Contents

Strength and Failure of Materials 1.1 Stable and Unstable Deformations 1.2 Plasticity A. Plastic Deformation under Uniaxial Stress, A. Plastic Stress-strain Relationships for Tri- axial Stress, 4. 1.3 Failure by Plastic Instability A. Instability of Plastic Extension: the Ulti- mate Tensile Strength, 5; B. Instability of the Plastic Expansion of Tubes, Vessels, and Flates, 6; C. Ultimate Stress and Working Stress, 7. 1.4 Creep A. The Andrade Analysis of the Creep Curve, 8; B. Transient Creep, 9; C. Viscous Creep, 10; D. Creep under Triaxial Stress, 11; E. The Mechanism of Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory 1.6 Ductile Fractures A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Struc- tural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.0 Codes and Standards 2.1 Codes and Standards 2.2 Design Considerations: Loadings 2.3 Design Limits, Allowable Stresses, and Allowable 2.4 Other Loading, 47. 2.5 Combination of Deflections and Reactions 48 2.6 Evaluation of Deflections and Reactions 48 2.7 Design Significance of Inspection and Tests 50 Chapter 3 Local Components 52 53.1 Fipe Bends: Structural Loading (Static and Cyclic) 52 Pipe Bends: Structural Loading (Static and Cyclic) 53 Branch Connections: Static Pressure Loading 64 83.1 Franch Connections: Static Pressure Loading 65 85 87 88 89 80 81 81 81 82 81 82 83 81 82 84 84 84 85 85 84 84 85 85 84 85 85	Nomenclature		xiii	2.4	Stress Evaluation a. Internal Pressure up to 3000 psi Maximum, 43; b. Internal Pressure over 3000 psi, 44; c. External Pressures, 46; d. Expansion, 47;	
1.1 Stable and Unstable Deformations 1.2 Plasticity A. Plastic Deformation under Uniaxial Stress, A. Plastic Deformation under Uniaxial Stress, A. Plastic Extension under Uniaxial Stress, A. Plastic Extension under Uniaxial Stress, C. Plastic Stress-train Relationships for Tri- axial Stress, 4. 1.3 Failure by Plastic Instability A. Instability of Plastic Extension: the Ulti- mate Tensile Strength, 5; B. Instability of the Plastic Expansion of Tubes, Vessels, and Plates, 6; C. Ultimate Stress and Working Stress, 7. 1.4 Creep A. The Andrade Analysis of the Creep Curve, 8; B. Transient Creep, 9; C. Viscous Creep, 10; D. Creep under Triaxial Stress, 11; E. The Mechanism of Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory The Brittle Fractures A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Com- pound Stress, 23; D. Influence of a Com- pound Stress, 23; D. Influence of a Com- pound Stress, 23; D. Influence of a Com- pound Stress, 23; C. Periodically Varying Thermal Stresses, 26; H. Thormal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits Codes and Standards Design Limits, Allowable Stresses, and Allowable 10 Design Limits, Allowable Stresses, and Allowable 11 September 2 Design Considerations: Loadings 12 Design Considerations: Loadings 13 Design Limits, Allowable Stresses, and Allowable 14 Selected Chart-form Solutions 15 A. Plastic Design Limits, Allowable Stresses, and Allowable 26 Design Limits, Allowable Stresses, and Allowable 27 Design Considerations: Loadings 28 Design Limits, Allowable Stresses, and Allowable		Chapter 1				
A. Plasticity A. Plasticity A. Plastic Deformation under Uniaxial Stress, 2; B. Triaxial Stress: Yield Conditions, 3; C. Plastic Stress-strain Relationships for Triaxia Stress, 4. 1.3 Failure by Plastic Instability of Plastic Extension: the Ultimuste Tensile Strength, 5; B. Instability of the Plastic Expansion of Tubes, Vessels, and Plates, 6; C. Ultimate Stress and Working Stress, 7. 1.4 Creep A. The Andrade Analysis of the Creep Curve, 8; B. Transient Creep, 9; C. Viscous Creep, 10; D. Creep under Triaxial Stress, 11; E. The Mechanism of Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory 1.6 Duetile Fractures 1.7 The Brittle Fracture of Steel ("Notch Brittlenses") 1.8 Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Spreimens vs. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.1 Codes and Standards 2.2 Design Considerations: Loadings 3.2 Evaluation of Deflections and Tests 5 Design Limits, Allowable Stresses, 3; d. 7, Approximating the Effect of Curved Pipe and				2.5		
