

Plates and shells : theory and analysis / Ansel C. Ugural. – Fourth edition. – Boca Raton ; London ; New York, © 2018

Spis treści

Preface	xv
Acknowledgments	xix
Author	xxi
Symbols	xxiii
Section I Fundamentals	
1. Basic Concepts	3
1.1 Introduction	3
1.2 Methods of Analysis	3
1.2.1 Case Studies in Analysis	5
1.3 Loading Classes and Equilibrium	5
1.3.1 Conditions of Equilibrium	5
1.3.2 Free-Body Diagrams	6
1.4 Units and Conversion	7
1.5 Stress Defined	8
1.5.1 Components of Stress	9
1.5.2 Sign Convention	10
1.6 Internal-Force Resultants	10
1.7 Differential Equations of Equilibrium	13
1.8 Transformation of Stress	15
1.8.1 Mohr's Circle for Stress	16
1.9 Strain Defined	19
1.10 Components of Strain	20
1.10.1 Conditions of Compatibility	21
1.10.2 Large Strains	22
1.11 Transformation of Strain	23
1.12 Engineering Materials	24
1.12.1 Stress-Strain Diagrams	25
1.13 Hooke's Law, Poisson's Ratio	26
1.14 General Properties of Materials	29
1.14.1 Metals	30
1.14.2 Plastics	30
1.14.3 Ceramics	30
1.14.4 Composites	31
1.15 Engineering Design	32

1.15.1 Design Procedure	32
1.16 Factor of Safety	33
1.16.1 Selection of a Factor of Safety	34
1.17 Problem Formulation and Solutions	35
1.17.1 Numerical Accuracy and Significant Digits	35
1.17.2 Computational Tools	35
Problems	36
References	42

2. Simple Structural Members 43

2.1 Introduction	43
2.2 Types of Structures	44
2.3 Axially Loaded Members	45
2.3.1 Columns	48
2.4 Stress Concentration Factors	50
2.5 Torsion of Circular Bars	50
2.5.1 Shear Stress	51
2.5.2 Angle of Twist	52
2.6 Rectangular Torsion Bars	53
2.7 Theory of Beams	54
2.8 Stresses in Beams	55
2.8.1 Normal Stress	55
2.8.2 Shear Stress	56
2.8.3 Shear Flow	57
2.9 Deflection of Beams	62
2.9.1 Method of Integration	62
2.9.2 Method of Superposition	66
2.10 Thin-Walled Pressure Vessels	68
2.11 Yield and Fracture Criteria	69
2.11.1 Maximum Principal Stress Theory	70
2.11.2 Coulomb-Mohr Theory	70
2.11.3 Maximum Shear Stress Theory	71
2.11.4 Maximum Distortion Energy Theory	72
2.11.5 A Typical Case of Combined Loadings	72
2.12 Strain Energy	75
2.13 Castigliano's Theorem	77
2.13.1 Statically Indeterminate Structures	79
Problems	80
References	87

Section II Plates

3. Plate-Bending Theory 91

3.1 Introduction	91
3.2 Historical Development of Plate and Shell Theory	92
3.3 General Behavior and Theory of Plates	93

3.4 Strain-Curvature Relations	94
3.4.1 Mohr's Circle of Curvature	96
3.5 Stresses and Stress Resultants	97
3.6 Equations for Transformation of Moment	99
3.7 Variation of Stress within a Plate	101
3.8 Governing Equation for Deflection of Plates	103
3.8.1 Reduction of Plate-Bending Problem to That of Deflection of a Membrane	103
3.9 Boundary Conditions	105
3.10 Exact Theory of Plates	107
3.11 Methods for Solution of Plate Deflections	109
3.11.1 Cylindrical Bending of Plate Strips	110
3.11.2 Variously Loaded Plates	113
3.12 Strain Energy of Plates	116
3.13 Energy Methods in Theory of Plates: Variational Principles	117
3.13.1 The Principle of Virtual Work	117
3.13.2 The Principle of Minimum Potential Energy	118
3.13.3 The Ritz Method	119
3.14 *Natural Frequencies of Plates by the Energy Method	120
Problems	121
References	124
4. Circular Plates	127
4.1 Introduction	127
4.2 Basic Relations in Polar Coordinates	127
4.3 The Axisymmetrical Bending	131
4.4 Equations of Equilibrium for Axisymmetrically Loaded Circular Plates	133
4.5 Uniformly Loaded Circular Plates	134
4.5.1 Plate with Clamped Edge	134
4.5.2 Plate with Simply Supported Edge	136
4.5.3 Comparison of Deflections and Stresses in Built-in and Simply Supported Plates	137
4.6 ^Effect of Shear on the Plate Deflection	139
4.7 Local Stresses at the Point of Application of a Concentrated Load	140
4.8 Circular Plates under a Concentrated Load at the Center	141
4.8.1 Plate with Clamped Edge	141
4.8.2 Plate with Simply Supported Edge	142
4.8.3 A Short Catalog of Solutions	143
4.9 Annular Plates with Simply Supported Outer Edges	143
4.9.1 Plate Loaded by Edge Moments	143
4.9.2 Plate Loaded by Shear Force at Inner Edge	146
4.10 Deflection and Stress by Superposition	149
4.10.1 Design Tables for Annular Plates	149
4.11 The Ritz Method Applied to Bending of Circular Plates	153
4.12 Asymmetrical Bending of Circular Plates	157
4.13 *Deflection by the Reciprocity Theorem	159

