# The Study on the Determination Method of 3D Joint Roughness Coefficient

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**Abstract**

In view of the limitations of existing 2D research methods and theories, three 3D joint roughness characteristic parameters were put forward in this article, through consulting a great many of studies on rock joint shear mechanism. Those 3D characteristic parameters can reflect both shear properties and anisotropy of rock joint surface. Moreover, based on the 3D high resolution laser scanning technology and GIS technology, the author precisely measured the accidented surface terrain of porphyritic granite joint and extracted the 3D characteristic parameters successfully. What is more, after precisely analysing the roughness features in different directions of a typical rock joint surface, a new computational Equation of $JRC^{3D}$ was obtained.

**Keywords**

Rock joint • 3D joint roughness coefficient • 3D laser scanning • GIS

## 354.1 Introduction

Since the term "Joint Roughness Coefficient" (JRC) was raised by Barton to describe rock joint roughness features, the following researchers have devoted most of their time to the quantitative mathematical description of it, such as: Barton and Choubey (1977) calculated JRC by traditional statistical analysis, Kulatilake et al. (1997) launched the research with fractal geometry method. Nevertheless, the calculation methods mentioned above are all on the basis of analysing rock joint 2D contour curves, using 2D joint roughness characteristic parameters to describe rock joint roughness features. In other words (from a purely statistical standpoint), due to finite amount of information, 2D characteristic parameters have large deviations and limitations (Du 1997; Du et al. 2004). Thus, in order to describe the rock joint roughness features more correctly and comprehensively, 3D joint roughness characteristic parameters should be adopted.

## 354.2 The Selection of 3D Joint Roughness Characteristic Parameters

The research (Cao et al. 2011) about morphology characteristic evolution of the rock joint surface during the shear test reveals that the peak shear strength of rock joint is mainly reflected by the gradient distribution of surface terrain of rock joint surface in different shear directions in terms of other conditions unchanged. Therefore, the key point of choosing 3D joint roughness characteristic parameters associated with shear properties is how to describe the gradient distribution characters.

Furthermore, in view of the "Self-locking" effect of joint surface in the process of shearing, according to statics of rigid bodies, the affected surfaces (the basic analysis unit) of "Self-locking" effect are those whose tilted angle $\theta \geq \frac{\pi}{2} - \varphi_b$ ($\varphi_b$ is the basic angle of friction for rock). So based on the results of the test (fresh porphyritic granite's basic angle of friction $\varphi_b = 35 - 49°$), the affected surfaces on fresh

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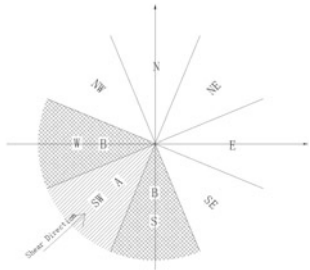

**Fig. 354.1** The principal oblique directions associated with the shearing action

porphyritic granite's joint surface are those whose tilted angle $\theta \geqslant 41 - 55°$ (in this article, average value $\theta \geqslant 48°$ is selected).

To sum up, three 3D joint roughness characteristic parameters were put forward in this article on the basis of the research achievements about mechanical parts' surface roughness (Dong et al. 1994), they are defined as follows:

The gentle (<48°) and steep (>48°) inclined surfaces' total area in the principal oblique directions associated with the shearing action, as a percentage of the total surface area of rock joint, ($P_{\leq 48°}$, $P_{\geq 48°}$)

$$P_{\geq(\leq)48°} = \frac{N_{\geq(\leq)48°}}{N_T} \times 100 \qquad (354.1)$$

The aggregate total area, in the principal oblique directions associated with the shearing action, as a percentage of the total surface area of rock joint ($P_D$)

$$P_D = \frac{P_{\geq 48°} + P_{\leq 48°}}{N_T} \times 100 \qquad (354.2)$$

where: $N_{\geq(\leq)48°}$ is the gentle ($\leqslant 48°$) and steep ($\geqslant 48°$) inclined surfaces' total area; $N_T$ is the total surface area of rock joint

According to the projection law of force, the principal oblique directions associated with the shearing action are that: the direction opposite to the orientation of shear (A) and those adjacent to A(B) (see Fig. 354.1).

