ARTICLE IN PRESS

Journal of Rock Mechanics and Geotechnical Engineering xxx (2018) 1–21

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full Length Article

Effects of confinement on rock mass modulus: A synthetic rock mass modelling (SRM) study

I. Vazaios*, K. Farahmand, N. Vlachopoulos, M.S. Diederichs

Department of Geological Sciences and Geological Engineering, Queen's University, Kingston, Ontario, K7L 3N6, Canada

ARTICLE INFO

Article history:
Received 16 June 2017
Received in revised form
23 October 2017
Accepted 21 January 2018
Available online xxx

Keywords:
Synthetic rock mass modelling (SRM)
Discrete fracture network (DFN)
Rock mass modulus
Geological strength index (GSI)
Confinement

ABSTRACT

The main objective of this paper is to examine the influence of the applied confining stress on the rock mass modulus of moderately jointed rocks (well interlocked undisturbed rock mass with blocks formed by three or less intersecting joints). A synthetic rock mass modelling (SRM) approach is employed to determine the mechanical properties of the rock mass. In this approach, the intact body of rock is represented by the discrete element method (DEM)-Voronoi grains with the ability of simulating the initiation and propagation of microcracks within the intact part of the model. The geometry of the pre-existing joints is generated by employing discrete fracture network (DFN) modelling based on field joint data collected from the Brockville Tunnel using LiDAR scanning. The geometrical characteristics of the simulated joints at a representative sample size are first validated against the field data, and then used to measure the rock quality designation (RQD), joint spacing, areal fracture intensity (P_{21}), and block volumes. These geometrical quantities are used to quantitatively determine a representative range of the geological strength index (GSI). The results show that estimating the GSI using the RQD tends to make a closer estimate of the degree of blockiness that leads to GSI values corresponding to those obtained from direct visual observations of the rock mass conditions in the field. The use of joint spacing and block volume in order to quantify the GSI value range for the studied rock mass suggests a lower range compared to that evaluated in situ. Based on numerical modelling results and laboratory data of rock testing reported in the literature, a semi-empirical equation is proposed that relates the rock mass modulus to confinement as a function of the areal fracture intensity and joint stiffness.

1. Introduction

Design of modern structures built within or on hard rock masses has become more challenging, as the rock-related construction, such as open pit and underground mining, is increasingly getting larger and excavating deeper. As such, the stresses as well as the ensuing stress paths become higher and more complex in nature. Given the fact that such deep excavations are under complex in situ conditions, the development and application of advanced numerical models are essential in order to adequately predict the short- and long-term responses of the rock mass to perturbations caused by engineered alterations. Development of such advanced models requires the introduction to constitutive models with the capability of representing the reality of rock behaviour under different loading paths and deformation states. In terms of continuum-based models (e.g. finite element method models), the deformability and strength of the jointed rock control the material behaviour. In these types of numerical codes, the values of rock mass deformability and strength under different loading conditions (i.e. various confinements and loading/unloading cycles) are defined via constitutive models. It is well-documented (Hutchinson and Diederichs, 1996; Martin, 1997; Min and Jing, 2004; Arzúa et al., 2014) that the values of these two parameters for a given jointed rock are highly dependent on the magnitude of the confining stress acting on the rock. Therefore, the confinement-dependency of such parameters needs to be accounted for in the implementation of the constitutive model. The main objective of this paper is to propose a formula that infers the rock mass modulus according to the magnitude of confining stress that the rock is being exposed to by taking into account other relevant and important factors that affect its deformability.

* Corresponding author.
E-mail address: ioannis.vazaios87@gmail.com (I. Vazaios).
Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

