Abstract

Modelling of reinforced jointed rock mass is a challenging task when interaction mechanism between rock, joint, grout and reinforced element is taken into account. Most of the existing numerical studies on finite element modelling of rock joints and bolts are needed to be aligned with element mesh if their explicit representation is considered. This thesis presents a novel numerical procedure incorporating the interaction between rock, joint, grout and bolt to gain a better understanding of the behaviour of rock bolts leading to an improvement in ground support. The first part of the thesis deals with jointed rock mass problems, second part comprises of the analysis of interaction between rock mass and rock bolt, whereas the last parts describes the analysis of discontinuous rock mass reinforced by fully grouted bolts. First part is devoted to develop extended finite element method (XFEM) in order to incorporate rock joints so as not to force the mesh to conform to the joints surface. The method is extended in such a way that multiple number of discontinuities can be considered and external traction force can be applied on any arbitrary boundary including the surface of the discontinuity. The second part is devoted to develop numerical procedures for the analysis of grouted bolts in continuous rock masses so that bolts need not to be aligned with the element mesh. In order to achieve this, two independent approaches have been considered. In the first approach, finite element method (FEM) and finite difference method (FDM) are coupled for the analysis of bolt-grout interactions in elasto-plastic rock mass. Bolt-grout interactions are evaluated based on FDM and are embedded into the FEM. In the second approach, a new rock-bolt element, called 'enriched finite element (EFE)' is proposed and implemented to analyze the interaction between fully grouted bolts and rock mass. The nodes of an enriched element have additional degrees of freedom for determining displacements, stresses developed in the bolt rod. The stiffness of the enriched element is formulated based on properties of rock mass, bolt rod and grout, orientation of the bolt and borehole diameter. Decoupling at grout-bolt interface and elasto-plastic behaviour of rock mass has also been incorporated into the EFEM procedures.

In order to study rock bolt behaviour in discontinuous rock mass, a new bolt-crossing-joint element, called 'doubly enriched finite element (DEFE)' has been developed within the framework of XFEM by introducing strong displacement discontinuities in the form of rock joints and reinforcement effects in the form of rock bolts. In this procedure, discontinuity plane and reinforcement can be incorporated in an element at any arbitrary direction without mesh realignment. The 'dowel action' of reinforced bolt has been considered and embedded into the stiffness matrix. Decoupling at bolt-grout interface and stick-slip characteristics of joint have also been considered along with material non-linearity. The numerical results of the developed procedures are compared with several existing analytical as well as experimental results. Numerical difficulties, finite element size and mesh orientation dependencies that result from conventional continuum approaches for modelling discontinuous rock mass reinforced by rock bolt have been eliminated in the proposed procedures. The numerical computation of the developed procedure is generic in nature and can be applied in reinforced structural problems.

Keywords: Rock mass, strong discontinuity or joint, grouted rock bolt, XFEM, Heaviside function, decoupling or de-bonding, Mohr-Coulomb yield criterion, reinforced tunnel.