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# Evaluation of surface roughness of rock-like joints using close range photogrammetry method

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**Abstract.** The surface roughness of the joints affects their hydraulic and mechanical behavior. There are various methods for assessing the surface roughness of discontinuities. With the development of photography technology and the release of powerful software, a photogrammetric analyzer has been introduced as a non-contact surface evaluation method. In this research, a three-dimensional model of the fracture surface was constructed using the close-range photogrammetric procedure and the joint roughness coefficient (JRC) is derived from the surface profiles. Also, the surface profiles were surveyed using the Profilometers (Barton Comb) and the JRC values were obtained using the $Z_2$ method. Calculations were performed in two sampling steps of 0.42 and 1.27 mm. Ultimately, the results of the two methods were compared. A Sony Cybershot HX1 digital camera was used to capture the images. To process the images and build the 3D model, they were loaded in the "Agisoft metashape" software. A point cloud data was obtained with very high accuracy with a distance of 0.13 mm between points in the 3D model. The results show that the JRC values obtained from the photogrammetry method, for the upper surface of the joint, recorded 8% and 11% difference from the joint surface for sampling intervals of 1.27 and 0.42 mm, respectively. While for the bottom surface of the joint, these differences were 6.1% and 10% for sampling intervals of 1.27 and 0.42 mm, respectively.

**Keywords**
Close-range photogrammetry, roughness, 3D point cloud, image processing, $Z_2$ parameter

## 1. Introduction

Joints affect not only the shear strength, but also the permeability of the rockmass and the fluid seepage flow in the rockmass structures. In addition, in reservoir engineering, joints may affect the stability of the production well during drilling, the stimulation of the well when the fractures are affected by stress at the growth threshold, and surveying the mature fractures [3]. To predict the hydraulic and mechanical properties of the rockmass, the geometry of the joint network, the hydraulic and mechanical properties of the joints and the intact rock must be specified. The surface roughness of fractures plays an important role in the mechanical response of rock fractures [5]. The strength, deformability and hydraulic properties of the joints are affected by the roughness of the joint surface [9]. Therefore, investigating the impact of joint roughness on mechanical behavior of rockmass and the hydraulic conductivity of the joints is significantly important [4,9]. Many researchers have tried to develop methods and systems for determining the surface roughness of natural rock fractures [11,15]. Surface roughness assessment methods can be divided into contact and non-contact methods. Contact methods include profilograph, comb profiling, shadow profilometer. Non-contact methods also include laser scanning, X-ray tomography and photogrammetry [2,3,8]. Due to the advancement of technology in the field of cameras, the development of smartphone cameras, the existence of powerful image processing software and the provision of diverse and quality outputs, photogrammetry became a practical and appropriate way to evaluate the joint surface conditions [1,13]. Nelson et al. [10] conducted a study on small-scale joints implementing the photogrammetric method. The results showed that the final quality of the surface model obtained from photogrammetry is highly dependent on the lighting conditions. For the study conducted in the laboratory scale, the digitization error is evenly distributed over the entire sample surface. Dzugala [4] conducted a study to validate the values of the friction angle determined using photogrammetry. The validation is performed by comparing the values of peak and residual friction angles obtained from the analysis of digital models generated by photogrammetry and the results of multistage cutting experiments. Janiszewski et al. [6] proposed a method for digitizing tunnel surfaces using a photogrammetric process to remotely measure discontinuities. To validate the photogrammetric results, the studied part of the tunnel has also been taken manually. Saricam and Ozturk [12] proposed an automated stop for rough analysis in the laboratory. Image processing is done with MATLAB software. In this study, the effect of factors such as depth of field, brightness, the ratio of the distance from the camera to the target from the baseline, image size and overlap of images by stereo photogrammetry has been investigated. In another study, Torkan et al. [14] evaluated the effect of roughness, normal stress, aperture, water pressure, and changes in boundary conditions on fluid flow in a granite artificial fracture using short-range photogrammetry along with laboratory measurements. The aim of this study was to evaluate the joint surface using short range photogrammetric method. For this purpose, a three-dimensional model with high accuracy texture was constructed and two-dimensional surface profiles were determined in specific positions. The JRC values of the mentioned profiles were determined using the statistical parameter $Z_2$. In addition, surface profiles were drawn using a manual profilometer and JRC values were estimated in the same way. Finally, the JRC values obtained using both methods were compared with each other.

