Journal of Rock Mechanics and Geotechnical Engineering 9 (2017) 318–328

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full Length Article

Classification and assessment of rock mass parameters in Choghart iron mine using P-wave velocity

Mohammadreza Hemmati Nourani [a], Mohsen Taheri Moghadder [b], Mohsen Safari [c,*]

[a] Department of Mining and Metallurgy, Yazd University, Yazd, Iran
[b] Department of Mining Engineering, Shahid Bahonar University of Kerman, Kerman, Iran
[c] Department of Mining Engineering, Birjand University of Technology, Birjand, Iran

ARTICLE INFO

Article history:
Received 18 June 2016
Received in revised form
9 November 2016
Accepted 14 November 2016
Available online 8 December 2016

Keywords:
Rock mass classification
P-wave velocity
Q system
Rock mass rating (RMR)
Geophysical methods

ABSTRACT

Engineering rock mass classification, based on empirical relations between rock mass parameters and engineering applications, is commonly used in rock engineering and forms the basis for designing rock structures. The basic data required may be obtained from visual observation and laboratory or field tests. However, owing to the discontinuous and variable nature of rock masses, it is difficult for rock engineers to directly obtain the specific design parameters needed. As an alternative, the use of geophysical methods in geomechanics such as seismography may largely address this problem. In this study, 25 seismic profiles with the total length of 543 m have been scanned to determine the geomechanical properties of the rock mass in blocks I, III and IV-2 of the Choghart iron mine. Moreover, rock joint measurements and sampling for laboratory tests were conducted. The results show that the rock mass rating (RMR) and *Q* values have a close relation with P-wave velocity parameters, including P-wave velocity in field (V_{PF}), P-wave velocity in the laboratory (V_{PL}) and the ratio of V_{PF} to V_{PL} (i.e. $K_P = V_{PF}/V_{PL}$). However, *Q* value, totally, has greater correlation coefficient and less error than the RMR. In addition, rock mass parameters including rock quality designation (RQD), uniaxial compressive strength (UCS), joint roughness coefficient (JRC) and Schmidt number (RN) show close relationship with P-wave velocity. An equation based on these parameters was obtained to estimate the P-wave velocity in the rock mass with a correlation coefficient of 91%. The velocities in two orthogonal directions and the results of joint study show that the wave velocity anisotropy in rock mass may be used as an efficient tool to assess the strong and weak directions in rock mass.

1. Introduction

Rock mass classification is one of the most efficient tools used in rock mechanics and an essential element of feasibility studies prior to any excavation or disturbances made to rock. In most cases, rock mass is so complex and heterogeneous that its qualifications are hard to be discerned by conventional tests. In these cases, geophysical methods such as seismography may be useful for estimating the properties of rock mass.

Generally, the transmission velocity of the seismic waves in the rock mass depends on the parameters such as density and rock strength, water condition, stress, orientation, spacing, separation, roughness, weathering and type of filling material for discontinuities. So all of the parameters involved in a classification system such as Q and rock mass rating (RMR) affect the seismic wave velocity as well. Therefore, it is possible to obtain the variations of Q and RMR as a function of the seismic wave velocity parameters. Very useful studies have been conducted in this field. For example, Barton (1991) proposed a basic model for studying the relationship between P-wave velocity and Q value. This model was changed later for seismic analysis in other regions (Barton, 1995, 2007). Cha et al. (2006) and Zafirovski et al. (2012) investigated the relationship between the RMR and the compression and shear wave velocities near the Earth's surface. However, very few studies were done on the relationship between the RMR and the seismic wave velocity. Successful researches have been carried out on the relation between rock quality designation (RQD) and compression wave velocity. For example, Deere et al. (1967) and McDowell (1993) introduced the relations in terms of the ratio of P-wave velocity

* Corresponding author. Fax: +98 5632252098.
E-mail address: msafari@birjandut.ac.ir (M. Safari).

Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

http://dx.doi.org/10.1016/j.jrmge.2016.11.006
1674-7755

in rock mass to that in intact rock. Moreover, Bery and Saad (2012) found a relation between RQD and compression wave velocity using linear regression.

The primary objective of this study is to obtain equations to calculate the RMR and Q at level 1150 of block I, level 1110 of block III and levels 1130 and 1140 of block IV-2 in Choghart iron mine (Fig. 1) as a function of P-wave velocities in rock mass and intact rock. The estimations of P-wave velocity in rock mass as a function of RQD, uniaxial compressive strength (UCS), joint roughness coefficient (JRC) and Schmidt number (RN), as well as the relation between discontinuity orientation and anisotropy of P-wave velocity in rock mass, are additional objectives.

To investigate the relation between Q and RMR classification systems and P-wave velocity in rock mass, first of all, the required parameters of these two classification systems are measured in the field. Then, the two systems are calculated for the 5-m pieces of the surfaces by multivariate regressions among Q, RMR and P-wave velocities in rock mass and intact rock. In addition, some relations are obtained to calculate the values of Q and RMR in the blocks of studied area. The relations between parameters of rock mass and intact rock and P-wave velocity are also focused on.

