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*Research Article*

# Correlation between the Joint Roughness Coefficient and Rock Joint Statistical Parameters at Different Sampling Intervals

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Joint roughness coefficient (JRC) is a major factor that affects the mechanical properties of rock joints. Statistical methods that are used to calculate the JRC increasingly depend on a sampling interval ($\Delta x$). The variation rules of fitting parameters $a$, $b$, and $b/a$ at different $\Delta x$ values were analyzed on the basis of the relationship between the JRC and statistical parameter $Z_2$. The relationship between the fitting parameters $a$ and $b$ was deduced in accordance with the ten standard profiles proposed by Barton. Empirical formulas for the JRC, $Z_2$, and $\Delta x$ were also established. The estimation accuracy of the JRC was the highest in the analysis of $\Delta x$ values within 0.1–5.0 mm. JRC tests were conducted through inverse value comparative analysis. Results showed that the outcome calculated using the general formula and the JRC inverse values demonstrate improved agreement and verify the rationality of the general formula. The proposed formula can perform rapid and simple JRC calculation within the $\Delta x$ range of 0.1–5.0 mm using $Z_2$, thereby indicating favorable application prospects.

## 1. Introduction

The roughness of a rock joint directly affects the strength, deformation, and seepage characteristics of a rock mass. Barton and Choubey [1] established ten typical profiles through a back-calculation test to quantify the joint roughness coefficient (JRC). The JRC can be visually estimated from the standard profiles that correspond to values within [0, 20] in laboratory tests. Subsequently, many researchers have proposed various improvements to calculate JRC values more precisely than visual assessment [2–5]. To facilitate the application of JRCs in rock engineering practices, a series of new parameters and methods, such as statistical methods [6–10], straight edge method [11, 12], fractal dimension method [13–17], and other quantitative methods, has been introduced to evaluate the JRCs of the ten standard profiles. The statistical parameter method has been extensively used in previous studies, given its convenience. This method mainly includes the first derivative root mean square ($Z_2$), the structure function of the profile (SF), the roughness profile index ($R_P$), the root mean square (RMS) roughness index of the profile, the profile elongation index ($\delta$), and other relevant parameters [18]. $Z_2$ is the most commonly used among these statistical parameters.

Tse and Cruden [7] established the regression equations between the JRC and $Z_2$ using a 0.5 mm sampling interval ($\Delta x$). Yu and Vayssade [8] used three $\Delta x$ values (i.e., 0.25, 0.5, and 1.0 mm) to describe the effect of the sampling interval on the relationship between the JRC and $Z_2$. These researchers determined that $Z_2$ cannot be used without considering the effect of sampling intervals. Since then, the relationship between $Z_2$ and $\Delta x$ has been thoroughly studied.

Compared with other statistical parameters, Wu et al. [19] suggested that $Z_2$ and SF must be adopted to evaluate the JRC value and propose an empirical relationship between the JRC and $Z_2$ at $\Delta x = 0.25$ mm, 0.5 mm, and 1 mm. In addition, Zhang et al. [20] proposed an appropriate expression of the $Z_2$ and JRC for $\Delta x = 0.5$, 1.0, 2.0, and 4.0 mm. Although these tests can be conducted with high accuracy, limitations, such as low accuracy, resolution, and ease of use, still exist.

Recently developed scanning devices can digitize JRCs automatically and more accurately than previous technologies. Tatone and Grasselli [21, 22] developed a roughness evaluation methodology and proposed a new relationship between the JRC and $Z_2$ at four $\Delta x$ values (0.044, 0.25, 0.5, and 1 mm) by analyzing 2D profiles and 3D surface topography using a laser scanner. Furthermore, Song et al. [23] analyzed the variation in $Z_2$ using $\Delta x$ and applied a quadratic polynomial to describe the relationship between $Z_2$ and $\Delta x$. In summary, strong sensitivity to sampling intervals has been extensively accepted. However, the specific expression of the relationship between $Z_2$ and $\Delta x$ remains unclear.

Some studies have suggested that the relationships between the arbitrary sampling intervals, JRC of natural rock joints, and $Z_2$ can be quantitatively characterized on the basis of some statistical relationships, such as power functions [24]. This insight provides a new way of establishing a unified expression. Nevertheless, some drawbacks have been observed in previous research. First, the fitting parameters in the current formula vary for each profile. Second, only the $\Delta x$ upper bound is defined, and the effect of the $\Delta x$ lower bound on the joint surface roughness evaluation is ignored.

To overcome the limitations of previous studies, the ten standard profiles presented by Barton are digitally extracted to characterize the relationship between the JRC and $Z_2$ at different $\Delta x$ values. The present study establishes a new formula to estimate JRC values. Moreover, a method for the association model and reliability analysis is proposed. Finally, the results are summarized to derive a conclusion.

