Iranian Journal of Engineering Geology
Summer 2023, Vol.16, No.2

Determination of rock mass elastic constant using discontinuous numerical modeling and validation with analytical relations

M. Javadi*[1], M. Dadrasi[2]

Abstract

In this paper, the determination of equivalent elastic properties of fractured rock masses has been studied using discontinuous numerical method. For this purpose, the discontinuous media of the jointed rock mass with different jointing patterns (including one horizontal joint set, one vertical joint set, two perpendicular horizontal and vertical joint sets, and two non-orthogonal joint sets) were modeled in UDEC software and the induced strain were calculated. Then, the elastic properties of rock mass were calculated by inserting strains obtained from numerical methods into compliance matrixes. In order to verify this procedure, the results of back calculated elastic properties of rock mass from numerical models were compared with those obtained from analytical solutions. Finally, the method of back calculated elastic properties of rock mass from numerical models was applied for confining stress boundary condition (the case without analytical solutions) under different rotation angle of discontinuities and scales. The results of this study show that there is a good consistency between the back calculated elastic properties of rock mass from numerical models and analytical solution; where the relative error is about 4% to 6% for most of the cases. This consistency indicates the accuracy of back calculated elastic properties of rock mass from numerical models and this method can be applied for other cases especially those without analytical solution. Application of this method for rock mass under confining stress (the case without analytical solution) indicates that the elastic properties highly depend to rotation angle. In addition, the method of back calculated elastic properties of rock mass from numerical models can determined the Poisson's coefficients in different directions.

Keywords: *Elastic properties of rock mass, Discontinuous numerical modeling, Analytical Solutions, Anisotropy, UDEC.*

[1] Assistant Professor, Faculty of Mining, Geophysics, and Petroleum Engineering, Shahrood University of Technology m.javadi@shahroodut.ac.ir

* Corresponding Author

[2] MSc of Tunnel and Underground Spaces Engineering, Department of Mining Engineering, Amirkabir University o Technology, m.dadrasi@aut.ac.ir

Extended Abstract:

1. Introduction

This article discusses the importance of determining the elastic modulus of rock masses and the methods used to achieve this. Two methods for determining the elastic modulus of rock masses are direct and indirect, with indirect methods being categorized as experimental, analytical, and numerical. Discontinuous numerical methods are particularly useful for modeling rock mass behavior (Jing, 2003), but there have been relatively few studies on the deformation behavior of rock masses with continuous non-orthogonal discontinuities under confining stress. This article focuses on the use of the back-calculation method based on discontinuous numerical modeling to determine the elastic coefficients of rock masses containing continuous orthogonal and non-orthogonal discontinuities. The method was used to investigate the effect of the rotation angle of the discontinuities on the directional elastic modulus of the rock mass.

2. Theory and background

Anisotropic materials exhibit behavior that depends on the direction of loading, and that their stress-strain response can be expressed using Hooke's law. The fourth-order elasticity tensor, which includes all the elastic stiffness moduli, is used to express this relationship. By inverting the equation, the elastic compliance tensor can be obtained. The number of elastic constants can be reduced from 81 to 21 by imposing the condition of symmetry on the elasticity tensor. Materials with different forms of symmetry have a reduced number of independent stiffnesses in their elasticity matrix. For instance, materials with three mutually perpendicular or orthotropic symmetry planes have only 9 independent stiffnesses. Amadei and Goodman, (1981) developed an analytical relationship for calculating the elastic constants of a rock mass, which assumes three orthogonal joints and treats the rock mass as an orthotropic continuous medium. The model is based on several key assumptions, including the isotropic nature of the intact rock, the negligible thickness of the joint set, and the absence of Poisson's effect and any change in the state of stress. If two of joint sets are not orthogonal, the anisotropy and elastic constants of rock mass can be calculated using the equations developed by Huang et al., (1995). For the other non-ideal cases of joint geometry, there is no analytical equations for calculating of rock mass elastic constants. In such case, the indirect method can be applied based on the back-calculation results of discontinuous numerical models (Min, 2003; Ma et al., 2019).

