

# Contents

<i>Preface</i>	<i>page</i>	xi
<i>Acknowledgements</i>		xiii
<b>1 Introduction</b>		1
1.1 Aims		1
1.2 Rock fractures		1
1.3 Notation and basic concepts		3
1.4 Some definitions from structural geology		13
1.5 How to solve fracture problems		17
1.6 Accuracy, significant figures, and rounding		20
1.7 Summary		22
1.8 Main symbols used		23
1.9 Worked examples		23
1.10 Exercises		26
References and suggested reading		26
<b>2 Stress</b>		28
2.1 Aims		28
2.2 Some basic definitions		28
2.3 The concept of stress		29
2.4 Principal stresses		35
2.5 Stresses on an arbitrary plane		36
2.6 Mohr's circles		38
2.7 Special stress states		42
2.8 Stress fields		46
2.9 Summary		49
2.10 Main symbols used		51
2.11 Worked examples		52
2.12 Exercises		61
References and suggested reading		62
<b>3 Displacement and strain</b>		63
3.1 Aims		63
3.2 Basic definitions		63
3.3 Displacement		66
3.4 Strain		71

3.5	Deformation of a rock body	76
3.6	Measuring strain	77
3.7	Summary	81
3.8	Main symbols used	81
3.9	Worked examples	82
3.10	Exercises	87
	References and suggested reading	87
<b>4</b>	<b>Relation between stress and strain</b>	<b>89</b>
4.1	Aims	89
4.2	One-dimensional Hooke's law	89
4.3	Three-dimensional Hooke's law	92
4.4	Elastic constants	95
4.5	Rock stress	110
4.6	Crustal stress and strain fields	113
4.7	Strain energy	118
4.8	Summary	120
4.9	Main symbols used	122
4.10	Worked examples	123
4.11	Exercises	128
	References and suggested reading	129
<b>5</b>	<b>Loading of brittle rocks to failure</b>	<b>132</b>
5.1	Aims	132
5.2	Behaviour of rock under loading	132
5.3	The experimental stress-strain curve	133
5.4	The main stages leading to brittle failure	139
5.5	The brittle-ductile transition	140
5.6	Summary	144
5.7	Main symbols used	145
5.8	Worked examples	146
5.9	Exercises	150
	References and suggested reading	151
<b>6</b>	<b>Stress concentration</b>	<b>153</b>
6.1	Aims	153
6.2	Basic definitions	153
6.3	Analogies and elliptical holes	156
6.4	Circular holes and stress measurements	162
6.5	Cavities	167
6.6	Holes close to a free surface	172
6.7	Holes in anisotropic rocks	176
6.8	Summary	180

6.9	Main symbols used	181
6.10	Worked examples	182
6.11	Exercises	187
	References and suggested reading	188
<b>7</b>	<b>Theories of brittle failure of rocks</b>	<b>190</b>
7.1	Aims	190
7.2	Failure and strength	190
7.3	The Coulomb material	193
7.4	The Coulomb criterion for rocks	195
7.5	Some empirical criteria	203
7.6	The theory of Griffith	205
7.7	The Griffith criterion for rocks	212
7.8	A combined rock-failure criterion	213
7.9	Tresca and von Mises criteria	214
7.10	Summary	221
7.11	Main symbols used	223
7.12	Worked examples	224
7.13	Exercises	229
	References and further reading	231
<b>8</b>	<b>Extension fractures and shear fractures</b>	<b>233</b>
8.1	Aims	233
8.2	Basic types of rock fractures	233
8.3	Tension fractures	237
8.4	Hydrofractures	239
8.5	Shear fractures	244
8.6	Summary	245
8.7	Main symbols used	245
8.8	Worked examples	246
8.9	Exercises	252
	References and suggested reading	253
<b>9</b>	<b>Displacements and driving stresses of fractures</b>	<b>255</b>
9.1	Aims	255
9.2	Crack geometries	255
9.3	Displacement modes of cracks	260
9.4	Tension fractures	265
9.5	Hydrofractures	270
9.6	Dip-slip faults	273
9.7	Strike-slip faults	274
9.8	Summary	275
9.9	Main symbols used	276

