

# Contents

<i>Foreword</i>	vii
<i>List of Figures</i>	xix
<i>List of Tables</i>	xxi
<i>Acknowledgments</i>	xxiii
1. Science of seismology	1
Preliminary remarks . . . . .	1
1.1 Purpose and methodology: Historical sketch . . . . .	2
1.2 Classification . . . . .	10
Closing remarks . . . . .	11
1.3 Exercises . . . . .	14
2. Seismology and continuum mechanics	19
Preliminary remarks . . . . .	19
2.1 On axiomatic formulation . . . . .	21
2.2 Kinematic descriptions . . . . .	23
2.2.1 Spacetime . . . . .	23
2.2.2 Motion . . . . .	24
2.2.3 Coordinates . . . . .	27
2.3 Field equations . . . . .	28
2.3.1 Balance equations . . . . .	28
2.3.2 Continuity equation . . . . .	29
2.3.3 Cauchy equation of motion . . . . .	31
Closing remarks . . . . .	33
2.4 Exercises . . . . .	34

3.	Hookean solid: Material symmetry	41
	Preliminary remarks . . . . .	41
3.1	Hookean solids . . . . .	42
3.2	Material symmetry . . . . .	45
3.2.1	On symmetries . . . . .	45
3.2.2	On tensor rotations . . . . .	48
3.2.3	Finite and infinitesimal elasticities . . . . .	49
3.2.3.1	Deformation gradient . . . . .	49
3.2.3.2	Elasticity tensor . . . . .	52
3.2.3.3	Prestressed linearly elastic materials . . . . .	54
3.2.3.4	Material symmetry: Finite elasticity . . . . .	57
3.2.3.5	Material symmetry: Relation between finite and infinitesimal elasticities . . . . .	58
3.2.4	Symmetry classes . . . . .	61
3.2.4.1	Material-symmetry conditions . . . . .	61
3.2.4.2	Hooke's law in $\mathbb{R}^3$ and $\mathbb{R}^6$ . . . . .	64
3.2.4.3	Index symmetries . . . . .	65
3.2.4.4	Kelvin notation . . . . .	67
3.2.4.5	Monoclinic tensor . . . . .	69
3.2.4.6	Orthotropic tensor . . . . .	75
3.2.4.7	Tetragonal tensor . . . . .	76
3.2.4.8	Transversely isotropic tensor . . . . .	78
3.2.4.9	Trigonal tensor . . . . .	79
3.2.4.10	Cubic tensor . . . . .	79
3.2.4.11	Isotropic tensor . . . . .	79
3.2.4.12	Relations among elasticity parameters . . . . .	80
3.2.4.13	Diclinic solids . . . . .	85
3.2.4.14	Hexagonal solids . . . . .	87
	Closing remarks . . . . .	88
3.3	Exercises . . . . .	89
4.	Hookean solid: Effective symmetry and equivalent medium	95
	Preliminary remarks . . . . .	95
4.1	Effective symmetries . . . . .	96
4.1.1	On accuracy . . . . .	96
4.1.2	Fixed orientation of coordinate system . . . . .	103
4.1.2.1	Monoclinic tensor . . . . .	104
4.1.2.2	Orthotropic tensor . . . . .	105
4.1.2.3	Tetragonal tensor . . . . .	106

4.1.2.4	Transversely isotropic tensor . . . . .	107
4.1.2.5	Trigonal tensor . . . . .	107
4.1.2.6	Cubic tensor . . . . .	108
4.1.2.7	Isotropic tensor . . . . .	109
4.1.3	Optimal orientation of coordinate system . . . . .	110
4.2	Equivalent media . . . . .	113
4.2.1	Introduction . . . . .	113
4.2.2	Equivalence parameters for isotropic layers . . . . .	116
4.2.2.1	Formulæ . . . . .	116
4.2.2.2	Justification . . . . .	118
4.2.2.3	Interpretation . . . . .	129
4.2.3	Equivalence parameters for TI layers . . . . .	130
	Closing remarks . . . . .	132
4.3	Exercises . . . . .	134
5.	Body waves	159
	Preliminary remarks . . . . .	159
5.1	Wave equations . . . . .	160
5.1.1	Assumptions and formulation . . . . .	160
5.1.2	Particular case: Isotropy and homogeneity . . . . .	161
5.1.3	Particular case: Inhomogeneous string . . . . .	167
5.1.4	Particular case: String with friction . . . . .	171
5.2	Solutions of wave equation . . . . .	171
5.2.1	Introduction . . . . .	171
5.2.2	Product solution . . . . .	172
5.2.3	d'Alembert solution . . . . .	173
5.2.3.1	d'Alembert's approach . . . . .	173
5.2.3.2	Euler's approach . . . . .	174
5.2.3.3	Spherical-symmetry approach . . . . .	177
5.2.4	Fourier-transform solution . . . . .	178
5.2.5	Green's-function solution . . . . .	182
5.3	On approximations . . . . .	185
	Closing remarks . . . . .	188
5.4	Exercises . . . . .	189
6.	Surface, guided and interface waves	197
	Preliminary remarks . . . . .	197
6.1	Introduction . . . . .	198

