A re-examination of joint roughness coefficient (JRC)

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Roughness?

Sandpaper

Silk cloth
http://www.my-walls.net/silk-cloth-material-texture/
Shear strength between rock surfaces

Common shear strength models

- Mohr-Coulomb model (cohesion and friction angle)
- Bilinear model
- JRC-JCS model (Barton criterion)

Bilinear model (Patton, 1966)

The *irregularity* of discontinuity surfaces could be approximated by asperity angle $i$ + basic friction angle $\phi_b$.

At low normal stresses, shear loading causes the discontinuity surfaces to *dilate* as shear displacement occurs.

$$\tau = \sigma \tan \phi$$
Bilinear model

JRC-JCS model (Barton criterion)

- shear surfaces become continuously damaged as asperities are sheared
- failure locus stabilizes at an angle $\phi_b$

$$\tau = \sigma_n \tan \left( \phi_b + JRC \log_{10} \left( \frac{JCS}{\sigma_n} \right) \right)$$

where $JRC$ is the joint roughness coefficient and $JCS$ is the joint wall compressive strength.
Roughness profiles and corresponding JRC values

Field estimates of JRC

- The length of the surface of interest may be several metres or even tens of metres

- How to determine JRC value for the full scale surface?

Barton and Choubey (1977)
Comments

• quick and general judgments of joint roughness ☹

• subjective assessment ☹

• not entirely adequate for quantifying the rock joint roughness profile ☹
There are solutions…

- Plenty correlations of $JRC$ with both statistical and fractal parameters (Tse and Cruden 1979; Reeves 1985; Maerz et al. 1990; Yu and Vayssade 1991; Xie and Pariseau 1994; Aydan et al. 1996; Yang and Chen 1999; Yang et al. 2001; Grasselli and Egger 2003; Tatone and Grasselli 2010)

- Tse and Cruden (1979):
  \[ JRC = 32.2 + 32.47 \log Z_2 \]
  *where* $Z_2$ : the root mean square (slope-based roughness parameter)

- Different fitting coefficients

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Slope based parameter

Slope 1

\[ \text{Amplitude} = A \]

Slope 2

\[ \text{Amplitude} = A \]

Slope 2 > Slope 1, so ……
Amplitude based parameter

Slope = m

Amplitude 1

Slope = m

Amplitude 2

Amplitude 2 > Amplitude 1, so ……

Outline

1. Background (√)
2. Motivation (√)
3. Research objectives
4. Methodology
5. Results
6. Summary and conclusions
Research Objectives

- Revisiting the correlation between roughness parameter $Z_2$ and JRC
- Understanding reasons of discrepancies?
- More representative correlations?

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Methodology

Digitalization of profiles

- Download paper containing the original profiles (Barton and Choubey 1977) from the website of the Rock Mechanics and Rock Engineering
- No printing and scanning!
- Check horizontality of the profiles
- Check cleanliness of the profiles

The coordinates of the points lying on the individual profiles retrieved for those RGB values < 255 are identified and stored (max RGB = 255 = white).

- About 360-370 pixels in the horizontal direction (x axis) can be obtained for each profile and the 10 cm scale bar
- Due to line thickness, an array of points at one particular x.

Inaccurate representation!!
> Obtain central line of each profile by averaging the values of y coordinates at each x coordinate (not manually).

> The interval of the x coordinate is about 0.27 mm, which is obtained by

\[ \text{profile length / no. of pixels along the horizontal direction} \]

> Ready for calculating \( Z_2 \)

\[
Z_2 = \left[ \frac{1}{L} \int_{x=0}^{x=L} \left( \frac{dy}{dx} \right)^2 \, dx \right]^{1/2} = \left[ \frac{1}{\Delta x} \left( y_{i+1} - y_i \right)^2 \right]^{1/2}
\]

\( L = \) length of the profile
\( \Delta x = \) sampling interval
\( M = \) number of the sampling points
Recall - slope based parameter

Slope 1

Slope 2

Amplitude = A

Slope 2 > Slope 1, so slope 2 is rougher

$Z_2$ values are calculated at three different sampling intervals

- 0.27 mm (small)
- 0.54 mm (medium)
- 1.08 mm (large)
How about previous results (small sampling intervals)?

