# Contents

#### **CHAPTER 1**

#### **Stress**

- **1.1** Introduction 1
- **1.2** Analysis of Internal Forces; Stress 2
- **1.3** Axially Loaded Bars 4
  - a. Centroidal (axial) loading 4
  - b. Saint Venant's principle 5
  - c. Stresses on inclined planes 6
  - d. Procedure for stress analysis 7
- **1.4** Shear Stress 18
- **1.5** Bearing Stress 19

#### **CHAPTER 2**

#### Strain

- **2.1** Introduction 31
- 2.2 Axial Deformation; Stress-Strain Diagram 32
  - a. Normal (axial) strain 32
  - b. Tension test 33
  - c. Working stress and factor of safety 36
- **2.3** Axially Loaded Bars 36
- **2.4** Generalized Hooke's Law 47
  - a. Uniaxial loading; Poisson's ratio 47
  - b. Multiaxial loading 47
  - c. Shear loading 48
- **2.5** Statically Indeterminate Problems 54
- **2.6** Thermal Stresses 63

#### **CHAPTER 3**

### Torsion

- **3.1** Introduction 75
- **3.2** Torsion of Circular Shafts 76
  - a. Simplifying assumptions 76
  - b. Compatibility 77
  - c. Equilibrium 77
  - d. Torsion formulas 78
  - e. Power transmission 79
  - f. Statically indeterminate problems 80

- **3.3** Torsion of Thin-Walled Tubes 91
- **\*3.4** Torsion of Rectangular Bars 99

## **CHAPTER 4**

#### Shear and Moment in Beams 107

- **4.1** Introduction 107
- 4.2 Supports and Loads 108
- 4.3 Shear-Moment Equations and Shear-Moment Diagrams 109
  - a. Sign conventions 109
  - b. Procedure for determining shear force and bending moment diagrams 110
- **4.4** Area Method for Drawing Shear-Moment Diagrams 122
  - a. Distributed loading 122
  - b. Concentrated forces and couples 124
  - c. Summary 126

### **CHAPTER 5**

### Stresses in Beams

- Introduction 139 5.1
- **5.2** Bending Stress 140
  - a. Simplifying assumptions 140
  - b. Compatibility 141
  - c. Equilibrium 142
  - d. Flexure formula; section modulus 143
  - e. Procedures for determining bending stresses 144
- **5.3** Economic Sections 158
  - a. Standard structural shapes 159
  - b. Procedure for selecting standard shapes 160
- 5.4 Shear Stress in Beams 164
  - a. Analysis of flexure action 164
  - b. Horizontal shear stress 165
  - c. Vertical shear stress 167

139

75

1

31

<sup>\*</sup> Indicates optional sections.

- d. Discussion and limitations of the shear stress formula 167
- e. Rectangular and wide-flange sections 168
- f. Procedure for analysis of shear stress 169
- **5.5** Design for Flexure and Shear 177
- **5.6** Design of Fasteners in Built-Up Beams 184

### CHAPTER 6 Deflection of Beams

- 6.1 Introduction 195
- 6.2 Double-Integration Method 196
  - a. Differential equation of the elastic curve 196
  - b. Double integration of the differential equation 198
  - c. Procedure for double integration 199

**195** 

- **6.3** Double Integration Using Bracket Functions 209
- \*6.4 Moment-Area Method 219
  - a. Moment-area theorems 220
  - b. Bending moment diagrams by parts 222
  - c. Application of the moment-area method 225
- 6.5 Method of Superposition 235

### **CHAPTER 7** Statically Indeterminate Beams 249

- 7.1 Introduction 249
- **7.2** Double-Integration Method 250
- **7.3** Double Integration Using Bracket Functions 256
- **\*7.4** Moment-Area Method 260
- **7.5** Method of Superposition 266

### CHAPTER 8

### Stresses Due to Combined Loads 277

- **8.1** Introduction 277
- 8.2 Thin-Walled Pressure Vessels 278
  - a. Cylindrical vessels 278
  - b. Spherical vessels 280

- **8.3** Combined Axial and Lateral Loads 284
- **8.4** State of Stress at a Point (Plane Stress) 293
  - a. Reference planes 293
  - b. State of stress at a point 294
  - c. Sign convention and subscript notation 294
- **8.5** Transformation of Plane Stress 295
  - a. Transformation equations 295
    - b. Principal stresses and principal planes 296
    - c. Maximum in-plane shear stress 298
    - d. Summary of stress transformation procedures 298
- **8.6** Mohr's Circle for Plane Stress 305
  - a. Construction of Mohr's circle 306
  - b. Properties of Mohr's circle 307
  - c. Verification of Mohr's circle 308
- 8.7 Absolute Maximum Shear Stress 314
  a. Plane state of stress 315
  b. General state of stress 316
- **8.8** Applications of Stress Transformation to Combined Loads 319
- 8.9 Transformation of Strain; Mohr's Circle for Strain 331
  - a. Review of strain 331
  - b. Transformation equations for plane strain 332
  - c. Mohr's circle for strain 333
- **8.10** The Strain Rosette 338
  - a. Strain gages 338
  - b. Strain rosette 339
  - c. The  $45^{\circ}$  strain rosette 340
  - d. The  $60^{\circ}$  strain rosette 340
- 8.11 Relationship between Shear Modulus and Modulus of Elasticity 342