A. Plastic Deformation under Uniaxial Stress, A. Plastic Stress-strain Relationships for Triaxial Stress, 4. 1.3 Failure by Plastic Instability A. Instability of Plastic Extension: the Ultimate Tensile Strength, 5; B. Instability of the Plastic Expansion of Tubes, Vessels, and Plates, 6; C. Ultimate Stress and Working Stress, 7. 1.4 Creep A. The Andrade Analysis of the Creep Curve, 8; B. Transient Creep, 9; C. Viscous Creep, 10; D. Creep under Traxial Stress, 11; E. The Mechanism of Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory 1.6 Ductile Fractures 1.7 The Brittle Fracture of Steel ('Notch Brittleness') 1.8 Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.1 Codes and Standards 30 Design Considerations: Loadings 31 Design Considerations: Loadings 32 Design Considerations: Loadings 32 Design Considerations: Loadings 32 Design Limits, Allowable Stresses, and Allowable 32. Proximate of Inspection and Testa Significance of Inspection and Testa Significance of Inspection and Testa Structural Loading (Static and Cyclic) 52 Pipe Bends: Internal Pressure Scructural Loading (Static and Cyclic) 52 Pipe Bends: Internal Pressure Scructural Loading (Static and Cyclic) 52 Pipe Bends: Internal Pressure Scructural Loading (Static and Cyclic) 52 Pipe Bends: Internal Pressure Scructural Loading (Static and Cyclic) 52 Pipe Bends: Internal Pressure Scructural Loading (Static and Cyclic) 52 Pipe Bends: Internal Pressure Scructural Loading (Static and Cyclic) 52 Pipe Bends: Internal Pressure Scru				0.6	·	
2. B. Triaxial Stress. Yield Conditions, 3; C. Plastic Stress-train Relationships for Triaxial Stress, 4. 1.3 Failure by Plastic Instability A. Instability of Plastic Extension: the Ultimate Tensile Strength, 5; B. Instability of the Plastic Expansion of Tubes, Vessels, and Plates, 6; C. Ultimate Stress and Working Stress, 7. 1.4 Creep A. The Andrade Analysis of the Creep Curve, 8; B. Transient Creep, 9; C. Viscous Creep, 10; D. Creep under Triaxial Stress, 11; E. The Mechanism of Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory 1.6 Ductile Fractures 1.7 The Brittle Fracture of Steel ("Notch Brittleness") 1.8 Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Structural Parks, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits Codes and Standards 2.1 Codes and Standards 2.2 Design Considerations: Loadings 3.3 Preliminary Segregation of Lines with Adequate Flexibility: Code Rules Selected Chart-form Solutions 3.4 Bends and Miters: Summary 3.5 Branch Connections: Repeated Loading 3.6 Branch Connections: Repeated Loading 3.7 Branch Connections: Comparison with Code Requirements 3.8 Branch Connections: Practical Considerations and Summary 3.9 Corrugated Pipe 3.10 Bolted Flanged Connections: Practical Considerations 4.11 Scope and Merits of Approximate Methods 4.12 Simplified Method for Flexibility Analysis 5. Chapter 2 5. The Brittle Fracture of Steel ("Notch Brittleness") 5. The Brittle Fracture of Steel ("Notch Brittleness") 6. The Simplified Method for Flexibility Analysis 6. The Simplified General Method for Square-corner Systems 6.	1.2		2			
A. Instability of Plastic Extension: the Ultimate Tensile Strength, 5; B. Instability of the Plastic Expansion of Tubes, Vessels, and Plates, 6; C. Ultimate Stress and Working Stress, 7. 1.4. Creep A. The Andrade Analysis of the Creep Curve, 8; B. Transient Creep, 9; C. Viscous Creep, 10; D. Creep under Triaxial Stress, 11; E. The Mechanism of Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5. Types of Fracture; Molecular Cohesion; the Griffith Theory 1.6. Ductile Fractures 1.7. The Brittle Fracture of Steel ("Notch Brittleness") 1.8. Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Specimens vs. Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.1 Codes and Standards 2.2 Design Considerations: Loadings 2.3 Design Considerations: Loadings 2.3 Design Considerations: Loadings 2.4 Design Considerations: Loadings 2.5 Design Considerations: Loadings 2.6 Design Considerations: Loadings 2.7 A. The Andrade Analysis of the Creep Curve, 8; B. Transient Creep, 9; C. Viscous Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Tests,		2; B. Triaxial Stress: Yield Conditions, 3; C. Plastic Stress-strain Relationships for Tri-		2.1	Design Significance of Inspection and Tests	50
