

# Contents

<b>1</b>	<b>Bending of a Three-Layered Plate with Surface Stresses</b> . . . . .	<b>1</b>
	Holm Altenbach and Victor A. Eremeyev	
1.1	Introduction . . . . .	1
1.2	Surface Elasticity . . . . .	2
1.3	Equilibrium of a Symmetric Three-Layered Plate . . . . .	3
1.3.1	Static Equations for a Three-Dimensional Plate-Like Solid	3
1.3.2	Transition to the Two-Dimensional Static Equations . . . .	5
1.3.3	Effective Stiffness Parameters . . . . .	6
1.4	Conclusions and Future Steps . . . . .	8
	References . . . . .	9
<b>2</b>	<b>A Numerical Study on the Potential of Acoustic Metamaterials</b> . . . . .	<b>11</b>
	Fabian Duvigneau and Sascha Duczek	
2.1	Introduction . . . . .	11
2.2	Models for the Parametric Studies . . . . .	14
2.3	Numerical Results . . . . .	18
2.3.1	Influence of the Distribution of the Spherical Inclusions .	18
2.3.2	Influence of the Material Properties of the Spherical Inclusions . . . . .	24
2.3.3	Influence of a Fixed Density-Volume-Product . . . . .	25
2.3.4	Influence of the Volume of the Inclusions . . . . .	27
2.3.5	Influence of the Number of Layers with Different Material Properties . . . . .	28
2.3.6	Discussion . . . . .	29
2.4	Conclusions . . . . .	30
	References . . . . .	32
<b>3</b>	<b>Electromechanical Degradation of Piezoelectric Patches</b> . . . . .	<b>35</b>
	Hassan Elahi, Marco Eugeni, and Paolo Gaudenzi	
3.1	Introduction . . . . .	35
3.2	Experimentation . . . . .	37

3.3	Results and Discussions .....	40
3.4	Conclusions .....	42
	References .....	43
<b>4</b>	<b>Hybrid-Mixed Solid-Shell Element for Stress Analysis of Laminated Piezoelectric Shells through Higher-Order Theories .....</b>	<b>45</b>
	Gennady M. Kulikov, Svetlana V. Plotnikova, and Erasmo Carrera	
4.1	Introduction .....	46
4.2	Sampling Surface Shell Formulation .....	48
4.3	Hu-Washizu Variational Equation .....	50
4.4	Hybrid-Mixed Solid-Shell Element Formulation .....	52
4.5	Numerical Examples .....	57
4.5.1	Three-Layer Piezoelectric Cylindrical Shell .....	57
4.5.2	Three-Layer Piezoelectric Spherical Shell .....	61
4.6	Conclusions .....	65
	References .....	65
<b>5</b>	<b>Finite Element Approach for Composite Magneto-Piezoelectric Materials Modeling in ACELAN-COMPOS Package .....</b>	<b>69</b>
	Natalia V. Kurbatova, Dmitry K. Nadolin, Andrey V. Nasedkin, Pavel A. Oganesyan, and Arcady N. Soloviev	
5.1	Introduction .....	70
5.2	Piezomagnetolectric Boundary Problems .....	71
5.3	Finite Element Approximations .....	73
5.4	Homogenization of Two-Phase Piezomagnetolectric Materials ...	75
5.5	Inhomogenous Polarization .....	78
5.6	Three-Dimensional Models for Composite Materials .....	81
5.7	Conclusions .....	86
	References .....	87
<b>6</b>	<b>Robust Displacement and Mixed CUF-Based Four-Node and Eight-Node Quadrilateral Plate Elements .....</b>	<b>89</b>
	Thi Huyen Cham Le, Michele D'Ottavio, Philippe Vidal, and Olivier Polit	
6.1	Introduction .....	89
6.2	Variable Kinematics Plate Model .....	93
6.2.1	Variational Statements .....	93
6.2.1.1	The Principle of Virtual Displacements .....	93
6.2.1.2	Reissner's Mixed Variational Theorem .....	94
6.2.2	Variable Kinematics Assumptions .....	95
6.2.3	The Stress and Strain Fields .....	96
6.2.3.1	PVD Formulation .....	97
6.2.3.2	RMVT Formulation .....	97
6.3	Finite Element Approximations .....	98
6.3.1	Displacement-Based Finite Elements .....	98
6.3.2	RMVT-Based Finite Elements .....	101