## 2. Association Model Establishment

*2.1. Statistical Model of the JRC and $Z_2$.* The RMS value of the first deviation formula for profile $Z_2$ is expressed as follows:

$$\begin{aligned} Z_2 &= \left[\frac{1}{L}\int_{x=0}^{x=L}\left(\frac{dy}{dx}\right)^2 dx\right]^{1/2}, \\ &= \left[\frac{1}{M(\Delta x)^2}\sum_{i=1}^{m}\left(y_{i+1}-y_i\right)^2\right]^{1/2}, \end{aligned} \tag{1}$$

where $\Delta x$ and $L$ are the sampling interval and horizontal length of the profile (mm), respectively, and $M$ is the total number of sampling intervals. A reconstruction method for the ten standard JRC profiles is introduced through AutoCAD and MATLAB coding. First, the standard profiles are imported into AutoCAD for digitization. The image is saved in JPG format and scaled to real-world dimensions using a 10 cm scale bar. Second, a MATLAB procedure is conducted using equation (1). Finally, the images are inputted to obtain the corresponding $Z_2$ values of the ten standard profiles, and the JRC–$Z_2$ formula is fitted under different $\Delta x$ values.

Several studies on the fitting curves of the relationship between the JRC and $Z_2$ are summarized in Table 1. The fitting curves for each reference can be expressed as

$$\mathrm{JRC} = a + bf\left(Z_2\right), \tag{2}$$

where $f(Z_2)$ is the function of $Z_2$, and $a$ and $b$ are the fitting parameters. Table 1 summarizes the main findings of the proposed calculation models with the same $\Delta x$ value. When the sampling interval varies, the fitting equations are also altered. This result is consistent with the findings of Yu and Vayssade [8]. In accordance with these results, the compatibility of six empirical models, namely, $\sqrt{Z_2}$, $\lg(Z_2)$, $Z_2$, $\tan(Z_2)$, $\tan^{-1}(Z_2)$, and $(Z_2)^2$ is discussed. To evaluate the fitting effect of the six models, ten sampling intervals (0.1–1 mm) are used to obtain the statistical relationship between the JRC and $Z_2$. The calculation results are listed in Table 2. These results indicate that the correlation coefficients of statistical model fittings 1–4 are 0.98, 0.96, 0.96, and 0.96, respectively. By comparison, the correlation coefficients of statistical models 5 and 6 are less than 0.90, thereby presenting relatively poor fitting results. Therefore, statistical models 1–4 can provide the ideal expressions for the following analysis.

*2.2. Formula Derivation.* Taking model 1 as an example, the $\Delta x$ values of 0.1, 0.5, and 1 mm are selected to analyze the effect of sampling intervals on the relationship between the JRC and $Z_2$. A unique best-fit curve is established through each sampling interval (Figure 1). The shapes of the JRC–$Z_2$ fitting curves under different $\Delta x$ values are identical. Moreover, these configurations show that the $\Delta x$ value mainly reflects the variation in fitting parameters $a$ and $b$ in the JRC–$Z_2$ fitting curves.

Section 2.1 suggests that the statistical model between the JRC and $Z_2$ and the fitting parameters $a$ and $b$ can be determined, but the variation remains unexplored. A MATLAB calculation result is exported to investigate the effect of $\Delta x$ variations on $a$ and $b$ in Model 1 (Figure 2). The correlation of the fitting parameters with $\Delta x$ is represented by the following equation: $b = 37.95 + 1.23\Delta x - 1.23a$. The relative coefficient is approximately 0.984, thereby indicating that the different values of $a$ and $b$ in the JRC–$Z_2$ statistical model depend on the $\Delta x$ of the profiles. Therefore, the JRC–$Z_2$ fitting curve under different $\Delta x$ values must be predicted.

The graphical variation in $a$ and $b$ as a function of $\Delta x$ is illustrated in Figures 3 and 4, respectively. The results for $a$ indicate nonlinear growth and eventual stabilization of the increase in $\Delta x$. By contrast, $b$ decreases nonlinearly with the increase in $\Delta x$. The resulting equations can be expressed as

$$\begin{aligned} a &= -13.96\Delta x^{-0.24}\,(R = 0.987), \\ b &= 57.58\Delta x^{-0.04}\,(R = 0.756). \end{aligned} \tag{3}$$

Generally, when the joint surface is increasingly smooth, the calculated values for the rock joints gradually decrease.

Table 1: Relationship between JRC and $Z_2$.

