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# Assessment and Classification of Rock Mass Properties in Iran Central Iron Ore Mines

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## ABSTRACT

In order to optimizing of the blasting operations,we need to evaluate rock mass properties in studying mines. For this purpose, three methods of line mapping, seismic refraction method and experimental tests were used. Properties of 7730 discontinuities were measured at 1780 meters long of the scanline. To determine $V_{pf}$ (the velocity of longitudinal waves in rock mass) 73 seismic profile was run at 1771 meters long of seismic profiles. Also for characterization of intact rock such as UCS (uniaxial compressive strength), UTS (uniaxial tensile strength), density, $V_{pl}$(the velocity of longitudinal waves in intact rock) and Schmidt hardness, the standard tests were used. For Engineering assessment, rock mass was classified according to the RMR classification system. Finally, in addition to analysis of each parameter and present the results for studying mines, equations to estimate RMR based on the results of seismic survey and relationships to predict some properties of intact rock were developed.

**KEY WORDS:** rock mass classification, RMR, seismic refraction methods, discontinuities, line mapping.

## 1. INTRODUCTION

Various factors are influential in blasting operation results in superficial mines. Generally, we can classify them in three categories: rock mass properties, blast design parameters and explosive properties. Rock mass properties are among the most important variables influencing blasting results [1] -[5]. Two different rock masses, when subjected to identical blast geometry and energy input from explosives, will produce quite different degrees of fragmentation. This is because the rock masses have inherently different resistance to fragmentation by blasting and referred to as the blastability of a rock mass [3]. Firstly, to study the blastability in the study area needs to develop a strong database of effective parameters on blasting results. For this purpose, According to studies conducted by various people in this field, the required parameters selected and measured [3], [4] and [6] -[15].

In this research rock mass property by line mapping method, seismic refraction method and experimental tests were evaluated.Inline mapping method Discontinuity properties include orientation, spacing, persistence, aperture, roughness, waviness and infilling materials at 1780 meters long of the scanline were evaluated. By seismic refraction method $V_{pf}$ at 1815 meters long of seismic profiles was measured. For determining of intact rock properties include UCS, UTS, density, $V_{pl}$ and Schmidt hardness standard experimental tests were used. In engineering assessments to evaluate the effect of rock mass properties, we need to classify it. The RMR classification system was used for this purpose. Therefore RMR for the rock mass in studying areas was determined. Finally, relationships were developed to estimate RMR from seismic results. The complete database integrity in relationships for estimating the tensile strength and Young's modulus under uniaxial compression strength and the estimated values based on the velocity Schmidt hardness longitudinal cases in the rock presented. Also, to complement the database In case of lack of information, equations to estimate the tensile strength and Young's modulus based on uniaxial compression strength and equation to estimate Schmidt hardness based on $V_{pl}$ were developed.

## 2. GEOLOGY OF STUDY AREAS

The studied areas consist of Choghart, Chadormalu, Sechahun iron stone mines. These mines located in Bafgh block in ferriferous zone of Anarak-Bafgh-Kerman. The geographical situation of study areas represented in Figure 1. From the geology point of view, Choghart ore deposit situated in Precambrian formations of central Iran (Morad series). This series had been affected by different changes such as metamorphism and metasomatism. The enclosing rocks of this ore deposit are mainly granite, quartz albitophyr and metasomatits. From the tectonic point of view in

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Choghart ore deposit, three main categories of structural factors and faulting operate that can indicate significant Panafrican, Cimmerian and Alpine events. The Panafrican structures can be suggested as the main factors of ore centralization and regional changes. These structures are the deep faults with N-S and E-W strikes [16].