rate Tensile Strength, 5; B. Instability of the Plastic Expansion of Tubes, Vessels, and Plates, 6; C. Ultimate Stress and Working Stress, 7. 1.4 Creep A. The Andrade Analysis of the Creep Curve, 8; B. Transient Creep, 9; C. Viscous Creep, 10; D. Creep under Triaxial Stress, 11; E. The Mechanism of Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory 13 1.6 Ductile Fracture of Steel ("Notch Brittle- ness") 1.7 The Brittle Fracture of Steel ("Notch Brittle- ness") 1.8 Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of a Com- pound State of Stress, 25; E. Influence of Notches and of Surface Plaws, 25; F. Patigue Tests on Specimens vs. Fatigue Tests on Struc- tural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.1 Codes and Standards 3.2 Pipe Bends: Structural Pressure 3.2 Pipe Bends: Structural Pressure 3.3 Miter Bends Branch Connections: Static Pressure Loading 3.4 Branch Connections: Static Pressure Loading 62 3.5 Branch Connections: Comparison with Code Requirements 3.8 Branch Connections: Comparison with Code Requirements 3.8 Branch Connections: Practical Considerations and Summary 4.3 Bolted Flanged Connections: Practical Considerations and Summary 5. Corrugated Pipe 6. 3.1 Bolted Flanged Connections: Practical Considerations 5. Branch Connections: Practical Considerations and Summary 6. Corrugated Pipe 7. Corrugated Pipe 8. Bolted Flanged Connections: Practical Considerations 8. Branch Connections: Practical Considerations and Summary 7. Summary 8. Bolted Flanged Connections: Practical Considerations 8. Branch Connections: Practical Considerations and Summary 8. Bolted Flanged Connections: Practical Considerations 8. Branch Connections: Practical Considerations 9. Bolted Fla	1.3	A. Instability of Plastic Extension: the Ultimate Tensile Strength, 5; B. Instability of the Plastic Expansion of Tubes, Vessels, and Plates, 6; C. Ultimate Stress and Working Stress, 7.	5		Chapter 3	
Plastic Expansion of Tubes, Vessels, and Plates, 6; C. Ultimate Stress and Working Stress, 7. 1.4 Creep A. The Andrade Analysis of the Creep Curve, 8; B. Transient Creep, 9; C. Viscous Creep, 10; D. Creep under Triaxial Stress, 11; E. The Mechanism of Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory 1.6 Ductile Fracture of Steel ("Notch Brittleness") 1.7 The Brittle Fracture of Steel ("Notch Brittleness") 1.8 Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.1 Codes and Standards 2.2 Design Considerations: Loadings 2.3 Pipe Bends: Structural Loading (Static and Cyclic) 3.4 Miter Bends Bends and Miters: Summary 3.5 Branch Connections: Repeated Loading 3.6 Branch Connections: Repeated Loading 3.7 Branch Connections: Repeated Loading 3.8 Branch Connections: Repeated Loading 3.9 Branch Connections: Practical Considerations and Summary 3.9 Branch Connections: Practical Considerations: Practical Considerations: Native Bends 3.10 Bolted Flanged Connections: Practical Considerations 3.11 Pipe Bends: Internal Pressure 3.2 Pipe Bends: Internal Pressure 3.3 Miter Bends 3.4 Pipe Bends: Internal Pressure 3.5 Branch Connections: Repeated Loading 3.6 Branch Connections: Repeated Loading 3.7 Corrugated Pipe 3.10 Bolted Flanged Connections: Practical Considerations: Practical Considerations: Practical Considerations: Practical Considerations: Practical Considerations: Practical Considerations of Structural Pressure 3.1 English Structural Loading Structure Interessure 3.2 Design A					Local Components	52
Stress, 7. 1.4 Creep A. The Andrade Analysis of the Creep Curve, 8; B. Transient Creep, 9; C. Viscous Creep, 10; D. Creep under Triaxial Stress, 11; E. The Mechanism of Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory 1.6 Ductile Fracture of Steel ("Notch Brittleness") 1.7 The Brittle Fracture of Steel ("Notch Brittleness") 1.8 Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flavs, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2. Design Considerations: Loadings 2. Design Considerations: Loadings 3. Sends and Miters: Summary 3. Bends and Miters: Summary 3. Branch Connections: Repeated Loading 3. Branch Connections: Comparison with Code Requirements 3. Branch Connections: Practical Considerations and Summary 6. Grapter 4 3. Bends and Miters: Summary 3. Branch Connections: Repeated Loading 3. Branch Connections: Practical Considerations and Summary 6. Grapter 4 3. Bends and Miters: Summary 3. Branch Connections: Comparison with Code Requirements 3. Branch Connections: Comparison with Code Requirements 3. Branch Connections: Comparison with Code Requirements 3. Branch Connections: Practical Considerations and Summary 6. Corrugated Pipe 3. Design Limita A Gundal Practical Considerations and Summary 6. Simplified Method for Flexibility and Fatigue, 27; 1. Damage by Overstress, 27; K. Corrosion 8. Simplified Method for Flexibility Code Rules 9. Chapter 4 9. Simplified Method for Square-corner Systems 9.				3.1	Pipe Bends: Structural Loading (Static and Cyclic)	52