| No. | Sampling interval (mm) | Fitting relationship | $R$ | Reference | Model |
|---|---|---|---|---|---|
| 1 | 0.25 | $\mathrm{JRC} = -16.99 + 56.15\sqrt{z_2}$ | 0.967 | [8] | $\mathrm{JRC} = a + b\sqrt{Z_2}$ |
| | 0.5 | $\mathrm{JRC} = -14.83 + 54.42\sqrt{z_2}$ | 0.973 | | |
| 2 | 0.25 | $\mathrm{JRC} = 28.43 + 28.10\,\lg(Z_2)$ | 0.951 | [8] | $\mathrm{JRC} = a + b\,\lg(Z_2)$ |
| | 0.5 | $\mathrm{JRC} = 32.20 + 32.47\,\lg(Z_2)$ | 0.973 | [7] | |
| | | $\mathrm{JRC} = 32.69 + 32.98\,\lg(Z_2)$ | 0.993 | [9, 10] | |
| | 1 | $\mathrm{JRC} = 27.25 + 22.70\,\lg(Z_2)$ | 0.938 | [20] | |
| | 2 | $\mathrm{JRC} = 27.62 + 21.19\,\lg(Z_2)$ | 0.938 | | |
| | 4 | $\mathrm{JRC} = 28.40 + 19.90\,\lg(Z_2)$ | 0.947 | | |
| 3 | 0.25 | $\mathrm{JRC} = -4.51 + 60.32Z_2$ | 0.968 | [8] | $\mathrm{JRC} = a + b(Z_2)$ |
| | 0.5 | $\mathrm{JRC} = -3.47 + 61.79Z_2$ | 0.973 | [8] | |
| | 1 | $\mathrm{JRC} = -2.31 + 64.22Z_2$ | 0.983 | [8] | |
| | | $\mathrm{JRC} = -2.044 + 60.68Z_2$ | 0.966 | [20] | |
| | 2 | $\mathrm{JRC} = -1.562 + 67.53Z_2$ | 0.972 | [20] | |
| | 4 | $\mathrm{JRC} = -0.732 + 75.80Z_2$ | 0.956 | | |
| 4 | 0.25 | $\mathrm{JRC} = -5.06 + 64.28\tan(Z_2)$ | 0.969 | [8] | $\mathrm{JRC} = a + b\tan(Z_2)$ |
| | 0.5 | $\mathrm{JRC} = -3.88 + 65.18\tan(Z_2)$ | 0.975 | | |
| | 1 | $\mathrm{JRC} = -2.57 + 66.86\tan(Z_2)$ | 0.983 | | |
| 5 | 0.5 | $\mathrm{JRC} = -5.05 + 1.20\tan^{-1}(Z_2)$ | 0.973 | [7] | $\mathrm{JRC} = a + b\tan^{-1}(Z_2)$ |
| | 0.25 | $\mathrm{JRC} = -2.30 + 116.3(Z_2)^2$ | 0.929 | | |
| 6 | 0.5 | $\mathrm{JRC} = -2.73 + 130.87(Z_2)^2$ | 0.934 | [8] | $\mathrm{JRC} = a + b(Z_2)^c$ |
| | 1 | $\mathrm{JRC} = -3.00 + 157(Z_2)^2$ | 0.945 | | |

Table 2: Fitting results of the six models.

| Model | $\Delta x$ (mm) | $A$ | $b$ | $R$ |
|---|---|---|---|---|
| $\mathrm{JRC} = a + b\sqrt{Z_2}$ | 0.1 | −21.78 | 64.47 | 0.980 |
| | 0.2 | −19.91 | 62.42 | 0.981 |
| | 0.5 | −17.53 | 59.85 | 0.986 |
| | 1 | −15.10 | 57.74 | 0.984 |
| $\mathrm{JRC} = a + b\,\lg(Z_2)$ | 0.1 | 32.60 | 36.02 | 0.973 |
| | 0.2 | 32.00 | 33.63 | 0.974 |
| | 0.5 | 30.74 | 29.91 | 0.970 |
| | 1 | 29.72 | 26.42 | 0.963 |
| $\mathrm{JRC} = a + b(Z_2)$ | 0.1 | −6.11 | 64.31 | 0.962 |
| | 0.2 | −5.27 | 64.29 | 0.964 |
| | 0.5 | −4.43 | 64.31 | 0.974 |
| | 1 | −3.51 | 68.17 | 0.975 |
| $\mathrm{JRC} = a + b\tan(Z_2)$ | 0.1 | −5.31 | 59.36 | 0.964 |
| | 0.2 | −5.31 | 59.36 | 0.961 |
| | 0.5 | −5.31 | 59.36 | 0.971 |
| | 1 | −3.16 | 65.09 | 0.974 |
| $\mathrm{JRC} = a + b\tan^{-1}(Z_2)$ | 0.1 | 24.66 | −3.31 | 0.813 |
| | 0.2 | 23.55 | −2.84 | 0.838 |
| | 0.5 | 21.11 | −2.08 | 0.843 |
| | 1 | 19.11 | −1.47 | 0.885 |
| $\mathrm{JRC} = a + b(Z_2)^c$ | 0.1 | 1.85 | 116.42 | 0.862 |
| | 0.2 | 2.18 | 122.66 | 0.835 |
| | 0.5 | 2.35 | 134.41 | 0.844 |
| | 1 | 2.54 | 162.41 | 0.826 |

