Quantitative study on joint roughness coefficient (JRC) of rock mass

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Abstract. Ten Barton’s standard roughness rating profile curves have been digitized by the interpolation approach with MATLAB software. It is proved that the way of digitizing the JRC curves is feasible, based on the contrastive analysis of slope root-mean-square of the JRC curves provided in this article and the others. Considering both asperity inclination angle and amplitude, a new parameter, degree of impedance, has been proposed to determine morphology characteristics of joint. On the other hand, the degree of impedance can be further corrected with considering the elongation rate and equivalent depth, and the degree of impedance for joint with different sampling intervals has been calculated, which shows that the degree of impedance can better reflect the size effect of joint.

1. Introduction

For evaluating the rock mass, much attention has been paid to the rock structures and its shear strength. The shear strength mainly depends on the joint roughness coefficient (JRC) and the strength of the filled or unfilled rock mass. Furthermore, shear strength of joint is one of the decisive factors which have an import influence in the engineering properties of rock mass. Therefore, it is necessary to study the shear strength of joint.

The primary ways for obtaining the shear strength of joint are shear test, shear strength formula, experience, and inverse calculation. The shear strength formula method is widely applied in engineering because of its clear physical meaning and the ability to take geological environment into account. The main shear strength models are as follows: bilinear strength model (Patton, 1966), clipping effect model (Jaeger, 1971), clipping and dilatancy model (Ladanyi and Archambault, 1969), the JRC–JCS model (Barton and Choubey, 1977), hyperbola model (Maksimovic, 1992), and dilatancy- incisor model (Shen Mingrong and Zhang Qing-zhao, 2010). JRC is the key parameter for the empirical estimation of joint shear strength by using the JRC-JCS model, which reflects the roughing range and the undulation of rock mass.

Usually, roughness coefficient of joint is obtained through comparison with the standard roughness rating profile curves proposed by Barton. However, this method is greatly influenced by human factors, and it is difficult to obtain precise values of JRC.

At present, there are four main methods to quantify the joint roughness of two-dimensional structural contour line:

(1) Statistical parameter description method, which mainly include the following parameters: amplitude (Tse R, 1979; Jean M.Bennett, 1999), inclination angle (Yu XB, 1991; TANG Zhi-cheng, 2011) and trace length (Ei-Soudani SM, 1978).
(2) Fractal geometry description method (Lee YH, 1990; Yang Geng-she, 1993; Zhu Yu-xue, 1994; Feng Xia-ting, 1999; You Zhi-cheng, 2014). The fractal dimension is mostly obtained by box-counting method and stick-measuring and then the relationship with JRC is established.

(3) Comprehensive parameter description method (Kulatilake PHSW, 2006; Kulatilake PHSW, 2008; SUN Fu-ting, 2013; Chen Shi-jiang, 2012; Li Hua, 2014), multi-parameter fractal dimension joint representation method and other comprehensive parameter description method.

(4) Straight edge method (Barton N, 2012; Du Shi-gui, 1996). The roughness coefficient value is obtained by the maximum undulation and the length of the contour curve of the joint.

In this paper, the inclination angle was characterized by gradient, and joint morphology was described by the combination of inclination angle and amplitude. On the basis of considering the shear direction, the effective quantification of joint was realized by the elongation and the equivalent. Meanwhile, the impedance (ω) that describing the joint has been proposed, and the relationship between the impedance and JRC was established and verified.

2. Quantitative characterization of the joint topography

The research shows that the larger the inclination angle is, the more likely it is to contact friction (Grasselli G, Wirth J, etc., 2002; Gentier S, Riss J, etc., 2000), in addition, the degree of friction is greater with higher amplitude (Fan Xiang, Cao Ping, etc., 2012). Therefore, JRC can be comprehensively reflected by the inclination angle and the amplitude of joint.

2.1 Characterization of the joint roughing range and the undulation of joint

Taking the 10 standard rating profile curves proposed by Barton as an example: firstly, GetData Graph Digitizer software was used to digitize above curves. Then, the sample data was interpolated to obtain sufficient precision by MATLAB software. Finally, considering the existence of a 90-degree steep ridge, the gradient value was used to represent joint amplitude.

Define the structure plane projection length is $x$, and the amplitude height is $h$. The formula of joint profile curve can be defined as $h=f(x)$. The inclination angle is the gradient value of the curve of $f(x)$, the inclination angle is expressed as $\theta_i = 0.5(\theta_i + \theta_{i+1})$. At the same time, considering the resistance of the shear angle is different in different shear direction, $\theta_i$ is 0 when $\theta_i \leq 0$.

The roughness inclination angle is given as

$$\theta_i = \begin{cases} 0, & \theta_i + \theta_{i+1} \leq 0 \\ 0.5(\theta_i + \theta_{i+1}), & \theta_i + \theta_{i+1} > 0 \end{cases}. \quad (1)$$

The amplitude reflects the protrusion of the joint, and it can be calculated by the elevation difference, and the amplitude given by

$$h_i = \begin{cases} 0, & h_{i+1} - h_i \leq 0 \\ h_{i+1} - h_i, & h_{i+1} - h_i > 0 \end{cases}. \quad (2)$$

The dispersion degree of roughness inclination angle and amplitude can be expressed by variance, standard deviation or discrete coefficient. To ensure the dispersion degree is greater than 1, the following expression can be used

$$K = 1 + c_v = 1 + \frac{\sigma}{\mu}. \quad (3)$$

Where $K$ is the correction factor, $c_v$ is the discrete coefficient, $\sigma$ is the standard deviation, $\mu$ is the mean value.