Problems	160
References	166
5. Rectangular Plates	167
5.1 Introduction	167
5.2 Navier's Solution for Simply Supported Rectangular Plates	167
5.3 Simply Supported Rectangular Plates under Various Loadings	170
5.4 Levy's Solution for Rectangular Plates	176
5.4.1 Simply Supported Rectangular Plate under Uniform Loading	178
5.5 Levy's Method Applied to Rectangular Plates under Nonuniform Loading	185
5.6 Rectangular Plates under Distributed Edge Moments	190
5.7 Method of Superposition Applied to Bending of Rectangular Plates	194
5.7.1 Rectangular Plate with Simple and Fixed Edges under Uniform Load	194
5.7.2 Fixed-Edge Rectangular Plate Carries Uniform Load	196
5.8 *The Strip Method	197
5.9 *Simply Supported Continuous Rectangular Plates	200
5.10 *Rectangular Plates Supported by Intermediate Columns	203
5.11 Rectangular Plates on Elastic Foundation	206
5.11.1 Simply Supported Plates	206
5.11.2 Plates with Arbitrary Boundary Conditions	207
5.12 The Ritz Method Applied to Bending of Rectangular Plates	208
Problems	217
References	222
6. Plates of Various Geometrical Forms	225
6.1 Introduction	225
6.2 *Method of Images	225
6.3 Equilateral Triangular Plate with Simply Supported Edges	228
6.3.1 Equilateral Triangular Plate under Uniform Moment M_0 along Its Boundary	228
6.3.2 Equilateral Triangular Plate under Uniform Load p_0	229
6.4 Elliptical Plates	230
6.4.1 Uniformly Loaded Elliptic Plate with Clamped Edge	230
6.4.2 Uniformly Loaded Elliptic Plate with Simply Supported Edge	232
6.5 Sector-Shaped Plates	232
6.6 *Stress Concentration around Holes in a Plate	235
Problems	238
References	239
7. Numerical Methods	241
7.1 Introduction	241
7.2 Finite Differences	241
7.3 Solution of the Finite Difference Equations	246
7.3.1 Load Representation	247

7.4 *Plates with Curved Boundaries	256
7.5 *The Polar Mesh	259
7.6 *The Triangular Mesh	260
7.7 The FEM	263
7.8 Properties of a 2D Finite Element	265
7.8.1 Displacement Matrix	265
7.8.2 Strain, Stress, and Elasticity Matrices	265
7.9 General Formulation of the FEM	267
7.10 Beam Element	270
7.10.1 Methods of Assemblage of the $[k]_e$ s	271
7.11 Triangular Finite Element	277
7.11.1 Displacement Function	277
7.11.2 The Stiffness Matrix	279
7.11.3 External Nodal Forces	279
7.12 Rectangular Finite Element	281
7.12.1 Displacement Function	281
7.12.2 The Stiffness Matrix	282
7.12.3 External Nodal Forces	282
Problems	286
References	291
8. Anisotropic Plates	293
8.1 Introduction	293
8.2 Basic Relationships	293
8.3 Determination of Rigidities	296
8.4 Rectangular Orthotropic Plates	298
8.4.1 Application of Navier's Method	298
8.4.2 Application of Levy's Method	300
8.4.3 Application of the Finite Difference Method	301
8.5 Elliptic and Circular Orthotropic Plates	303
8.6 Deflection by the Energy Method	304
8.7 *Plates of Isotropic Multilayers	307
8.8 The Finite Element Solution	309
8.9 A Typical Layered Orthotropic Plate	312
8.10 Laminated Composite Plates	314
8.11 Sandwich and Honeycomb Plates	319
8.11.1 Design of Sandwich-Type Beams and Plates	320
Problems	321
References	323
9. Plates under Combined Loads	325
9.1 Introduction	325
9.2 Governing Equation for the Deflection Surface	325
9.3 Buckling of Plates	329
9.4 Application of the Energy Method	333
9.5 *The Finite Difference Solution	340

