

Baotang Shen • Ove Stephansson • Mikael Rinne

Modelling Rock Fracturing Processes

A Fracture Mechanics Approach Using
FRACOD

 Springer

Contents

1	Introduction	1
	References	3
2	Introduction to Rock Fracture Mechanics	5
2.1	Griffith Flaws and Energy Balance Theory	7
2.2	Loading Modes and Associated Displacements	10
2.3	Stress Intensity Approach	11
2.4	Relationship Between G and K	14
2.5	Stress Intensity Factor K and the Critical Value K_C	15
2.6	Stress Intensity Factor and Crack Velocity	15
2.7	Charles' Law	17
	References	18
3	Numerical Method	19
3.1	Displacement Discontinuity Method (DDM)	19
3.1.1	DDM in an Infinite Solid	19
3.1.2	Numerical Procedure	21
3.2	Simulation of Rock Discontinuities	24
3.3	Fracture Propagation Criterion	26
3.4	Fracture Propagation Using DDM	28
3.5	Fracture Initiation Criterion in FRACOD	29
3.5.1	Fracture Initiation Criterion	29
3.5.2	Probability of New Crack Formation	31
	References	32
4	Iteration Process in FRACOD	33
4.1	Iteration for Joint Sliding	33
4.2	Iteration for Fracture Propagation	35
5	Modelling Time Dependency	39
5.1	Subcritical Fracture Model for a Mode I Fracture Under Pure Tension	39

5.2	Subcritical Fracture Model for Shear and Compression	41
5.3	Simulation of Subcritical Crack Growth	42
	References	43
6	Simulation of Multiple Region System	45
6.1	Theoretical Formulation for Multi-Region Function	45
6.2	Numerical Implementation	53
7	Solving Gravitational Problems	55
7.1	Theoretical Background	55
7.2	Code Implementation	57
	Reference	58
8	Sequential Excavation Function	59
8.1	Theoretical Considerations	60
8.2	Numerical Implementation in FRACOD	62
9	Thermo-Mechanical Coupling	63
9.1	Governing Equations for Thermo-Elasticity	63
9.1.1	Constitutive Equations	64
9.1.2	Transport and Balance Laws	64
9.1.3	Field Equations for Thermo-Elasticity	65
9.1.4	Fundamental Solutions in Thermo-Elasticity	65
9.2	Thermo-Mechanical Coupling in FRACOD	66
9.2.1	Fictitious Heat Source Method for Thermo-Elasticity	67
9.2.2	Time Marching Scheme for Transient Heat Flow	70
9.3	Implementation of Thermal Mechanical Coupling in FRACOD ..	73
9.4	Temperature Dependent Rock Properties	74
	References	75
10	Hydro-Mechanical Coupling	77
10.1	Numerical Considerations	78
10.2	Iteration Scheme	78
10.3	Fluid Time Step	80
	References	82
11	Anisotropic Rock Strength Function	83
11.1	Fracture Initiation	83
11.2	Fracture Propagation	86
11.3	Numerical Implementation	87
12	Rock Properties for FRACOD Modelling	89
12.1	Mechanical Properties of Intact Rock	89
12.2	Mechanical Properties of Fracture Surface Contact	92
12.3	Fracture Toughness and Critical Strain Energy Release Rate	94
12.3.1	Mode I Fracture Toughness	94
12.3.2	Mode II Fracture Toughness	97
12.4	Thermal Properties of Rock	98
	References	100

13	FRACOD Verification Tests	101
13.1	Tensile Fracture Propagation	101
13.2	Shear Fracture Propagation	102
13.3	Multiple Region Model	105
13.4	Subcritical Crack Growth: Creep	106
13.5	Gravity Problems	109
13.6	Thermo-Mechanical Coupling	110
13.7	Fluid Flow in Fractures	112
13.8	Hydraulic Fracturing	118
	References	121
14	Application Case Studies	123
14.1	Borehole Breakout in a Geothermal Reservoir	124
14.1.1	Input Properties	125
14.1.2	Modelling Results	126
14.1.3	Back-Analysis of Horizontal Stress Magnitude	127
14.1.4	Stress State in the Habanero No. 1 Well Granite	131
14.2	Rock Fracturing and Related Permeability Change in Excavation Damage Zone: EDZ	133
14.2.1	Predicting Conductivity in EDZ Using FRACOD	134
14.2.2	Comparison of FRACOD Prediction with EDZ Measurements of the ZEDEX Experiment in Äspö Hard Rock Laboratory, Sweden	136
14.2.3	FRACOD Modeling of Permeability Measurements in the Tunnel Sealing Experiment (TSX) of URL, Canada	137
14.2.4	Summary	141
14.3	Underground Lined Rock Cavern for LNG Storage	143
14.3.1	Summary	145
14.4	Modelling Fracture Propagation and Failure in a Rock Pillar Under Mechanical and Thermal Loading	147
14.4.1	Layout and Parameters	149
14.4.2	Back-Calculations of the Excavation Induced Stresses ...	152
14.4.3	Modelling of Thermo-Mechanical Effects	154
14.4.4	Summary	158
14.5	Modelling Uniaxial and Triaxial Tests	160
14.5.1	Brittle Failure Under Compression	160
14.5.2	Model Description	161
14.5.3	Input Parameters and Loading Steps	162
14.5.4	Summary	166
	References	167
	Index	171