## 2. Methodology

In order to evaluate the surface using a photogrammetric technique, samples were prepared by molding process from the main surface of the joint. The main samples were hard calcareous samples from Asmari Formation. The samples were divided into two halves under indirect tension by applying linear load and the most suitable ones were selected as the studied joint. In this study, two-component compact silicone was used to make the mold and the joint surface was repeated by making samples (replica) of grout (Figure 1).

**Figure 1.** Replica samples prepared by molding from the main fracture surface.

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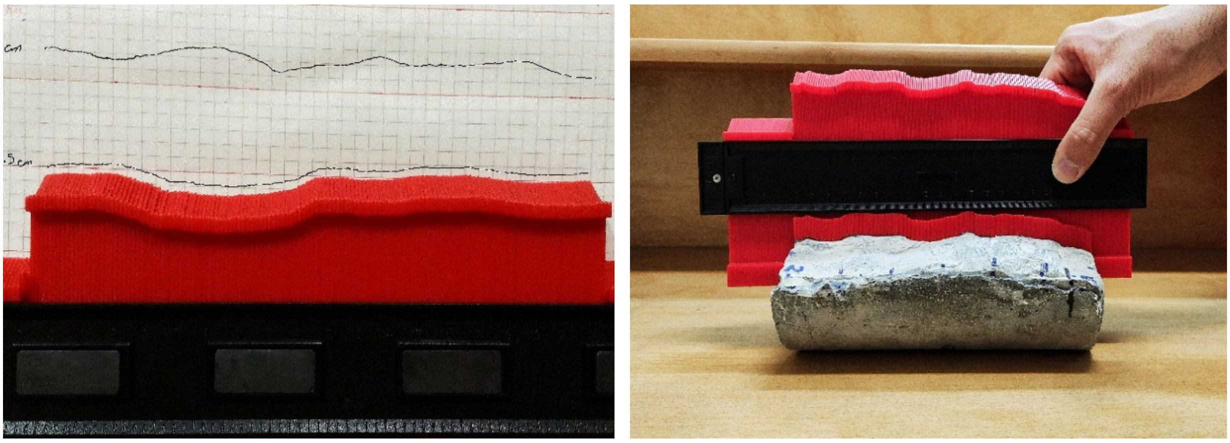
### *2.1. Assessment of joint surface using manual profilometer*

The $Z_2$ parameter is presented by Myers and is related to the surface roughness slope [10]. This parameter is known as the first derivative of the root mean square of the profile [7] and is calculated based on Equation (1) [12].

$$Z_2 = \left[ 1/L \sum_{i=1}^{N-1} \frac{(y_{i+1} - y_i)^2}{(x_{i+1} - x_i)} \right]^{0.5} \tag{1}$$

Where, $y_i$ is the height component of the profile points, $x_i$ is the component of the profile points along the length and $L$ is the length of the profile along the horizon.

For roughness estimation calculations, the desired profiles must first be digitized therefore the JRC can be calculated using the obtained point coordinates and the existing relationships. The process of digitizing profiles is as follows, First, surface profiles were drawn in the desired areas using a manual profilometer. Profiles with 19 cm length were obtained with an accuracy of one millimeter (Figure 2).



(a) (b)

**Figure 2.** (a) Drawing the profiles of the joint A using a manual profile. (b) Positioning the profile on the joint surface so that the needles are properly placed on the surface

An electronic version of the profiles was obtained using a graphic tablet. The captured images were converted to bitmap image files. In the next step, the images were digitized using Origin software at intervals of 0.42 and 1.27 mm. Each profile was converted into two 10 cm profiles, and according to the acceptable range provided by Li and Zhang [8], from the $JRC = 32.2 + 32.47 \log Z_2$ (equation 1) provided by Tsang and Cruden at a sampling distance of 27 mm, $JRC = 28.06 + 25.57 \log Z_2$ (Equation 2) presented by Yu and Vaysadeh at a sampling distance of 0.42 mm was used to calculate the JRC.

