moment of Beams)、梁的正应力与剪应力(Normal Stress and Shearing Stress in Beams)、梁的挠度与转角(Deflection and Slope of Beams)、应力分析与强度理论(Analysis of Stresses and Theories of Strength)、组合载荷(Combined Loadings)、压杆稳定(Stability of Columns)、能量法(Energy Methods)、动载荷(Dynamic Loadings)和静不定结构(Statically Indeterminate Structures)；附录部分包括截面几何性质(Geometrical Properties of Areas)、型钢几何性质(Geometrical Properties of Rolled-Steel Shapes)、常用截面的惯性矩与极惯性矩(Moment of Inertia、and Polar Moment of Inertia of Commonly-Used Areas)和常用梁的挠度与转角(Deflections and Slopes of Commonly-Used Beams)。

本书可作为高等院校航空、航天、机械、土木、水利、建筑、船舶、汽车、材料和力学等专业本科教学的材料力学双语教材，也可供相关专业的高校教师、研究人员和技术人员参考。

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Preface 前 言

1. 本书编写的背景和目的

材料力学英文原版教材价格昂贵，学生无法承受，因此国内现有的材料力学双语教材主要是国外英文原版教材的影印版。然而，英文影印版教材存在如下缺点：

(1) 影印版教材都是多年前的老版英文原版教材的影印本，目前国内还没有最新英文原版教材的影印本，因此学生往往无法及时获取最新的专业知识。

(2) 影印版教材使用的主要是英制单位，而我国采用的是公制单位，因而学生往往对此感到很不适应。

(3) 影印版教材使用的往往是美国的技术规范，而我国采用的是国标或行标，因此学生学习后往往不能按照我国的技术规范进行工程设计。

(4) 影印版教材书本很厚，内容偏多，与我国的教学基本要求和教学大纲不配套，因此学生感到影印版教材重点和难点不突出，内容不够精炼。

基于上述现状，作者考虑编写这本材料力学双语教材，以满足材料力学双语教学需要。

2. 本书具有的特点和特色

(1) 英文编写。让学生在学习专业知识的同时能够通过英语进行思维，通过英语分析问题和解决问题，提高英语应用能力。

(2) 语言简洁。双语教学对学生来说首先是专业知识的获取，其次才是英语能力的提高，特别是学生在通过英语学习专业知识的过程中，要承受来自英语语言和专业知识的双重压力，因此本书不追求语言上的深奥，而是力求采用简洁的英语让学生获取专业知识。

(3) 内容合适。本书内容由作者根据多年的教学经验进行编写，紧扣教学大纲，能满足教学的基本要求；章节安排由浅入深，循序渐进，符合认识规律；概念清晰，论述严谨，便于学生掌握重点，理解难点；例题和习题由作者设计和编写，做到举一反三；所有图形和图像均由作者绘制或拍摄，图形美观，图像清晰。