6.2	Surface waves: Homogeneous elastic halfspace . . . . .	200
6.3	Guided waves: Homogeneous layer above halfspace . . . . .	209
6.3.1	Elastic layer above rigid halfspace . . . . .	209
6.3.2	Elastic layer above elastic halfspace . . . . .	212
6.4	Existence of surface and guided waves . . . . .	216
6.4.1	Introduction . . . . .	216
6.4.2	Elasticity parameters and mass densities . . . . .	216
6.4.3	On Love waves in homogeneous halfspace . . . . .	217
6.4.4	On $P$ waves in homogeneous halfspace . . . . .	217
6.5	Interface waves: Homogenous halfspaces . . . . .	219
6.5.1	Introduction . . . . .	219
6.5.2	Elastic and liquid halfspaces . . . . .	220
6.5.3	Liquid halfspaces . . . . .	231
6.6	Existence of interface waves . . . . .	235
6.6.1	Introduction . . . . .	235
6.6.2	Elasticity parameters and mass densities . . . . .	236
6.6.3	On $SH$ waves as interface waves . . . . .	236
	Closing remarks . . . . .	238
6.7	Exercises . . . . .	239
7.	Variational principles in seismology . . . . .	241
	Preliminary remarks . . . . .	241
7.1	Historical comments . . . . .	242
7.2	Fermat's principle . . . . .	243
7.2.1	Isotropic layered medium . . . . .	243
7.2.2	Isotropic continuously inhomogeneous medium . . . . .	246
7.2.3	Global optimization and causality . . . . .	249
7.2.4	Stationarity versus minimization . . . . .	251
7.2.5	Mathematical justification . . . . .	252
7.2.5.1	Fermat's principle . . . . .	252
7.2.5.2	Head waves . . . . .	254
7.2.6	Physical interpretation . . . . .	257
7.2.6.1	Macroscopic interpretation . . . . .	257
7.2.6.2	Microscopic interpretation . . . . .	259
7.2.6.3	Phase consideration . . . . .	259
7.2.7	On teleology of Fermat's principle . . . . .	260
7.3	Hamilton's principle . . . . .	264
7.3.1	Action . . . . .	264
7.3.2	Wave equation . . . . .	265

7.3.3	Mathematical justification . . . . .	266
7.3.4	Physical interpretation . . . . .	267
7.4	Conserved quantities . . . . .	268
7.4.1	Introduction . . . . .	268
7.4.2	Ray parameter . . . . .	268
7.4.2.1	Isotropy . . . . .	268
7.4.2.2	Anisotropy . . . . .	270
7.4.3	Hamiltonian and Lagrangian . . . . .	272
7.4.3.1	Ray theory . . . . .	272
7.4.3.2	Classical mechanics . . . . .	274
	Closing remarks . . . . .	274
7.5	Exercises . . . . .	275
		276
8.	Gravitational and thermal effects in seismology	283
	Preliminary remarks . . . . .	283
8.1	Gravitation . . . . .	284
8.1.1	Body forces . . . . .	284
8.1.2	Wave speeds . . . . .	287
8.2	On weak gravitational waves . . . . .	291
8.3	Temperature . . . . .	298
8.3.1	Propagation and diffusion . . . . .	298
8.3.2	Isothermal and adiabatic formulations . . . . .	299
8.3.2.1	Lamé parameters . . . . .	299
8.3.2.2	Bulk moduli . . . . .	301
	Closing remarks . . . . .	301
8.4	Exercises . . . . .	303
9.	Seismology as science	307
	Preliminary remarks . . . . .	307
9.1	Hypotheticodeductive formulation . . . . .	308
9.1.1	Hypotheses . . . . .	308
9.1.2	Deductive argumentation . . . . .	310
9.2	Theory versus data . . . . .	313
9.2.1	Introduction . . . . .	313
9.2.2	Theory-ladenness of data . . . . .	313
9.2.3	Underdetermination of theory by data . . . . .	314
9.3	Bayesian inference . . . . .	315
9.4	Predictions versus explanations . . . . .	318

9.4.1	Introduction . . . . .	318
9.4.2	Covering-law model . . . . .	319
9.4.3	Inference to best explanation . . . . .	321
9.5	Realistic approach versus instrumental approach . . . . .	321
9.6	Coherence theory of justification . . . . .	323
	Closing remarks . . . . .	324
9.7	Exercises . . . . .	326
Appendix A On covariant and contravariant transformations		331
	Preliminary remarks . . . . .	331
A.1	Contravariant transformations . . . . .	332
A.2	Covariant transformations . . . . .	333
A.3	Mixed transformations . . . . .	334
A.4	Transformations in Cartesian coordinates . . . . .	334
	Closing remarks . . . . .	335
Appendix B On covariant derivatives		337
	Preliminary remarks . . . . .	337
B.1	Metric tensor . . . . .	338
B.2	Christoffel symbol . . . . .	341
B.3	Covariant derivative . . . . .	342
	Closing remarks . . . . .	344
Appendix C List of symbols		347
C.1	Mathematical relations and operations . . . . .	347
C.2	Physical quantities . . . . .	348
C.2.1	Greek letters . . . . .	348
C.2.2	Roman letters . . . . .	348
<i>Bibliography</i>		351
<i>Index</i>		363
About the Author		380