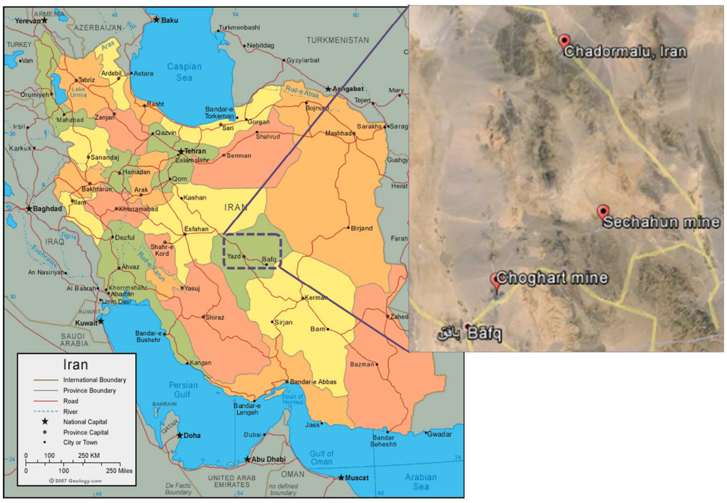


**Figure 1.** Geographical situation of study areas

Sechahun ore rocks consist of the Morad series rocks. In Sechahun ore deposit domain, intrusive rocks are mainly composed of diorite, granite, granophyre and syenite. In addition dikes with different combinations have nearly E-W strikes and high dips 75°-80°. Chadormalu ore deposit consists of two north and south anomalies. This ore deposit because metasomatic and magmatic condition and high tectonic activities contains the complex geological condition. Discontinuities in ore deposits, mostly contain NW-SE strikes and 70°- 80° NW dip angles. Mineral mass has been suffering of fraction by granitic and dioritic dikes which have 15°-45° dip angle and 1-20 meters thickness. In Cambrian period, ore deposit domain consisted of granite gneiss to biotite gneiss and part of amphibolite facies. Ore deposit rocks included crystalline schist, fine grain schist, quartzite schist, biotite schist and quartzite, amphibolite and marbles. In Upper Cambrian period, it consisted of volcanic rocks, dolomites and sandstones [17].

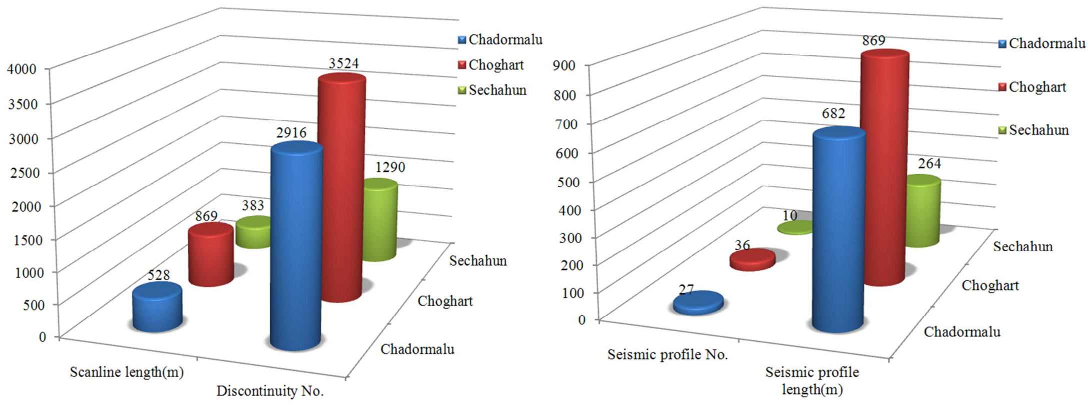


**Figure 2.** Left) Scanlines length and number of discontinuities surveyed and right) number and length of the surveyed seismic profile in studying mines.

## 3. MEASUREMENT METHODS OF ROCK MASS PROPERTIES

### 3.1. Line mapping

In order to measure engineering geological properties of rock mass in rock outcrops, line mapping method used. In this method desirable engineering properties are surveyed along the scanline on the rock outcrop. In line mapping, often the length of scanline has been variably from 10-100 meter. Priest and Hudson suggested that the length of scanline must be at least fifty times the average spacing of discontinuities [18]. While as the International society of rock mechanic has advised, the length of a scanline is normally 50-100 meter [19], [20]. In this method, we can choose the length of scanline according to major changes of rock mass properties such as lithological changes, structural changes or even presence of a fault or fault zone or numerous changes in the weathering rate of rock mass and then by considering these changes we can use a new scanline for surveys of rock mass properties.

In this study, discontinuities properties in 51 blasting blocks measured in a length of 1780 meters of the scanline. Such that along these scanlines properties of 7730 discontinuities were evaluated. Most surveys with survey of 3524 discontinuities along the 869 m scanline relate to Choghart mine. Then in Chadormalu mine 2916 discontinuities in a length of 528 meters of the scanline and in Sechahun mine 1290 discontinuities in a length of 383 meters of the scanline have been surveyed (figure2).

