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Determining the surface roughness coefficient by 3D Scanner

Določitev koeficienta hrapavosti razpoke s 3D skenerjem

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Abstract

Currently, several test methods can be used in the laboratory to determine the roughness of rock joint surfaces. However, true roughness can be distorted and underestimated by the differences in the sampling interval of the measurement methods. Thus, these measurement methods produce a dead zone and distorted roughness profiles. In this paper a new rock joint surface roughness measurement method is presented, with the use of a camera-type three-dimensional (3D) scanner as an alternative to current methods. For this study, the surfaces of ten samples of tuff were digitized by means of a 3D scanner, and the results were compared with the corresponding Rock Joint Coefficient (JRC) values. Up until now such 3D scanner have been mostly used in the automotive industry, whereas their use for comparison with obtained JRC coefficient values in rock mechanics is presented here for the first time. The proposed new method is a faster, more precise and more accurate than other existing test methods, and is a promising technique for use in this area of study in the future.

Izvleček

Za določitev hrapavosti površine razpoke v hribini se v laboratoriju uporablja več metod. Realna hrapavost se lahko popači z uporabo različnih intervalov in merilnih metod. Pri vseh dosedanjih meritvah se pojavi mrtvi kot meritve, ki popači sliko površine razpoke. V predstavljenem članku je uporabljena nova metoda meritve hrapavosti razpok v hribini z uporabo 3D skenerja. Za predstavljeno študijo je bilo skeniranih 10 vzorcev tufa, rezultati pa so se primerjali z koeficientom hrapavosti razpoke (JRC). Do sedaj se je 3D skener večinoma uporabljal v avtomobilski industriji. Primerjava z JRC faktorjem na področju mehanike hribin, je s tem članokom predstavljena prvič. Predlagana nova metoda je hitra in bolj precizna od do sedaj uporabljenih metod, zato ima veliko možnosti, da se uveljavi tudi na področju mehanike hribin.

Introduction

One of the most challenging tasks in engineering rock mechanics is characterization of rock joints and jointed rock mass properties. Surface roughness has a major influence on the hydro-mechanical behaviour of rock fractures, and needs to be characterized accurately.

Rock joint roughness has been researched over the last 30 years because of its important influence on the shear strength of rock joints. Since Barton (1973) first proposed the Joint Roughness Coefficient (JRC) for the quantification of rock joint roughness, this property has been quantified by various parameters (Carr & Warriner, 1989; Maerz et al., 1990; Kulatilake et al. 1995; Yu, 1991), which include the root mean square of the first derivative of the profile – Z2, the micro-average inclination angle A_i, the roughness profile index R_p, and the fractal dimension D.

Rock joint surface roughness has also been measured by several different methods in the laboratory. The most commonly used methods are mechanical profilometry (Barton & Choubey, 1977; Brown & Scholz, 1985), shadow profilometry (Maerz & Franklin, 1990), stylus profilometry (Swan, 1983; Kulatilake et al., 1995), and laser profilometry (Huang et al., 1992; Lanaro, 2000). Stylus profilometry and laser profilometry produce very detailed profiles of the roughness, but their performance is time-consuming and complex.

Until now 3D scaner was mostly used in the automotive industry, firstly in this study is used for the comparison with JRC coefficient and the surface Roughness Coefficient (Rs).

Methods

Calculations of roughness parameters

The usually used three-dimensional roughness parameters include the 3D mean angle Φ_s, the 3D root mean square of the first derivative Z_{2s} and the surface roughness coefficient R_s (Belem et al., 2000). Many researchers have tried to apply 3D measurements to characterize the shape of rock joint surfaces (Lanaro, 2000; Fardin et al. 2001), but they did not use the actual 3D data.

