

Contents

| | | |
|----------|---|-----------|
| 1 | Cross-Anisotropy of Rocks | 1 |
| 1.1 | Introduction | 1 |
| 1.2 | Motivation and Structure of this Dissertation | 7 |
| 2 | Constitutive Equation for Linear-Elastic, Cross-Anisotropic Material | 9 |
| 2.1 | Derivation from the General Representation Theorem | 9 |
| 2.2 | Constitutive Equation in terms of Material Parameters $E_1, E_2, G_2, \nu_1, \nu_2$ | 14 |
| 2.3 | Relation of Parameters a_1, a_2, a_3, a_4, a_5 and $E_1, E_2, G_2, \nu_1, \nu_2$ | 17 |
| 2.4 | Constraints | 18 |
| 3 | Laboratory and Field Tests | 23 |
| 3.1 | Laboratory Tests | 23 |
| 3.1.1 | Uniaxial Compression Test | 25 |
| 3.1.2 | Own Attempts to Measure Elasticity Parameters of Cross-Anisotropic Rock | 26 |
| 3.2 | Field Tests | 35 |
| 3.2.1 | Flat Jack Test | 38 |
| 3.2.2 | Plate Loading Test | 39 |
| 3.2.3 | Seismic Methods | 40 |
| 3.2.4 | Convergence Measuring Method | 41 |
| 3.2.5 | Dilatometer Test | 43 |
| 3.2.6 | Hydraulic Pressure Chamber Test | 50 |
| 3.2.7 | Radial Jack Test | 50 |
| 3.2.8 | Comparison of Different Tests in Same Field | 64 |

| | |
|--|-----------|
| <i>Contents</i> | xiii |
| 4 Analytical Solutions of Cavity Expansion | 65 |
| 4.1 Mathematical Fundamentals on Cavity Expansion | 65 |
| 4.1.1 Equilibrium and Compatibility Equations | 65 |
| 4.1.2 Polar Representation of the Displacements | 67 |
| 4.2 Previous Work | 69 |
| 4.3 Approximate Solution for Cavity Expansion in Cross-Anisotropic Rock | 80 |
| 4.4 Back Analysis of Material Parameters | 83 |
| 4.4.1 Isochoric Deformation | 86 |
| 4.4.2 Example of Back Analysis | 88 |
| 5 Numerical Analysis of Cavity Expansion | 97 |
| 5.1 Finite Element Method Outline | 97 |
| 5.2 Application of the Constitutive Model | 98 |
| 5.3 Simulation of Element Tests | 100 |
| 5.4 Modelling of Cavity Expansion | 106 |
| 5.4.1 Domain Size and Boundary Conditions | 106 |
| 5.4.2 Analysis Steps | 113 |
| 5.4.3 Evaluation Process | 114 |
| 5.5 Setup of the Model for Cavity Expansion Tests | 114 |
| 5.5.1 Influence of the Numerical Configuration | 116 |
| 5.5.2 Influence of the Foliation Orientation | 117 |
| 5.5.3 Parametric Study | 127 |
| 5.5.4 Loading a Limited Strip vs. the Entire Cavity | 135 |
| 5.5.5 Free vs. Suppressed Out-of-Plane Displacement | 135 |
| 5.5.6 Soft Layer | 137 |
| 5.6 Implementation of Parameters Obtained from the Approximate So- lution | 141 |
| 5.7 Overview of the Numerical Results | 153 |

| | | |
|----------|---|------------|
| 6 | On Small-Scale Experiments on Cross-Anisotropic Materials | 155 |
| 6.1 | Physical Modelling | 155 |
| 6.1.1 | Small-Scale Cavity Expansion Test | 155 |
| 6.2 | Artificial Cross-Anisotropic Material | 157 |
| 6.2.1 | Literature Review | 157 |
| 6.2.2 | Experimental Attempts | 160 |
| 7 | Summary and Conclusions | 170 |
| A | Graphical Representation of Radial Displacements | A.1 |
| B | Compliance Matrix in terms of A_1, A_2, A_3, A_4, A_5 | B.1 |
| C | Kaunertal Hydroelectric Power Plant | C.1 |
| D | UMAT by means of $E_1, E_2, G_2, \nu_1, \nu_2$ | D.1 |
| E | UMAT by means of a_1, a_2, a_3, a_4, a_5 | E.1 |