### 3.2.SEISMIC REFRACTION METHOD

In this research, seismic refraction method was used to obtain seismic wave velocity in the rock mass. Equipment used for the seismic data acquisition included the source of creating seismic waves, geophone, battery, connector cables and recorder. Seismic waves are created by the energy incurred to the ground. In field seismic surveys, we can create seismic waves manually or by using heavy machinery or with explosive materials. In this study a handy hammer (18 kg weight) used as a seismic source. In this research, used geophones were electromagnetic PE-3 geophones made by a Netherlands sensor company with a natural frequency of 10 Hz and used seismograph, were TERRALOC Mk8 made by the Sweden ABEM company. This seismograph is twelve - channel and possesses 80 GB internal memory and 2-4000 Hz frequency range [21].

To set up the seismograph, for primary survey and observation of recorded data in the field, SeisTw software, installed on seismograph was used and for final processing of data and getting the $V_{pf}$, Reflex-Win 5.0.5 software, was used.By considering the length and condition of blasting blocks, appropriate arrangement of geophones with spacing of 2, 3 or 5 meters were used. 7 shotpoints were used in all surveys in the length of the profile that 3 shotpoints were placed through the profile and 4 of them were out of it.In this study, seismic properties of rock mass have been surveyed along 73 seismic profiles. By considering different spacing applied for geophones in these profiles, the length of all surveyed profiles is 1815 meter.Figure2 shows the number and length of the surveyed seismic profile in studying mines.

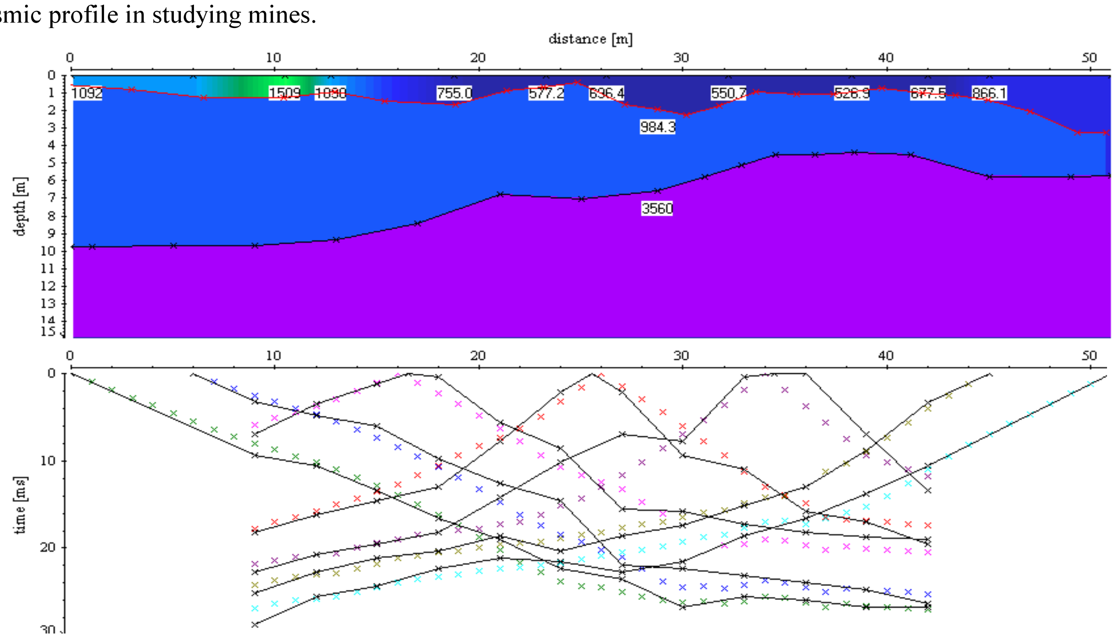


**Figure 3.** 2-D model of seismic velocity variations associated with E2964-1 blasting blocks of Chadormalu mine in Reflex-Win 5.0.5 software.

After processing of the seismic data by Reflex-Win 5.0.5 software and obtain a two-dimensional model of seismic velocity variations ofground (Figure3), at any point along the seismic profiles, the average of $V_{pf}$ was calculated from the following equation.

$$(1) V_{P(average)} = \frac{\sum d_i}{\sum \frac{d_i}{v_{pfi}}}$$

In the above equation $d_i$ and $V_{pfi}$ are depth and p-wave velocity of $i^{th}$ ground layer.

