Chapter 1
Introduction

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Abstract The ability to predict and realistically reproduce rock mass behaviour using a numerical model is a pivotal step in solving many rock engineering problems. Several different types of numerical methods have been developed for various geomechanical problems. Although many existing numerical codes can model the behaviour of jointed or fractured rock mass, most do not consider the fracture initiation and propagation – a dominant mechanism, particularly in hard rocks. This book aims to introduce several unique numerical approaches to complex rock failure problems and demonstrate their capabilities through case studies and applications.

The book contains 20 chapters which are broadly grouped into three parts. Part I describes the theoretical background of fracturing mechanics and latest understanding of rock fracturing mechanisms from laboratory tests and field tests. Part II describes the fundamentals of various numerical methods and codes for both basic fracture modelling and coupled processes. Part III describes a large number of case studies using various numerical codes for real rock engineering problems, including tunnel failure, fault re-activation, mine stability, water inrush, hydraulic fracturing, long term stability of rocks, and other key geomechanics issues related to EGS geothermal energy, CO_2 Geosequestration, LNG underground storage, nuclear waste disposal and civil engineering.

Ove Stephansson died before publication of this work was completed.

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It is our intension that this book will provide readers the latest developments in numerical methods and modelling tools for predicting the rock failure process involving explicit fracturing and thermal-hydraulic-mechanical coupling.

Rock mass is increasingly employed as the host medium for a vast array of human activities. Facilities like storage areas, wells, tunnels, underground power stations are located in a variety of rock types and under different rock mechanical conditions. Excavation stability is imperative for all such constructions, in both the short and long term.

Understanding the long-term behaviour of a rock mass is crucial for safety and performance assessments of geological radioactive waste disposal. Hydro-thermal-mechanical couplings of the ongoing processes around these repositories are particularly important. The understanding of fracturing of rock masses has also become a critical endeavour for energy extraction and storage. Small-scale breakouts around single wells in petroleum engineering can devastate the oil and gas extraction from source rock. The large-scale fracturing of rock formations for improved oil, gas and heat extraction is an essential field of development in the petroleum and geothermal industries. CO_2 geosequestration is a complex new field of rock engineering where fracturing of the overburden rock during pressurization must be prevented while fracturing of the storage formation might be needed. All these intricate design tasks require powerful prediction and modelling tools.

Failure of brittle rock is often associated with a rapid and violent event, as detected in short-term loading strength laboratory tests. From these test results, the mechanical properties of rock including fracture mechanics parameters are obtained. When rock is stressed close to its short-term strength, slow crack growth (also called subcritical crack propagation) occurs. With time, this slow fracturing process may generate critical stress concentrations that lead to a sudden unstable failure event. Slow subcritical crack growth (SCG) is thought to play an important role in long-term rock stability at all scales and for all kinds of rocks, ranging from laboratory samples to earthquake-generated faults. When sudden rock movement occurs in nature or around excavations the consequences can be catastrophic.

The ability to predict and realistically reproduce rock mass behaviour using a numerical model is a pivotal step in solving many rock engineering problems. Numerical modelling can improve our understanding of the complicated failure processes in rock and the many factors affecting the behaviour of fractured rock. When our models manage to better capture the fundamental failure mechanisms observed in the laboratory, our ability to generate reliable large-scale models improves, as does our ability to predict the short- and long-term behaviour of rock masses *in situ*. Our ability to identify conditions where time is an important variable for the stability and long-term behaviour of rock excavations is likewise enhanced.

Several different types of numerical methods have been developed for various geomechanical problems (Jing 2003). Since every method and code has its advantages and disadvantages, the choice of a suitable code should be carefully assessed for each rock-engineering problem. Code suitability depends on the character of the problem and the goal of the study. The mechanical behaviour of the rock mass is largely influenced by the presence of natural discontinuities like fractures, joints and faults. Hence, numerical methods that allow the introduction of displacement discontinuities into the continuous medium are often required in solving rock engineering problems.