https://doi.org/10.1016/j.jrmge.2018.01.002
1674-7755

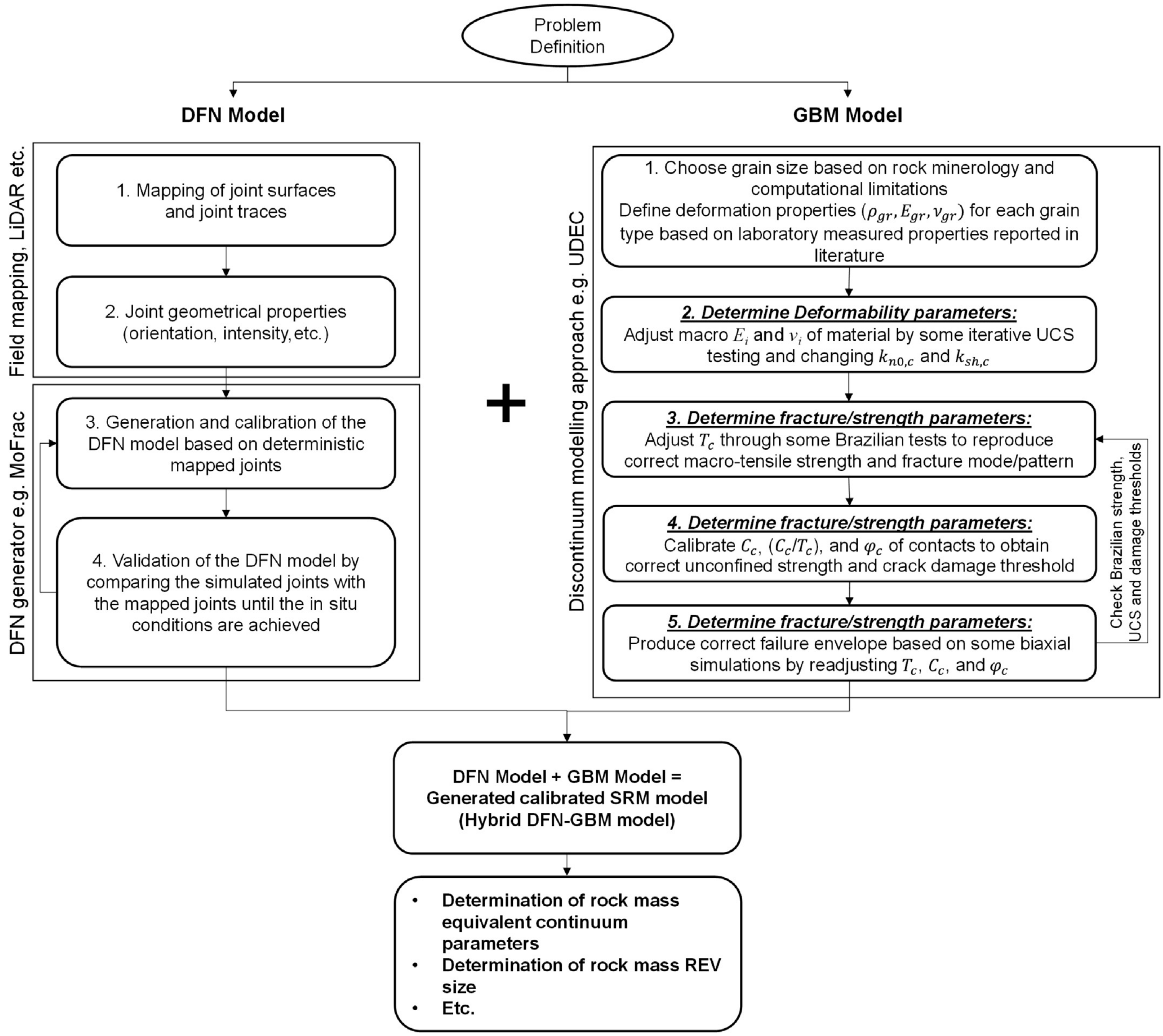

Fig. 1. Flowchart illustrating the calibration procedure for the combined DFN-grain based models. The DFN model can be created separately from the GBM model and then they can be merged in order to create the SRM model.

In order to estimate the deformability of a jointed rock, a so-called synthetic rock mass modelling (SRM) approach is used in which the intact part of the rock and discontinuities are represented respectively by a collection of Voronoi grains, and discrete fracture network (DFN) joints. In order to create such constructs, firstly the appropriateness of an SRM model to estimate the unconfined rock mass strength and deformability needs to be examined. The determination of the mechanical properties of the representative sample is undertaken at a representative volume considering the scale-dependency of the rock mass properties. In order to achieve this, a representative rock mass volume based on the concept of the "representative elementary volume (REV)" is established (Bear, 1972; Hudson and Harrison, 1997). The determination of the REV size for the studied rock mass is achieved by analysing the geometrical characteristics of the discontinuities (e.g. rock quality designation (RQD), joint spacing, and block volume measurements). Next, the quantified degree of blockiness is served to calculate a range of values for the geological strength index (GSI) (Hoek et al., 1998). By knowing the intact rock strength properties and the rock mass GSI value, the unconfined compressive strength (UCS) and deformability modulus ($E_{\rm rm}$) of the rock mass are estimated respectively by the empirical Hoek-Brown criterion (Hoek et al., 2002) and the Hoek–Diederichs formula (Hoek and Diederichs, 2006) and compared to those obtained from the SRM results at the REV size. Secondly, a series of biaxial compression tests is simulated under various confining stresses in order to investigate the sensitivity of the rock mass modulus to confinement. According to the calculated rock mass modulus, a semi-empirical solution is proposed that accounts for the influence of confinement, fracture intensity, and indirectly joint surface condition. This semi-empirical solution can serve as a constitutive model for estimating rock mass deformability based on stress

Please cite this article in press as: Vazaios I, et al., Effects of confinement on rock mass modulus: A synthetic rock mass modelling (SRM) study, Journal of Rock Mechanics and Geotechnical Engineering (2018), https://doi.org/10.1016/j.jrmge.2018.01.002