### CHAPTER 9

### **Composite Beams**

### 349

- 9.1 Introduction 349
- **9.2** Flexure Formula for Composite Beams 350
- **9.3** Shear Stress and Deflection in Composite Beams 355
  - a. Shear stress 355
  - b. Deflection 356
- **9.4** Reinforced Concrete Beams 359
  - a. Elastic Analysis 360
  - b. Ultimate moment analysis 361

<sup>\*</sup> Indicates optional sections.

463

#### **CHAPTER 10** Columns

### 371

- **10.1** Introduction 371
- **10.2** Critical Load 372
  - a. Definition of critical load 372
    - b. Euler's formula 373
- **10.3** Discussion of Critical Loads 375
- **10.4** Design Formulas for Intermediate Columns 380
  - a. Tangent modulus theory 380
  - b. AISC specifications for steel columns 381
- **10.5** Eccentric Loading: Secant Formula 387
  - a. Derivation of the secant formula 388
  - b. Application of the secant formula 389

#### **CHAPTER 11** Additional Beam Topics *397*

- **11.1** Introduction 397
- **11.2** Shear Flow in Thin-Walled Beams 398
- **11.3** Shear Center 400
- **11.4** Unsymmetrical Bending 407
  - a. Review of symmetrical bending 407
  - b. Symmetrical sections 408
  - c. Inclination of the neutral axis 409
  - d. Unsymmetrical sections 410
- **11.5** Curved Beams 415
  - a. Background 415
  - b. Compatibility 416
  - c. Equilibrium 417
  - d. Curved beam formula 418

# **CHAPTER 12**

### **Special Topics**

- **12.1** Introduction 425
- **12.2** Energy Methods 426
  - a. Work and strain energy 426
  - b. Strain energy of bars and beams 426
  - c. Deflections by Castigliano's theorem 428
- **12.3** Dynamic Loading 437
  - a. Assumptions 437
  - b. Mass-spring model 438
  - c. Elastic bodies 439
  - d. Modulus of resilience; modulus of toughness 439
- **12.4** Theories of Failure 444
  - a. Brittle materials 445
  - b. Ductile materials 446

- **12.5** Stress Concentration 452
- **12.6** Fatigue Under Repeated Loading 458

### **CHAPTER 13** Inelastic Action

- **13.1** Introduction 463
- **13.2** Limit Torque 464
- **13.3** Limit Moment 466
- **13.4** Residual Stresses 471
  - a. Loading-unloading cycle 471
  - b. Torsion 471
  - c. Bending 472
  - d. Elastic spring-back 473
- **13.5** Limit Analysis 477
  - a. Axial loading 477
  - b. Torsion 478
  - c. Bending 479

### APPENDIX A **Review of Properties of Plane Areas**

- **A.1** First Moments of Area: Centroid 487
- A.2 Second Moments of Area 488
  - a. Moments and product of inertia 488
  - b. Parallel-axis theorems 489
  - c. Radii of gyration 491
  - d. Method of composite areas 491

  - moments and products of inertia 500
  - b. Comparison with stress transformation equations 501
  - c. Principal moments of inertia and principal axes 501
  - d. Mohr's circle for second moments of area 502

### APPENDIX B

Tables

425

- Average Physical Properties of Common **B.1** Metals 510
- **B.2** Properties of Wide-Flange Sections (W-Shapes): SI Units 512
- Properties of I-Beam Sections (S-Shapes): **B.3** SI Units 518

487

509

- A.3 Transformation of Second Moments
  - of Area 500
  - a. Transformation equations for

- B.4 Properties of Channel Sections: SI Units 519
- B.5 Properties of Equal and Unequal Angle Sections: SI Units 520
- B.6 Properties of Wide-Flange Sections (W-Shapes): U.S. Customary Units 524
- B.7 Properties of I-Beam Sections (S-Shapes): U.S. Customary Units 532
- **B.8** Properties of Channel Sections: U.S. Customary Units 534
- B.9 Properties of Equal and Unequal Angle Sections: U.S. Customary Units 535

Answers to Even-Numbered	
Problems	<b>539</b>
Index	547