9.6 Plates with Small Initial Curvature	344
9.7 *Bending to a Cylindrical Surface	346
Problems	350
References	352
10. Large Deflection of Plates	355
10.1 Introduction	355
10.2 Plate Behavior When Deflections are Large	355
10.3 Comparison of Small- and Large-Deflection Theories	356
10.3.1 An Approximate Method for the Circular Plates	356
10.3.2 Exact Solution for the Circular Plate Problem	359
10.4 General Equations for Large Deflections of Plates	360
10.5 Deflections by the Energy Method	362
10.6 The Finite Element Solution	366
10.6.1 Rectangular Finite Element	367
Problems	369
References	371
11. Thermal Stresses in Plates	373
11.1 Introduction	373
11.2 Stress, Strain, and Displacement Relations	373
11.3 Stress Resultants	374
11.4 The Governing Differential Equations	376
11.5 Simply Supported Rectangular Plate Subject to an Arbitrary Temperature Distribution	377
11.6 Simply Supported Rectangular Plate with Temperature Distribution Varying over the Thickness	378
11.7 Analogy between Thermal and Isothermal Plate Problems	380
11.7.1 Plates with Clamped Edges	380
11.7.2 Plates with Simply Supported or Free Edges	381
11.8 Axisymmetrically Heated Circular Plates	382
Problems	386
References	387
Section III Shells	
12. Membrane Stresses in Shells	391
12.1 Introduction	391
12.2 Theories and General Behavior of Shells	391
12.3 Load Resistance Action of a Shell	392
12.4 Geometry of Shells of Revolution	395
12.5 Symmetrically Loaded Shells of Revolution	396
12.6 Some Typical Cases of Shells of Revolution	398
12.6.1 Spherical Shell	399
12.6.2 Conical Shell	400
12.6.3 Circular Cylindrical Shell	401

12.7 Axially Symmetric Deformation	413
12.8 Asymmetrically Loaded Shells of Revolution	415
12.9 *Shells of Revolution under Wind Loading	417
12.10 Cylindrical Shells of General Shape	419
12.11 *Folded Structures	424
12.12 *Shell of General Form	424
12.13 *Breakdown of Elastic Action in Shells	428
Problems	430
References	436
13. Bending Stresses in Shells	439
13.1 Introduction	439
13.2 Shell Stress Resultants	439
13.3 Force, Moment, and Displacement Relations	441
13.4 Compound Stresses in a Shell	443
13.5 Strain Energy in the Bending and Stretching of Shells	444
13.6 Axisymmetrically Loaded Circular Cylindrical Shells	444
13.7 A Typical Case of the Axisymmetrically Loaded Cylindrical Shell	448
13.8 Shells of Revolution under Axisymmetrical Loads	451
13.8.1 Conical Shells	453
13.8.2 Spherical Shells	453
13.8.3 Cylindrical Shells	454
13.9 Governing Equations for Axisymmetrical Displacements	454
13.10 Spherical Shells under Axisymmetrical Load	456
13.11 Comparison of Bending and Membrane Stresses	458
13.12 *Simplified Theory of Spherical Shells under Axisymmetrical Load	460
13.13 The Finite Element Representations of Shells of General Shape	463
13.14 The Finite Element Solution of Axisymmetrically Loaded Shells	464
Problems	467
References	468
14. Applications to Pipes, Tanks, and Pressure Vessels	471
14.1 Introduction	471
14.2 Pipes Subjected to Edge Forces and Moments	471
14.2.1 Long Pipes	472
14.2.2 Short Pipes	474
14.3 Reinforced Cylinders	476
14.3.1 Cylinders with Collars That Prohibit Deflection	477
14.3.2 Cylinders with Collars That Resist Deflection	478
14.3.3 Cylinders with Closed Ends	478
14.4 Cylindrical Tanks	478
14.5 Thermal Stresses in Cylinders	481
14.5.1 Uniform Temperature Distribution	482
14.5.2 Radial Temperature Gradient	482
14.6 Thermal Stresses in Compound Cylinders	484
14.7 Discontinuity Stresses in Pressure Vessels	488

14.8 Cylindrical Vessel with Hemispherical Heads	489
14.8.1 Cylinder with Semispherical and Heads of Equal Thickness	490
14.8.2 Junction of a Cylinder and Sphere of Different Thickness	492
14.9 Cylindrical Vessels with Ellipsoidal Heads	493
14.10 Cylindrical Vessel with Flat Heads	493
14.11 *Design Formulas for Conventional Pressure Vessels	495
Problems	498
References	501
15. Cylindrical Shells under General Loads	503
15.1 Introduction	503
15.2 Differential Equations of Equilibrium	503
15.3 Kinematic Relationships	505
15.4 The Governing Equations for Deflections	507
15.5 *Approximate Relations	508
15.6 A Typical Case of Asymmetrical Loading	509
15.7 Curved Circular Panels	512
15.8 *A Simple Theory of Bending of Curved Circular Panels	514
15.9 *Curved Circular Panels with Variously Supported Edges	517
15.10 Inextensional Deformations	521
15.11 A Typical Layered Orthotropic Cylindrical Shell	524
15.12 Laminated Composite Cylindrical Shells	528
15.13 *Symmetrical Buckling under Uniform Axial Pressure	530
15.14 Nonsymmetrical Buckling under Uniform Compression	533
15.15 Buckling of Conical Shells	536
15.16 Buckling of Cylindrical and Spherical Pressure Vessels	536
Problems	537
References	538
Appendix A: Fourier Series Expansions	539
Appendix B: Tables	545
Appendix C: Introduction to Finite Element Analysis	555
Appendix D: Introduction to MATLAB®	569
Answers to Selected Problems	573
Index	577