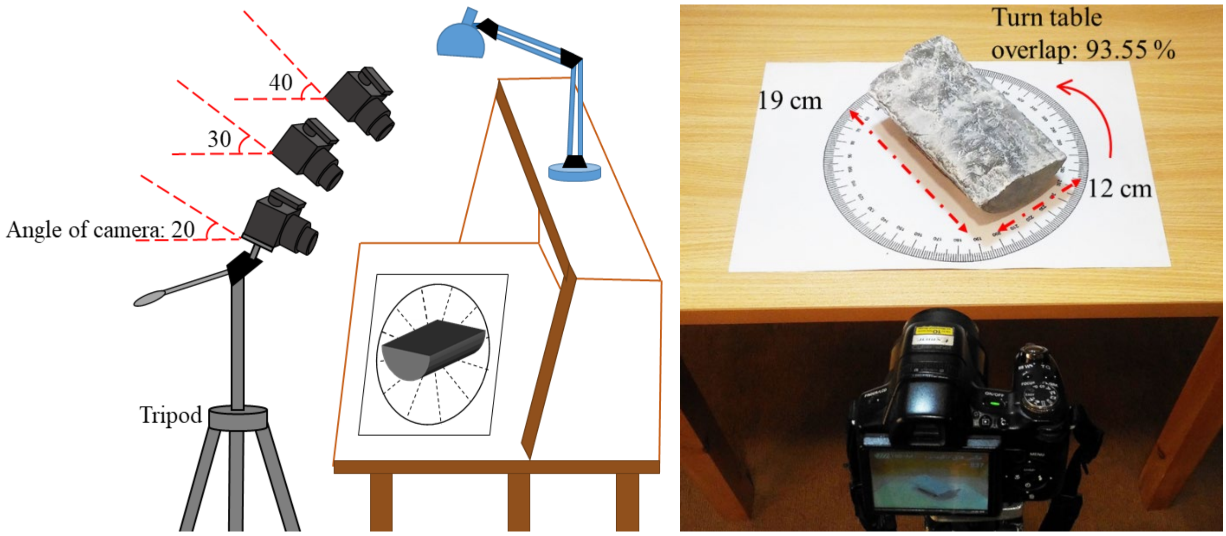
### *2.2. Evaluation of joint surface using short-range photogrammetric method*

#### *2.2.1. Joint surface imaging process*

In this study, in a 360-degree rotation and at angles of 20, 30 and 40 degrees, 108 photos were taken of the sample. The minimum distance between the camera and the specimen is considered in choosing these angles. The camera was mounted on a tripod at a height of approximately 95 cm. By changing the angle, the height of the tripod changed according to the desired position of the camera relative to the sample. The specimen was placed on a calibrated plate, a pedestal was made, and the specimen was placed on it to allow rotation. The sample was rotated clockwise by as much as 10 degrees for each image. In such a way that there was 93.55% overlap between each image and the next image. When shooting, the light should be evenly distributed across the desired surface (not so sharp) so as not to cast shadows on the surface. For this purpose, a height-adjustable lamp was used and glued to the double-layer lamp of the trace paper. The configuration of the photogrammetric process performed in this study and the photogrammetric process is shown in Figure 3.

*2.2.2. Image processing and 3D model making*

After the shooting step, the images are uploaded to the "Agisoft metashape" software as a digital images processing software.




(a) (b)

**Figure 3.** (a) Schematic diagram of photogrammetric process. (b) Sample placed on the rotating plate.

To build the 3D model according to the procedure defined by the software, the following procedure was performed: (a) Upload images to software; (b) alignment of the images, in this step the software searches for points indicating the desired target specifications in the images and matches them with the corresponding points in other images. The program also finds the camera position for each image and estimates the camera calibration parameters, internal orientation (IO) and external orientation (EO) parameters. Finally, a point cloud and a set of camera positions are visualized. The point cloud shows the image alignment results and is not used directly in further processing, as shown in Figure (4); (c) creating a dense point cloud metadata, this cloud is formed by estimating the positions of the camera and the corresponding image; (d) Mesh construction; (e) fabrication; (f) construction of an orthomosaic is created by reflecting images based on their EO/IO data on a mesh or DEM (digital elevation model). The other two components, the digital elevation model and the tiled model, were not applicable in this study. Figure 4 and figure 5 show the final three-dimensional model based on the dense point cloud metadata.

