

# Contents

<i>Preface</i>	ix
1 Introduction	1
2 Contact Laws	6
2.1 Introduction	6
2.2 Contact between Two Isotropic Elastic Solids	7
2.3 Indentation of Beams	9
2.4 Indentation of Plates	13
2.5 Indentation of a Laminate	15
2.6 Elastoplastic Models	19
2.7 Conclusion	24
2.8 Exercise Problems	24
3 Impact Dynamics	26
3.1 Introduction	26
3.2 Beam Theories	27
3.2.1 Bending of a Beam by a Uniform Load	27
3.2.2 Higher-Order Beam Theory	29
3.2.3 Timoshenko Beam Theory	31
3.2.4 Bernoulli-Euler Beam Theory	32
3.2.5 Static Loading on Beams	32
3.2.6 Recovery of Accurate Stresses from Beam Models	35
3.2.7 Harmonic Wave Propagation	36
3.2.8 Free Vibrations of Beams	39
3.2.9 Effect of Geometrical Nonlinearities	44
3.2.10 Summary	46
3.2.11 Exercise Problems	47
3.3 Plate Theories	48
3.3.1 First-Order Shear Deformation Theory	48
3.3.2 Classical Plate Theory (CPT)	54

3.3.3	Higher-Order Plate Theory (HOPT)	55
3.3.4	Static Deflections of Plates	59
3.3.5	Harmonic Wave Propagation	63
3.3.6	Free Vibrations of Plates	70
3.3.7	Transient Response of a Plate	71
3.3.8	Variational Models	75
3.3.9	Effect of Boundary Conditions	79
3.3.10	Summary	82
3.3.11	Exercise Problems	82
3.4	Impact Models	83
3.4.1	Spring-Mass Models	83
3.4.2	Energy Balance Models	86
3.4.3	Response of Bernoulli-Euler Beam to Impact by a Mass	89
3.4.4	Impact on a Simply Supported Plate (Classical Plate Theory)	96
3.4.5	Impact on a Simply Supported Plate (SDPT)	99
3.4.6	Approximate Solution for Wave-Controlled Impacts	113
3.4.7	Summary	126
3.4.8	Exercise Problems	127
3.5	Theory of Shells	128
3.5.1	Equations of Motion	128
3.5.2	Simply Supported Panels	131
3.5.3	Exercise Problems	132
3.6	Scaling	132
4	Low-Velocity Impact Damage	135
4.1	Impact Tests	136
4.2	Failure Modes in Low-Velocity Impact Damage	140
4.2.1	Morphology of Low-Velocity Impact Damage	140
4.2.2	Damage Development	144
4.2.3	Qualitative Models for Predicting Delamination Patterns	145
4.3	Experimental Methods for Damage Assessment	148
4.3.1	Nondestructive Techniques	148
4.3.2	Destructive Techniques	150
4.3.3	Observation of Damage Development during Impact	151
4.4	Parameters Affecting Impact Damage	151
4.4.1	Material Properties	152
4.4.2	Target Stiffness	154
4.4.3	Projectile Characteristics	154

4.4.4 Layup and Stitching	157
4.4.5 Preload	158
4.4.6 Environmental Conditions	158
4.5 Summary	158
4.6 Review Questions	159
5 Damage Prediction	161
5.1 Introduction	161
5.2 Damage in Thick Laminates	162
5.3 Damage in Thin Laminates	163
5.4 Damage Initiation	165
5.5 Propagation of Delaminations during Impact	168
5.6 Conclusion	170
5.7 Exercises	171
6 Residual Properties	172
6.1 Introduction	172
6.2 Compressive Strength	172
6.2.1 Test Procedures	173
6.2.2 Experimental Results	177
6.2.3 Prediction of Residual Compressive Strength	185
6.3 Buckling	186
6.3.1 Thin-Film Delaminations	189
6.3.2 Delaminated Beam-Plates	190
6.3.3 Buckling of Beam-Plates with Multiple Delaminations	193
6.3.4 Buckling of Delaminated Plates	195
6.4 Residual Tensile Strength	198
6.4.1 Experimental Results	199
6.4.2 Prediction of Residual Tensile Strength	201
6.5 Residual Flexural Strength	205
6.6 Fatigue	206
6.7 Effect of Impact Damage on Structural Dynamics Behavior	209
6.8 Exercise Problems	213
7 Ballistic Impact	215
7.1 Introduction	215
7.2 Experimental Techniques	216
7.3 Ballistic Limit and Residual Velocity of the Projectile	217
7.4 Failure Modes	219
7.5 Prediction of Ballistic Limit	220
7.6 Ceramic-Composite Armor	224
8 Repairs	228
8.1 Introduction	228

8.2 Mechanically Fastened Patches	230
8.3 Adhesive Bonded Joints	231
8.3.1 Peel and Shear Stresses in a Double-Lap Joint	232
8.3.2 Bonded Metal Patch Repair	235
8.3.3 Bonded Composite Repair	236
8.3.4 Staggered Bonded Repair	236
8.3.5 Repair of Composite Sandwich Structures	237
8.3.6 Resin Injection	237
8.4 Repair of Thermoplastic Composites	238
9 Impact on Sandwich Structures	240
9.1 Introduction	240
9.2 Contact Laws	240
9.2.1 Compressive Behavior of Core Materials	241
9.2.2 Contact between a Sandwich Beam and a Cylindrical Indentor	245
9.2.3 Contact between a Sandwich Plate and a Spherical Indentor	247
9.3 Impact Dynamics	248
9.4 Impact Damage	249
9.4.1 Failure Modes	249
9.4.2 Governing Parameters	251
9.4.3 Improved Sandwich Construction	254
9.4.4 High-Velocity Impacts	255
9.5 Residual Properties	255
<i>References</i>	258
<i>Index</i>	287