6.4	Numerical Results . . . . .	102
6.4.1	Eigenvalues of the Stiffness Matrix . . . . .	103
6.4.2	Transverse Shear Locking Test . . . . .	106
6.4.2.1	PVD Based Elements: ED2 Model . . . . .	107
6.4.2.2	RMVT Based Elements: EM2 and EM2c Models . . . . .	109
6.4.2.3	Effectiveness of the QC4/CL8 Approach for Variable Kinematics Models . . . . .	110
6.4.3	The Distortion Tests . . . . .	111
6.4.3.1	The Square Plate Test . . . . .	111
6.4.3.2	The Circular Plate Test . . . . .	112
6.5	Conclusion . . . . .	113
	Appendix1 . . . . .	115
	Appendix2 . . . . .	115
	References . . . . .	116
<b>7</b>	<b>Effect of Magnetic Field on Free and Forced Vibrations of Laminated Cylindrical Shells Containing Magnetorheological Elastomers . . . . .</b>	<b>119</b>
	Gennadi Mikhasev, Ihnat Mlechka, and Svetlana Maevskaya	
7.1	Introduction . . . . .	120
7.2	Structure of Laminated Shell . . . . .	121
7.3	Basic Hypotheses . . . . .	123
7.4	Governing Equations . . . . .	124
7.4.1	Governing Equations in Terms of Stress Resultants and Couples . . . . .	124
7.4.2	Governing Equations in Terms of Displacements . . . . .	126
7.4.3	Equations of Technical Shell Theory . . . . .	127
7.4.4	Error of Governing Equations . . . . .	129
7.5	Free Vibrations of MRE-based Laminated Cylindrical Shells and Panels . . . . .	130
7.5.1	Lengthy Simply Supported Cylinders . . . . .	130
7.5.2	Medium-Length Cylindrical Panels . . . . .	134
7.5.3	Vibrations of Medium-Length Cylindrical Shells in Nonuniform Magnetic Field . . . . .	136
7.6	Forced Vibrations . . . . .	141
7.7	Conclusions . . . . .	145
	References . . . . .	146
<b>8</b>	<b>Impact-Induced Internal Resonance Phenomena in Nonlinear Doubly Curved Shallow Shells with Rectangular Base . . . . .</b>	<b>149</b>
	Yury A. Rossikhin (†), Marina V. Shitikova, and Mohammed Salih Khalid	
8.1	Introduction . . . . .	149
8.2	Problem Formulation and Governing Equations . . . . .	152
8.3	Method of Solution . . . . .	156

