DETERMINATION OF THE BLOCK VOLUME AND THE GEOLOGICAL STRENGTH INDEX (GSI) USING PHOTOGRAMMETRY APPROACH, CASE STUDY: GOLGOHOR IRON MINE OF SIRJAN

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Abstract: The most common method for surveying discontinuities is the scanline method, which has the shortcomings of insufficient safety, number of measurements, and accuracy of measurement. Furthermore, determination of the block volumes generated by discontinuities and measurement of the geological strength index (GSI) are other issues in characterization of the rock mass mechanical properties. The Golgohar iron mine has encountered the above noted issues and the need for a sophisticated and accurate method for measuring discontinuities is inevitable due to the highly fractured walls in mine No. 1 with high risk of failure.. This paper aims to develop a new approach for measurement of the mean block volume, rock quality designation (RQD), and the geological strength index GSI of the rock masses. Thus, the geometric properties of discontinuities in the 14th bench of the Northwest wall in mine No. 1 were measured using the photogrammetric method. To determine the geometric properties of the discontinuities on the slope face, control points were marked on the rock face and photos were taken from the rock surface. Then, using 3DM CalibCam, 3D point clouds and 3D photos were generated. The measurements were used to create a discrete fracture network (DFN) model. To generate the DFN model, FracMan software was used, which ultimately led to the determination of the mean block size, GSI, the mean spacing of each joint set, and the RQD of the rock mass. Results showed that the mean block volume is 0.13 m^3, and the GSI was measured to be 65. In order to investigate the ability of the proposed method in measuring RQD and GSI, results of twenty eight core logs from geotechnical boreholes were used. This investigation showed that the results of proposed model are in good agreement with the measured ones.

Keywords: Photogrammetric method, discontinuities, Discrete fracture method, Geological Strength index, Golgohar iron mine.

1- INTRODUCTION

The common approach for measurement of the orientation and geometrical characteristics of discontinuities in open pit mines is the scanline method where a survey line is defined at the bench of the slope and all individual discontinuities are surveyed. Undertaking this approach has several drawbacks due to the uneven bench and steepness of the slope. Limited number of discontinuities are surveyed due to the shortness of the survey line as well as having a linear measurement. Researchers suggested the use of multiple survey lines in different directions. Furthermore, discontinuities which are parallel to the slope are not surveyed since they have critical roles in slope stability and back breakage in the blasting process. The other common approach for measurement of discontinuities is the window mapping. In this method, all discontinuities that fall in a specified window are measured. This method has also some shortcomings such as the need to access discontinuities, low safety, low accuracy, and high costs. Photogrammetry is a new and effective technique in measurement of discontinuities. In this method, using common 2D photography and using special software, 3D photos are prepared and discontinuities are surveyed on these 3D photos. Using this method, a wide view of mine walls can be easily surveyed with high accuracy in a short time without the need to have access to the slopes and thus interruption in mining process. The other benefit of photogrammetry method over the scanline method is that the representative discontinuity surface is measured by digitizing multiple points on the discontinuity, while in the scanline method, only a limited section of discontinuity is used for measurement of the joint orientation which results in low accuracy of the measurement.

As discontinuities can be surveyed in the photogrammetry technique with high accuracy, in a safer way and in a short period of time, the geometrical characteristics of discontinuities such as orientation, spacing and persistency can be measured more rigorously with high accuracy. This approach can be combined with techniques such as discrete fracture network (DFN) to overcome the difficulties in determination of the mean block size and geomechanical parameters of rock masses, such as rock quality designation (RQD) and geological strength index (GSI).

This paper aims to determine the geometrical characteristics as well as in-situ block size and rock mass classification parameters of RQD and GSI using a combined method of photogrammetry and discrete fracture network in Golgohar iron mine, Sirjan. One of the main challenges in the determination of GSI is its dependency to the experience of user. To solve this problem, Kim et al. proposed the use of block volume and joint condition factor. However, determination of the block volume is challenging in jointed rock masses. This paper propose a new and efficient method for measurement of the block volume as well as GSI. Thus, a wall in Golgohar open pit mine was surveyed using photogrammetry method and discontinuities were surveyed using 3D photos. Then, the fracture network was simulated using the FracMan code. Finally, the distribution of block volumes were determined and GSI was measured using the measured joint surface condition.