因此，通过本书的学习，学生能够掌握材料力学的基本概念、基础理论、计算方法和工程应用。学生在掌握专业知识、培养专业技能的基础上，提高英语水平、强化英语应用能力。

3. 本书包含的主要内容和知识要点

本书是为高等院校本科专业编写的材料力学双语教材。本书以讲义形式在南京航空航天大学本科材料力学双语教学中已经使用多年，教学效果良好。

本书系统论述了材料力学的基本概念、基础理论、计算方法和工程应用。全书由13章正文和4个附录组成。第1章是应力与应变(Stresses and Strains)，阐述了材料力学的主要任务及其基本假设，讨论了外力和内力以及截面法在内力计算中的应用，重点论述了应力和应变的概念，详细分析了正应力、剪应力和挤压应力以及线应变和剪应变。第2章是关于材料的机械性能(Mechanical Properties of Materials)，讨论了塑性和脆性材料的拉压机械性能，重点阐述了低碳钢和铸铁在拉伸和压缩时所表现出来的机械性能及其应力应变曲线，详细分析了低碳钢在拉伸时的弹性阶段、屈服阶段、强化阶段和颈缩阶段以及这些阶段所对应的比例极限、弹性极限、屈服极限、强度极限、伸长率和断面收缩率等强度和塑性指标。第3章为杆的轴向拉伸与压缩(Axial Tension and Compression of Bars)，讨论了轴向拉压杆的轴力、应力和应变，详细分析了轴向拉压杆在横截面和斜截面上的应力以及轴向拉压杆的纵向和横向变形，研究了轴向拉压静不定问题。第4章涉及轴的扭转(Torsion of Shafts)，分析了扭转轴的扭矩、应力和应变，研究了扭转轴横截面上的剪应力以及扭转轴的扭转角，论述了扭转静不定问题。第5章与梁的剪力与弯矩(Shearing Force and Bending Moment of Beams)有关，讨论了弯曲梁的剪力和弯矩图，重点研究了利用载荷、剪力和弯矩之间的微分和积分关系进行剪力和弯矩图的绘制。第6章关于梁的正应力与剪应力(Normal Stress and Shearing Stress in Beams)，研究了纯弯曲梁横截面上的正应力和横力弯曲梁横截面上的正应力和剪应力，讨论了弯曲梁的强度设计。第7章是梁的挠度与转角(Deflection and Slope of Beams)，讨论了弯曲梁的变形和挠曲线微分方程，研究了计算弯曲梁挠度和转角的积分法和叠加法，分析了弯曲静不定问题。第8章为应力分析与强度理论(Analysis of Stresses and Theories of Strength)，阐述了应力状态、压力容器、广义胡克定律和强度理论，重点研究了平面应力变换、主应力、最大剪应力、最大拉应力理论、最大剪应力理论和最大畸变能理论。第9章涉及组合载荷(Combined Loadings)，阐述了组合载荷和叠加原理，详细研究了偏心拉压、工字梁横力弯曲、拉弯组合和弯扭组合。第10章关于压杆稳定(Stability of Columns)，讨论了细长杆在各种支撑条件下的临界载荷和临界应力以及中长杆和粗短杆的临界应力，重点研究了细长杆、中长杆和粗短杆的划分以及欧拉公式和经验公式的选用。第11章与能量法(Energy Methods)有关，讨论了外力功和应变能，重点论述了功能原理、卡氏定理和单位载荷法以及这些方法在静定结构和静不定结构中的应用。第12章

为动载荷(Dynamic Loadings),详细讨论了垂直和水平冲击问题,重点分析了最大动应力和最大动位移的计算。第 13 章是静不定结构(Statically Indeterminate Structures),介绍了静不定结构以及外力和内力静不定,重点讨论了采用力法分析静不定结构以及结构和载荷对称性质在静不定问题求解中的应用。附录Ⅰ为截面几何性质(Geometrical Properties of Areas),讨论了静矩与形心、惯性矩与极惯性矩、惯性半径与极惯性半径、惯性积和平行移轴定理。附录Ⅱ是型钢几何性质(Geometrical Properties of Rolled-Steel Shapes),包括工字钢、槽钢、等边角钢和不等边角钢。附录Ⅲ和附录Ⅳ分别为常用截面的惯性矩与极惯性矩(Moment of Inertia and Polar Moment of Inertia of Commonly-Used Areas)和常用梁的挠度与转角(Deflections and Slopes of Commonly-Used Beams),可供学生查阅。

本书可作为高等院校航空、航天、机械、土木、水利、建筑、船舶、汽车、材料和力学等学科专业本科教学的材料力学双语教材,也可供相关专业的高校教师、研究人员和技术人员参考。