1.4 Creep A. The Andrade Analysis of the Creep Curve, 8; B. Transient Creep, 9; C. Viscous Creep, 10; D. Creep under Triaxial Stress, 11; E. The Mechanism of Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory 1.6 Ductile Fractures 1.7 The Brittle Fracture of Steel ("Notch Brittleness") 1.8 Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Compound State of Stress, 23; D. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flavs, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.1 Codes and Standards 2.2 Design Considerations: Loadings 2.3 Mater Bends 3.4 Bends and Miters: Summary 3.5 Branch Connections: Repeated Loading 3.6 Branch Connections: Comparison with Code Requirements 3.7 Barach Connections: Practical Considerations and Summary 3.8 Branch Connections: Practical Considerations and Summary 3.9 Corrugated Pipe 3.10 Bolted Flanged Connections: Practical Considerations and Summary 3.11 Soluted Flanged Connections: Practical Considerations and Summary 3.12 Joints Between Dissimilar Materials 3.13 Other Components 3.14 Piping and Equipment Intereffects 3.15 Simplified Method for Flexibility Analysis 4.1 Scope and Merits of Approximate Methods 4.2 Thermal Expansion 4.3 Preliminary Segregation of Lines with Adequate Flexibility: Code Rules 4.4 Selected Chart-form Solutions 4.5 Approximate Solutions 4.6 The Simplified General Method for Square-corner Systems 4.7 Approximating the Effect of Curved Pipe and				3.2	Pipe Bends: Internal Pressure	60
A. The Andrade Analysis of the Creep Curve, 8; B. Transient Creep, 9; C. Viscous Creep, 10; D. Creep under Triaxial Stress, 11; E. The Mechanism of Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory 1.6 Ductile Fracture of Steel ("Notch Brittle- ness") 1.7 The Brittle Fracture of Steel ("Notch Brittle- ness") 1.8 Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of a Superposed Steady Stress, 23; D. Influence of a Superposed Steady Stress, 23; D. Influence of a Com- pound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Struc- tural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits Codes and Standards 2. Design Considerations: Loadings 2. Design Considerations: Loadings 2. Design Limits, Allowable Stresses, and Allowable 3. Branch Connections: Repeated Loading 3. Branch Connections: Comparison with Code Requirements 3. Branch Connections: Comparison with Code Requirements 3. Branch Connections: Comparison with Code Requirements 3. Branch Connections: Practical Considerations and Summary 3. Branch Connections: Practical Considerations and Summary 3. Branch Connections: Practical Considerations and Summary 3. Branch Connections: Comparison with Code Requirements 3. Branch Connections: Comparison with Code Requirements 3. Branch Connections: Practical Considerations and Summary 3. Branch Connections: Practical Considerations and Summary 3. Branch Connections: Practical Considerations and Summary 3. Design Limits and Summary 3. Branch Connections: Practical Considerations 3. Design Limits and Materials 3. Design Limits and Materials 3. Design Limits and Materials 3. Design Limits and Material	1.4		0	3.3	Miter Bends	60
8; B. Transient Creep, 9; C. Viscous Creep, 10; D. Creep under Triaxial Stress, 11; E. The Mechanism of Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory 1.6 Ductile Fracture of Steel ("Notch Brittleness") 1.7 The Brittle Fracture of Steel ("Notch Brittleness") 1.8 Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2. Design Considerations: Loadings 3. Branch Connections: Repeated Loading 66 Branch Connections: Comparison with Code Requirements 3. Design Connections: Practical Considerations and Summary 3. Design Connections: Comparison with Code Requirements 3. Design Connections: Comparison with Code Requirements 3. Design Connections: Comparison with Code Requirements 3. Design Connections: Comparison with Code	1.4		٥	3.4	Bends and Miters: Summary	61
Mechanism of Creep, 11; F. Evaluation and Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory 1.6 Ductile Fractures 1.7 The Brittle Fracture of Steel ("Notch Brittleness") 1.8 Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2. Design Considerations: Loadings Design Considerations: Loadings 32 3. Branch Connections: Comparison with Code Requirements Spranch Connections: Practical Considerations and Summary 5. Branch Connections: Comparison with Code Requirements Summary 5. Branch Connections: Practical Considerations and Summary 5. Branch Connections: Comparison with Code Requirements 5. Design Considerations and Summary 5. Corrugated Pipe 3. Design Considerations and Summary 5. Design Consideration of Steel ("Notch Brittleness") 5. Ductile Fractures 5. Design Consideration of Steel ("Notch Brittleness") 5. Ductile Fractures 5. Ductile Fracture		8; B. Transient Creep, 9; C. Viscous Creep,		3.5	Branch Connections: Static Pressure Loading	62
