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Technical Note
Estimation of the Joint Roughness Coefficient (JRC) by Visual Comparison

By

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1. Introduction

The Joint Roughness Coefficient (JRC) is probably the most commonly-used measure of the roughness of rock joint surfaces in current use, and forms an important part of the Barton-Bandis rock joint shear strength criterion. The normal method of evaluating the JRC of a joint is by visual comparison of measured profiles against a set of standard JRC profiles produced by Barton and Choubey (1977). The aim of this study is purely to investigate the precision of the visual comparison technique in estimating the JRC value, using an Internet-based survey system. It does not attempt to evaluate the accuracy of this technique in comparison to others such as the tilt test, or those based on surface profile digitisation.

2. Techniques for Roughness Evaluation

A variety of methods have been proposed for the description of surface roughness, and rock surface roughness in particular. A number of methods are described by British Standard BS1134 (1988), most of which refer to variance of a surface away from an inferred planar reference surface, this variance being measured at prescribed intervals along the surface. The standards are principally aimed at quality control of machined surfaces. Relatively recently, fractal methods have been used in an attempt to quantify rock surface roughness (Miller, 1990; Durucan and Jeffery, 1993), however doubts have been cast on both the validity of the technique for rock surfaces and the accuracy of measurement required to apply the technique by den Outer et al. (1995). Ferrero and Giani (1990) have used geostatistical techniques to quantify joint roughness, and the technique has been extended by Roko et al. (1997) to predict fluid flow paths along joints.

For rock engineering purposes, a method of quantifying rock surface roughness is the Joint Roughness Coefficient (JRC) (Barton and Choubey, 1977). This method was originally purely visual, and is based on comparison of standard JRC profiles against the surface profile under consideration. Attempts to develop alternative methods of estimating JRC values have been carried out by several authors. For example, Tse and Cruden (1979) proposed the use of the Z_2 value to estimate JRC, where a discontinuity surface is digitised using a number of data points spaced at a small interval along a profile. The Z_2 value is calculated from the perpendicular distances of the data points above or below the centre line of the profile. An empirical relationship is used to calculate JRC from the Z_2 value.

Bandis (1980) also suggests a technique for field estimation of JRC using a straight edge and relating the amplitude of the roughness to JRC. The relationship is not precise, however, the data presented by Barton (1990) showing a 100% variation in JRC estimated by this technique when compared with the tilt test. Doubt has also been cast on the use of this technique at a large scale (Milne, 1990). Milne also describes a refinement of the visual comparison method for JRC estimation. In this technique, a photograph is taken of the shadow of a straight edge projected onto the rock surface at a 45° angle. The standard JRC profiles are included in the photograph so that they can be compared at the same scale. Milne suggests that the JRC values estimated by this technique can be improved by averaging the estimated values from several people.

3. JRC Evaluation by Visual Comparison

The evaluation of JRC visually is subjective and results will vary according to the opinion of the engineer making the comparison. Preliminary data obtained by the authors indicated a wide range of estimates of JRC values for a rock surface profile from a sample of ten people.

A survey of people involved in geotechnical engineering was carried out by the authors over the Internet, using a system created by one of the authors at the Camborne School of Mines Geomechanics Research Group Website (http://www.ex.ac.uk/~ajbeer/geomechanics/jrctest.htm). In order to maintain impartiality, an email was sent to the UK-based '*engineering-geotech*' mailing list, giving details of the above URL and simply requesting recipients to participate in the survey. No-one was thus approached by name and there was no selection of participants other than that they had themselves subscribed to the mailing list. Participants accessing the web page referred to above were asked to estimate the JRC of three sample profiles, which were obtained from a granite block using a comb-type profile gauge. It was decided to use three sample profiles in this study as it was felt by the authors that people might be unwilling to participate in a more extensive survey which would take up more of their time. It was considered more important for this initial study to obtain a large number of estimates than to cover a large number of profiles. Participants were also to indicate their level of experience as shown in Table 1.