由于作者水平有限和编写时间仓促,若有不周及不当之处,敬请读者批评指正。

作　者

2011 年 2 月于南京航空航天大学

Contents 目 录

Preface i
Chapter 1 Stresses and Strains 1
1.1 What Is Mechanics of Materials 1
1.2 Basic Assumptions of Materials 2
1.3 External Forces 2
1.4 Internal Forces 3
1.5 Stresses 6
1.6 Strains 11
1.7 Deformations of Members 13
Problems 15
Chapter 2 Mechanical Properties of Materials 16
2.1 Tensile or Compressive Test 16
2.2 Tension of Low-Carbon Steel 16
2.3 Ductile and Brittle Materials 19
2.4 Stress-Strain Curve of Ductile Materials Without Distinct Yield Point 20
2.5 Percent Elongation and Percent Reduction in Area 21
2.6 Hooke's Law 21
2.7 Mechanical Properties of Materials in Compression 22
Chapter 3 Axial Tension and Compression of Bars 23
3.1 Definition of Axial Tension and Compression 23
3.2 Axial Force 24
3.3 Normal Stress on Cross Section 24
3.4 Saint-Venant's Principle 26
3.5 Normal and Shearing Stresses on Oblique Section 26
3.6 Normal Strain 29
3.7 Deformation of Axially Loaded Bar 31

3.8 Statically Indeterminate Axially Loaded Bar ······ 33
3.9 Design of Axially Loaded Bar ······ 34
3.10 Stress Concentrations ······ 35
Problems ······ 36

Chapter 4 Torsion of Shafts ······ 39
4.1 Definition of Torsion ······ 39
4.2 Twisting Moment ······ 39
4.3 Hooke's Law in Shear ······ 40
4.4 Shearing Stress on Cross Section of Circular Shaft ······ 41
4.5 Normal and Shearing Stresses on Oblique Section of Circular Shaft ······ 44
4.6 Angle of Twist ······ 45
4.7 Statically Indeterminate Circular Shaft ······ 47
4.8 Design of Circular Shaft ······ 48
Problems ······ 49

Chapter 5 Shearing Force and Bending Moment of Beams ······ 53
5.1 Definition of Bending ······ 53
5.2 Shearing-Force and Bending-Moment Diagrams ······ 54
5.3 Relations Among Distributed Load, Shearing Force, and Bending Moment ······ 58
5.4 Relations Among Concentrated Load, Shearing Force, and Bending Moment ······ 61
Problems ······ 63

Chapter 6 Normal Stress and Shearing Stress in Beams ······ 66
6.1 Types of Bending ······ 66
6.2 Normal Stresses on Cross Section in Pure Bending ······ 67
6.3 Normal and Shearing Stresses on Cross Section in Transverse-Force Bending ······ 72
6.4 Design of Prismatic Beams in Bending ······ 77
Problems ······ 78

Chapter 7 Deflection and Slope of Beams ······ 81
7. 1 Deformation of Beams ······ 81
7. 2 Method of Integration ······ 83
7. 3 Method of Superposition ······ 85
7. 4 Statically Indeterminate Beams ······ 86
Problems ······ 88
Chapter 8 Analysis of Stresses and Theories of Strength ······ 92
8. 1 State of Stress ······ 92
8. 2 Transformation of Plane Stress ······ 93
8. 3 Principal Stresses for Plane stress ······ 95
8. 4 Maximum Shearing Stress for Plane Stress ······ 98
8. 5 Stresses in Pressure Vessels ······ 100
8. 6 Generalized Hooke's Law ······ 102
8. 7 Theories of Strength Under Plane Stress ······ 105
Problems ······ 112
Chapter 9 Combined Loadings ······ 115
9. 1 Definition of Combined Loadings ······ 115
9. 2 Stress in Bar Subjected to Eccentric Tension or Compression ······ 116
9. 3 Stress in I-Section Beam Subjected to Transverse Bending ······ 118
9. 4 Stress in Beam Subjected to Bending and Axial Tension/Compression ······ 122
9. 5 Stress in Shaft Subjected to Torsion and Bending ······ 125
Problems ······ 128
Chapter 10 Stability of Columns ······ 131
10. 1 Definition of Buckling ······ 131
10. 2 Critical Load of Long Slender Columns Under Centric Load with Pin Supports ······ 132
10. 3 Critical Load of Long Slender Columns Under Centric Load with Other Supports ······ 134
10. 4 Critical Stress of Long Slender Columns Under Centric Load ······ 136