Engineering Use of Creep Tests, 12; G. Creep Fracture, 13. 1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory 1.6 Ductile Fractures 1.7 The Brittle Fracture of Steel ("Notch Brittleness") 1.8 Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.1 Codes and Standards Design Considerations: Loadings 2.2 Design Considerations: Loadings 2.3 Design Limits, Allowable Stresses, and Allowable Engineering Use of Patigue, 26; Creep quirements 3.8 Branch Connections: Practical Considerations and Summary 3.9 Corrugated Pipe 3.10 Bolted Flanged Connections: Practical Considerations and Summary 3.11 Bolted Flanged Connections: Practical Considerations and Summary 3.12 Joints Between Dissimilar Materials 3.13 Other Components 3.14 Piping and Equipment Intereffects 4.1 Scope and Merits of Approximate Methods 4.2 Thermal Expansion 4.3 Preliminary Segregation of Lines with Adequate Flexibility: Code Rules 5.7 Chapter 4 5.8 Fatigue Connections: Practical Considerations and Summary 5.9 Corrugated Pipe 5.10 Bolted Flanged Connections: Practical Considerations 5.11 Bolted Flanged Connections: Practical Considerations 5.12 Distributed Connections: Practical Considerations 5.13 Distributed Connections: Practical Considerations 5.14 Distributed Connections: Practical Considerations 5.15 Distributed Connections: Practical Considerations 5.16 Distributed Connections: Practical Considerations 5.17 Distributed Connections: Practical Considerations 5.18 Distributed Connections: Practical Considerations 5.19 Distributed Connections: Practical Considerations 6.6 Distributed Connections: Practical Considerations 6.7 Distrib				3.6	Branch Connections: Repeated Loading	66
1.5 Types of Fracture; Molecular Cohesion; the Griffith Theory 1.6 Ductile Fractures 1.7 The Brittle Fracture of Steel ("Notch Brittlenes") 1.8 Fatigue 1.8 Fatigue 1.9 A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue, 22; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. 1.8 Chapter 2 1.9 Design Assumptions, Stress Evaluation, and Design Limits 1.0 Codes and Standards 1.1 Codes and Standards 1.2 Joints Between Dissimilar Materials 1.3 Other Components 1.4 Piping and Equipment Intereffects 1.5 Scope and Merits of Approximate Methods 1.6 Outlie Fractures 1.7 Chapter 4 1.8 Scope and Merits of Approximate Methods 1.9 Scope and Merits of Approximate Methods 1.0 Scope and Merits of Approximate Method for Square-corner Systems 1.0 The Simplified General Method for Square-corner Systems 1.0 Summary 1.1 Bolted Flanged Connections: Practical Considerations 1.8 Bolted Flanged Connections: Practical Considerations 1.0 Bolted Flanged Connections: Pra		Engineering Use of Creep Tests, 12; G. Creep		3.7		67
1.7 The Brittle Fracture of Steel ("Notch Brittleness") 1.8 Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Specimens vs. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.1 Codes and Standards Design Considerations: Loadings 3.10 Bolted Flanged Connections: General Background 74 3.11 Bolted Flanged Connections: Practical Considerations: Other Components Simplified Flanged Connections: Practical Considerations 3.12 Joints Between Dissimilar Materials 75 3.13 Other Components Simplified Method for Flexibility Analysis Simplified Method for Flexibility Analysis 95 4.1 Scope and Merits of Approximate Methods 95 4.2 Thermal Expansion 95 4.3 Selected Chart-form Solutions 95 4.4 Selected Chart-form Solutions 95 4.5 Approximate Solutions 95 The Simplified General Method for Square-corner Systems 105 2.1 Codes and Standards 30 Design Limits, Allowable Stresses, and Allowable 4.7 Approximating the Effect of Curved Pipe and	1.5	Types of Fracture; Molecular Cohesion; the	13	3.8		69
ness") 1.8 Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of a Compound State of Stress, 25; E. Influence of a Compound State of Stress, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits Codes and Standards Design Considerations: Loadings 20 3.11 Bolted Flanged Connections: Practical Considerations: Practical Considerations Practical Processor Prac	1.6	Ductile Fractures	15	3.9	Corrugated Pipe	70