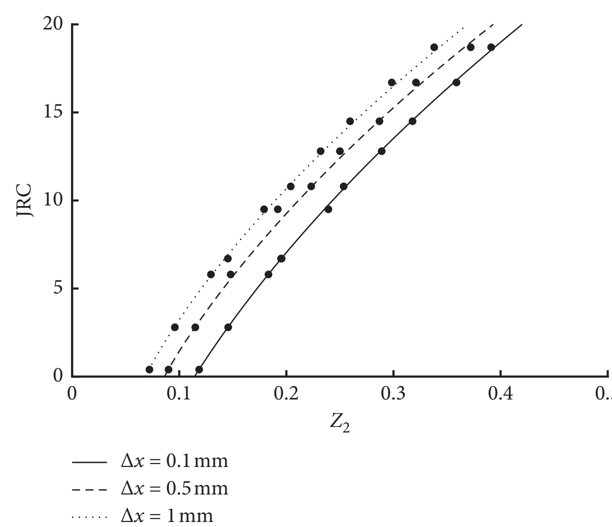


Figure 1: Relationship between the JRC and $Z_2$ at different $\Delta x$ values.

Consequently, the power functions of the current study are formulated because the data points obtained gradually decrease with the increase in $\Delta x$.

The correlation coefficient obtained by $a$ and $\Delta x$ using the power function model is very high ($R = 0.987$) and can be directly used to describe $a$. However, the correlation coefficient for $b$ and $\Delta x$ is relatively poor. Therefore, the variation in the relationship between $b/a$ and $\Delta x$ is recommended for fitting to establish the relationship between $b$ and $\Delta x$ (Figure 5). The parameter $b/a$ decreases with the increase in $\Delta x$. This outcome is consistent with the power function, and the correlation coefficient is 0.987. Consequently, $b/a$ reflects the variation in the fitting parameters with $\Delta x$. Therefore, the empirical formulas in a power law form are expressed as

$$\begin{aligned} \alpha(\Delta x) &= -13.96\Delta x^{-0.24}, \\ b(\Delta x) &= 55.90\Delta x^{0.01}. \end{aligned} \tag{4}$$

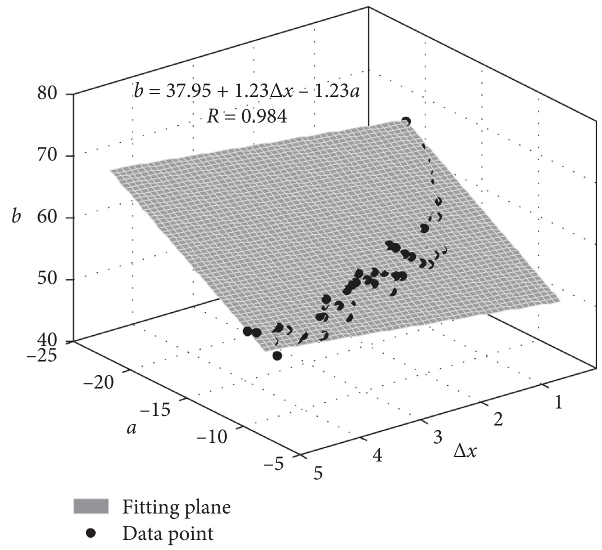


Figure 2: Relationship between $a$, $b$, and $\Delta x$.

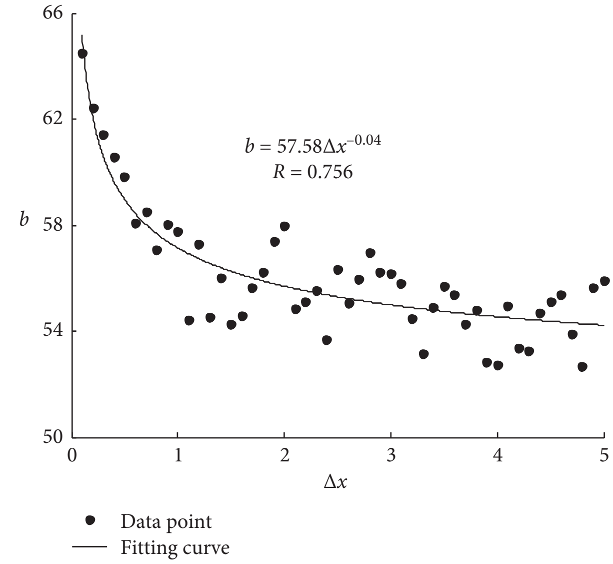


Figure 4: Relationship between $b$ and $\Delta x$.

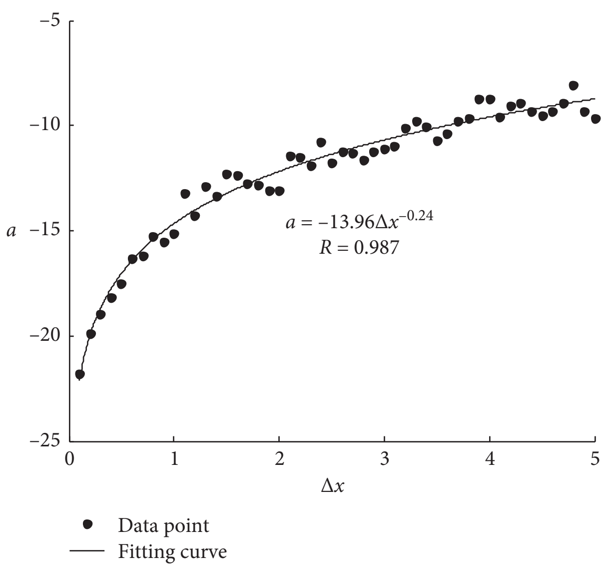


Figure 3: Relationship between $a$ and $\Delta x$.