10.5 Critical Stress of Intermediate Length Columns Under Centric Load ······ 137
10.6 Design of Columns Under Centric Load ······ 139
Problems ······ 140

Chapter 11 Energy Methods ······ 143
11.1 External Work ······ 143
11.2 Stain-Energy Density ······ 145
11.3 Strain Energy ······ 146
11.4 Principle of Work and Energy ······ 151
11.5 Castigliano's Theorem ······ 153
11.6 Unit Load Method ······ 157
11.7 Applications of Energy Methods ······ 160
Problems ······ 162

Chapter 12 Dynamic Loadings ······ 166
12.1 Definition of Impact Loadings ······ 166
12.2 Vertical Impact ······ 166
12.3 Horizontal Impact ······ 169
Problems ······ 172

Chapter 13 Statically Indeterminate Structures ······ 175
13.1 Concept of Statically Indeterminate Structures ······ 175
13.2 External and Internal Indeterminacy ······ 175
13.3 Force Method for Analysis of Statically Indeterminate Structures ······ 177
13.4 Force Method for Analysis of Symmetrical Indeterminate Structures ······ 182
Problems ······ 185

Appendix I Geometrical Properties of Areas ······ 191
I.1 First Moment and Centroid ······ 191
I.2 First Moment and Centroid of a Composite Area ······ 192
I.3 Moment of Inertia and Polar Moment of Inertia ······ 193
I.4 Radius of Gyration and Polar Radius of Gyration ······ 194

Ⅰ.5 Product of Inertia ······ 194
Ⅰ.6 Parallel-Axis Theorem ······ 195
Appendix Ⅱ Geometrical Properties of Rolled-Steel Shapes ······ 196
Ⅱ.1 I-Steel ······ 196
Ⅱ.2 Channel Steel ······ 198
Ⅱ.3 Equal Angle Steel ······ 200
Ⅱ.4 Unequal Angle Steel ······ 203
Appendix Ⅲ Moment of Inertia and Polar Moment of Inertia of Commonly-Used Areas ······ 206
Appendix Ⅳ Deflections and Slopes of Commonly-Used Beams ······ 207
Glossaries ······ 208
References ······ 221

Chapter 1 Stresses and Strains

Objectives of This Chapter

After completing this chapter, students will be able to

(a) Understand the concepts of strength, rigidity, and stability, and the assumptions of continuity, homogenization, and isotropy.

(b) Understand the concept of internal forces, and use the method of sections to determine internal force components of a member subjected to external loads.

(c) Understand the concepts of normal, shearing, and bearing stresses, and determine these stresses at any point within a member.

(d) Understand the concepts of normal and shearing strains, and determine these strains at any point within a member.

1.1 What Is Mechanics of Materials

Mechanics of materials is a branch of deformable body mechanics that studies

(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.

In mechanics of materials, members will no longer be assumed to be perfectly rigid as was considered in theoretical mechanics. The deformation analysis of various members under a variety of loads will be one of the important tasks in the study of mechanics of materials.

1.2 Basic Assumptions of Materials

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. If a material does not posses any kind of symmetry of mechanical properties, it is called anisotropic (or aeolotropic). Composite materials are typical examples of anisotropic materials.