The process used to calculate the roughness using the photogrammetric method is shown in Figure 6.

Three-dimensional models made in Agisoft software were output in ".STL" format and cross-sectioned using Cloudcompare v2.11.3 software. Four sections were considered on the surface in the specified locations and surface profiles were obtained. The same statistical calculations were performed on the profiles obtained by the photogrammetric method using the hand profilometer.

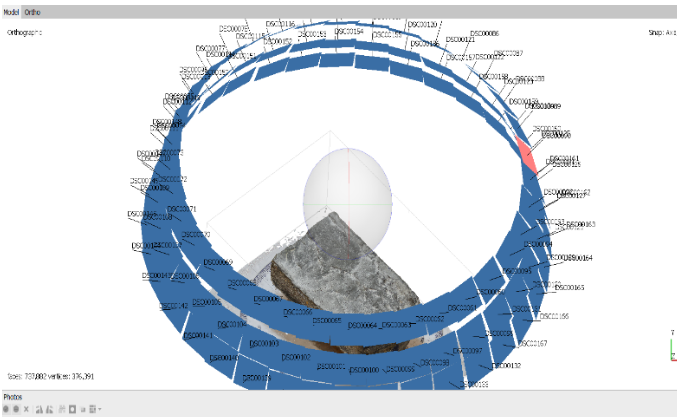


**Figure 4.** Camera positions in the photogrammetric process performed on the joint.

**Figure 5.** Three-dimensional model of the joint surface generated using photogrammetric process.

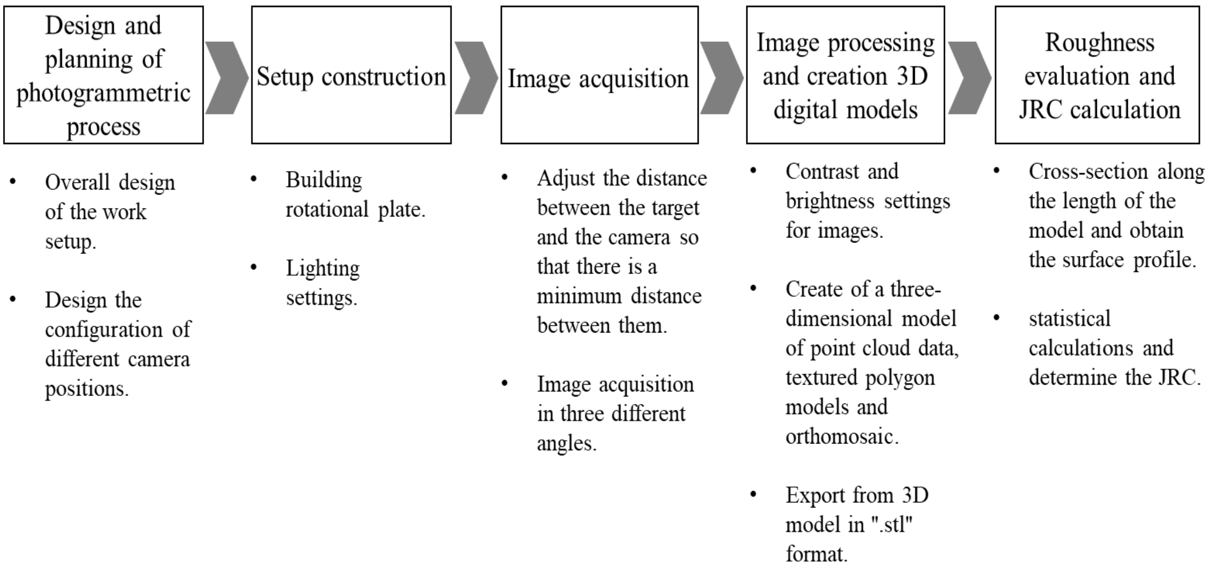



**Figure 6.** The process of calculating the joint roughness coefficient using three-dimensional models obtained from the photogrammetric process.

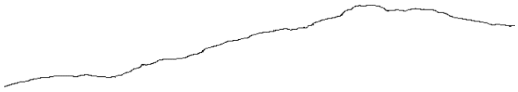
## 3. Results

*3-1- Evaluation results using manual profilometer*

The results of manual sampling from the sample surface are presented in Table 1. (Sixteen profiles were used and two of them are presented at the Table 1.)