![Graph showing previous results](image)

Note: reversal of axes

Different $Z_2$ values?

Two potential sources of error:

1. **Human error** - operator’s trace may deviate away from the profile

2. **Line thickness** - operator has to consistently trace the central line
How about previous results (small sampling intervals)?

To illustrate the significance of the potential errors, profile thickness is computed at the 0.27 mm sampling interval

- “max” and “min” = maximum thickness and minimum thickness of each profile
- “std.” = standard deviation
- “r_{ta}” = ratio of mean profile thickness to profile amplitude
- “profile amplitude” = distance between the highest point ($y_{max}$) and the lowest point ($y_{min}$) along the profile

Results: average “mean thickness” of the ten profiles is 0.492 mm, and the mode of thickness of all profiles is 0.54 mm.
Segmentation of JRC:6-8 (profile 4) and JRC:8-10 (profile 5)

- $Z_2$ values of three segments are calculated based on the same 0.27 mm sampling interval

<table>
<thead>
<tr>
<th>Segment Profile</th>
<th>a-b</th>
<th>b-c</th>
<th>c-d</th>
<th>a-d</th>
<th>Average (std.) of a-b, b-c, c-d</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 (JRC ∈ 6-8)</td>
<td>0.352</td>
<td>0.320</td>
<td>0.328</td>
<td>0.345</td>
<td>0.334 (0.017)</td>
</tr>
<tr>
<td>5 (JRC ∈ 8-10)</td>
<td>0.346</td>
<td>0.219</td>
<td>0.339</td>
<td>0.325</td>
<td>0.301 (0.071)</td>
</tr>
</tbody>
</table>

- profile 4 should be *rounder* than profile 5?
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Back to the earlier research objectives?

1. Revisiting the correlation between roughness parameter $Z_2$ and JRC (√)

2. Understanding reasons of discrepancies (√)

3. More representative correlations?
Proposal: include a new parameter called normalized amplitude $A_{nor}$

For a particular joint profile, $A_{nor}$ is defined as the ratio of the respective profile amplitude to the maximum profile amplitude among the 10 JRC profiles.

Profile 8 (JRC 14-16) has the maximum profile amplitude of 6.62 mm

$$JRC = k_1 \cdot \log(Z_2) + k_2 \cdot A_{nor}^k + k_4$$

where $k_1$, $k_2$, $k_3$ and $k_4$ are coefficients to be solved

$$JRC = 41.17 \log(Z_2) + 4.93 A_{nor}^{1.53} + 26.72$$
Small sampling interval (0.27mm)

\[ JRC = 41.17 \log(Z_2) + 4.93 A_{nor}^{1.53} + 26.72 \quad R^2 = 0.975 \quad (3) \]

Medium sampling interval (0.54mm)

\[ JRC = 33.86 \log(Z_2) + 3.19 A_{nor}^{2.02} + 28.92 \quad R^2 = 0.969 \quad (4) \]

Large sampling interval (1.08mm)

\[ JRC = 26.31 \log(Z_2) + 2.20 A_{nor}^{3.12} + 27.73 \quad R^2 = 0.959 \quad (5) \]
Summary and Conclusions

Methodology

Data cursor and document laser scanner (previous) vs MATLAB digitization (present)

Interesting finding

$Z_2$ values not always increasing with JRC values

![Graph showing JRC values]

Summary and Conclusions (continued)

A new proposed correlation

**Slope-based parameter**

$$JRC = 32.2 + 32.47 \log Z_2 \text{ (Tse and Cruden (1979))}$$

vs

**Slope-based + amplitude-based parameter**

$$JRC = k_1 \cdot \log(Z_2) + k_2 \cdot A_{nor}^{k_3} + k_4$$
Summary and Conclusions (continued)

Recommendation – automatic measurement of surface roughness by photogrammetry or laser scanning

Research

Old problem → New approach?

New problem → Old approach?

New problem → New approach?

Thank you

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