The sample profiles measured were each 10 cm long, so that they were the same length as the standard JRC profiles of Barton and Choubey (1977). The sample profiles and the standard profiles were then digitised at the same resolution so that they could be compared at the same scale. Viewing both the sample and

Table 1. Experience levels used in the on-line survey

Level 0	did not give experience level
Level 1	no technical background,
Level 2	no experience of JRC estimation,
Level 3	some experience of JRC estimation or
Level 4	very experienced at JRC estimation.

standard profiles on the web page (in adjacent frames) eliminated any scale effects arising from the visual estimation process, as the sample and standard profiles were displayed at the same scale, no matter what screen resolution was in use. Participants were asked to select which were, in their opinion, the most appropriate JRC values for each profile. Histograms of the estimations are shown in Fig. 1 (It should be noted that the screen images used in the survey of both the standard profiles and sample profiles are of higher quality than their appearance in Fig. 1, which is a screen capture, would indicate).

4. Analysis of Results

The survey was set up on 23rd November 1998 and as of 28th July, 2000, 125 estimations had been made for Profile A, 124 for Profile B and 122 for Profile C. One interesting observation during the course of the survey was that the distribution pattern of estimations for the three profiles was established relatively quickly, with the mean and standard deviation of the distributions changing very little after 50 or so estimations had been made, as shown in Fig. 2. This indicates that a sufficient number of estimations have been obtained to reveal any trends in the data.

The histograms of the roughness estimations for profiles A and B display what appear to be slightly skewed normal distributions, with the distribution of estimates being slightly more for profile B than profile A. This may be because the overall form of profile A is similar to the standard JRC profile of Barton and Choubey for the JRC range 10–12. Profile A could therefore be said to be ‘easier’ to compare with the standard profiles than profile B. The JRC estimations for profile C appear to show a bi-modal distribution (Fig. 1) and a very large distribution of estimates of roughness. Those participants who responded to the survey by contacting the authors indicated that they considered the profile almost impossible to gauge against the standard profiles, as it displays a ‘smooth’ left half, and a ‘rough’ right half. It must be emphasised that these sample profiles were taken randomly on a block of Carnmenellis granite using a profile gauge, and there was no intention of trying to confuse the participants in the survey.

4.1 Effect of Experience Level

The results of the survey were also analysed by experience level (as defined by the participants themselves), to try to reveal any trends, as shown in Figs. 3a and 3b.

