Journal of Mineral Resources Engineering, 9(1): 87-101, (2024)

Imam Khomeini International University
Vol. 9, No. 1, Spring 2024

نشریه مهندسی منابع معدنی
Journal of Mineral Resources Engineering
(JMRE)

Research Paper

Developing a Discrete Fracture Network through Applying Roughness for Simulating Discontinuities Properties of Rock Mass

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Received: 21 Nov. 2022 **Accepted: 25 Feb. 2023**

Abstract: Accurate simulation of geometrical properties of fractures is an important goal in rock engineering. One of the most capable methods for simulating the random nature of geometrical properties of fractures is Discrete Fracture Network (DFN) random modelling, which presents the heterogeneous nature of fractured rock mass with statistically defined geometrical properties. Up to now, all properties of fractures such as location, shape, orientation, size (persistence), spacing, and opening of joints have been simulated and applied in 3D DFN modelling. In this research, a statistical solution based on Kernel's non-parametric distribution is used for simulating roughness. Through this method, even those geometric properties of fractures which do not have their own specific distribution functions can be simulated. After simulating the roughness value, the roughness geometry should also be simulated in a way that evokes the roughness value. Therefore, in order to simulate the surface of fractures in this research, the DRS method is applied in 2D and then, developed into 3D. At the end, simulation of discontinuity's roughness is added as a separate package to DFN-FRAC^{3D} computer program. DFN-FRAC^{3D} computer program, as one of the most capable tools in this field, is able to develop a 3D fracture network block model by using the surveyed data and then simulating geometrical properties of the fracture; thus, by applying the results of this research in this compute software, all geometrical properties of fractures can be simulated. Finally, in order to explain the results of this research, outcomes of DFN-FRAC^{3D} computer program for both with and without applying the roughness property on DFN are compared.

Keywords: DFN-FRAC^{3D}, Roughness, Simulation, JRC, DRS.

How to cite this article
Ameri, E., Jalali, S. M. E., Rabiee, M. R., and Noroozi, M. (2024). *"Developing a Discrete Fracture Network through Applying Roughness for Simulating Discontinuities Properties of Rock Mass"*. Journal of Mineral Resources Engineering, 9(1): 87-101.
DOI: 10.30479/JMRE.2023.18080.1616

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INTRODUCTION

Determining the exact value of rock properties and better understanding of its behavior have resulted in extensive development of rock mass modelling [1]. The most important step in numerical modelling of the rock mass is accurate defining of discontinuities' network (geometric model creation). accurate defining the rock mass structure and creating an accurate geometric model will provide us with a better starting point for numerical modelling and mechanical and hydraulic analyses.

In order to accurately model the rock mass, joints' location inside the model have to be as much similar to the distribution of discontinuities inside the real rock mass as possible. One of the strongest simulation methods for joints' geometric properties is random 3D modelling through Discrete Fracture Network, which is also used for describing the modes of rock mass failures [2].

Up till now, many different rock characteristics such as spacing, orientation, trace length, and opening are simulated and used in Discrete Fracture Network; though not much work has been performed on the simulation of probability of discontinuities' roughness in limited extents. The most important research has been done on Rough Discrete Fracture Network in 2D by Wang et. al. In this method, the roughness is added to the separate joint network through sinusoidal, triangular or fractal methods and is used for studying the shear behavior of the rock mass [3]. In this research, roughness characteristic of the rock mass's discontinuities is simulated and used in DFN-FRAC^{3D}.

MATERIALS AND METHODS

Nearly half a century ago, the first models for random modelling were presented. During this period, random models of the network of discontinuity have been improved and many properties of discontinuities of the rock mass have been simulated.

In order to model the position of discontinuities, Poisson's homogenous model and heterogenous models, cluster models, and cox models are used [4]. In case of the size of discontinuities, many researches have come up with negative exponential distribution function, while some others have suggested normal log functions and many others have proposed the gamma distribution function [5-7]. For the orientation of discontinuities set, the three functions of normal distribution, Fisher distribution, and Bingham distribution have been focused on [8]. Hu et. al. used the negative exponential probability distribution function and were satisfied with it [9]. Opening of joints is another characteristic that different geological conditions and various scales show whether to use power distribution function or log normal [10].

