Determination on Mechanical Parameters of Rock Mass Using Fracture Tensors

Wenhui Tan, Yangfan Wu, Junfeng Wang and Zhonghua Sun

ABSTRACT

Determining mechanical parameters of rock masses correctly is still a big problem over the years. A new method using fracture tensors to determine mechanical parameters of rock masses is presented considering the characteristics of the structures of rock mass. That is, joints were measured in situ and statistically analyzed firstly, then, three-dimensional joints network model was built, the fracture tensors and mechanical parameters were calculated in different dimensions of rock mass models; at last, the relationship between fracture tensors and mechanical parameters of rock mass was established. Therefore, the rock mass strength and deformability parameters can be estimated in any given direction from a single power function without performing expensive and time-consuming in situ tests, as long as the intact rock and the joint properties from laboratory or field tests and the joint geometry system from field joint mapping are known. The results will be useful for evaluating the stability of jointed rock engineering.1

KEY WORDS

Mechanical Parameters of Rock Mass, Fracture Tensor, Three-dimensional Joints Network Simulation, Size Effect

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INTRODUCTION

Determining mechanical parameters of engineering rock mass reasonably is still a big problem over the years [1], currently, the ways to estimate mechanical parameters of rock mass are in-situ tests, empirical discriminant method based on rock mass classifications, analytical decomposition technique and numerical simulation method, etc. To obtain realistic results for jointed rock mass mechanical properties, many large volumes of rock of different sizes having a number of different known joint configurations should be tested at significant stress levels under different stress paths. Such an experiment program is almost impossible to carry out in the laboratory. With in situ tests, such an experimental program would be very difficult, time-consuming and expensive. Therefore, researchers try to use other approaches to obtain mechanical parameters of rock mass. Gao Qian, et al. [2] have obtained the equivalent parameters of rock mass in Changba Lead-zinc slope by orthogonal numerical test based on RMR of rock mass classification system and GPS monitoring data. Hu Sheng-ming et al. [3] used Hoek-Brown strength criterion to estimate the mechanical parameters of rock mass. Xia Kai-zong, et al. [4] have proposed an approach to predict mechanical parameters of rock mass with the wave velocities of the rock mass based on Hoek-Brown rule. Wu Qiong et al. [5] have studied size effect and anisotropic characteristics of mechanical parameters of jointed rock mass by 3-D stochastic fracture geometry model and numerical simulation with 3DEC for a dam. Yang Gengshe and Xie Dingyi [6] have measured the change of microstructure of a rock, and the change is quantified with the damage variable by CT count. Kemeny and Cook [7] have exported an equivalent model of rock mass, in which joint distributions are random completely, and defined fracture tensor by using energy theory of fracture mechanics. In 1982, Oda[8] put forward a concept of fracture tensor. The number of joint sets, joint density, orientation and size of rock mass can be reflected comprehensively by this variable. Xu Guang-li et al. (1991)[9] have introduced fracture tensor to stress-strain constitutive relation of jointed rock masses, and deduced a predictive equation of deformation modulus for rock mass changing with the dimensional orientation. Kulatilake et al. (1993) [10] put forward a concept of components of fracture tensor, and found that the value of a component in a certain direction is close to the parameters of deformation and seepage in the same direction. Xu Wei-ya and Zhang Gui-ke (2007) [11] have studied the equivalent parameter of shear strength of jointed rock mass by combining fracture tensor with damage mechanics.

Fracture tensor can capture the characteristics of jointed in rock mass comprehensively. Currently, research on jointed rock mass by using fracture tensor is very few, especially by incorporating three-dimensional stochastic joint geometry model, numerical simulation with 3DEC and fracture tensor into mechanical parameters estimation on rock mass. In this paper, the 3-D stochastic fracture geometry model, the scale effect on fracture system, the rule between fracture tensor
and mechanical parameters of rock mass in the slopes of Shuichang open pit mine is investigated.

**MODEL OF 3-D STOCHASIC FRACTURE NETWORK OF ROCKMASS**

Shuichang iron mine, located in Qinan district of Hebei Province, is the main supplier of iron ore for the Capital Steel Corporation and also the largest open-pit metal mine in China. The pit is 2,900 meters long and 1000 to 1400 meters wide. According to the latest mining program of Shuichang iron mine, the height of the final slope of the mine is 760 m and the deep-concave mining depth is 540 m.

In order to collect joints data in the north slopes of Shuichang open-pit mine, ShapeMetriX 3D system of 3GSM company in Austria is used. 13 areas are selected. The length of each area is from 50 to 100 meter. The joints of gneiss at the step of negative 80 meter in No.5 area was selected as an example, the left view (Figure 1a) and the right view (Figure 1b) gotten from in site were led to the system of ShapeMetrix 3D. Firstly, the key measurement areas is marked. Then, a series of technology, such as datum calibration, pixel-matching, biases correction of image deformation, were taken to combine three-dimensional models and realize the orientation and distance of joints. At last, 3D-view of rock surface (Figure 1c) and the dominant four joint sets (64.41° /81.02°, 320.09° /37.06°, 25.82° /44.31°, 134.5° /48.27°) are gotten[12], which are displayed by four different colors in Figure 1c. The data and distribution of dip angle, dip direction, trace length, space and breaking span of each joint set are used for three-dimensional stochastic joint network modeling by Monte-Carlo method. (Figure 2)

![Figure 1. Pictures of joints taken and synthesized.](image)
DETERMINING BY USING FRACTURE TENSOT MECHANICAL PARAMETERS OF ROCK MASS

Relationship Between Directional Fracture Tensor Components And The Size of The Rock Mass

It is of advantage to have a parameter that can express the combined effect of the following joint geometry features: (a) number of joint sets, (b) density of joints for each set, and (c) orientation and size distributions for each joint set. The fracture tensor [8] can be used to develop that kind of a parameter as explained below.