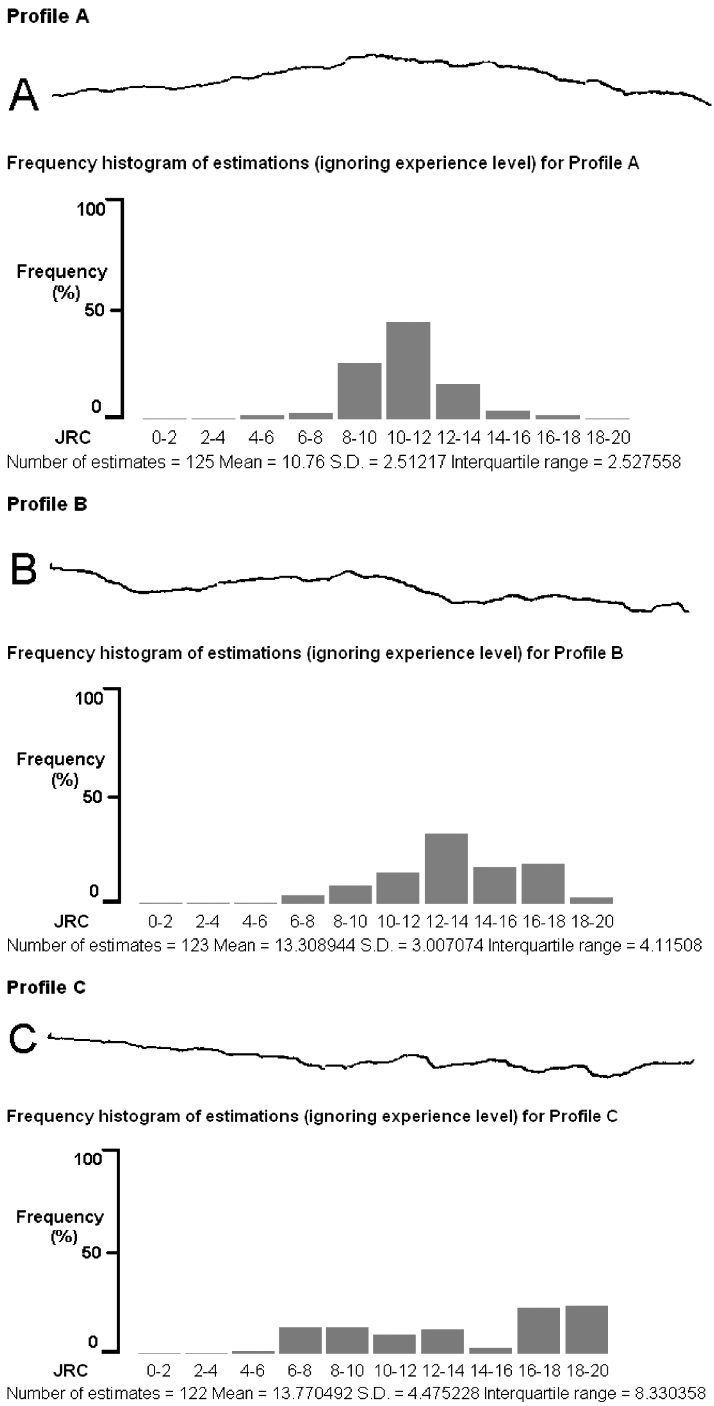
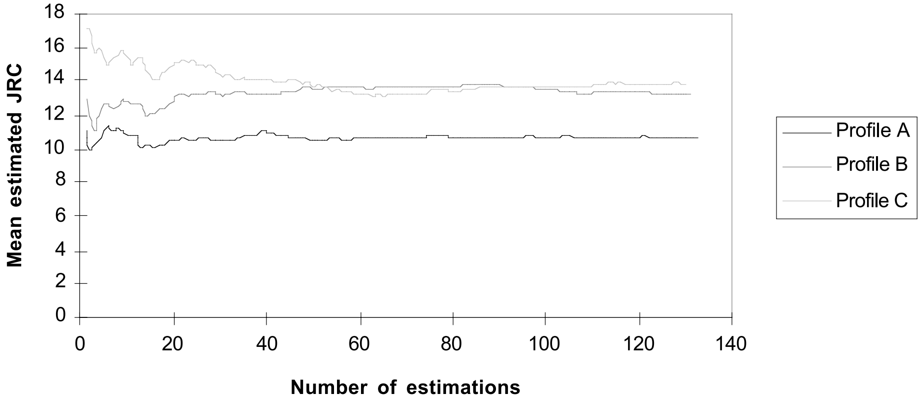


Fig. 1. Test profiles used in the survey and histograms of JRC estimates obtained from the on-line survey (http://www.ex.ac.uk/~ajbeer/geomechanics/jrctest.htm)



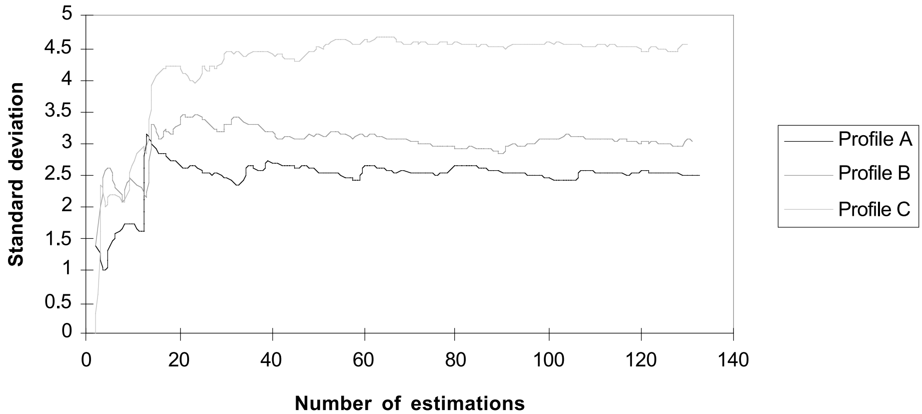


Fig. 2. Variation in mean estimated JRC and standard deviation of estimation distributions for Profiles A, B and C as the survey progressed