In order to implicate the probability distribution functions of geometric properties of discontinuities, many computer programs have been developed. One of these computer programs for simulating the properties of discontinuities of the rock mass is DFN-FRAC^{3D}. This program is able to produce a graphical image of the discontinuities' network in different orientations in addition to the numeral output through the gathered data. Some sampling tools such as planar and longitudinal sampling are also supported by this program in order to define the validation level of the model. This program is also capable of producing sections in different orientations and analyzing statistical effects of joints on sections. The main input for this program includes the volume of modelling, generation method of discontinuities location, form of discontinuity, volumetric intensity, orientation of discontinuities, persistence, spacing, and number of discontinuities, all as a text file. In addition to producing text output, DFN-FRAC^{3D} is capable of showing the network of produced joints through another program developed in Mathematica.

Roughness is one of the geometric properties which shows the convexes and concaves in laboratory and field scales. Quantifying the roughness is actually transforming the geometric image of convexes and concaves on the surface of a discontinuity into numbers through different empirical, experimental, and analytical methods, in which despite other properties of discontinuities, the simulation of roughness is performed in two steps; First, the simulation of the value of the roughness and second, the simulation of the geometry of the roughness. Since no specific distribution function has been proposed for determining the value of roughness of discontinuities, in this paper, Kernel function has been used for simulating the roughness. The method of using Kernel function for estimating the roughness value is presented in a paper by Ameri et al. [11].

FINDINGS AND ARGUMENT

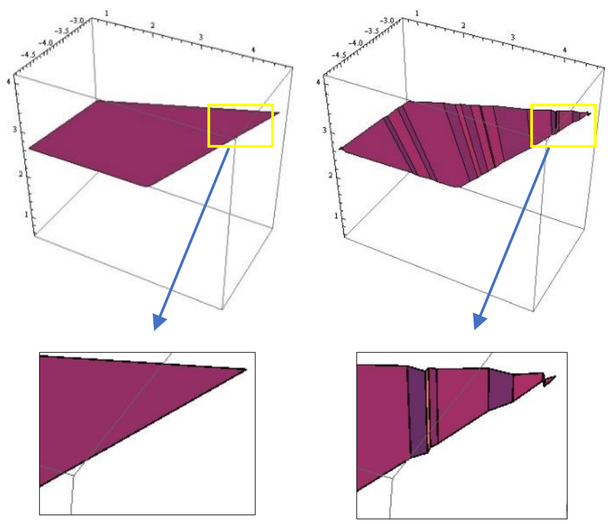
Despite other properties of discontinuities of the rock mass, the numerical value of roughness is determined through indirect methods. As previously explained, the roughness value is simulated through Kernel method; but, since different discontinuities with different convexes and concaves can have equal roughness values, a specific roughness value can be assumed for discontinuities with different convexes and concaves. Although, even if the roughness value is specifically determined, still the surface of the discontinuity should be simulated for the specific roughness value. In other words, the goal for measuring the roughness is to quantify it. Since quantifying the roughness requires analysis and engineering judgment, many researches have been performed on measuring and quantifying the roughness of the discontinuity for determining a numerical value that correctly represent the roughness of the surface. In this research, Barton's field measuring method is used for simulating the geometry of the roughness. Based on this method, JRC in large scale discontinuities is determined through a simple, diagram-based method, by measuring the length of the field profile and the distance between the minimum and the maximum convexes and concaves of the surface of the discontinuity. In this method, at the beginning, a specific length of the discontinuity is assumed in meters, then its largest depth is measured by millimeters. After that, these values are drawn on a diagram and the value of JRC which is relevant to the roughness of the surface of the discontinuity, is determined.

In this method, a selection has to be made from the different surfaces of discontinuity which have equal roughness value or, in other words, to be simulated. This method is previously explained through DRS method [12]. Steps of roughness simulation is explained in Figure 1.

DRS method is a 2D one; Thus, in order to describe the roughness in 3D, the largest diameter of the discontinuity should be determined in DFN-FRAC^{3D} computer software at first, which is defined as a plate (plane polygon). Then, the DRS method which is 2D, is implicated on this line (the largest diameter of the discontinuity). Implicating the roughness on the largest diameter covers the surface of the discontinuity in a better way; Therefore, the largest diameter is chosen as a section of the discontinuity on which the roughness is implicated on. After that, the roughness profile is developed perpendicular to the main diameter up to the boarders of the discontinuity. In Figure 2-A, a plane discontinuity is shown with its largest diameter specified. After implicating the roughness, this surface transforms from plane into undulant (Figure 2-B).