Assuming joints to be thin equivalent circular discs, the general form of the fracture tensor at the 3-D level for the kth joint set can be expressed as:

\[
F_{ij}^{(k)} = 2\pi \rho \int_{0}^{\infty} \int_{0}^{\Omega/2} r^3 n_i n_j f(n, r)d\Omega dr
\]

where \(\rho\) is the average number of joints per unit volume (joint intensity), \(r\) is the radius of the circular joint (joint size), \(n\) is the unit vector normal to the joint plane, \(f(n, r)\) is the joint probability density function of \(n\) and \(r\), \(\Omega/2\) is a solid angle corresponding to the surface of a unit hemisphere, and \(n_i\) and \(n_j\) \((i, j = x, y, z)\) are the components of vector \(n\) in the rectangular coordinate system considered here.

If there is more than one joint set in the rock mass, the fracture tensor for the rock mass can be expressed as:

\[
F_{ij} = \sum_{k=1}^{N} F_{ij}^{(k)}
\]

In order to study the relationship between the directional fracture tensor components and the size of the rock mass, a series models of jointed gneiss in No. 5
area were built with different sizes using 3DEC, the dimensions are: 2.5m×2.5m×2.5m, 5m×5m×5m, 7.5m×7.5m×7.5m, 9m×9m×9m, 10m×10m×10m, 11m×11m×11m, 12.5m×12.5m×12.5m, 15m×15m×15m, 17.5m×17.5m×17.5m, 20m×20m×20m. Some fictitious joints was introduced to build models of the rock mass, which behave as intact rock to the domain to interact with actual joints[13]. Figure 3 is the model of the jointed rock mass, whose size is 20m×20m×20m. For the smallest cubic block size of gneiss, physical and mechanical properties of intact rock, fictitious joints and actual fractures were assigned according to the values given in Table I and Table II. Mohr-Coulomb Failure Criterion and ideal elastic-plastic constitutive model were used to analyze the characteristics of strength and deformation of cubic rock blocks.

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Density, ρ/ kg·m⁻³</th>
<th>Elasticity modulus, E/ GPa</th>
<th>Bulk modulus, K/ GPa</th>
<th>Shear modulus, G/ GPa</th>
<th>Friction angle, ϕ°</th>
<th>Cohesion, C/ MPa</th>
<th>Tensile strength, σ₁/ MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gneiss</td>
<td>2630</td>
<td>61</td>
<td>22.6</td>
<td>16.2</td>
<td>43.86</td>
<td>18.53</td>
<td>4.58</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Shear stiffness, Kₛ/ GPa·m⁻¹</th>
<th>Normal stiffness, Kₙ/ GPa·m⁻¹</th>
<th>Friction angle, ϕ°</th>
<th>Cohesion, C/ MPa</th>
<th>Tensile strength, σ₁/ MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual joints</td>
<td>0.9</td>
<td>2.25</td>
<td>30</td>
<td>0.55</td>
<td>0</td>
</tr>
<tr>
<td>Fictitious joints</td>
<td>162</td>
<td>405</td>
<td>35</td>
<td>2.99</td>
<td>8.2</td>
</tr>
</tbody>
</table>

Figure 3. Relationship between fracture tensor components and block size.
Fracture tensor parameter values were calculated for each selected block size. In 3DEC, the three perpendicular directions $x$, $y$ and $z$ represent east, north and vertical up, respectively. The relationship between the calculated directional fracture tensor component values in these three perpendicular directions and the block size are given in Fig. 3. Fig. 3 shows that beyond a block size of about 12.5 – 15 m, the rate of increase of fracture tensor parameters is small compared to that of block sizes less than 12.5 m. For practical purposes, a block size of about 12.5 – 15 m may be used to represent the REV behavior, and the deformability modulus ($E_i$), strength ($S_i$), cohesion ($C_i$) in $x$, $y$ and $z$ directions are gotten (Figure 4).

**Relationship Between Directional Fracture Tensor Components And Rock Mass Mechanical Parameters**

Become the values of Fracture tensors $F_{ii}$, $F_{jj}$ and $F_{kk}$ and mechanical parameters are all related with rock sizes, the relationship between them can be built. Figure 5 shows that the rock mass strength and deformability parameters can be estimated in any given direction from a single power function without performing expensive and time-consuming in situ tests, as long as the intact rock and the joint properties from laboratory or field tests and the joint geometry system from field joint mapping are known.

![Figure 4](image-url)
Figure 4. Relations between rock block strength/deformability parameters and block size.

![Figure 5](image-url)
Figure 5. Relationship between directional fracture tensor components and rock mass mechanical parameters.
CONCLUSIONS

(1) Four fracture sets were gotten by 3GSM and used to perform a REV study in 3-D with respect to the fracture tensors as well as mechanical properties of the rock mass. A block size of about 12.5~15 m was found to be suitable to represent the REV behavior with respect to the fracture system of rock mass.

(2) The relations were developed between the rock mass strength/deformability parameters and fracture tensor components in 3-D. It is very useful information from a rock engineering viewpoint.

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