8.3.1	Solution of Equations at Order of $\varepsilon$ .....	157
8.3.2	Solution of Equations at Order of $\varepsilon^2$ .....	159
8.3.3	Impact-induced internal resonance $\omega_1 = 2\omega_2$ .....	159
8.3.3.1	Initial Conditions .....	165
8.3.3.2	Contact Force and Shell's Deflection at the Point of Impact .....	168
8.3.4	Solution of Equations at Order of $\varepsilon^3$ .....	170
8.3.4.1	Impact-Induced Three-to-One Internal Resonance .....	171
8.3.4.2	Phase Portraits .....	175
8.3.4.3	Initial Conditions .....	180
8.3.4.4	The Contact Force and Shell's Deflection at the Point of Contact .....	181
8.4	Conclusion .....	183
	References .....	185
	Appendix .....	187
<b>9</b>	<b>Ferrous Material Fill: Magnetization Channels, Layer-by-Layer and Average Permeability, Element-to-Element Field</b> .....	<b>191</b>
	Anna A. Sandulyak, Darya A. Sandulyak, Vera A. Ershova, and Alexander V. Sandulyak	
9.1	Introduction. Qualitative Assessment of Typical Intervals for the Volume Fraction of a Ferrous Component .....	192
9.2	Quantitative Assessment of Characteristic Intervals for the Volume Fraction of a Ferrous Component and its Values for the Filling Materials .....	193
9.3	Selective (in the Form of Chains of Channels) Magnetization of Ferrous Material. Concept of Layer-Tube Channels .....	194
9.4	Data of the In-Channel (Core and Layer-Tube) Magnetic Flux, Average Induction, and Permeability .....	196
9.5	Magnetizing Channel Layer Tubes: Local Permeability, Radial Profile .....	199
9.6	Magnetization Channel Core: Average Magnetic Permeability . . .	201
9.7	Generalized Dependencies for Comparison of the Calculated and Experimental Data .....	203
9.8	Magnetization Channel and Harness of the Channels (in the Ferromaterial Filling): Average Magnetic Permeability .....	204
9.9	The Physical Meaning of the Profile Permeability. Relative Field Strength Between Ferroelements .....	206
9.10	Conclusions .....	208
	References .....	209
<b>10</b>	<b>Modeling and Simulation of a Chemically Stimulated Hydrogel Bilayer Bending Actuator</b> .....	<b>211</b>
	Martin Sobczyk and Thomas Wallmersperger	
10.1	Introduction .....	211

10.2	Chemo-Electro-Mechanical Field Formulation . . . . .	213
10.2.1	Chemical Field . . . . .	214
10.2.2	Electrical Field . . . . .	214
10.2.3	Mechanical Field . . . . .	215
10.2.4	Numerical Solution Procedure . . . . .	216
10.3	Numerical Simulation of a Chemically Stimulated Bilayer . . . . .	217
10.4	Conclusion . . . . .	224
	References . . . . .	224
<b>11</b>	<b>Mathematical Modelling of Piezoelectric Generators on the Base of the Kantorovich Method . . . . .</b>	<b>227</b>
	Arkadiy N. Soloviev, Valerii A. Chebanenko, and Ivan A. Parinov	
11.1	Introduction . . . . .	227
11.2	Mathematical Modelling of PEG . . . . .	229
11.2.1	The Boundary-Value Problem in the Theory of Electroelasticity . . . . .	229
11.2.2	Modeling of Cantilever Type PEGs . . . . .	230
11.2.2.1	Numerical Experiment . . . . .	238
11.2.2.2	Comparison with Finite Element . . . . .	240
11.2.2.3	Parametric Studies . . . . .	242
11.2.3	Modelling of Stack Type PEG . . . . .	247
11.2.3.1	Parametric Studies . . . . .	251
11.2.3.2	Comparison With Finite Element . . . . .	255
11.3	Summary . . . . .	255
	References . . . . .	257
<b>12</b>	<b>Modeling of Dielectric Elastomers Accounting for Electrostriction by Means of a Multiplicative Decomposition of the Deformation Gradient Tensor . . . . .</b>	<b>259</b>
	Elisabeth Staudigl, Michael Krommer, and Alexander Humer	
12.1	Introduction . . . . .	259
12.2	Electromechanical Coupling by Electrostatic Force . . . . .	261
12.2.1	Kinematics in Nonlinear Elasticity . . . . .	261
12.2.2	Electro-Elastic Balance Laws . . . . .	263
12.2.2.1	Maxwell Equation and Electric Body Forces . . . . .	263
12.2.2.2	Conservation Laws . . . . .	264
12.2.3	Lagrangian (Material) Framework . . . . .	266
12.2.4	Constitutive Relations . . . . .	267
12.3	Electromechanical Coupling Using a Multiplicative Decomposition of the Deformation Gradient Tensor . . . . .	269
12.3.1	Total Stress . . . . .	272
12.3.2	Intermediate Configuration . . . . .	273
12.4	Electrostriction . . . . .	274
12.4.1	Homogeneously Deformed Plate . . . . .	276
12.4.1.1	Plane Stress . . . . .	277
12.4.1.2	Incompressibility . . . . .	277