### 3.3. EXPERIMENTAL TESTS

To measure intact rock properties derived cores of rock samples of each blasting blocks which were lack of any plane of weakness, studied in the laboratory and parameters such as density, UTS (uniaxial tensional strength) and UCS, elasticity modulus and Schmidt rebound hardnessof the samples were measured.Block samples for measurement of intact rock propertiesof each blasting block according to the lithological characteristics collected, coded and were transported to the laboratory.As much as possible, we tried the samples are free of any joints or fractures. After determination of hardness by Schmidt hammer in laboratory for further tests by diamond core drilling machine core samples with a diameter of 54 mm of each block sample were prepared. Then core samples were prepared according to ASTM D4543 standard [22].

For determining of rock hardness after calibration the plunger of the hammer is pressed against the flat and without fracture surface of rock.After 10 readings have removed 50% of minimum readings, by taking the average of the remaining readings and multiplied by the correction factor of the hammer, the hardness was obtained [23]. As regards the number of hardness is dependent on hammer orientation, in this study all reading is made at right angles to the surfaces. Density of rock samples was determined by immersion in water and weight divided by volume methods. Density values calculated by both methods were close together, but the mean of the two values obtained as the density of the sample was taken.To determine the compressive strength of intact rock, uniaxial compressive strength test was used.In this study sample characteristics and testing method in accordance with the recommendation of the International Society for Rock Mechanics (ISRM) were considered [24]. In all experiments axial load with constant rate 5 kN/s was applied to the sample. After the breakdown of the sample UCS was calculated by dividing the applied maximum load to the initial cross-sectional area of the sample. In order to determine the deformability of rock during uniaxial compressive test in accordance with ISRM guidelines concurrent withapplied axial load, axial deformation was measured [24]. Digital gauge with 0.01 mm accuracy to measure the axial deformation was used. After any experiment by dividing applied load on the sample to the initial cross-sectional area calculated axial stress and by dividing the length change of the sample to the initial length of the core sample calculated axial strain. Finally, for each test tangential Young's modulus at 50% of ultimate strength of the core samplewith plotting axial stress - strain curve was obtained.

Brazilian test was used to determine the tensile strength of the intact rock. In this experiment the sample is placed between the two arch-shaped jaw and axial load apply by the same device of determining the uniaxial compressive strength (figure 4).This test was performed according to the recommendations of ISRM. So that samples diameter and the ratio of length to diameter was 54 mm and 0.5, respectively. Finally, the tensile strength was calculated according to the following equation [25].

$$(2) \qquad \sigma_t = 0.636 \frac{P}{DT}$$

Where $\sigma_t$ is tensile strength (MPa), P is the failure load (N), D is the diameter of the specimen (mm) and Tis the thickness of the specimen in the center of the specimen (mm).

**Figure4.** Device of left) uniaxial compressive strength test and right) Brazilian test

P-waves measurements in intact rocks were taken using a digital ultrasonic apparatus called PUNDIT. This non-destructive and portable apparatus has two transducerswith the frequency of 54 kHz [26]. In this experiment, the $V_{pl}$ for each sample is determined by dividing the sample length (distance betweentransmitter and receiver) to the transit time (Figure 5).

**Figure5.** A view of $V_{pl}$ measurement on intact rock sample with the PUNDIT ultrasonic apparatus.

## 4. ROCK MASS CLASSIFICATION

Because the engineering behavior of the rock mass is a function of several factors,in order to assess rock mass effects on engineering operations in engineering projects rock mass classification systems are used.A classification system that has found wide application in engineering science related to earth isRMR (Rock Mass Rating) system.Among the different versions of this classification system is more useful version published in 1989 [27]. The system according to five basic parameters, strength of intact rock material, RQD, spacing of joints, condition of joints (includes joint aperture, persistence, roughness, joint surface weathering and alteration, and presence of infilling) and groundwater conditions gives the rock mass rating between 0 and 100.In this study $RMR_{basic}$ is that RMR rate without adjustment for joint orientation, was determined for all blocks.