9.10	Worked examples	277
9.11	Exercises	284
	References and suggested reading	285
<b>10</b>	<b>Toughness and fracture mechanics</b>	<b>288</b>
10.1	Aims	288
10.2	Toughness	288
10.3	Fracture mechanics	291
10.4	Toughness of rock	298
10.5	Core, damage zone, and process zone	299
10.6	Basic equations of $K$ and $G$	302
10.7	Toughness in terms of fracture displacements	306
10.8	Summary	309
10.9	Main symbols used	310
10.10	Worked examples	311
10.11	Exercises	315
	References and suggested reading	316
<b>11</b>	<b>Field analysis of extension fractures</b>	<b>319</b>
11.1	Aims	319
11.2	Types of extension fractures	319
11.3	Tension fractures	320
11.4	Joints	323
11.5	Mineral veins	332
11.6	Dykes	335
11.7	Inclined sheets	338
11.8	Sills	340
11.9	Man-made hydraulic fractures	341
11.10	Field measurements of fractures	342
11.11	Summary	345
11.12	Worked examples	346
11.13	Exercises	350
	References and further reading	351
<b>12</b>	<b>Field analysis of faults</b>	<b>354</b>
12.1	Aims	354
12.2	Dip-slip faults	354
12.3	Strike-slip faults	359
12.4	Slickensides and oblique-slip faults	367
12.5	Summary	368
12.6	Worked examples	369
12.7	Exercises	370
	References and suggested reading	371

<b>13 Evolution of extension fractures</b>	373
13.1 Aims	373
13.2 Development of tension fractures	373
13.3 Propagation of hydrofractures	377
13.4 Hydrofracture deflection and arrest	382
13.5 Hydrofracture aperture and overpressure	388
13.6 Tip stresses and surface deformation	400
13.7 Summary	404
13.8 Main symbols used	406
13.9 Worked examples	407
13.10 Exercises	412
References and suggested reading	413
<b>14 Evolution of faults</b>	416
14.1 Aims	416
14.2 Initiation of faults	416
14.3 Fault growth	430
14.4 Fault damage zone and core	439
14.5 Local stresses in fault zones	441
14.6 Fracture deflection and arrest	447
14.7 Evolution of fault slip	450
14.8 Summary	455
14.9 Main symbols used	457
14.10 Worked examples	458
14.11 Exercises	461
References and suggested reading	462
<b>15 Fluid transport in rocks – the basics</b>	466
15.1 Aims	466
15.2 Fluid transport in porous and fractured rocks	466
15.3 Darcy's law	467
15.4 The cubic law	470
15.5 Fluid transport in a single set of fractures	473
15.6 Fluid transport in two orthogonal sets of fractures	475
15.7 Fractures and permeability	477
15.8 Summary	482
15.9 Main symbols used	486
15.10 Worked examples	487
15.11 Exercises	491
References and suggested reading	492
<b>16 Fluid transport in faults</b>	496
16.1 Aims	496
16.2 Overview	496

---

16.3	Ground-water flow to fault zones	498
16.4	Ground-water flow along fault zones	502
16.5	Aperture and fluid pressure	507
16.6	Fluid transport in the damage zone	508
16.7	Fluid transport in the core	510
16.8	Permeability development	512
16.9	Summary	515
16.10	Main symbols used	517
16.11	Worked examples	518
16.12	Exercises	520
	References and suggested reading	520
<b>17</b>	<b>Fluid transport in hydrofractures</b>	<b>525</b>
17.1	Aims	525
17.2	Driving pressure and volumetric flow rate	525
17.3	Man-made hydraulic fractures	530
17.4	Vertical hydrofractures (dykes)	534
17.5	Inclined hydrofractures (cone sheets)	535
17.6	Mineral veins	536
17.7	Summary	539
17.8	Main symbols used	541
17.9	Worked examples	541
17.10	Exercises	551
	References and suggested reading	552
<b>Appendix A: Units, dimensions, and prefixes</b>	<b>557</b>	
A.1	SI base units	557
A.2	Derived SI units of some quantities	557
A.3	SI prefixes	558
<b>Appendix B: The Greek alphabet</b>	<b>559</b>	
<b>Appendix C: Some mathematical and physical constants</b>	<b>560</b>	
<b>Appendix D: Elastic constants</b>	<b>561</b>	
D.1	Typical Young's moduli and Poisson's ratios	561
D.2	Relations among the elastic constants for isotropic rock	562
<b>Appendix E: Properties of some crustal materials</b>	<b>564</b>	
E.1	Rock densities, strengths, and internal friction	564
E.2	General rock and fluid properties	565
	References	567
<i>Index</i>		570