A New Numerical Method for the Construction of Fracture-Pore Dual Media

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Abstract. Fracture-pore dual media plays an important role in soil and groundwater environmental protection. A new numerical method is developed to construct the fracture-pore dual media in this paper. In this method, the random fracture network with self-affine rough characteristic and the random porous medium with Berlin noise characteristic are constructed respectively, then the rough random fracture network and the random porous medium are superimposed to construct the fracture-pore dual medium. The construction of dual media is of great significance to the numerical simulation research in soil and groundwater environmental protection.

Keywords. Fracture-pore dual media, rough fracture network, random porous media, dual media construction

1. Introduction

In the fields of energy and environment, such as hydrogeology, oilfield development, rock/soil science, the medium containing both fracture and pore is generally called fracture-pore dual medium. The seepage channel of dual media plays a decisive role in the infiltration of polluted water [1-3]. Therefore, the construction method of dual medium model is of great significance to energy development and environmental protection.

It is difficult to describe the irregular seepage channels geometry in dual media. Previous scholars have proposed some excellent construction methods. Barenblatt et al. (1960) put forward the concept of dual medium for the first time, and believed that rock and soil have dual medium structure, pores and fractures are evenly distributed in the flow space and form a continuous medium system [4]. Then, Warren root model [5], Kazemi model [6] and deswaan model [7] are built to simulate the seepage space in real rock or soil. Zhang (2004) established a dual medium model based on Warren root model to conduct numerical simulation of flow and solute transport [8]; Fomin et al. (2011) established the fracture-pore dual medium model, which considered the distribution relationship between the local pores and fractures [9]; Zhang et al. (2016) constructed geometry models of different fracture widths and permeability by setting specific

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parameters for pores and fractures [10]. With the development and progress of computer technology, many scholars use CT scanning to construct dual media model. Shang et al. (1997) explained the advantage of using X-CT method to measure the porosity of dual media [11]; Dietrich et al. (2008) constructed the fracture-pore network model from macro to pore scale through discrete fracture network numerical method and experimental CT method [12].

At present, the pore-fracture dual medium model is mostly constructed by changing the skeleton particle arrangement to get the fracture channel, or directly hollow out the mass where the fracture is located, which cannot realistically construct the fine characteristics such as fracture roughness in the dual medium. This paper develops a new dual media construction method, which gives the fracture rough shape in the fracture network, and obtains a more refined and realistic dual medium model by superimposing the rough fracture network with random porous medium.

2. Construction of Random Rough Fracture Network

In order to construct the random rough fracture network, the fracture network composed of straight fractures is constructed firstly, and then the fracture aperture is assigned with self-affine feature. In this way, the random fracture network with self-affine rough feature is constructed.

2.1. Construction of Fracture Network Composed of Straight Fractures

In order to build a random fracture network, the RANSAC method is adopted, and the MATLAB is used to call the ADFNE function library created by Fadakar Alghalandis and Younes [13].

RANSAC method determines the geometry of the fracture by randomly sampling in the point cloud, the basic principle is

\[
\text{enter } \left\{ \begin{array}{l}
U = \{x_i\} \\
f(S): S \rightarrow p
\end{array} \right. \text{ and output } \left\{ \begin{array}{l}
C(p,x) \\
p^*
\end{array} \right.
\]

where \(U\) is a series of points, \(|U|=N\), \(f\) is the crack fitting function (such as the least squares method) used to calculate the fitting parameter \(p\) of the sample \(S\) in \(U\), \(C(\cdot)\) is the cost function, \(p\) and the optimal fracture parameter when \(p\) and \(p^*\) is the minimum cost function. The specific steps are described in detail in the job of Fadakar Alghalandis [14].

By invoking the ADFNE functions, the fracture network with a certain density and random length and tendency can be quickly constructed. For example, set the fracture density to 20 fractures/square unit, 50 fractures/square unit and 100 fractures/square unit respectively, and the length and direction are set as the default random values, the random discrete fracture network models with different fracture densities are obtained, as shown in Figures 1a-1c respectively.
2.2. Construction of Rough Fracture Network

Based on the construction method of discrete fracture network in Section 2.1, this paper creatively puts forward a set of construction method of rough fracture network. The process is shown in Figure 2 and it can be realized by MATLAB programming. The specific steps are as follows:

1. Read the fracture network image generated by the method detailed in Section 2.1.
2. Binarize the read image and transform it into a two-dimensional 01 matrix. The element value of the crack location is 0 and the other element values are 1.
3. Judge the value of matrix element column by column or row by row. When the element value is 0, write down the coordinates of the element, that is, the coordinate value of the fracture surface position.
4. Run the self-affine single fracture generation code to generate a one-dimensional array with self-affine characteristics according to the self-affine fracture construction method and some certain fracture roughness parameters. The element value of the array represents the aperture value of the fracture [15].
5. Re-assign the element of its adjacent position to 0 in the matrix according to the coordinates of the crack position obtained in Step (3). Here, the size of “adjacent” is the element value of the aperture matrix generated in Step (4), and one element value is taken for each position. If an integer value is added to the aperture matrix as a whole, the aperture of the fracture can be increased as a whole without changing the roughness characteristics.
6. By saving the new matrix obtained in the above steps as image output, the geometric model of rough fracture network with self-affine characteristics is obtained.

Through the above steps, the original straight fractures are endowed with self-affine characteristics and have certain roughness and apertures.
An example is shown in Figure 3, where Figure 3a shows a random discrete fracture network without roughness and aperture created by the method described in Section 2.1, Figure 3b shows the fracture network constructed by the method described in Figure 2 with self-affine characteristics, and its self-affine parameters are set as $\sigma = 0.006, H = 0.8$. The self-affine parameters in Figure 3c are the same as those in Figure 3b, but the overall fracture aperture increases by 0.005. Figure 3d shows the fracture network with self-affine characteristics, and its self-affine parameters are set to $\sigma = 0.012, H = 0.8$.

3. Porous Media Geometry Construction

BerlinNoise is a natural noise generation algorithm based on lattice generation. BerlinNoise is named after its inventor Ken Perlin [16]. The BerlinNoise algorithm is widely used as the basis for simulating uneven terrain, complex texture of rock surface, undulating waves, rolling smoke and so on. In this section, BerlinNoise is used to simulate complex porous media. The basic principle of BerlinNoise is shown in Figure 4.

Firstly, the research object is divided into equal step grids of X rows and Y columns. On this basis, we define a lattice structure in which each lattice vertex has a gradient vector. In the two-dimensional case, the lattice structure is a planar mesh. Then, given a point, it is two-dimensional coordinate in two-dimensional case. By calculating the distance vector from the point to the lattice vertex, and then multiplying the distance vector by the pseudo-random gradient vector of the corresponding vertex (randomly generated), $2^n$ point multiplication results will be obtained ($2^n$ vertices per lattice in n-
The transition curve is interpolated with the distance sampling weight value. The transition curve equation is: \( s(t) = 3t^2 - 2t^3 \), and then improved to \( s(t) = 6t^2 - 15t^3 + 10t^4 \). Finally, the Berlin noise is obtained, and then further processed according to the needs, which can be used in simulation occasions under different conditions.

![Figure 4](image)

**Figure 4.** Schematic diagram of BerlinNoise.

Combined with BerlinNoise function and MATLAB programming, complex porous media models with different porosity are generated. As shown in Figures 5a-5c, the BerlinNoise frequency is 1/30, 1/20 and 1/10 respectively, the amplitude is 1, and the porosity is controlled by isosurface function, both are 0.5.

![Figure 5](image)

**Figure 5.** Complex porous media generated by BerlinNoise simulation.

### 4. Direct Superposition

The direct superposition method is to add the fracture part in the fracture network to the porous media. The first step is to read the porous media image and fracture network image respectively through MATLAB, and binary them into a matrix consists of 0 and 1 respectively, 0 represents the void part and 1 represents the skeleton part, and then add the two matrices directly to obtain a new matrix consists of 0, 1 and 2. Then, replace all 1 in the matrix with 0, replace all 2 with 1, and keep 0 unchanged. Finally, the fracture-pore dual medium geometric matrix is obtained. Directly converting this matrix into an image can intuitively present the double medium geometry. The example is shown in Figure 6. The geometric model of fractured medium in Figure 6a is directly superimposed with the geometric model of porous medium in Figure 6b to obtain the geometric model of dual medium as shown in Figure 6c.
5. Conclusion

A new method for constructing the fracture-pore dual media with rough fracture network is proposed in this paper. The main achievements and conclusions are listed as follows:

(1) Based on the straight random fracture network construction method, the construction method of random rough fracture network is innovatively proposed.

(2) The Berlin noise method is creatively used to simulate porous media.

(3) The porous media and random rough fracture network are superimposed to obtain fracture-pore dual media with rough fracture network.

This research is of great significance to the construction of dual medium model and numerical simulation in related fields.

Acknowledgement

This work was supported by Sichuan Science and Technology Program (No. 2022JDRC0102).

References