The low number of estimates from participants who indicated that they had no technical experience (Level 1) is not surprising given that the details of the survey were circulated to a technical mailing list. The alternative route to the survey was via the CSM Geomechanics Research Group web page, which would be unlikely to be of interest to the non-specialist. Indeed, only Profile A received three estimates from persons in this category, Profiles B and C receiving one each. Ignoring level 0, which was those who did not submit an experience level, the average values of JRC estimated for each profile by the participants is remarkably close between experience levels 2 and 3, though showing a slight increase in each case. Those who considered themselves very experienced at JRC estimation tended to give a still higher average JRC estimate than these previous two categories. As might be expected, however, the range of estimations narrows with increasing experience level, as indicated by the standard deviations of JRC estimations obtained (Fig. 3b).

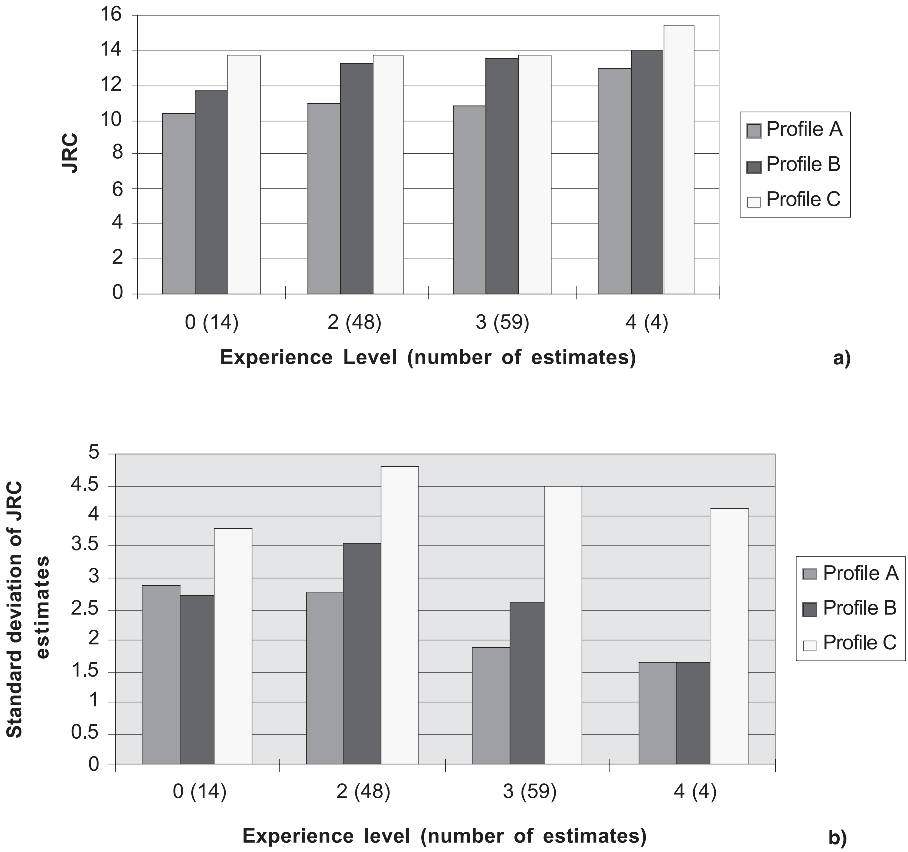


Fig. 3. a) Average estimated JRC by experience level; **b)** Standard deviations of JRC estmates for differing experience levels

0 Did not submit experience level
1 (Not included as there was only 1 estimate from this category)
2 No experience of JRC estimation
3 Some experience of JRC estimation
4 Very experienced at JRC estimation

4.2 Analysis of Overall Distribution Type

The Kolmogorov-Smirnov (K-S) test was used to test the hypotheses that the overall distribution of JRC estimates shown in Fig. 1 conformed to various distributions, using the method described by Miller and Freund (1965) and data from Lindley and Scott (1984). The K-S test was chosen because it makes no assumption about the nature of a distribution, and thus allows different hypothetical distributions to be tested. The test compares the value of the function $n^{1/2}D(n)$ (where n is the number of samples in the actual distribution and $D(n)$ is the maximum difference between the cumulative observed distribution and a hypothetical cumulative distribution) with a limiting value which is tabulated for different confidence levels. If the value tabulated is exceeded by the function, then the null hypothesis (that the observed distribution has arisen as a result of sampling the hypothetical distribution) must be rejected at the appropriate confidence level.