Step 1:	JRC value and the length of the field profile are determined.
Step 2:	Considering Bartone's roughness field measuring method, the maximum depth of the roughness (a) relevant to JRC value and L is calculated.
Step 3:	Length of the discontinuity is divided into n sections, so that the length of each section is a random value between zero and L, whilst each section has a convex or concave as large as a.
Step 4:	Considering a random value between zero and a as the height of the convex and a random value between zero and L as the distance between a two adjacent convexes, the geometric location of the convexes of the discontinuity is determined in 2D.
Step 5:	Using a random value between zero and the distance between 2 adjacent convexes, the distance between the concave from its adjacent convex is determined and by using the value of a, the geometric location of the concave is determined.
Step 6:	By determining the geometric locations of convexes and concaves and connecting these locations, the roughness of the discontinuity is determined with JRC value.

Figure 1. 2D DRS algorithm for simulating the roughness of the discontinuity's surface [12]



A: Discontinuity without roughness implication　　**B: Discontinuity with roughness implication**

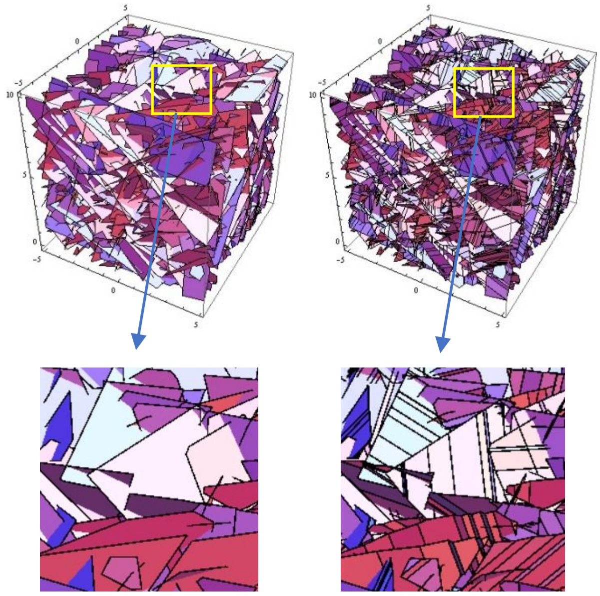
Figure 2. Implicating the roughness on the surface of a discontinuity

Steps of developing DRS from 2D into 3D are presented in Figure 3.

Since discontinuities are randomly simulated, the largest diameters of discontinuities are also random in essence. It should be noted that the presented algorithm is written in C++ programming language and is added to DFN-FRAC^{3D} as a module. By adding roughness property to DFN-FRAC^{3D}, an effective step is taken in improving DFN. Figure 4-A shows the output of DFN-FRAC^{3D} in Mathematica environment in which 1377 discontinuities are simulated without implicating roughness. Figure 4-B shows the same simulated discontinuities with roughness implication.

Step 1:	Selecting one of the surfaces of the discontinuity
Step 2:	Attributing one of the roughness data (which is randomly produced) to the surfaces of the selected discontinuity
Step 3:	Determining the largest diameter of the discontinuity
Step 4:	Implicating the roughness on the largest diameter through 2D DRS method
Step 5:	Developing the roughness profile from the largest diameter to the sides up to the boarders of the discontinuity
Step 6:	Creating of a polygon as the surface of the discontinuity with specific roughness

Figure 3. Algorithm for developing DRS method from 2D into 3D



A: Graphical output of DFN-FRAC^{3D} without implication of roughness

B: Graphical output of DFN-FRAC^{3D} with implication of roughness

Figure 4. Implication of roughness on simulated discontinuities

In fact, after implicating roughness on each discontinuity, the discontinuity transforms into several discontinuities which are different in slope and size.

CONCLUSIONS

Improving DFN in order to make the simulated geometric model more similar to the real one has always been under focus by researchers. Different properties of discontinuities have been simulated, but no one has simulated the roughness property. Roughness has a great effect on the mechanical properties of the rock mass; Thus, this research has taken a big step on improving the geometric modelling by simulating the geometry of the roughness through DRS method and adding it to DFN. Also, a computer program compatible with DFN-FRAC^{3D} has also been developed which is to be a step towards developing DFN.

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