The surface roughness coefficient R_s has been generally adopted, due to its simplicity (El Sodani, 1978; Lange et al. 1993; Gokhale & Underwood, 1990; Lee et al., 2002). Recently, it has been used to quantify the rock surface roughness (Belem et al., 2000; Lee et al., 2002). The following definition of the surface roughness coefficient R_s was suggested by El Sodani (1978):

$$Rs = \frac{A_t}{A_n}$$

where A_t, is the actual area of the surface, and A_n, is the nominal area, which is a projection of the actual area (Fig 1). Belem et al. (2000) later suggested the following specific roughness coefficient SR_S:

$$SR_s = R_s - 1$$

Previous researchers have obtained R_s from the correlation between R_s and R_L. Note that R_L is a two-dimensional parameter of the surface roughness.

$$SR_L = R_L - 1 = \frac{\sum(\Delta x_i^2 + \Delta y_i^2)^{1/2}}{L_n}$$

where Δx_i^2 and Δy_i^2 are heights measured from the estimated reference line, and L_n is the interval between the measurements.

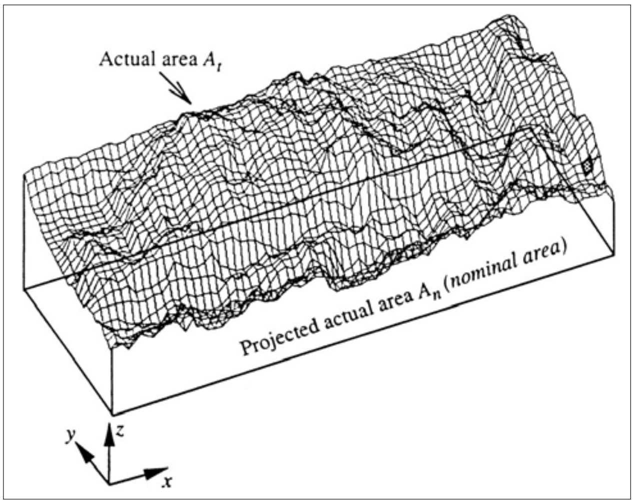

Fig. 1. Actual area and nominal surface area of the rock surface

Sl. 1. Dejanska površina in nominalna površina razpoke

Belem et al. (2000) used laser profilometry to measure the ground and sanded surfaces of granite and rough undulated replicas of mortar, and suggested the following correlation between R_s and R_L:

$$R_s \approx 2.3124\overline{R}_{Lxy} - 1.3138$$

where R_{Lxy} is the average of the R_L value in the x-direction and the R_L value in the y-direction. In experimental equations the 2D parameter R_L is more usable, since up until now 3D measurements of rock surfaces has been technically difficult and time-consuming.

For the calculation of peak shear strength, Barton's curvilinear shear strength criterion for rock joints is the most useful. It is expressed as follows:

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

where:
τ = the peak shear strength,
σ_n = the effective normal stress,
JRC = the joint roughness coefficient,
JCS = the joint wall compressive strength,
ϕ_b = the base friction angle.

The term "joint roughness coefficient" is perhaps misleading, since JRC is not a measure of roughness geometry, but an empirical parameter in a shear strength equation. It cannot be measured directly, but has to be estimated by visually comparing a rough joint with the standard set of comparator profiles published by Barton and Choubey (1997).

Use of a 3D Scanner

For measuring rock joint roughness, a camera-type digital 3D scanner was used, which is a combined system with photogrammetry and fringe projection. It uses two cameras to capture the same position or asperity, and can thus produce three-dimensional images showing the height of the asperity (Fig. 2). The measurement method used by the camera-type 3D scanner is presented from Fig. 3 to Fig.4.

Photogrammetry can be used for the measurement of sensor coordinates, as well as for the global matching of partial views (Fig. 3).

In fringe projection, the projector illuminates the stripe of the patterned light on an object and two cameras capture the deformed shape of fringe by the object (Fig. 4).