For the observed distribution of JRC estimates for each of the three profiles, A, B and C, two hypotheses were tested. The first hypothesis was that the observed distribution represented a sample from a normal distribution having the same mean and standard deviation as that estimated from the sample. The second hypothesis was that the distribution was random. In the case of the random distribution hypothesis, a lower limit was set to the hypothetical uniform distribution in each case to try to obtain a 'best fit' of the observed data to the hypothetical model. As the number of estimates ranged between 125 and 122, critical values for $n^{1/2}D(n)$ of 1.610 at the 1% level and 1.929 at the 0.1% level were assumed to be valid for all three actual distributions tested. Cumulative histograms of the three actual distributions and the hypothetical distributions against which they were tested are shown in Fig. 4. The values of $n^{1/2}D(n)$ for each distribution and model are shown in Table 2.

Because the normal distribution model for the estimations for profile C exceeded the critical value of $n^{1/2}D(n)$, as shown in Table 2, a third hypothetical model distribution was tested for this distribution. The third hypothetical distribution was obtained by assuming that distribution C arose as a combination of two separate normal distributions, split at the JRC = 14–16 interval, and combining these to give a bi-modal normal distribution. The means of the two distributions were 9.9 and 17.9 respectively.

The values obtained for the function $n^{1/2}D(n)$ indicate that, for the distributions shown by the JRC estimates for Profiles A and B, the hypothesis that these estimates form part of a normally distributed population cannot be rejected at the 1% level. The hypothesis that the distribution of JRC estimates for Profile C form part of a normal distribution must, however, be rejected at this level. In all three cases, the hypothesis that the observed distributions have arisen from uniformly distributed populations must be rejected at the 1% level. The hypothesis that the distribution of estimates for Profile C has arisen from a bi-modal normal distribution cannot be rejected at the 1% level.

5. Conclusions

In the case of each of the test profiles, the standard deviation of the JRC estimation distributions (Fig. 3b) decreased as experience level increased, indicating that increasing experience leads to a more precise estimate of JRC values by the visual comparison technique.

It can also be seen that the process of estimating JRC for joint surfaces by comparing surface profiles with standards does produce, under favourable circumstances, a distribution of results which cannot be shown not to be normally distributed at the 1% level. This supports the suggestion of Milne (1990) that better JRC values can be obtained by increasing the number of people used to estimate values, although results indicate that little benefit is accrued by using more