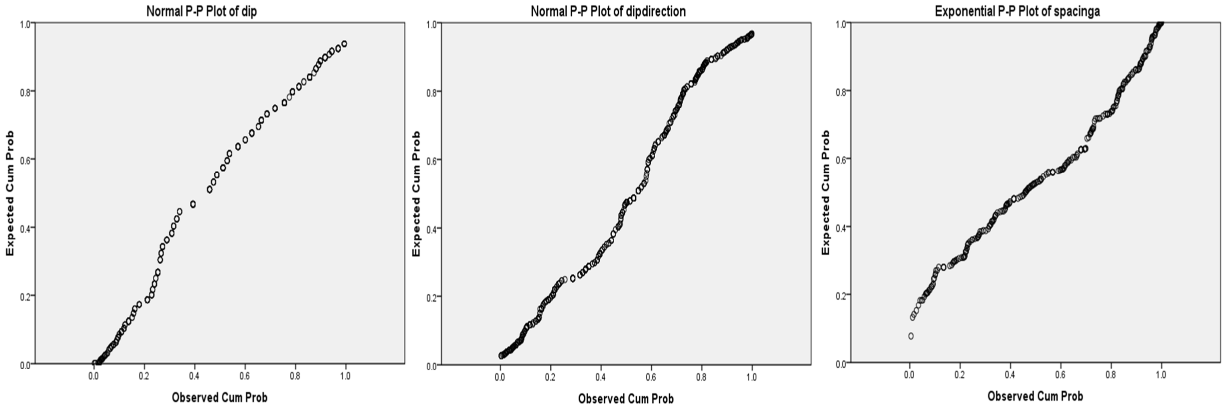


**Figure 6.**The p-p plots of dip, dip direction and spacing data of Choghart mine

## 5. RESULTS

For statistical analysis of discontinuities properties PASW statistics 18 software was used.Statistical study of discontinuities properties showed that %95.6 of discontinuity is of joint type in Choghart mine. %46 discontinuities have low persistence (1-3 m), %58.9 have open aperture (0.5-2.5 mm), %60.6 have clay infilling and %50.3 have moderate spacing (20-60 cm). Furthermore, %84.1 of these discontinuities have undulating surface and %60.2 of them have a smooth surface. In Chadormalu mine, the prominent type of discontinuities with %96.5 are related to joints. %60.4 the discontinuities have low persistence, %47.2 open aperture, %61.4 clay infilling and %52 moderate spacing. Surface of %52.5 of discontinuities is planar and %49 of them has a smooth surface. In Sechahun mine %91.3 discontinuities are of joint type. In addition, most of the discontinuities with %56 have low persistence, %55.8 open aperture, %73.7 clay infilling and %72.8 moderate spacing. Most of discontinuities have also %93.8 undulating surface and %75.3 have a smooth surface. Table 1 shows the frequency of discontinuity properties in studying mines.

Statistical analysis results of dip angle and dip direction data of discontinuities show that in Choghart, Chadormalu and Sechahun mines average dip direction are 182.8°, 182.4° and 169.5° and average dip angle are

60.2°, 63.1° and 58.9°, respectively. Furthermore, to investigate the distribution of data, P-P plots for dip angle, dip direction and spacing data were plotted. The linear shape of the normal P-P plot related to dip angle and dip direction is confirming normal distribution of data. The results also show that the data distribution of spacing is exponential. This claim is well seen in drawn exponential p-p plot for spacing data. Figure 6 shows the p-p plots of dip, dip direction and spacing data of Choghart mine.