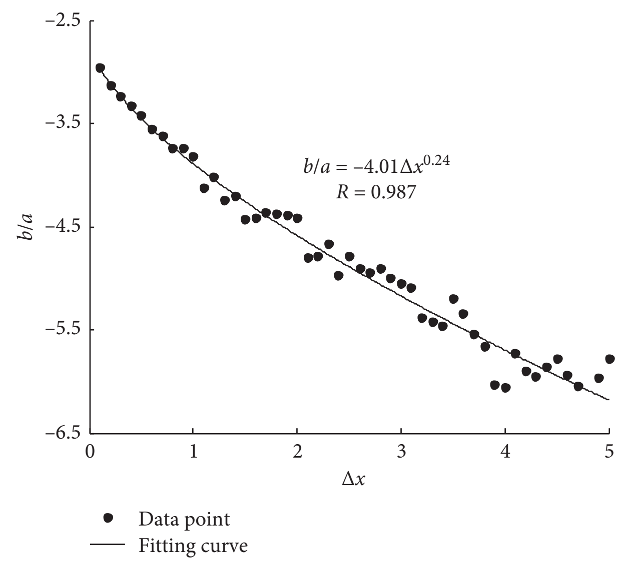


Figure 5: Relationship between $b/a$ and $\Delta x$.

The resulting equations using Model 1 will be used to estimate the relationship between the JRC and $Z_2$ for different sampling intervals and can be expressed as

$$\mathrm{JRC} = -13.96\Delta x^{-0.24} + 55.90\Delta x^{0.01}\sqrt{Z_2}. \quad (5)$$

Furthermore, the statistical model of JRC–$Z_2$ can be calculated using $\Delta x$.

## 3. Model Comparison Analysis

A new estimation equation for different sampling intervals is proposed to obtain improved empirical relationships among the hatching JRC, $a$, $b$, and $\Delta x$. This equation provides a quantitative description and demonstrates favorable application prospects. To verify the equation's accuracy and rationality, $\Delta x = 0.5$ mm is applied to disperse the standard JRC profiles. The $\Delta x$ value is substituted into the new equation to obtain the statistical model between the JRC and $Z_2$. The fitting curve is calculated and then compared with the previously published values using a sampling interval of 0.5. The comparison results are plotted in Figure 6, in which the fitting curve of the JRC and $Z_2$ obtained using the proposed empirical formula agrees well with the findings of the previous studies, thus indicating that the new empirical formula has high applicability.

Following the comparison of prediction results, an error analysis for the JRC values of the ten standard profiles is calculated using the proposed empirical formula and the back-calculation value proposed by Barton and Choubey (Figure 7). The relative errors of both calculations are less

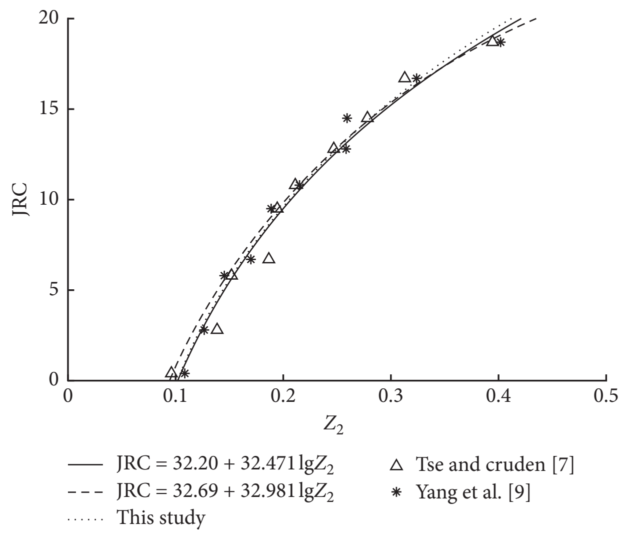


FIGURE 6: Relationship between the JRC and $Z_2$ from different researchers ($\Delta x = 0.5$ mm).