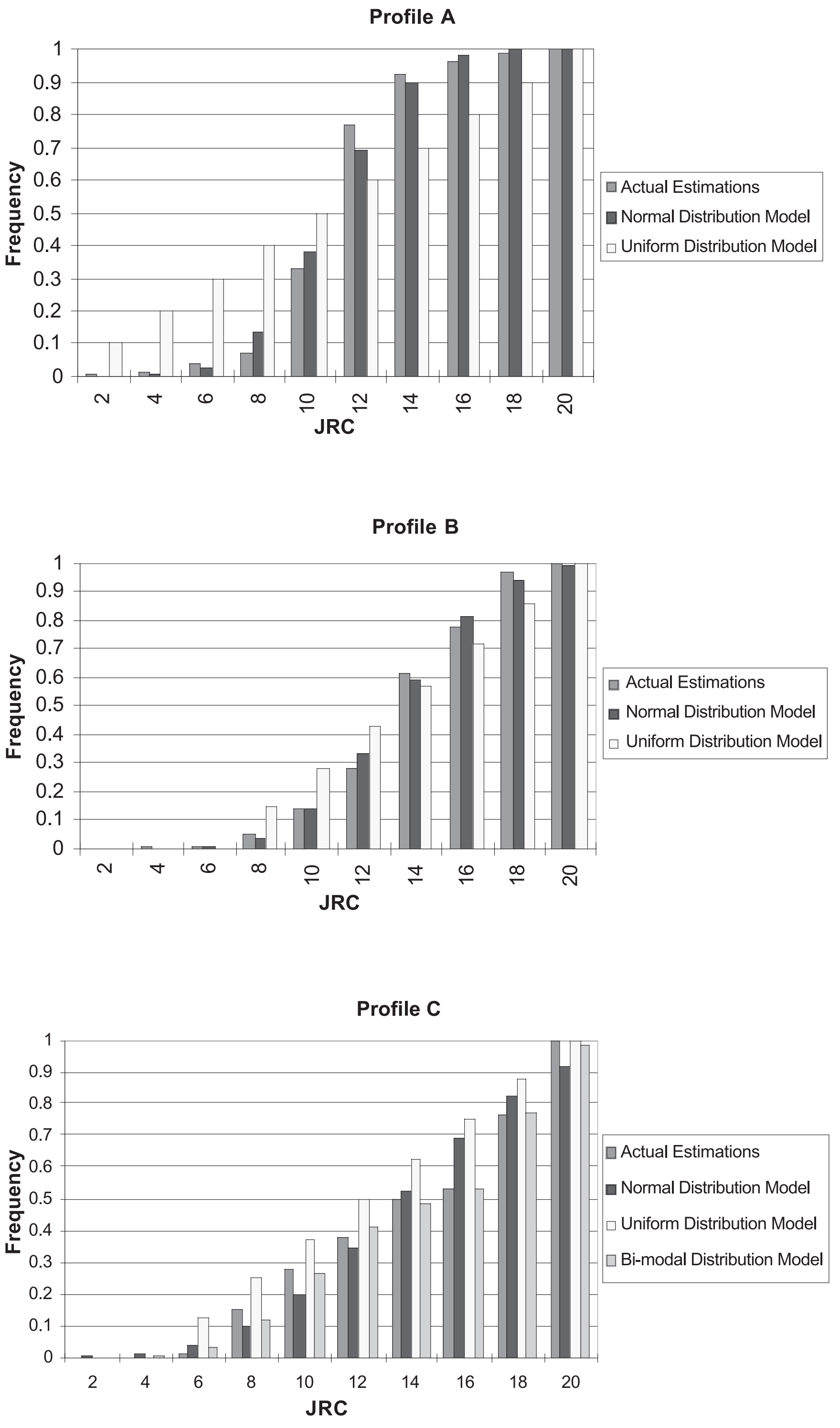


Fig. 4. Cumulative frequency of actual estimation distribution and hypothetical distributions of JRC estimates for the test profiles

Table 2. Values of the function $n^{1/2}D(n)$ for the cumulative distributions shown in Fig. 4. Values which exceed the critical value at the 1% confidence level are shown in bold

Distribution model	Profile A	Profile B	Profile C
Normal	0.889	0.530	**1.738**
Uniform	**3.667**	**1.636**	**2.399**
Bi-modal normal	–	–	0.371

than 50 people. The favourable circumstances would appear to be when the observed joint profile has a similar form to one of the standard JRC profiles produced by Barton and Choubey (1977).

However, with more problematic profiles, the precision of the visual estimation process can be seen to break down. In the case of Profile C in this survey, the distribution of estimates for JRC can be shown not to be derived from a single normally or uniformly distributed population. Moreover, it cannot be disproved at the 1% level that the observed distribution is not, in fact, bi-modal. If the distribution is bi-modal, then the large difference between the means of the two populations (8.9 and 17.9) should perhaps give cause for concern as to the accuracy and repeatability of the visual estimation technique.

This study has clearly demonstrated the effectiveness of the Internet as a medium for carrying out surveys of this type. Such a survey can be considered for all practical purposes 'blind', as participants are not selected by name, but rather by their subscription to a mailing list through which the survey's Internet address is notified. This helps to eliminate possible sampling bias arising from selection of participants. The results can also be viewed directly on-line by the participants on completion of the survey. It is suggested that this technique forms a useful teaching aid for visual assessment of joint roughness.

In order to comprehensively evaluate the limitations of estimating JRC values for 'problematic' profiles (such as test profile C in this study), a more extensive survey of JRC evaluation by visual comparison has recently (20/3/2001) been initiated at the same URL as mentioned above, using a much wider range of profiles from several different joint faces in different rock types.

Finally, the important implications for rock engineering design of the range of JRC values indicated by the visual comparison technique form the subject of ongoing research.

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