Fig. 2. The camera and scanner

Sl. 2. Kamera in skener

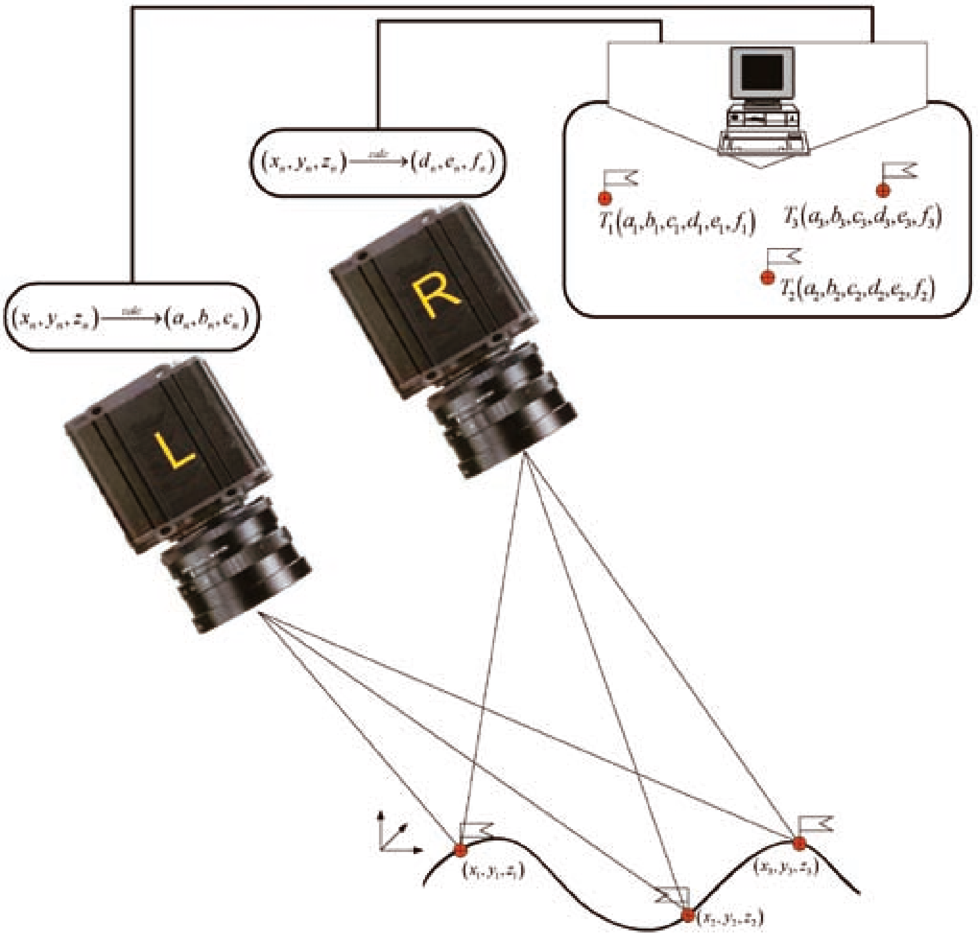

Fig. 3. The photogrammetry concept

Sl. 3. Princip izvedbe fotogrametrije

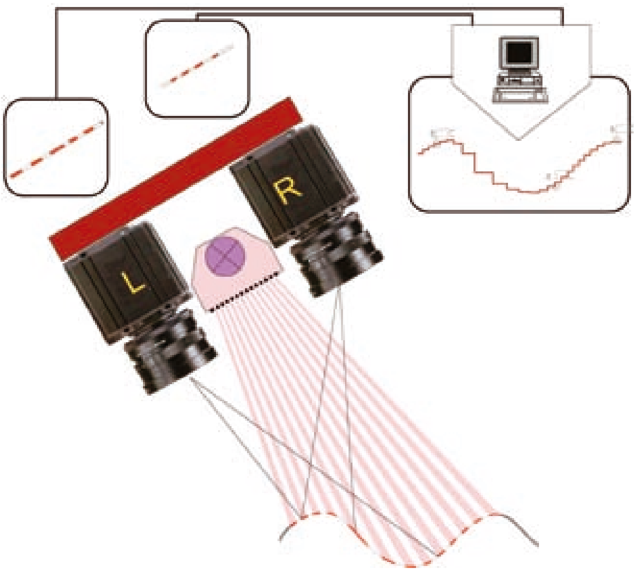

Fig. 4. The concept of measurement with the fringe (stripe) projection method

Sl. 4. Koncept meritve s pasovno projekcijsko metodo

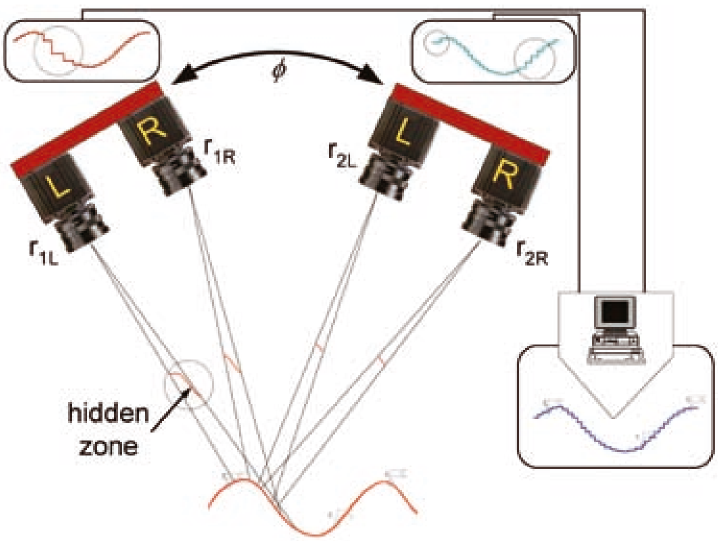

Fig. 5. Removing of hidden places with scans in different directions

Sl. 5. Zmanjševanje mrtvih kotov površin z večkratnim skeniranjem

An accurate roughness profile may be obtained by specific fringe characteristics. Therefore, the roughness underestimation of unevenness can be improved.

The specific asperity can be captured several times at different locations (r) and angles (φ), so that all hidden zones can be visible (Fig. 5). While this method can quickly provide the high density cloud point, it is very sensitive to environmental conditions.

In this study, fringe projection has been used to obtain the high density cloud point, and photogrammetry was used to establish the coordinate information and to modify the data affected by the environment. Although this method requires a merging process because of image overlapping with "multi-viewing", it produces a high resolution image quickly and conveniently (Reich et al., 2000; Lee & Ahn, 2004).

The selected system for this study was Advanced TOpometric Sensor (ATOS I), which combines photogrammetry and fringe projection. Because this system can yield high density three-dimensional point clouds for each image, it also requires a high computing system. ATOS have been used in the field of engineering for product digitization in industries such as the automotive industry. Details of the selected system are summarized in Table 1.

Table 1. The camera-type 3D scanning system (ATOS I).
Preglednica 1. 3D skener s kamero (ATOS I)

Item	Value
Measured Points	800.000
Measurement Time (seconds)	0.8
Measuring Area (mm^2)	125 x 100 - 1000 x 800
Point Spacing (mm)	0.13-1.00
Measuring volume (mm^3)	125 x 100 x 90 to 1000 x 800 x 800
Measuring points per individual scan	1032 x 776 pixels

The camera-type 3D scanner has several advantages:

- the scanning process is fast and the image is accurate
- the large scale of the specimen can be digitized
- the scanning process can be performed in the field
- the rock surface is not damaged during digitizing.

Roughness measurements

For the study, ten samples of tuff were prepared. The diameter of the samples was about 6 cm. Digitalized images were obtained by the 3D scanner. The samples as imaged by the camera-type 3D scanner are shown in Fig. 6. The surface roughness is from planar to rough.