3. Methodology

This study used the discontinuous numerical method and UDEC software to obtain the elastic constants of jointed rock through back analysis of the numerical model results. Numerical models were generated and analyzed using a square-shaped domain with two types of discontinuities. Several different geometrical patterns of rock mass discontinuities and boundary conditions were applied on numerical models.

This study demonstrates the use of numerical modeling to analyze different geometric arrangements of discontinuities in rock masses and extract their equivalent parameters, such as elastic modulus and Poisson's ratio. In order to verify this methodology, the results of ideal numerical models were compared with analytical methods of Amadei and Goodman, (1981) and Huang et al., (1995). Both of these methods can be applied for calculation of the equivalent elastic properties of rock masses under uniaxial loading conditions, but not for other loading conditions like confining stress or shear stress. Therefore, the back calculation method based on the numerical method was used to determine the elastic coefficients of rock masses with non-perpendicular continuous discontinuities under confining stress.

4. Results

Different arrangement of discontinuities arrangement in the numerical model were analyzed in this paper. For the single horizontal joint set under vertical uniaxial normal loading condition, the calculated elastic modulus of rock mass of analytical (Amadei and Goodman, 1981) and back calculation methods are 20 and 21 GPa, respectively, where the relative error between two methods is under 5%. For the single horizontal joint set under vertical uniaxial normal loading condition, the relative error of these methods is about 3.5%. In the case of two symmetric joint set, the calculated elastic modulus of rock mass of analytical (Huang et al., 1999) and back calculation methods are 28.4 and 29 GPa, respectively, where the relative error is lower than 2%. For other cases, the results obtained from the numerical model are compared with analytical methods, and the two methods were found to be in good agreement. This comparison concludes that the numerical model is a reliable method for calculating the elastic constants of jointed rock masses, even in complex geometrical arrangements of joint sets. This method can be a valuable tool for engineers and geologists in predicting the behavior of rock masses. Application of this method for rock masses with non-perpendicular continuous discontinuities under confining stress indicates that the elastic constants of jointed rock were influenced by the geometrical arrangement of the joint sets and concluded that the method used in the study was effective in determining the elastic constants of jointed rock.

5. Conclusion

The paper examines the use of a discrete numerical method to determine the elastic mechanical properties of rock masses. The method is applied to a rock mass containing a joint set and non-perpendicular layering surfaces under confining stress. The results obtained from the numerical method are compared with analytical solutions. The comparison indicates that the numerical method is highly efficient and produces low relative error values for the equivalent elastic modulus and Poisson's ratio. The study also shows that the values of the elastic coefficients of the rock mass are strongly dependent on the rotation angle of the discontinuities. Additionally, the back-calculation method based on the numerical method has a high ability to determine the Poisson's coefficient of the rock mass, which is superior to analytical relationships in this respect. Based on the several investigations, the results suggest that the numerical method is an effective tool for determining the elastic mechanical properties of rock masses.

References:

Amadei, B., Goodman, R., 1981. A 3-D constitutive relation for fractured rock masses. Proceedings of the international symposium on the mechanical behavior of structured media, Ottawa. pp. 249-268.

Jing, L., 2003. A review of techniques, advances and outstanding issues in numerical modelling for rock mechanics and rock engineering. International Journal of Rock Mechanics and Mining Sciences, vol. 40, no. 3, pp. 283-353.

Ma, G., Li, M., Wang, H., Chen, Y., 2019. Equivalent discrete fracture network method for numerical estimation of deformability in complexly fractured rock masses. Engineering Geology, https://doi.org/10.1016/j.enggeo.2020.105784

Min, K. B., Jing, L., 2003. Numerical determination of the equivalent elastic compliance tensor for fractured rock masses using the distinct element method. International Journal of Rock Mechanics and Mining Sciences, vol. 40, no. 6, pp. 795-816.