12.4.1.3	Electrostatic Force	278
12.4.1.4	Traction Boundary Condition	279
12.5	Electromechanical Stability	280
12.5.1	Stiffening Effect of Electrodes	285
12.6	Conclusion and Outlook	287
	References	288
<b>13</b>	<b>Mechanics of Axially Moving Structures at Mixed Eulerian-Lagrangian Description</b>	<b>291</b>
	Yury Vetyukov	
13.1	Introduction	291
13.2	Linear Waves in a Moving String	293
13.3	Large Vibrations of an Axially Moving String	294
13.3.1	Mixed Eulerian-Lagrangian Description of the Kinematics of Motion	296
13.3.2	Mixed Form of the Variational Equation of Virtual Work	297
13.3.3	Finite Element Approximation	298
13.3.4	Lagrange's Equation of Motion of the Second Kind	299
13.3.5	Example Solution	300
13.4	Finite Deformations of an Axially Moving Plate	302
13.4.1	Kinematic Description	303
13.4.2	Deformation and Strain Energy	305
13.4.3	Finite Element Scheme	308
13.4.4	Benchmark Problem	310
13.4.5	Time Stepping and Boundary Conditions	311
13.4.6	Simulation of a Moving Plate	313
13.5	Mixed Eulerian-Lagrangian Formulation in the Analysis of a Belt Drive	315
13.5.1	Problem Statement	316
13.5.2	Problem-Specific Coordinate System	317
13.5.3	Mixed Lagrangian-Eulerian Kinematic Description	319
13.5.4	Finite Element Approximation and Energy	319
13.5.5	Simulation Results	320
13.5.6	Work in Progress and Outlook	321
	References	323
<b>14</b>	<b>A software platform for the analysis of porous die-cast parts using the finite cell method</b>	<b>327</b>
	Mathias Würkner, Sascha Duczek, Harald Berger, Heinz Köppe, Ulrich Gabbert	
14.1	Introduction	327
14.2	The Finite Cell Method	329
14.2.1	Fundamentals of the Finite Cell Method	329
14.2.2	Numerical Integration	332
14.3	Concept of the Software Platform	333
14.4	Trouble Shooting the STL Data Set	335

14.5	Verification of the Software Platform .....	337
14.6	Summary and Outlook .....	339
	References .....	341
<b>15</b>	<b>Refined One-Dimensional Models for the Multi-Field Analysis of Layered Smart Structures .....</b>	<b>343</b>
	Enrico Zappino and Erasmo Carrera	
15.1	Introduction .....	343
15.2	Thermo-Piezo-Elastic One-Dimensional Model .....	346
15.2.1	Kinematic Approximation .....	347
15.2.1.1	Classical Beam Models .....	347
15.2.1.2	Refined One-Dimensional Models .....	348
15.2.1.3	Taylor Expansion Models (TE) .....	349
15.2.1.4	Lagrange Expansion Models (LE).....	349
15.2.2	Geometrical Relations.....	350
15.2.3	Constitutive Relations .....	351
15.2.4	Governing Equation .....	352
15.2.5	Loading Vector .....	354
15.2.6	Rotation and Assembly of the Fundamental Nucleus ....	355
15.2.7	The Stiffness Matrix Assembly .....	356
15.3	Numerical Results.....	356
15.3.1	Piezo-Elastic Model Assessment .....	357
15.3.2	Cantilever Beams with Piezo-Patches .....	358
15.3.3	Thermo-Piezo-Elastic Model Assessment .....	361
15.4	Conclusions .....	363
	References .....	363

Analysis and Modelling of Advanced Structures and  
Smart Systems

Altenbach, H.; Carrera, E.; Kulikov, G. (Eds.)

2018, XVIII, 366 p. 192 illus., 72 illus. in color.,

Hardcover

ISBN: 978-981-10-6764-8