2- METHODS

A slope wall in bench no.14 located in Northwest of mine no. 1 of Golgohar iron mine was surveyed. The hosted rock was magnetite and the type of discontinuities were joints. The slope angle was roughly 65 degrees with height of 15 m. The equipment were used for photogrammetry were a digital camera (Canon 5DMKII0244), a tripod, a paint spray, a total station surveying camera and a ranging rod for surveying control points.

The first step in photogrammetry is the determination of the interior parameters of the camera which is called calibration. Calibration parameters include focal length (C), principal point offset (X_p, Y_p), radial distortion (K_1, K_2, K_3, K_4), decentring distortion (P_1,P_2) and scaling factors (B_1, B_2). These parameters are dependent on the camera type, lens type and photography distance which are calibrated to avoid distortion in photos.

Then, several control points (at least three points) are chosen on the slope before taking photos. These points are surveyed with high accuracy using total station surveying camera which are used to scale photos and specifying the location of studied points in mine. Loose and broken rocks were removed from studied viewpoints and camera was located at a distance of around 50 m from the slope. Two stations were chosen for taking photos where the distance between these two stations were one fifth of photography distance and the overlap between photos were more than 60 percent.

2D photos were then inserted to the 3DM CalibCam software and the location of control points were defined in the software. Then, a point cloud were generated in the software and using these points, 3D photos of slope were generated. Using the point cloud, a network of connected triangles were generated, which is called digital terrain model (DTM). Then, discontinuities were surveyed using 3DM Analyst code.

In the second stage, geometrical characteristics of discontinuities (including dip, dip direction and the size and location of joints) were imported to the FracMan code to simulate the fracture network. To measure the mean block volume, multi-dimensional spacing (MDS) method was used. The spacing of discontinuities was measured in direction perpendicular to each joint set, which was then used to determine the mean block volume.
RQD can be measured using the following equation,

$$RQD = 115 - 3.3\, J_v \tag{1}$$

where, J_v is the number of joints in a unit block volume which can be measured as,

$$J_v = \frac{S_2 \times S_3 + S_1 \times S_3 + S_1 \times S_2}{Vb \times \sin\gamma_1 \times \sin\gamma_2 \times \sin\gamma_3} \tag{2}$$

where, S_1, S_2 and S_3 are the average spacing of the joint sets, γ_1, γ_2 and γ_3 are the angles between joint sets and V_b is the mean block volume, which can be determined using FracMan code.
Kim et al. proposed a method for determination of GSI in a quantitative appraoch. In this method, GSI can be measured using block volume (V_b) and joint condition factor (J_c). The mean block volume can be measured using the output of FracMan code. The joint condition factor is dependent on the joint roughness, scale, alteration and infillings, which is measured using site investigations. Then, GSI can be estimated using the proposed graph or using the following equation,

$$GSI = \frac{26.5 + 8.79\, \mathrm{Ln}\, J_C + 0.9\, \mathrm{Ln}\, V_b}{1 + 0.0151\, \mathrm{Ln}\, J_c - 0.0253\, \mathrm{Ln}\, V_b} \tag{3}$$

where, V_b unit is cm^3.
To investigate the validity of the proposed method, results of 28 core logs were used in which GSI values were measured using the following equation,

$$GSI = \frac{52\frac{Jr}{Ja}}{1+\frac{Jr}{Ja}} + \frac{RQD}{2} \tag{4}$$

where, Jr and Ja are joint surface roughness and joint alteration parameters, respectively.

3- FINDINGS AND ARGUMENT

The density of pre-cracks and loading rate are two important factors affecting the failure mechanism of pre-caced specimens which were considered in this study. Results of numerical simulations showed that the failure mechanism of pre-cracked specimens are more influenced by the loading rate than the density of pre-cracks. İn other words, the loading rate dictates the crack pattern of pre-craked speciemns with different crack densities. Table 1 summarizes the types of responsible cracks on the failure pattern of specimens with different loading rates.