The digital camera was used to establish the global coordinate system and the reference points, and the measuring sensors were calibrated with a calibration plate. After the sample had been placed on a flat working table, several markers were fixed on the sample and to the table around it (Fig. 7), and a global coordinate system and reference points were established. The samples were then digitized with 7–8 shots taken by the 3D scanner. The measurement window size was 100 x 80 (length x width in millimeters), and the measuring point distance was about 0.1 mm.

Image processing software was applied to acquire 3D profiles of the rock joints for the analysis of the point cloud data. The procedures were as follows:

First, the point cloud data were polygonized, and triangulated irregular networks (TINs) were generated. After that a horizontal plane was formed for the calculated surface area of the sample. For this process, the image processing software of the ATOS system was used.

Fig. 6. The ATOS I 3D scanner and the sample
Sl. 6. 3D skener ATOS I in vzorec

Fig. 7. A sample of tuff, with markers
Sl. 7. Vzorec tufa z označbami

Results and discussion

Roughness coefficients (R_S) were calculated from the above-stated equation. The actual area of the surface (A_t) and the nominal area (A_n) were calculated by using the image processing programs from ATOS I.

The results for all ten samples are presented in Table 2. The calculated R_s value was between 1.02, which is for a plane joint, and 1.38, which indicates a very rough rock surface. The specific roughness coefficient was then calculated from the roughness coefficient. Some typical 3D scans are presented in Figures 9 to 11.

After 3D scanning of all the samples, the JRC factor was measured by using a Barton comb. The results are presented in Table 2. These are 2D measurements, so they cannot have the same accuracy as 3D scanning. The 2D profile measured with Barton comb was compared with the profiles published by Barton & Choubey (1977), and also in the ISRM standard. According to the ISRM standard, there are 10 profiles assessed with JRC from 1–20 (two points for every profile). Even with measurements using the Barton comb, the number of JRC's was very difficult to determined. It varied according to the direction of the profile, and depended on the observer's view and estimation. Each sample was measured in different directions, and the average JRC was calculated at the end. The results are presented in Table 2.

Table 2. Results of the measurements with the 3D scanner and results of the measurements of the coefficient JRC

Preglednica 2. Rezultati meritev s 3D skenerjem in rezultati meritev koeficienta JRC

Depth m	A_t mm^2	A_n mm^2	R_S	SR_S	JRC
20	3274	3014.4	1.08612	0.08612	11
21.0	3584	2797.74	1.281034	0.281034	14
21.2	3327	3066.21	1.085053	0.085053	9
21.6	3255	3165.12	1.028397	0.028397	7
24.1	3659	3066.21	1.19333	0.19333	15
24.7	3475	2873.1	1.209495	0.209495	13
25.1	3609	3064.64	1.177626	0.177626	15
25.4	3593	3114.88	1.153495	0.153495	14
25.7	3631	2621.115	1.385288	0.385288	19
26.0	3357	2968.87	1.130733	0.130733	13

