

Contents

<i>Preface</i>	<i>page</i> xiii
1 Introduction	1
1.1 What this book is about	1
1.2 Definition of a continuum	5
1.3 Governing equations	7
1.4 Vectors and tensors	10
1.5 Solving the equations	11
1.6 The art of modeling	12
2 Review of elementary mechanics	14
2.1 Introduction	14
2.2 Newton's laws	15
2.3 Vectors, coordinates, and components	17
2.4 Position and velocity vectors	20
2.5 Cylindrical and spherical coordinates; left- and right-handed Cartesian axes	22
2.6 Vector statistics	24
2.7 Example of the use of coordinates	25
2.8 Numerical solution of the equations of motion	29
2.9 Work, energy, and power	31
2.10 Application to meteorite impact	36
2.11 Application to fluid drag and lift	37
2.12 Stream power	40
2.13 The equations of motion including drag	41
2.14 Rotation using the vector product	45
2.15 The vector product (cross-product)	47
2.16 Rotation of vectors about an axis	48
2.17 Moments and torque	52
2.18 Angular momentum and moment of inertia	53

viii	<i>Contents</i>	
2.19	Centrifugal and tidal forces	54
2.20	Coriolis forces	56
2.21	Review problems	59
2.22	Suggested reading	66
3	Dimensional analysis and the theory of models	69
3.1	Introduction	69
3.2	Dimensions and dimensional homogeneity	70
3.3	Dimensionless products and the pi theorem	72
3.4	Scale models	83
3.5	More on modeling	86
3.6	Uses of dimensional analysis	89
3.7	Review problems	91
3.8	Suggested reading	98
4	Stress	100
4.1	Introduction	100
4.2	Friction	102
4.3	Rock falls and avalanches	106
4.4	Strength	109
4.5	Experimental results for rock friction	116
4.6	Definition of stress	117
4.7	Notation and sign convention	118
4.8	Symmetry of stress components	120
4.9	Equilibrium of a small prism	122
4.10	The stress ellipsoid	124
4.11	The Mohr circle of stress	126
4.12	Failure: the Navier–Coulomb criterion	128
4.13	Friction and faulting in the earth’s crust	131
4.14	Stress fields and trajectories	133
4.15	State of stress beneath a level ground surface	134
4.16	Sliding on slopes	136
4.17	Tensor components of stress	142
4.18	Why stress is a tensor	152
4.19	Review problems	153
4.20	Suggested reading	160
5	Pressure, buoyancy, and consolidation	162
5.1	Concept of pressure in a fluid	162
5.2	Pressure in a solid (geostatic pressure)	164
5.3	Buoyancy	165
5.4	Is buoyancy a surface or a body force?	167
5.5	Isostasy	170

	<i>Contents</i>	ix
5.6	Rise and intrusion of magma in the crust	172
5.7	Forces on settling grains	175
5.8	Buoyancy in debris flows	177
5.9	Effective and neutral stress	178
5.10	Consolidation	180
5.11	Geopressured zones	183
5.12	Effect of neutral stresses on shear strength	185
5.13	Review problems	186
5.14	Suggested reading	192
6	Flow through porous media	193
6.1	Darcy's law	193
6.2	Hydraulic head	195
6.3	Hydraulic conductivity	198
6.4	Nature of permeability: relation to porosity, tortuosity, and specific surface area	201
6.5	Gradient and curl and their application to Darcy's law and other diffusion equations	203
6.6	Divergence and the conservation of mass	207
6.7	Flow to a well	209
6.8	Flow nets	211
6.9	Numerical solution of the Laplace equation	214
6.10	Dispersion by flow	215
6.11	Refraction of groundwater flow	217
6.12	The water table: flow near a topographic surface	220
6.13	Fluids of different densities: the freshwater lens	221
6.14	Effect of groundwater on sliding on an infinite slope	222
6.15	Theory of consolidation	224
6.16	Review problems	228
6.17	Suggested reading	233
7	Strain	234
7.1	Definitions	234
7.2	Measures of strain	236
7.3	Plane strain	238
7.4	Approach through Taylor's theorem	244
7.5	Generalization to three dimensions	247
7.6	Measurement of strain	248
7.7	Strain ellipse, Mohr circle of strain	248
7.8	Review problems	251
7.9	Suggested reading	254

x	<i>Contents</i>	
8	Elasticity	255
8.1	Constitutive equations	255
8.2	Hooke’s law	256
8.3	Generalized Hooke’s law	258
8.4	Rigidity modulus	261
8.5	Bulk modulus	262
8.6	Lamé’s constants	263
8.7	Measurement of stress in rocks	265
8.8	Hydraulic fracturing of petroleum reservoir rocks	267
8.9	State of stress in the crust of the earth	270
8.10	Flexure of plates	271
8.11	Equations of motion: Navier’s equation	280
8.12	Application to seismic waves	284
8.13	Review problems	289
8.14	Suggested reading	295
9	Viscous fluids	296
9.1	Constitutive equations	296
9.2	Equation of motion	301
9.3	Kinematics of flow and material acceleration	304
9.4	Navier–Stokes equation	307
9.5	Inviscid flows: the Euler and Bernoulli equations	312
9.6	Irrotational flows	315
9.7	Boundary layers	317
9.8	Steady, uniform viscous flow between parallel plates	320
9.9	Flow through a tube	324
9.10	Geological applications	324
9.11	Viscous flow past a sphere or cylinder	331
9.12	Review problems	333
9.13	Suggested reading	335
10	Flow of natural materials	337
10.1	Introduction	337
10.2	Mechanical models of natural materials	338
10.3	Flow of materials down slopes	344
10.4	Ice	348
10.5	Debris	353
10.6	Lava	356
10.7	Rock rheology and sedimentary basins	357
10.8	Review problems	360
10.9	Suggested reading	363

	<i>Contents</i>	xi
11	Turbulence	365
11.1	Description of turbulence	365
11.2	Origin of turbulence	371
11.3	Boundary layers and flow separation	373
11.4	Reynolds stresses	378
11.5	Diffusion	382
11.6	Velocity distribution in a turbulent boundary layer	387
11.7	Review problems	391
11.8	Suggested reading	393
12	Thermal convection	395
12.1	Introduction	395
12.2	Conduction	396
12.3	Thermal instability	398
12.4	Geometry of convection	400
12.5	Equations of motion	403
12.6	Lorenz equations	404
12.7	Numerical simulation of convection	407
12.8	Review problems	407
12.9	Suggested reading	408
<i>Appendix A</i>	List of symbols and vector notation	410
<i>Appendix B</i>	Properties of common fluids and rocks	416
<i>Appendix C</i>	Sets of linear equations	422
<i>Appendix D</i>	Partial derivatives and differential equations	430
<i>References</i>		438
<i>Index of names</i>		451
<i>Subject index</i>		455