In this article, due north direction is 0° and the exposure is divided into eight individual directions: N (337.5–22.5°), NE (22.5–67.5°), E (67.5–112.5°), SE (112.5–157.5°), S (157.5–202.5°), SW (202.5–247.5°), W (247.5–292.5°), NW (292.5–337.5°).

## 354.3 3D Visualized Analysis of the Rock Joint Surface

Based on the 3D high resolution laser scanning technology and GIS technology, a typical porphyritic granite joint surface, on which there are distinct scarps, bulges and pits, was used as an example of how to analysing the roughness features in different directions, and Z-SCAN800 handheld laser scanner (Z-Corporation, US) was utilized to obtain the basic material- point cloud data.

Then, the point cloud data were imported into a GIS software like "ArcGis" or "MapGis" in order to use its spatial modeling and analysis technology to build the high precision digital elevation models, gradient models and exposure models without losing precision. On the basis of the cross statistical analysis between the original scan data and properties of every picture element (the basic analysis unit) which were obtained by raster reclassification, the 3D characteristic parameters were extracted successfully (Figs. 354.2, 354.3).

## 354.4 The Characters of the Gradient Distribution

The statistical results of 3D joint roughness characteristic parameters of the typical porphyritic granite joint surface is showed in Table 354.1:

According to the gentle ($\leqslant 48°$) and steep ($\geqslant 48°$) inclined surfaces' exposure distribution (Fig. 354.3), what is possible to see from this table is that:

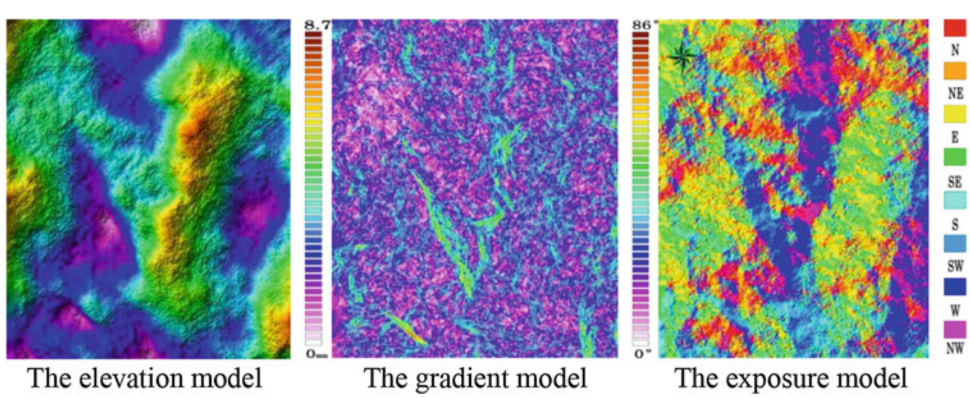


**Fig. 354.2** The typical porphyritic granite joint surface's 3D visualized analysis models

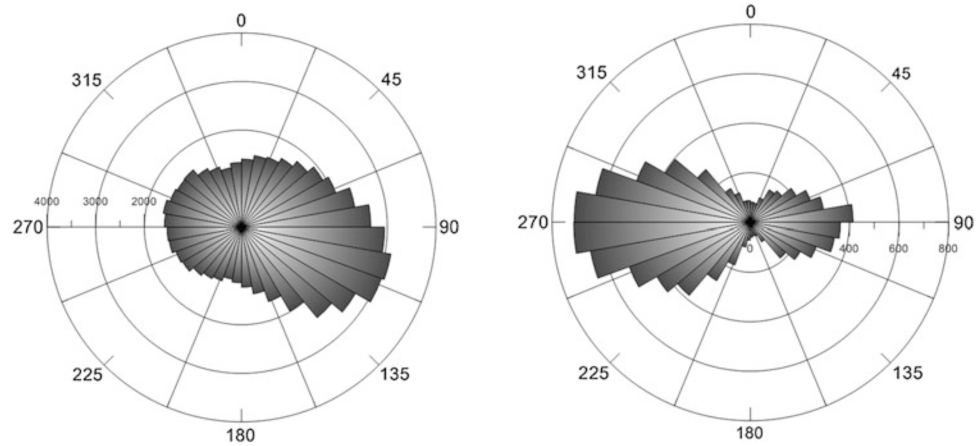


**Fig. 354.3** The typical porphyritic granite joint surface's gentle (⩽48°) and steep (⩾48°) inclined surfaces' exposure rose diagram