1.8 Fatigue A. General Features, 20; B. The Mechanism of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits Codes and Standards Design Considerations: Loadings 20 3.11 Bolted Flanged Connections: Practical Considerations 3.12 Joints Between Dissimilar Materials 75 3.13 Other Components 3.14 Piping and Equipment Intereffects Simplified Method for Flexibility Analysis 4.1 Scope and Merits of Approximate Methods 4.2 Thermal Expansion 4.3 Selected Chart-form Solutions 4.4 Selected Chart-form Solutions 4.5 Approximate Solutions 99 4.6 The Simplified General Method for Square-corner Systems 102 2.1 Codes and Standards 2.2 Design Considerations: Loadings 2.3 Design Limits, Allowable Stresses, and Allowable	1.7	The Brittle Fracture of Steel ("Notch Brittle-		3.10	Bolted Flanged Connections: General Background	74
of Fatigue, 22; C. Influence of a Superposed Steady Stress, 23; D. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.1 Codes and Standards Design Considerations: Loadings 2.2 Design Considerations: Loadings Design Limits, Allowable Stresses, and Allowable 3.13 Other Components 3.14 Piping and Equipment Intereffects Chapter 4 Simplified Method for Flexibility Analysis 4.1 Scope and Merits of Approximate Methods 4.2 Thermal Expansion 4.3 Preliminary Segregation of Lines with Adequate Flexibility: Code Rules 4.4 Selected Chart-form Solutions 4.5 Approximate Solutions 4.6 The Simplified General Method for Square-corner Systems 105 2.1 Codes and Standards 2.2 Design Considerations: Loadings 2.3 Design Limits, Allowable Stresses, and Allowable	1.8	ness'')		3.11		77
Steady Stress, 23; D. Influence of a Compound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Specimens vs. Fatigue Tests on Specimens vs. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.1 Codes and Standards 2.2 Design Considerations: Loadings 2.3 Design Limits, Allowable Stresses, and Allowable Simplified Method for Flexibility Analysis 4.1 Scope and Merits of Approximate Methods 4.2 Thermal Expansion 4.3 Preliminary Segregation of Lines with Adequate Flexibility: Code Rules 4.4 Selected Chart-form Solutions 4.5 Approximate Solutions 4.6 The Simplified General Method for Square-corner Systems 102 2.3 Design Limits, Allowable Stresses, and Allowable 4.7 Approximating the Effect of Curved Pipe and				3.12	Joints Between Dissimilar Materials	7 9
pound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Structural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27; J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Chapter 2 Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.1 Codes and Standards Design Considerations: Loadings 2.2 Design Considerations: Loadings Design Limits, Allowable Stresses, and Allowable 3.14 Priping and Equipment Interencets 4.1 Scope and Method for Flexibility Analysis 4.1 Scope and Merits of Approximate Methods 4.2 Thermal Expansion 4.3 Preliminary Segregation of Lines with Adequate Flexibility: Code Rules 4.4 Selected Chart-form Solutions 4.5 Approximate Solutions 30 The Simplified General Method for Square-corner Systems 4.6 The Simplified General Method for Square-corner Systems 4.7 Approximating the Effect of Curved Pipe and					•	81
J. Damage by Overstress, 27; K. Corrosion Fatigue, 28. Simplified Method for Flexibility Analysis 4.1 Scope and Merits of Approximate Methods 4.2 Thermal Expansion 90 4.3 Preliminary Segregation of Lines with Adequate Flexibility: Code Rules 90 4.4 Selected Chart-form Solutions 90 4.5 Approximate Solutions 90 4.6 The Simplified General Method for Square-corner 90 90 90 90 90 90 90 90 90 90 90 90 90		pound State of Stress, 25; E. Influence of Notches and of Surface Flaws, 25; F. Fatigue Tests on Specimens vs. Fatigue Tests on Struc- tural Parts, 26; G. Periodically Varying Thermal Stresses, 26; H. Thermal Fatigue, 27;		3.14		83
4.1 Scope and Merits of Approximate Methods 4.2 Thermal Expansion Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 30 4.4 Selected Chart-form Solutions 4.5 Approximate Solutions 2.1 Codes and Standards 30 4.6 The Simplified General Method for Square-corner Systems 30 2.3 Design Limits, Allowable Stresses, and Allowable 4.7 Approximating the Effect of Curved Pipe and					<u>-</u>	00
Chapter 2 Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.1 Codes and Standards 2.2 Design Considerations: Loadings 2.3 Design Limits, Allowable Stresses, and Allowable 4.2 Thermal Expansion 9.2 4.3 Preliminary Segregation of Lines with Adequate Flexibility: Code Rules 9.2 4.4 Selected Chart-form Solutions 4.5 Approximate Solutions 9.7 4.6 The Simplified General Method for Square-corner Systems 10.2 4.3 Preliminary Segregation of Lines with Adequate Flexibility: Code Rules 9.3 4.4 Selected Chart-form Solutions 9.4 4.5 Approximate Solutions 9.4 4.7 Approximating the Effect of Curved Pipe and		Fatigue, 28.				
Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits Codes and Standards Design Considerations: Loadings Design Considerations: Loadings Design Limits, Allowable Stresses, and Allowable 4.3 Preliminary Segregation of Lines with Adequate Flexibility: Code Rules 9.4 Selected Chart-form Solutions 4.5 Approximate Solutions 9.6 The Simplified General Method for Square-corner Systems 10.2 Approximating the Effect of Curved Pipe and					•••	
Chapter 2 Design Assumptions, Stress Evaluation, and Design Limits 2.1 Codes and Standards Design Considerations: Loadings Design Limits, Allowable Stresses, and Allowable Flexibility: Code Rules 92 4.4 Selected Chart-form Solutions 4.5 Approximate Solutions 4.6 The Simplified General Method for Square-corner Systems 102 4.7 Approximating the Effect of Curved Pipe and					-	91
and Design Limits 30 4.5 Approximate Solutions 93 2.1 Codes and Standards 30 4.6 The Simplified General Method for Square-corner Systems 102 2.2 Design Considerations: Loadings 32 Systems 102 2.3 Design Limits, Allowable Stresses, and Allowable 4.7 Approximating the Effect of Curved Pipe and					Flexibility: Code Rules	92
2.1 Codes and Standards 30 4.6 The Simplified General Method for Square-corner Systems 102 2.2 Design Considerations: Loadings 32 Systems 102 2.3 Design Limits, Allowable Stresses, and Allowable 4.7 Approximating the Effect of Curved Pipe and			30			94
2.2 Design Considerations: Loadings 32 Systems 102 2.3 Design Limits, Allowable Stresses, and Allowable 4.7 Approximating the Effect of Curved Pipe and	2.1					97
2.3 Design Limits, Allowable Stresses, and Allowable 4.7 Approximating the Effect of Curved Pipe and				4.6		102
			34	4.7	_	107

CONTENTS

x

	Chapter 5			Chapter 8	
	Flexibility Analysis by the General Analytical Method	115		Supporting, Restraining, and Bracing the Piping System	231
5.1	Scope and Field of Application of the General		8.1	Terminology and Basic Functions	231
	Analytical Method	115	8.2	Layout Considerations to Facilitate Support	233
5.2	Calculating Aids	116	8.3	The Elements of the Supporting System: Their	
5.3	General Outline of Operations	117		Selection and Location	236
5.4	The Solution of Simultaneous Equations	117	8.4	Fixtures	243
5.5	Single Plane Calculations	119	8.5	Pipe Attachments	248
5.6		120	8.6	Structures and Structural Connections	251
5.7	Circular Members	123	8.7	Erection and Maintenance of the Supporting, Restraining, and Bracing System	254
5.8	General Shape Coefficients	125		straining, and Dracing System	201
5.9	The Secondary Term	125			
5.10	Effects of Direct and Shear Forces	127		Chapter 9	
5.11	Working Planes and Cyclic Permutation	127		Vibration: Prevention and Control	257
5.12	Multiplane Pipe Lines with Two Fixed Ends	128	9.1	Introduction	257
5.13	Hinged Joints and Partially Constrained Ends	129	9.2	Fundamental Considerations in Piping Vibration	258
5.14	Skewed Members	134	•	a. Definitions, 258; b. Types of Vibration, 258;	
5.15	Branched Systems	145		c. Sources of Periodic Excitation, 259; d. Vibration Prevention and Control, 259.	
5.16	Intermediate Restraints	146	0.9	Structural Natural Frequency Calculations	260
5.17	Calculation of Deformations at any Point	153	9.3	a. The Spring-Mass Model, 260; b. Frequency	200
5.18	Symmetrical Pipe Lines	157		and Mass Effectiveness Factors for Different	
5.19	Inversion Procedures	157		End Constraints, 261; c. Variable Stiffness and	
5.20	Cold Springing	166		Variable Mass, 263; d. Combined Bending- Torsion, 264; e. Approximate Natural Fre-	
5.21	Weight Loading	170		quencies of Pipe Bends with Two Members	
5.22	Wind Loading	185		(Vibration Perpendicular to Plane of Bend), 265; f. Plates and Radial Mode in Pipe, 266.	
	Clarentes 6		9.4	Structural Resonance and Magnification Factors	267
	Chapter 6	100	9.5	Damping of Structural Vibrations	270
	Flexibility Analysis by Model Test	198		a. Hydraulic Snubbers, 270; b. Elastic Foundations for Rotating Machinery, 271.	
6.1	The Experimental Approach	198	9.6	Acoustic Natural Frequency Calculations	273
6.2	The Routinized Model Test	198	0.0	a. The Organ Pipe and Resonators, 273;	
6.3	The Kellogg Model Test	200		b. Special Cases of Multiple Resonator Formu-	
6.4	The Kellogg Model Test Laboratory and Equipment	201		las, 274; c. Piping Systems with Branches and Enlargements, 276.	