$K_1$ is the dispersion of inclination angle, $K_2$ is the dispersion of amplitude, $K_1$ and $K_2$ can be expressed as
\[ K_1 = (1 + c_1)^{0.5} = (1 + \frac{\sigma_1}{\mu_1})^{0.5} = (1 + \frac{1}{m-1} \sum_{i=1}^{m} (\bar{\theta}_i - \bar{\theta}))^{0.5} \]  (4)

\[ K_2 = (1 + c_2)^{0.5} = (1 + \frac{\sigma_2}{\mu_2})^{0.5} = (1 + \frac{1}{m-1} \sum_{i=1}^{m} (\bar{h}_i - \bar{h}))^{0.5} \]  (5)

Where \( \bar{\theta} \) is the mean value of roughing range, \( \bar{h} \) the mean value of undulation, \( m \) is the sampling number.

On the basis of coefficient of variation, the dispersion of the inclination angle and amplitude in formula (4) and (5) was defined. The characteristic parameter formula of the fluctuation distribution defined by Song Leibo(2017) was based on the normal distribution characteristic of the inclination angle. The forms are similar, but the sampling parameters are different.

2.2 Calculation for JRC
Joint inclination angle and amplitude can represent roughness, which can be modified by the elongation and the equivalent height. The elongation is the ratio of the joint profile curve length to its projection length on the x axis, and the equivalent height of amplitude is the ratio between the area of the joint profile curve with x axis to \( L_0 \). The zero point of amplitude is the lowest point of the joint profile curve.

![Figure 1. Figure with the diagram of equivalent height.](image)

In this paper, a new parameter, the impedance(\( \omega \)) the inclination angle and amplitude, can be used to characterize joint roughness on account of the inclination angle and amplitude, and it is given by

\[ \omega_{th} = \begin{cases} 
0, & \theta_i \leq 0 \text{ or } h_i \leq 0 \\
\theta_i h_i, & \theta_i > 0 \text{ and } h_i > 0 
\end{cases} \]  (6)

The impedance can be further modified by the elongation and the equivalent height, the modified formula is as follows

\[ \omega_{th} = \begin{cases} 
0, & \theta_i \leq 0 \text{ or } h_i \leq 0 \\
\theta_i h_i K_1 K_2 (\mu_0 + d^\sigma_i), & \theta_i > 0 \text{ and } h_i > 0 
\end{cases} \]  (7)

3. Example verification

3.1 The relationship between JRC and \( \omega \)
In order to verify the accuracy of the quantitative method, the mean square root of the slope of the quantization curves were compared with others (Wang Chang-shuo, Wang Liang-qing, and Ge Yun-feng, 2017; Yu Xian-bin, Vaysade B,1991; Tatone BSA, Grasselli G, 2016). The contrast curve was shown in Figure 2.
3.2 The relationship between JRC and $\omega$

The result of $Z_2$ by the quantitative method was in good agreement with other authors in terms of numerical values and variation trends. The digital method was considered feasible basis on interpolation methods. The impedance of each standard profile curve by this digital method was reliable.

The impedance of the ten standard curves were obtained according to formula (7). Figure 3 presented the relationship curve between JRC and $\omega$.

The fitting function between JRC and $\omega$ is:

$$JRC = a(1 - e^{-b\omega})$$

(8)

The parameters of fitting function are shown in table 1.

| Parameters | Value | $a$  | $b$  | Adj.R-Square |
|------------|-------|------|------|---------------|

Table 1. The parameters of fitting function

The correlation between joint roughness coefficient and Impedance was well based on the Figure.2 and Table 1, and the variance is 0.95. It was reasonable to characterize joint roughness with impedance from the result of fitting. The specific fitting function between JRC and $\omega$ is:

$$JRC = 22.02137 \times (1-e^{-0.07262\omega})$$

(9)
Considering that the values of $JRC$ are 0~20, the corresponding impedance value are 0~32.8868.

3.3 The Result of $JRC$ ’s Size Effect

Ge Yunfeng (2016) studied the variation of joint roughness under different sampling sizes from selecting different sizes of concentric square sampling window. Due to lack of the sampling point, this paper quoted his data and used MATLAB software to interpolation to obtain sufficient precision. Figure 4 presented the variation of impedance with sampling size.

![Figure 4. Figure with the Variation of impedance with sampling size](image)

As shown in Figure 4, the impedance index is stable at 0.24 when the sample size is longer than 1.4m, and it is proved that the method of using impedance to characterize the joint is feasible.

4. Conclusion

The accuracy quantization of $JRC$ is intimately connected to the practical application effect of Barton Shear strength model. The paper adopted the inclination angle and amplitude of joint to characterize the joint roughness, and considered the shearing directionality. It is more universal for description of joint.

The concept of the equivalent height of joint was proposed. The formula of joint impedance was optimized by using the elongation and the equivalent height, which enhanced the applicability and accuracy of the formula.

Using the interpolation method to digitize the standard roughness rating profile curves, the results prove that this method is feasible. From the analysis result of the dimension effect of the joint, the digital method is reasonable.

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