Abstract

Rock mass is composed of porous matrix, discontinuities like joints and fractures, sills and dykes, faults and folds, and others. Pore spaces in rock matrix and joints or fractures may also be partially or fully filled with water. An excavation made in such rock mass triggers deformation in rock matrix as well as allows water to flow through interconnected pore spaces and fracture networks. As a result, reinforcement in terms of rock bolts or shotcrete/concrete lining are installed around the excavation boundary to control deformation and excessive flow of water. Modelling of reinforced jointed rock mass with dual permeability is a challenging task when interaction mechanisms between rock, fluid, fracture, bolt and grout are considered. Existing numerical methods have limitations in handling rock bolts due to mesh dependencies and combining with fluid filled fractured porous media. This thesis develops algorithms in the framework of eXtended Finite Element Method (XFEM) platform for implementing rock bolts as reinforcement within a dual permeable media. This thesis presents detailed numerical procedures for the treatment of a bolt crossing intersecting cohesive jointed element and hydro-mechanical-reinforcement coupling for single phase flow through fractured porous media. Apart from that, direct shear experiments on bolted joint samples are conducted to validate the developed codes.

The highlight of the thesis is in the development of a new "*triply*" enriched element which can be intersected by crossing joints and a rock bolt. For this element, special Heaviside functions are required to describe jumps in displacements and pressure across the joints as well as junction variables to define crossing of joints. Joints and bolt can be oriented in any direction within an element and thereby eliminating mesh dependency. Material non-linearity is considered using Drucker-Prager plasticity model. Stick-slip behaviour of rock joints along with coupling/de-coupling of grouted bolts are integrated within the framework. Generalised Biots theory, Darcys law and Cubic law explain the background of fluid flow, pressure rate and velocity relationships through porous media and joints/fractures respectively. Temporal discretization of finite element equation is achieved using generalised HHT-α method. Discretized form of stiffness matrix of this enriched rock-joint-bolt element is provided for easy implementation in XFEM codes. Several benchmark examples are solved and comparative results are presented to show the efficacy of the proposed method. Lastly, constant normal load direct shear tests for reinforced jointed samples are conducted and the results are compared with the numerical results. A novel bolt performance index is also proposed in this thesis to show the influence of bolt angle and normal load on shear resistance from the samples. Finally, the thesis presents a generic version of hydro-mechanical-reinforcement algorithm which can be further extended and applied in numerous structural problems in rock engineering.

Keywords: Rock mass, Strong discontinuity or joint, Grouted rock bolt, XFEM, Heaviside function, Decoupling or de-bonding, Drucker-Prager yield criterion, Reinforced tunnel, Fractured porous media.