Statistical parameters such as $Z_2$ are not independent and the ratio of sampling distance is sensitive. As the sampling distance decreases, $Z_2$ and subsequently JRC increase. The changes in JRC values in the sampling steps are in the range of 2.41 to 5.42 for the upper surface and in the range of 1.68 to 5.41 for the lower surface.

**Table 1.** The JRC values obtained statistical calculations

| Profile No. | Digitized profile of 10-cm long Joint A | The JRC values obtained from statistical calculations | |
|---|---|---|---|
| | | Eq. 1 SI=1.27mm | Eq. 2 SI=0/42mm |
| 1 |  A-up-2.5-part1 | 14.61 | 17.02 |
| 2 |  A-up-2.5-part2 | 7.91 | 13.33 |

**A:** Name of the fracture sample studied
**UP:** High fracture level
**Down:** The lower level of the joint
**Part1:** Indicates the first part extracted with a length of 10 cm from a length of 19 cm.
**Part2:** Indicates the second part extracted with a length of 10 cm from a length of 19 cm

### *3.2. Evaluating the results from close-range photogrammetry*

A total of eight models were prepared from the studied joint surface using photogrammetric method. The specifications and parameters of each of the built models are presented in Table 2.

**Table 2.** Characteristics of models obtained by photogrammetric method

| Number of primary sparse point cloud | Average distance of model points (mm) | Number of point cloud metadata | Model |
|---|---|---|---|
| 49,668 | 0.14 | 1,562,405 | A – up |
| 52,063 | 0.14 | 1,637,745 | A – down |
| 50,441 | 0.14 | 1,631,192 | B – up |
| 47,486 | 0.14 | 1,535,631 | B – down |
| 50,513 | 0.14 | 1,620,042 | C – up |
| 40,583 | 0.14 | 1,505,963 | C – down |
| 59,417 | 0.13 | 1,645,274 | D – up |
| 56,222 | 0.13 | 1,578,886 | D – down |

After performing photogrammetry and calculating the joint roughness coefficient, 8 and 10% difference were observed between the profiles obtained from the model and those from the manual profilometer for the upper surface in the sampling steps of 1.27 and 0.42 mm, respectively. For the lower surface these difference values were 6.1% and 10% for the sampling steps of 1.27 and 0.42, respectively. It is noteworthy that different percentages of photogrammetric results have been reported in all studies in this field.

Variations in JRC values for the upper joint surface are shown in Figures 7 and 8. The calculated JRC value of some profiles is greater than 20, since the value of the $Z_2$ parameter is beyond the allowable range [7]. In fact, this indicates a weakness and bug in the JRC concept as well as its computational formula, which does not support some profiles. As mentioned earlier, the JRC is depended on the sampling interval, and as the sampling interval decreases, its value increases. In this case the calculated JRC values greater than 20, are occurred when the sampling interval is 0.42.

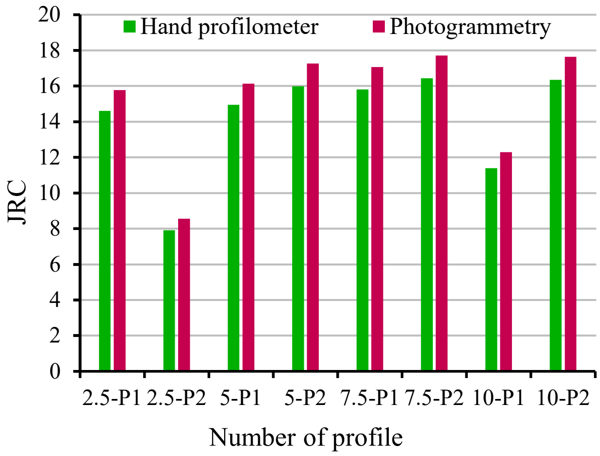



**Figure 7.** Difference between JRC values obtained from manual profilometer and photogrammetric method, for the upper joint surface and at the sampling step of 1.27 mm.