6.5	Typical Model Tests	202	9.7	Acoustic Resonance and Magnification Factors	277
0.0	Typical Model Lesus	202	9.8	Flow Pulsation Smoothing	279
			0.0	a. Tuned Resonators, 279; b. Surge Tanks,	
	Chapter 7			279; c. Gas Pulsation Dampener Principles,	
	Approaches for Reducing Expansion Effects:			280; d. Acoustic Expansion Tank, 281; e. Comparison of Gas Pulsation Smoothing Devices,	
	Expansion Joints	210		282; f. Hydraulic Hammer, 283; g. Magni-	
7.1	Introduction	210		tude and Direction of Forces on Piping Bends,	
7.2	Sources of Excessive Expansion Effects	210	•	285.	
7.3	Approaches for Reducing Expansion Effects	210	9.9	Illustration of Vibration Analysis of a Simple Piping System	285
7.4	Packed Type Expansion Joints	212		a. General Data and Estimates, 285; b. Esti-	
7.5	Bellows Type Expansion Joints	214		mates of Structural Natural Frequencies of	
	 a. Discussion, 214; b. Bellows Details, 214; c. Support and Protection of Bellows, 216; d. Fabrication of Bellows Joints, 217; e. Establishing Purchasing Requirements for Bellows Joints, 219; f. Materials and Deterioration, 220; g. Fatigue Basis for Predicting Bellows Life, 220; h. Testing and Quality Control of Bellows Joints, 222. 			Piping System, 285; c. Estimate of Lower Bounds of Structural Natural Frequencies, 286; d. Effect of Elasticity of Machine Foundation, 286; e. Estimate of Hydraulic Snubber Force and Damping Requirement for Reduction of Amplitude of Vibration, 287; f. Resonance Effect due to Wind Velocity, 287; g. Estimate of Acoustic Natural Frequencies, 287; h. Esti-	: :
7.6	Expansion Joints with Built-In Constraints	223		mate of Acoustic Frequency of the System Corresponding to its First Harmonic (2nd	
7.7	Establishing Expansion Joint Movement Demands	226		Mode), 288; i. Estimates of Some Possible Resonator Frequencies, 288; j. Estimate of	:

		CONTEN	NTS		хi
	Volume and Pressure Drop Requirement of		C- 3	Modulus of Elasticity, Carbon and Alloy Steels	342
	 Hydraulic Filters (Bottles) in the Compressor Discharge Lines, 290; k. Tuned Resonator Geometry, 290. Piping Vibration "Trouble Shooting" a. Background, 291; b. Vibration Measurement, 292; c. "Trouble Shooting" Procedure, 293. 		C- 4	Chart for Criterion in Par. 620(a) in Code for Pressure Piping ASA B31.1	343
9.10		291	C- 5	Length of Leg Required, Two-Member System, Both Ends Fixed, Thermal Expansion in Plane of Members	344
			C- 6	Moments and Forces, Two-Member System, Both Ends Fixed, Thermal Expansion in Plane of Members	345
	Appendix A		C- 7	Length of Leg Required, Two-Member System, Both Ends Fixed, One Support Displaced in the Direction of Adjoining Member	346
	History and Derivation of Piping Flexibility Analysis	295	C- 8	Moments and Forces, Two-Member System, Both Ends Fixed, One Support Displaced in the Direc-	
A.1	History of Piping Flexibility and Stress Analysis	295		tion of the Adjoining Member	347
A.2	Bibliography on Piping Flexibility and Stress Analysis Derivation of the General Analytical Method	297 299	C- 9	Length of Leg Required, Two-member System, Both Ends Fixed, One Support Displaced Normal to Plane of Members	348
A.3	Derivation of the General Analytical Method	299	C-10	Moments and Forces, Two-Member System, Both Ends Fixed, One Support Displaced Normal to Plane of Members	349
	Appendix B		C-11	Required Height, Symmetrical Expansion Loop	350
B.1	Derivation of Acoustic Vibration Formulas Multiple Resonator of nth Order	328 328	C-12	Moments and Forces, Symmetrical Expansion Loop	351
B.2	General Characteristic Equation for a Branched	020	C-13	Guided Cantilever Chart	352
15.2	Piping System	329		Correction Factor f, Guided Cantilever Method	353
B.3	Tuned Resonator Relations	331	C-15	Design Data: Trigonometric Constants for Circu-	
B.4	Simplified Surge Filter Analysis	333		lar Members	354
			C-16	Span vs. Stress, Horizontal Pipe Lines, Uniform Load	356
	Appendix C			Span vs. Natural Frequency and vs. Deflection, Horizontal Pipe Lines, Uniform Load	357
	Charts and Tables	336	C-18	Correction Factors for Use with Charts C-16 and	0.0
	Properties and Weights of Pipe	336		C-17	358
C- 2	Thermal Expansion, Carbon and Alloy Steels	341		Index	359