**Table 354.1** The statistical results of rock joint sample

| The direction of shearing | The principal oblique directions associated with the shearing action | $P_{(\leq 48^\circ)}$ (%) | $P_{(\geq 48^\circ)}$ (%) | $P_d$ (%) |
|---|---|---|---|---|
| N | SE/S/SW | 30.504 | 3.704 | 34.20819 |
| NE | S/SW/W | 25.506 | 6.781 | 32.2873 |
| E | SW/W/NW | 27.076 | 8.187 | 35.26301 |
| SE | N/W/NW | 27.500 | 6.572 | 34.07217 |
| S | NE/N/NW | 28.947 | 3.470 | 32.41638 |
| SW | N/NE/E | 37.033 | 3.788 | 40.82026 |
| W | NE/E/SE | 43.184 | 4.350 | 47.53366 |
| NW | E/SE/S | 39.675 | 3.724 | 43.39903 |

When the shearing direction is W, SW or NW, in the principal oblique directions associated with the shearing action, there are relatively less steep inclined surfaces (about 3.7 ∼ 4.3 %) and more gentle inclined surfaces (around 37 ∼ 43.1 %) on the join surface, and the value of $P_D$ ranges from 40.8 to 47.5 %. On the contrary, When the shearing direction is NE, E or SE, in the principal oblique directions associated with the shearing action, there are relatively more steep inclined surfaces (almost 6.6 ∼ 8.2 %) and less gentle inclined surfaces (approx 25.5 ∼ 27.5 %) on the join surface, and the value of $P_D$ ranges from 32.3 to 35.3 %.

The value ranges of $P_{\leq 48^\circ}, P_{\geq 48^\circ}, P_D$ demonstrated a noticeable gap in different shearing directions also reveal a strong sensitivity of these three 3D joint roughness characteristic parameters to anisotropy of surface terrain of rock joint.

## 354.5 The Determination of 3D Joint Roughness Coefficient

In order to confirm the relation between joint surface's gradient distribution and $JRC^{3D}$, the author measured twelve closed and non-filled porphyritic granite joint samples' (100 × 100 mm) direct shear peak strength, as well as the gentle and steep inclined surfaces' total area (⩽48°, ⩾48°) and aggregate total area of each joint, in the principal oblique directions associated with the shearing action, as a percentage of the total surface area of that joint ($P_{\leq 48^\circ}, P_{\geq 48^\circ}, P_D$). According to the test results, the $JRC^{3D}$ of each joint was calculated successfully using Barton's JRC-JCS model and used for stepwise regression as well as three 3D joint roughness characteristic parameters $P_{\leq 48^\circ}, P_{\geq 48^\circ}, P_D$. Eventually, the computational Equation of $JRC^{3D}$ at low normal stress level was obtained:

$$JRC^{3D} = 2.738 P_{\geq 48^\circ} + 0.216 P_D - 12.146 \qquad (354.3)$$

Coefficient of determination $R^2$ = 0.879, F-statistic is 32.605, significance probability $P < 0.05$, the regression is significant difference, $P_{\leq 48^\circ}$ was removed, because its significance testing did not meet the requirements The regression parameters are as follows:

Compared with the measurement data in Tables 354.1 and 354.2, the value ranges of the test joint samples' gentle and steep inclined surfaces' total area (<48°, >48°) and aggregate total area of each joint, in the principal oblique