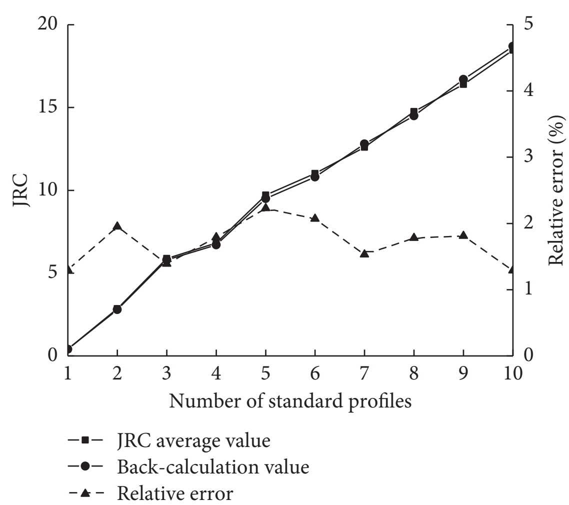


FIGURE 7: Calculated value of the JRC ($\Delta x = 0.5$ mm).

TABLE 3: Calculated JRC values at different $\Delta x$ values.

| Back-calculation value of JRC | Sampling interval (mm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.05 | 0.1 | 0.5 | 1 | 2 | 4 | 5 | 6 | 10 |
| 0.4 | **0.37** | 0.41 | 0.40 | 0.41 | 0.40 | 0.39 | 0.40 | 0.38 | **0.36** |
| 2.8 | 2.88 | 2.82 | 2.78 | 2.78 | 2.90 | 2.69 | 2.72 | 2.67 | **2.57** |
| 5.8 | 5.62 | 5.81 | 5.81 | 5.68 | 5.71 | 5.61 | 5.74 | 5.68 | **5.33** |
| 6.7 | **7.07** | 6.73 | 6.82 | 6.91 | 6.64 | 6.53 | 6.57 | 6.49 | 6.38 |
| 9.5 | **8.61** | 9.75 | 9.74 | 9.34 | 9.67 | 9.22 | 9.29 | 9.27 | 9.10 |
| 10.8 | 10.54 | 10.67 | 11.02 | 10.98 | 10.78 | 10.32 | 10.65 | 10.44 | **10.21** |
| 12.8 | **13.87** | 12.87 | 12.60 | 12.71 | 12.71 | 12.50 | 12.77 | 12.62 | 12.48 |
| 14.5 | 14.15 | 14.56 | 14.76 | 14.31 | 14.59 | 14.16 | 14.32 | 14.21 | 14.47 |
| 16.7 | **15.25** | 16.83 | 16.40 | 16.44 | 16.54 | 16.19 | 15.93 | 15.90 | 16.38 |
| 18.7 | 19.58 | 18.54 | 18.46 | 18.47 | 18.60 | 17.84 | 18.25 | **17.70** | **17.31** |

Note: bold values in the table are the JRC values with relative errors greater than 5%.

than 5%, thereby indicating that the data from the current study are consistent with the previously published values for the 0.5 point spacing. To further verify the applicability of different $\Delta x$ values, nine typical sampling intervals from 0.05 mm to 10 mm are established to digitize the standard JRC profiles dispersedly, and the corresponding back-

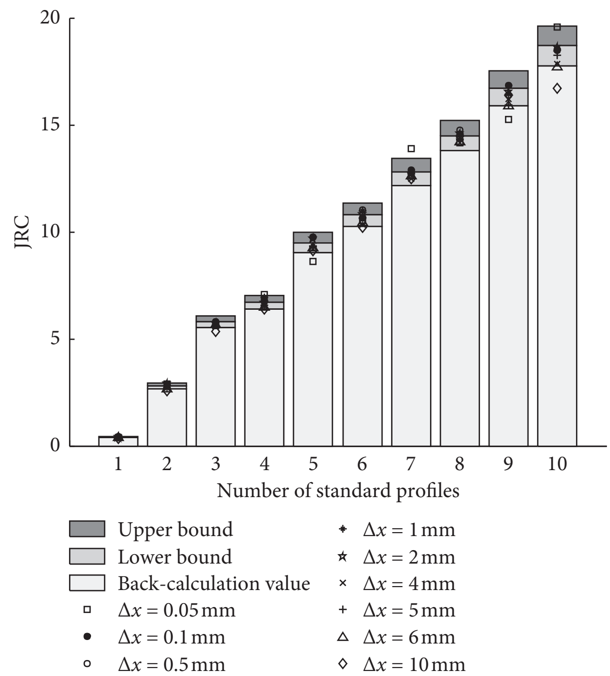


Figure 8: Comparison of the JRCs at different $\Delta x$ values. Note: $JRC_{upper} = 1.05JRC_{back\text{-}calculation\ value}$ and $JRC_{lower} = 0.95JRC_{back\text{-}calculation\ value}$.

calculation values are also listed in Table 3. The effective $\Delta x$ is defined when $\Delta x$ agrees with equation (6) in determining the upper and lower bounds of the $\Delta x$ values.

$$\left|\frac{JRC_{\Delta x}-JRC_{back\text{-}calculation\ value}}{JRC_{back\text{-}calculation\ value}}\right| \times 100\% \leq 5\%. \tag{6}$$