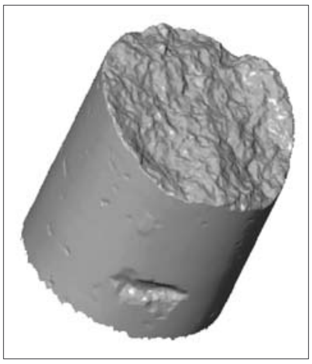

Fig. 8. Scan of the sample from a depth of 21 m

Sl. 8. Skenirani vzorec iz globine 21 m

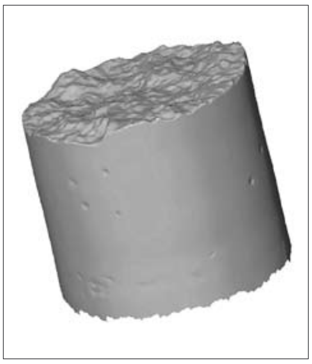

Fig. 9. Scan of the sample from a depth of 21.2 m

Sl. 9. Skenirani vzorec iz globine 21.2 m

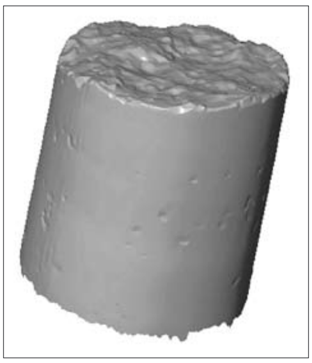

Fig. 10. Scan of the sample from a depth of 21.6 m

Sl. 10. Skenirani vzorec iz globine 21.6 m

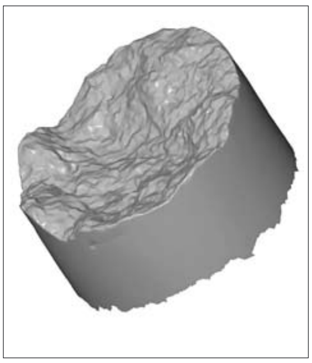

Fig. 11. Scan of the sample from a depth of 25.1 m

Sl. 11. Skenirani vzorec iz globine 25.1 m

The coefficient of correlation between JRC and Rs amounts to 0.8, which shows good correlation between these two parameters (Fig. 12). It is well-known that JRC values are subject to the observer's subjective estimation, but that on the other hand this parameter is the very important for the shear stress calculation according to Barton's equation. Avoiding subjectivity, better results might be obtained by digitizing the standard profiles, measuring the Roughness coefficients (RS), and correlating them with the published JRC values.

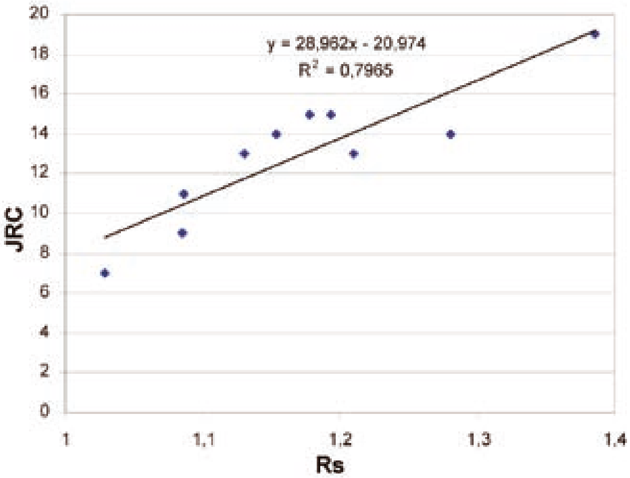

Figure 12. Comparison between the coefficients R_s and JRC

Slika 12. Primerjava med koeficientoma R_s in JRC

Conclusions

Up until now the 3D scanner has been more frequently used in the automotive industry, but, as presented in the paper, it could be very useful tool for the rock joint measurement.

The roughness coefficients were measured with the 3D scanner for tuff samples. From the results of these measurements, values of the surface roughness coefficient (R_S) were calculated. The results were compared with the values of the Rock Joint Coefficient (JRC), and quite good correlation was achieved.

Most of the methods for rock surface measurement are carried out by means of 2D measurements, which deviate considerably from the precision 3D measurement. This is very obvious in the case of very rough rocks with cracks. This new technology can now be used to perform precise measurements of the surface joints and make accurate calculations. In future work, as further calculations of shear joints characteristics based on empirical estimates of 2D profiles and visual assessments are performed, additional shear tests of various materials will be needed. In this way it will be possible to predict accurately the maximum shear stresses based on the 3D measurements. The proposed camera-type 3D scanner in this study produced more accurate values of the roughness parameters since it effectively removed the dead zone on the joint surface.

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