1.3 External Forces

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

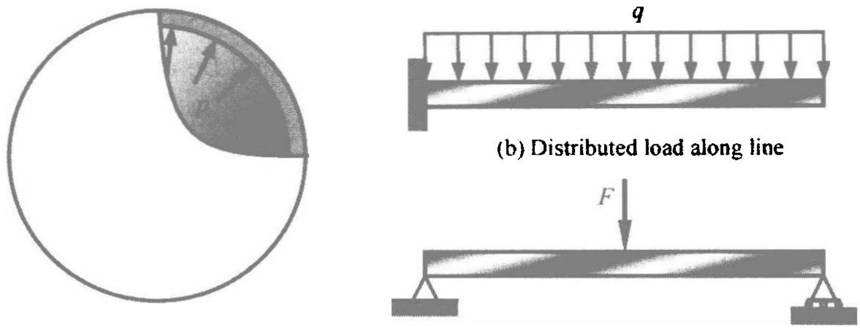
1. Surface Force

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. 1a). If the surface force is applied along a narrow area, this force is defined as a distributed load along a line (Fig. 1. 1b). 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. 1c).

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 particles forming the body.



(a) Distributed load on surface

(b) Distributed load along line

(c) Concentrated load

Fig. 1.1

1.4 Internal Forces

When various external loads are applied to a member, then 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. 2a), to be passed through the member where the distributed internal forces are 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. 2b).

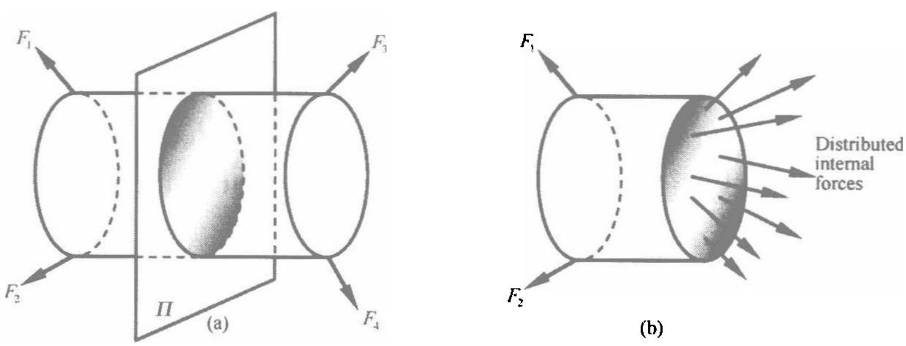


Fig. 1.2

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 the resultant couple $\boldsymbol{M}_O$ about point O on the cut plane, which are caused by the distributed internal forces (Fig. 1.3a).

Generally speaking, the resultant force $\boldsymbol{R}$ and the 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. 1.3b).

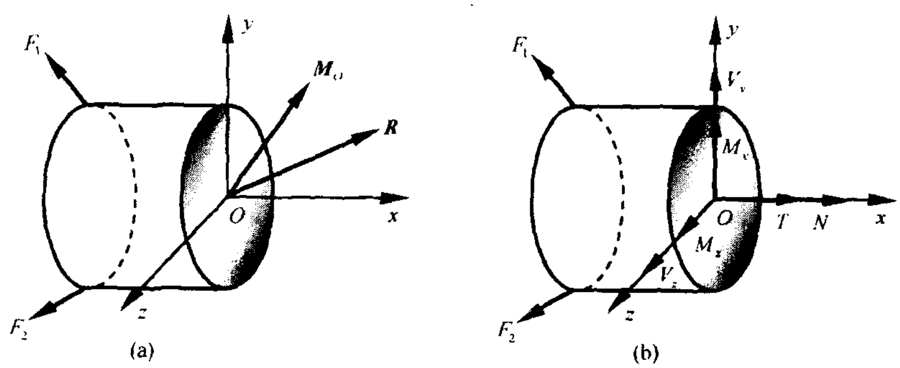


Fig. 1.3

1. Normal Force

The normal component, along the x direction, of the resultant force is called the normal force (axial 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. Twisting Moment

The normal component, rotating about the x axis, of the resultant couple is called the twisting moment (torque, or torsional moment), 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.