**Table 354.2** The regression parameters of JRC[3D]

| Sample no. | Direct shear peak strength | Joint roughness coefficient | The gentle and steep inclined surfaces' total area and aggregate total area of each joint | | |
|---|---|---|---|---|---|
| No. | $\tau_p$ (MPa) | $JRC^{3D}$ | $P_{\le 48^\circ}$ (%) | $P_{\ge 48^\circ}$ (%) | $P_D$ [%] |
| 1 | 6.71 | 1.50 | 30.86 | 3.57 | 34.43 |
| 2 | 7.29 | 3.50 | 31.31 | 3.67 | 34.98 |
| 3 | 7.67 | 4.72 | 32.09 | 3.86 | 35.95 |
| 4 | 9.10 | 8.78 | 38.64 | 3.57 | 42.21 |
| 5 | 9.35 | 9.41 | 40.36 | 4.06 | 44.42 |
| 6 | 9.54 | 9.87 | 41.97 | 3.64 | 45.61 |
| 7 | 11.49 | 14.01 | 27.13 | 6.39 | 33.52 |
| 8 | 11.96 | 14.86 | 28.30 | 6.49 | 34.79 |
| 9 | 12.30 | 15.45 | 27.38 | 6.82 | 34.20 |
| 10 | 12.62 | 15.97 | 26.86 | 7.12 | 33.98 |
| 11 | 14.02 | 18.06 | 37.08 | 8.33 | 45.41 |
| 12 | 14.57 | 18.80 | 37.66 | 8.21 | 45.87 |

During those tests, the normal stress ($\sigma_n$) was 7 MPa, the rock compressive strength (JCS) was 108.02 MPa, the basic friction angle ($\varphi_b$) was 42°

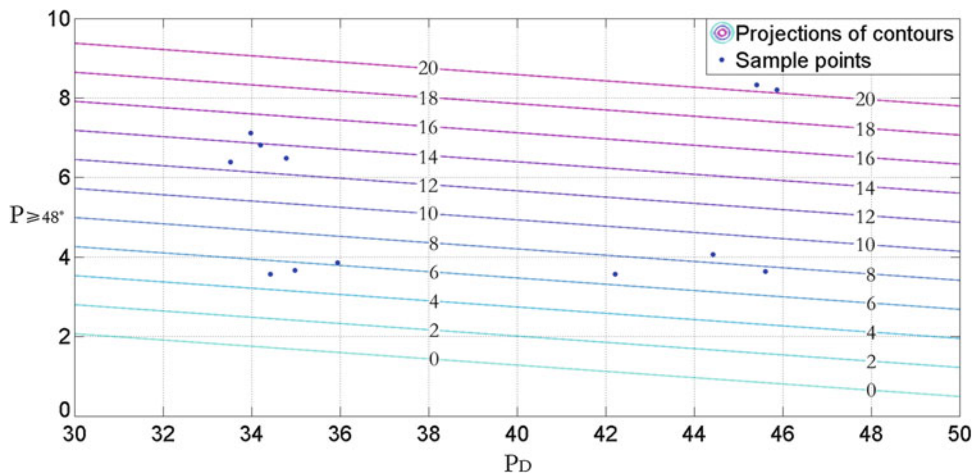


**Fig. 354.4** the diagram reflecting the relationship between $JRC^{3D}$, $P_{\ge 48^\circ}$ and $P_D$, test sample points' projection drawing

directions associated with the shearing action, as a percentage of the total surface area $P_{\le 48^\circ}, P_{\ge 48^\circ}, P_D$ roughly correspond to that of the visual analysis joint sample's.

To further validate the accuracy of the computational Equation of $JRC^{3D}$, another five joint samples' data (Sample No. 13 to 17 in the same batch) was put into the Eq. (354.3) to calculate the $JRC^{3D}$. Compared with the test results, the outcome is that: although the value of $JRC^{3D}$ calculated by Eq. (354.3) is generally smaller than that obtained by the direct shear test, the error is under 10 %, it has good forecast effect (The value of $JRC^{3D}$ obtained by the test are 6.34, 9.03, 11.87, 12.81, 16.69 respectively, and the value of $JRC^{3D}$ calculated by Eq. (354.3) are 6. 17, 9.80, 11.17, 11.67, 16.55 respectively).

In order to more intuitively and visually reflect the relation between the gradient distribution of joint surface and the $JRC^{3D}$ and meet the demand of further researches, the author pictured the "isolines" (where $JRC^{3D}$ = 1, 2…0.19, 20) on the plane formed by the relation between $JRC^{3D}$, $P_{\ge 48^\circ}$ and $P_D$, and projected them onto the $P_{\ge 48^\circ} - P_D$ plane. Eventually, the diagram reflecting the relation between $JRC^{3D}$, $P_{\ge 48^\circ}$ and $P_D$ was obtained (Fig. 354.4).

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