Table 1. Types of responsible cracks on the failure pattern of specimens at different loading rates

	Loading rate (mm/step)		
Number of pre-crack	0.002	0.02	0.2
	Responsible cracks on the failure pattern of specimens		
1	oblique cracks	oblique – coplanar cracks	coplanar cracks
3	oblique cracks	oblique – coplanar cracks	coplanar cracks
6	oblique – coplanar cracks	oblique – coplanar cracks	coplanar cracks
9	oblique cracks	oblique – coplanar cracks	coplanar cracks
36	coplanar cracks	oblique – coplanar cracks	coplanar cracks

The measured geometrical characteristics of discontinuities using photogrammetry were dip, dip direction, length (trace length) and central location of discontinuities. In total, 989 joints were surveyed, which included 3 joint sets, and a number of random joints. The stereographic view of these discontinuities are presented in Figure 1. The mean orientation of discontinuities were determined in DIPS software which are now available in Table 1. The angles between joint sets were measured (1&3=88°, 1&2=87.7° and 2&3=54°).

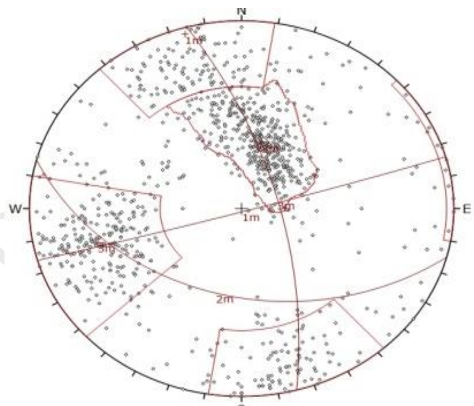

Figure 1 Stereographic presentation of surveyed discontinuities

Table 1 Mean orientation of each joint sets

Joint Set	1	2	3	Random
Number of Joint	200	402	240	147
Dip (Deg.)	88	40	70	
Dip Direction (Deg.)	164	195	75	

The data was imported into FracMan code and a fracture network was simulated. Then, the distribution of block volumes was measured, as shown in Figure 2. Using this distribution graph, D_{80} and D_{50} were determined to be 1.5 and 0.48 m^3, respectively.

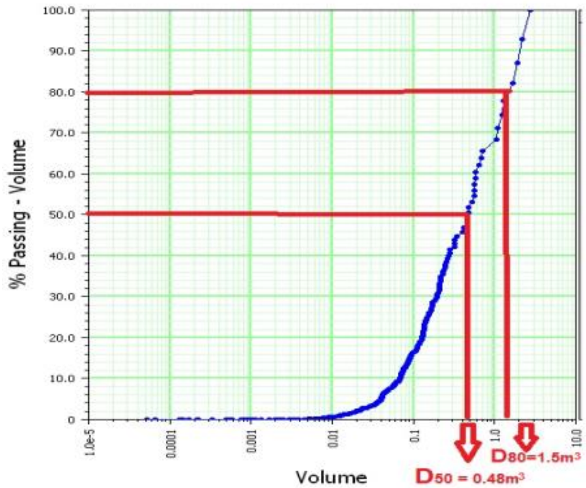

Figure 2 Distribution graph of block volumes

The mean block volume was measured to be 0.13 m^3, and the mean joint frequency in volume was measured using Eq. (2). The filed investigations of the joints conditions showed that the joints are in good condition, rough, and slightly weathered, which means J_c = 3.1.

To investigate the validity of the proposed method, results of 28 core logs were used and compared as represented in Table 2. This clearly shows that the measured RQD and GSI using combined photogrammetry and DFN are in good agreement with core logs results.

Table 1 Comparison of RQD and GSI using core logs and combined photogrammetry and DFN

Measurement Methods	Photogrammetry & DFN	Core logs
RQD	75.76	74
GSI	65	62

4- CONCLUSIONS

Determination of the block volume and GSI is a challenging task in understanding the mechanical properties of rock masses. In this research, a combined photogrammetry and discrete fracture network method was proposed to overcome these difficulties. A rock slope located in Golgohar iron mine was used as a case study. Discontinuities were measured using photogrammetry approach and then were used as the input to FracMan software to generate fracture network model. The distribution of block volumes, as well as joint set spacings were determined. Then GSI and RQD were determined using investigation of the joint surface conditions. The validity of results were evaluated using geotechnical core logs, which showed that the proposed method is a robust approach for estimation of GSI and RQD.

The proposed method can be employed for evaluation of uncertainty in the estimation of the geomechanical properties of rock masses, which is recommended for future studies.

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