The error analysis of the data points and the JRC values with relative errors greater than 5% are listed in Table 3. Within the $\Delta x$ range of 0.1–5 mm, the calculated JRC values fluctuate in the bounded area and agree with the JRC back-calculation values (Figure 8). The errors exceed 5% when $\Delta x$ is less than 0.1 mm or greater than 5 mm. This finding is mainly because the size of $\Delta x$ is directly related to different geometric characteristics. The surface morphology of a joint is mainly divided into three categories, namely, macroscopic geometric contours, surface undulating morphology, and microroughness (Figure 9). When $\Delta x$ is greater than or equal to $\Delta x_1$, the curve feature reflects the geometric contour of the rock joint, with the largest level reflecting the geometric and macroscopic shapes of the rock joint. The geometric features of the intermediate fluctuation form are neglected by the $Z_2$ parameter. When $\Delta x$ is less than or equal to $\Delta x_3$, the curve feature reflects the microscopic rough undulating form of the rock joints, with the minimum level surface roughness reflecting only the minor subsurface geometric characteristics on the valley's surface. When $\Delta x$ is between $\Delta x_1$ and $\Delta x_3$, $Z_2$ not only reflects the surface morphology fluctuation degree but also the variation in the geometric contour. The JRC value can be accurately calculated using the $Z_2$ formula in the range of $\Delta x_2$ because the macroscopic geometric contours and surface undulations of the rock joint surface morphology are the main factors that affect mechanical properties. Combined with the relative error values displayed in Table 3 and Figure 8, the $\Delta x$ values within 0.1–5 mm agree with the range of values within $\Delta x_2$. Therefore, the effective $\Delta x$ of the new empirical formula is suggested to be within this range. Within this range, the proposed empirical formula can accurately describe the relationship between the JRC and $Z_2$ at different $\Delta x$ values.

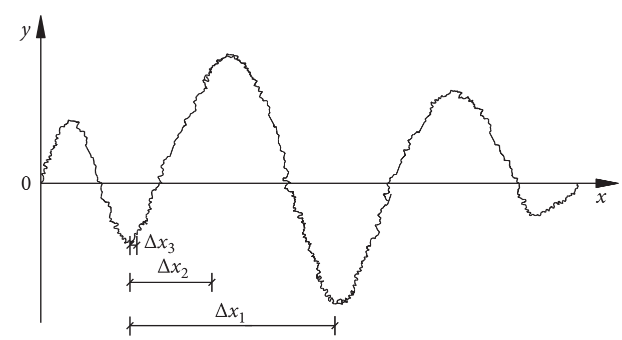


Figure 9: Sketch map of the $\Delta x$ values.

Models 2, 3, and 4 are also analyzed, and their empirical formulas are summarized in Table 4. The applicable range of $\Delta x$ values is from 0.1 mm to 5 mm. Figure 10 illustrates the comparison of the four empirical formulas at different $\Delta x$ values with high coincidence degree, thus denoting that these empirical formulas can accurately describe the relationship between the JRC and $Z_2$ at different $\Delta x$ values. Moreover, the relationship between the JRC and $Z_2$ at different $\Delta x$ values can be simply and quickly calculated using the proposed formula. The SF, $R_p$, $\delta$, and other statistical parameters can be used to analyze the relationship between the JRC and $\Delta x$ through the above-mentioned method.

Table 4: Relationship between JRC, $Z_2$, and $\Delta x$.

| Number | Model | Empirical formula |
|---|---|---|
| 1 | $\mathrm{JRC} = a + b\sqrt{Z_2}$ | $\mathrm{JRC} = -13.96\Delta x^{-0.24} + 55.90\Delta x^{0.01}\sqrt{Z_2}$ |
| 2 | $\mathrm{JRC} = a + b\,\lg(Z_2)$ | $\mathrm{JRC} = 0.03\Delta x^{0.04} + 25.12\Delta x^{-0.18}\lg(Z_2)$ |
| 3 | $\mathrm{JRC} = a + bZ_2$ | $\mathrm{JRC} = 5.75\Delta x^{-0.41} + 70.28\Delta x^{0.09}Z_2$ |
| 4 | $\mathrm{JRC} = a + b\tan(Z_2)$ | $\mathrm{JRC} = -2.58\Delta x^{-0.40} + 67.19\Delta x^{0.11}\tan(Z_2)$ |