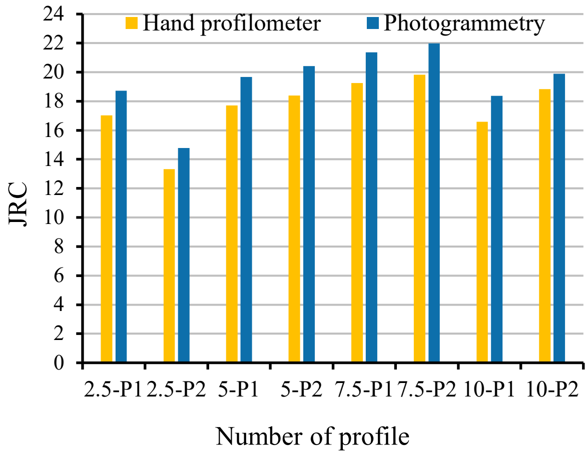



**Figure 8.** Difference between JRC values obtained from manual profilometer and photogrammetric method, for the upper joint surface and at the sampling step of 0.42 mm.

For the lower joint surface, changes in JRC values are shown in Figures 9 and 10.

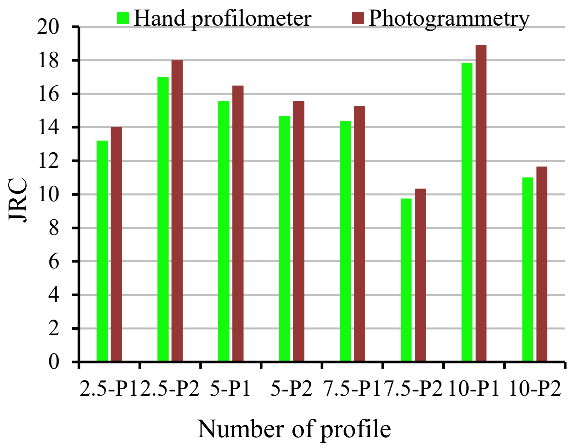



**Figure 9.** Difference between JRC values obtained from manual profilometer and photogrammetric method, the lower joint surface and at the sampling step of 1.27 mm.

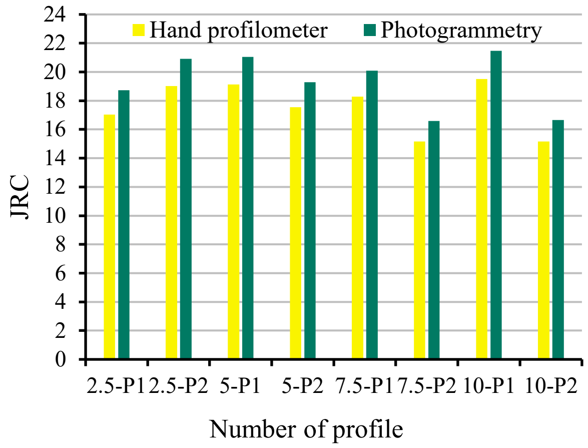



**Figure 10.** Difference between JRC values obtained from manual profilometer and photogrammetric method, for the lower joint surface and at the sampling step of 0.42 mm.

## 4. Conclusion

The development of tools related to photography and image processing software has made the photogrammetric method applicable in various fields of engineering sciences. In this study, short-range photogrammetric method was used to evaluate the level of concrete joints (rock-like samples). It was shown that this method allows the creation of accurate three-dimensional models of joint surfaces and is a suitable method for surface evaluation. The accuracy of three-dimensional models was generated in the scale of hundredth of a millimeter, which is 0.13 and 0.14 mm. The sparse point cloud based on which the textured three-dimensional model is obtained was used to extract surface profiles and calculate the JRC value. Both manual (contact) and short-range (non-contact) photogrammetry methods were performed and the results were compared. For the upper joint surface in the sampling step of 1.27 and 0.42 mm, 8 and 11% difference were detected, respectively, between the profiles obtained from photogrammetric models and those from the manual profilometer. While for the lower joint surface, in the sampling step of 1.27, 6.1% and in the sampling step of 0.42, 10% difference was observed. Due to the capabilities of photogrammetry, including less cost and time to create digital models, high accuracy and the possibility of obtaining a variety of outputs, the prospect of using photogrammetry is very promising. Due to recent advances in UAVs, 3D photogrammetric scanning and assessment of areas inaccessible to humans has also become more widely available.

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