2. Measurement of intact rock properties

Since block III was extremely fractured, it was not possible to prepare standard cylindrical samples of the intact rock. The RN reflected on 5-m pieces of the surfaces was measured and the UCS values were estimated by the graph as shown in Fig. 2. The P-wave velocity in intact rock samples was also measured. The fracture intensity in rock mass may be estimated by comparing the P-wave velocity in intact rock with the one in rock mass. High ratio of the P-wave velocity in rock mass to that in intact rock indicates good quality of rock mass.

The strength of intact rock was measured by uniaxial compression test on rock cores. A loading rate of 1 kN/s was adopted, and the ratio of length to diameter of samples was approximately 2.5. The results are shown in Table 1. Since the cores of block III did not have standard dimensions, the Schmidt hammer over the bench was used instead. At level 1140 of block IV-2, point load strength test was applied due to the lack of standard cylindrical shape.

The P-wave velocity in intact rock was measured by putting the ultrasonic transducers on either side of the rock core. It was calculated by dividing the core length by transmission time. The results for different cores are shown in Table 1.

In order to determine the density of blocks (Table 1), the mass and volume were measured by digital scale and graduated cylinder, respectively.

3. Rock mass characteristics measurement

The rating and values of the parameters of the RMR and Q systems depend on the characteristics of rock mass, such as RQD, discontinuity conditions and spacing.

3.1. Joint study

Joint study of blocks I, III and IV-2 was carried out to measure the required parameters such as RMR, RQD, joint spacing (SP), number of joint set, joint orientation and degree of weathering and roughness by image processing of surfaces, Schmidt hammer, compass and Barton profile meter. The results are shown in Tables 2–7.

3.2. Seismology

In this study, 25 seismic profiles with a total length of 543 m were studied. To investigate the influence of discontinuity orientation on P-wave velocity at blocks I and III, the seismic profiles are set perpendicular to each other. Therefore, one longitudinal profile and several transverse profiles were taken for each step. The number of transverse profiles depends on the anisotropy of discontinuities in the studied area. The number of geophones for each study was 6 or 12. In long benches, the longitudinal profiles were studied in several steps to avoid wave attenuation. Based on the wave attenuation in the field, the space between geophones varied from 2 m to 5 m, and 6 shots per profile were recorded. Data analysis was performed using the zoned software ST2D. This software is portable and free, which can recognize non-standard or bad data. It determines the velocity changes relative to depth and length. The results for different blocks are illustrated in Figs. 3–6. Velocity changes along the length and width of the blocks are also shown in Table 8.

The topographic analysis results of blocks I and III show that the velocities along the length and width of benches are not equal in some profiles. This phenomenon is mostly attributed to the anisotropy of joint orientations in the benches because the rock is of the same type across the width of the bench. In all analyses, the highest and lowest velocities were 1.1 km/s and 0.7 km/s, respectively.

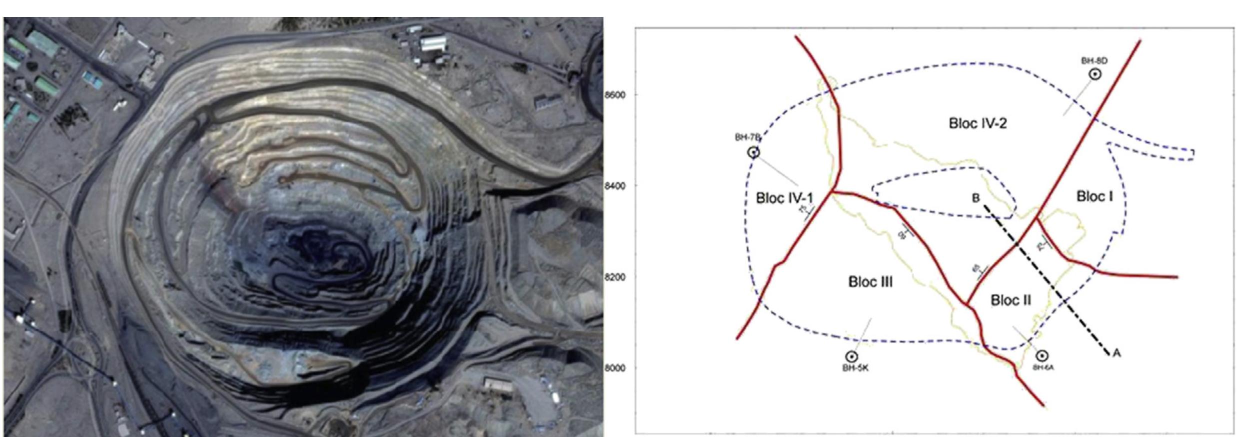

Fig. 1. Studied area in Choghart iron mine.