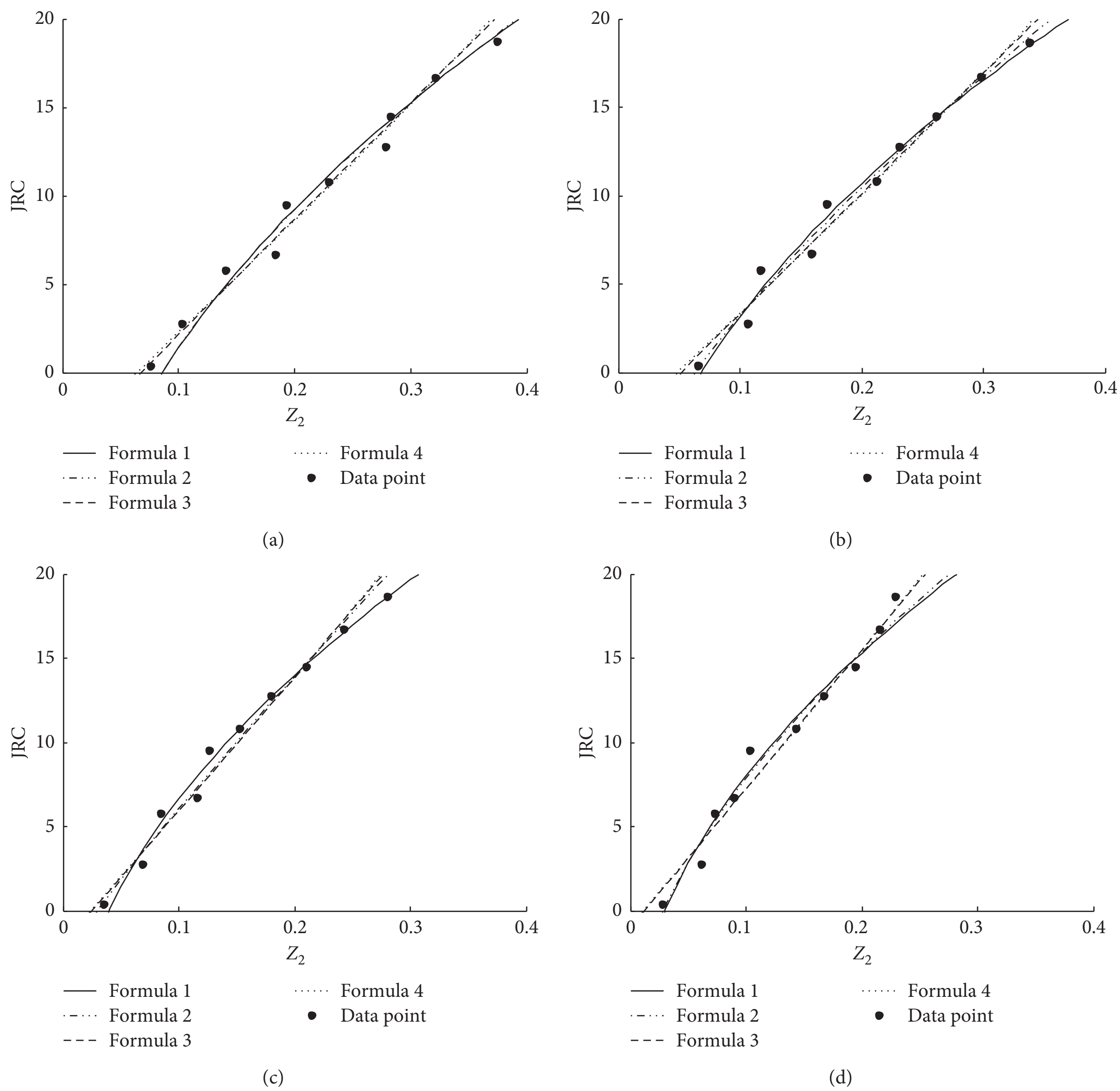


Figure 10: Comparison of the empirical equations for JRC–$Z_2$: (a) $\Delta x = 0.5$ mm, (b) $\Delta x = 1$ mm, (c) $\Delta x = 3$ mm, and (d) $\Delta x = 5$ mm.

## 4. Conclusions

In this study, four empirical formulas are proposed to establish the relationship between the JRC and $Z_2$ at different $\Delta x$ values, and the capability is validated using the ten standard profiles. The main conclusions are provided as follows:

(1) Ten standard profiles are reconstructed using AutoCAD and MATLAB coding to analyze the relationship between the JRC and $Z_2$ at different $\Delta x$ values. The power function relationship between the fitting parameters and the $\Delta x$ values shows that the sampling interval has a strong connection to the JRC.

(2) Four empirical formulas are proposed to estimate the effect of $\Delta x$ on JRC estimation, which can bypass the limitation of $\Delta x$ and quickly obtain a JRC at different $\Delta x$ values. In comparison with the previous formula, the high consistency of the calculated JRC values of the ten standard profiles and the back-calculation

values signifies the high applicability of the new empirical formula.

(3) The effective $\Delta x$ of the new empirical formula is obtained by analyzing the relative errors between the data points and the JRC values and the geometric features of the fluctuation. The results show that the proposed empirical formula can accurately describe the relationship between the JRC and $Z_2$ at different $\Delta x$ values when the $\Delta x$ values are within 0.1–5 mm.

In summary, this study presents a method that can be adopted to calculate the relationship between 2D JRCs and the statistical parameters at different $\Delta x$ values conveniently. This method has an important practical value in evaluating the sampling effect on the JRCs of rock joints. However, the proposed empirical formula only applies to 2D profiles. Therefore, a 3D joint morphology must be considered in the future to broaden the applicability of the model.

## Data Availability

All the data in figures and tables, which are used to support the findings of this study, are included within the article.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this article.

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