Example 1.1

Consider a member AB, which is fixed at the left end and subjected to three external loads, F_1, F_2, and M_e, at the free end (Fig. E1.1a). Determine internal force components on the midsection C of the member.

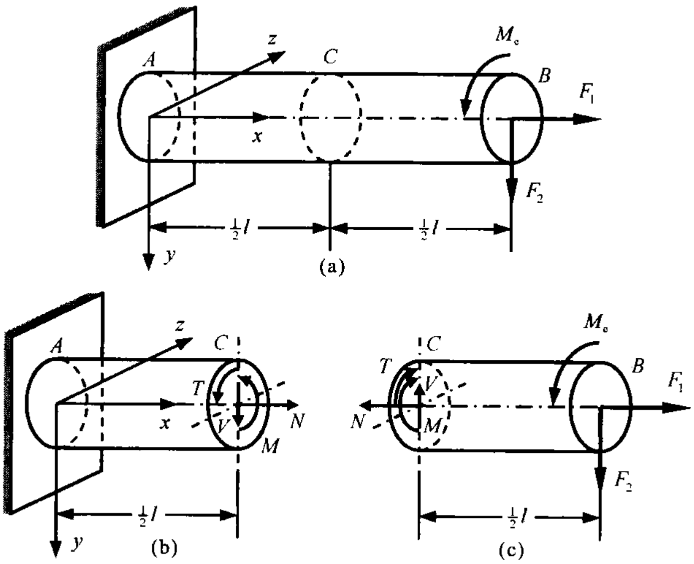


Fig. E1.1

Solution

Using the method of sections, the member AB is sectioned at the midsection C into two parts, AC and BC (Figs. E1.1b and E1.1c). Considering the equilibrium of portion BC, we have

$$\sum F_x = 0: \ F_1 - N = 0$$

$$\sum F_y = 0: \ F_2 - V = 0$$

$$\sum (M_C)_x = 0: \ M_e - T = 0$$

$$\sum (M_C)_z = 0: \ F_2\left(\frac{1}{2}l\right) + M = 0$$

Solving these equations for the internal force components, then we obtain

$$N = F_1, \quad V = F_2, \quad T = M_e, \quad M = -\frac{1}{2}F_2 l$$

1.5 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. 4a), 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. 4b). ΔN is the normal component perpendicular to the area ΔA. ΔV_y and ΔV_z are the two tangential components within the area ΔA.

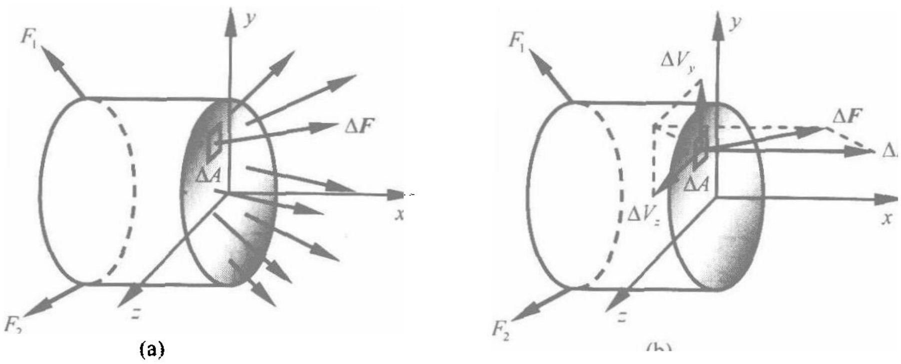


Fig. 1.4

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

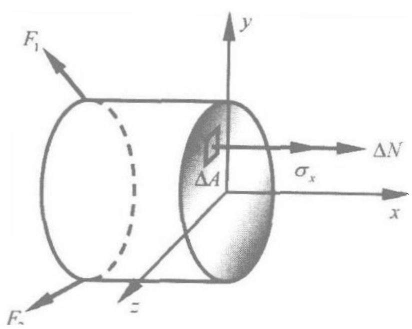


Fig. 1.5