Numerical methods can be subdivided into "Continuum methods" and "Discontinuum methods". Continuum methods (or continuum approaches) do not take into account the presence of distinct discontinuities. If natural discontinuities are numerous, then the substitution, at a certain scale, of a discontinuous medium with a continuous one is required. The mechanical characteristics of the continuous medium must be such that its behaviour is equivalent from a mechanical point of view to that of the discontinuous medium. The effects of fractures are smoothed out and the heavily jointed rock mass is considered as an equivalent continuous medium.

The Discontinuum methods (or "Explicit joint approaches") allow one to incorporate discrete discontinuities in the displacement field, that is, individual joints in the rock mass can be modelled explicitly. Discontinuum methods may describe the fracturing process using fracture mechanics principles.

Although many existing numerical codes can model the behaviour of jointed or fractured rock mass, most do not consider the fracture initiation and propagation – a dominant mechanism, particularly in hard rocks. A very limited number of codes can model the fracture propagation but are usually not designed for application at engineering scales. This book aims to introduce several unique numerical approaches to complex rock failure problems and demonstrate their capabilities through case studies and applications.

Much of the work described in this book is based on many years' studies from an international collaboration project, named "*Understanding and predicting coupled fracturing/fluid flow/thermal processes of jointed rocks in 2-D and 3-D*" and the project was led and supported by CSIRO, Australia. This project was first initiated in 2007 with the original aim of developing the mechanical – thermal – hydraulic coupled functions in a fracture mechanics based code FRACOD. The objectives had been achieved during the first and second phases of the project during 2007–2011 and 2011–2016. As a result of this project, a book titled "*MODELLING ROCK FRACTURING PROCESSES – A Fracture Mechanics Approach Using FRACOD*" (Shen et al. 2014) was published which describes the details of the unique fracture mechanics based code FRACOD.

Since 2016, the international collaboration project has moved into its 3rd phase and the scope of the project has been significantly widened. While the project still has its focus on FRACOD development and applications, other codes which have the capability in modelling rock fracturing processes (such as PFC, TOUGH, RFPA) are included in the study for the purpose of comparison and cross validation. More importantly, all these code developments and validations are ultimately for the real world rock engineering applications. Therefore, much of the focus in the project now has been applications and case studies using various numerical codes to solve engineering problems involving coupled rock fracturing processes. These latest researches form bulk of the contents in the book.

The book contains 20 chapters which are broadly grouped into three parts. Part I (Chaps. 2, 3, 4 and 5) describes the theoretical background of fracturing mechanics and latest understanding of rock fracturing mechanisms from laboratory tests and field tests. 2D and 3D fracture propagation tests and hydraulic fracturing laboratory and field experiments are presented.

Part II (Chaps. 6, 7, 8, 9 and 10) describes the fundamentals of various numerical methods and codes for both basic fracture modelling and coupled processes. It includes the latest developments in the two- and three-dimensional version of the fracture mechanics based code FRACOD, coupled fracture modelling with RFPA, TOUGH-based hydraulic fracturing models, and coupled fracture modelling with distinct element methods.

Part III (Chaps. 11, 12, 13, 14, 15, 16, 17, 18, 19 and 20) describes a large number of case studies using various numerical codes for real rock engineering problems. These case studies includes:

- Modelling tunnel failure and fault re-activation of CO_2 geosequestration using FRACOD
- FRACOD modelling for LNG underground storage
- Numerical applications to EGS geothermal energy
- Mine stability and water inrush in coal mine
- FRACOD applications to nuclear waste disposal
- Modelling hydraulic fracturing in coal-bearing strata
- Applications of Rock Failure Process Analysis (RFPA) to rock engineering
- Coupled hydro-mechanical PFC modelling of fault reactivation and its application to EGS
- Lifetime prediction of rocks
- Simulation of hydraulic driven fractures

The authors of each chapter are the leading experts in the relevant fields and have many years' experience in numerical modelling and coupled processes. It is our intension that this book will provide readers the latest developments in numerical methods and modelling tools for predicting the rock failure process involving explicit fracturing and thermal-hydraulic-mechanical coupling.

References

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