**Table1:**frequency of discontinuity properties in studying mines

| Discontinuities properties | | Frequency percent | | |
|---|---|---|---|---|
| | | Sechahun mine | Chadormalu mine | Choghart mine |
| Type | Fault | 8.7 | 3.5 | 4.3 |
| | Joint | 91.3 | 96.5 | 95.6 |
| | Contact | - | - | 0.1 |
| Persistence(m) | Very Low <1 | 2.6 | - | 1.4 |
| | Low 1–3 | 56 | 60.4 | 46 |
| | Medium 3–10 | 37.3 | 31.2 | 35 |
| | High 10–20 | 3.9 | 8.3 | 15.5 |
| | Very High >20 | 0.2 | 0.1 | 2.1 |
| Aperture(mm) | Very tight <0.1 | - | - | 1 |
| | Tight 0.1–0.25 | 3 | 2.5 | 2 |
| | Partly open 0.25–0.5 | 31.2 | 28.6 | 16.6 |
| | Open 0.5–2.5 | 55.8 | 47.2 | 58.9 |
| | Moderately wide 2.5–10 | 4.7 | 13.1 | 14.3 |
| | Very wide 1–10 | 5.1 | 8.1 | 6.7 |
| | Extremely wide 10–100 | 0.2 | 0.5 | 0.5 |
| Spacing(cm) | Extremely close <2 | - | - | 6.9 |
| | Very close 2–6 | 0.4 | 5.3 | 2.9 |
| | Close 6–20 | 22.6 | 35.7 | 30.8 |
| | Moderate 20–60 | 72.8 | 52 | 50.3 |
| | Wide 60–200 | 4.2 | 6.8 | 8.7 |
| | Very wide 200–600 | - | 0.2 | 0.4 |
| Infilling materials | Clean | 0.1 | - | 2.2 |
| | surface staining | 16.3 | 33.6 | 21.3 |
| | Clay | 73.7 | 61.4 | 60.6 |
| | Fe oxide | 2.4 | - | 5.2 |
| | other-specify | 7.5 | 5 | 10.7 |
| Waviness | Planar | 6.2 | 52.5 | 15.5 |
| | Undulating | 93.8 | 47.5 | 84.1 |
| | Stepped | - | - | 0.4 |
| Roughness | Rough | 16.4 | 47.6 | 32.2 |
| | Smooth | 75.3 | 49.7 | 60.2 |
| | Slickensided | 8.3 | 2.7 | 7.5 |

Seismic studies indicate that in the study minesmean, maximum and minimum $V_{pf}$are1462.9, 2919.2 and 868.2 m/s respectively.Also, the mean, maximum and minimum VI that is obtained by dividing $V_{pf}$ to $V_{pl}$and is an indicator of the fracturing degree of the rock mass are 0.28, 0.52, 0.16, respectively. In table 2 statistical summaries of$V_{pf}$ and VI are presented separately for studying mines.

**Table 2:** Seismic refraction results and velocity index of rock mass in studying areas

| Mine | Choghart | | Chadormalu | | Sechahun | |
|---|---|---|---|---|---|---|
| | $V_{pf}$(m/s) | VI | $V_{pf}$(m/s) | VI | $V_{pf}$(m/s) | VI |
| **Mean** | 1265 | 0.24 | 1343 | 0.27 | 2134 | 0.39 |
| **Maximum** | 1652 | 0.35 | 2146.8 | 0.43 | 2919.2 | 0.52 |
| **Minimum** | 967.3 | 0.17 | 868.2 | 0.16 | 1668.3 | 0.31 |

The results of experiment on intact rocks showed that rocks in studying mines with the mean density 2.77 t/m3 has hardness 49.1- 63.8 and an average of 59.1. The maximum UCS of rock samples was 110.5 MPa and the minimum and mean value of UCS was 15.23 and 58.5 MPa, respectively. Also, the mean, maximum and minimum Young's modulus of intact rocks was 12.79, 21.99 and 6.51, respectively, and maximum, minimum and mean values of UTS was 12.15, 1.74 and 6.41, respectively. The statistical results confirm that the values of maximum, minimum and mean $V_{pl}$ calculated respectively 6166.7, 4023.4 and is 5273 m/s. The result of descriptive statistic of amounts of mentioned parameters is represented in Table 3.

**Table 3:** Descriptive statistic results of measured parameters of intact rock

| Mine | | $V_{pl}$ (m/s) | Density (ton/m$^3$) | UCS (MPa) | E (GPa) | UTS (MPa) |
|---|---|---|---|---|---|---|
| **ChoghartMine** | Mean | 5366.8 | 2.83 | 59 | 10.7 | 6.2 |
| | Max. | 5796.1 | 3.42 | 100.8 | 12.5 | 7.2 |
| | Min. | 4693.3 | 2.58 | 15.3 | 7 | 3.7 |
| **ChadormaluMine** | Mean | 5514.4 | 2.75 | 50.5 | 10.3 | 3.3 |
| | Max. | 6166.7 | 2.86 | 69.8 | 11.5 | 6.7 |
| | Min. | 4621.1 | 2.7 | 41.6 | 6.5 | 1.7 |
| **SechahunMine** | Mean | 5019.1 | 2.69 | 62.2 | 16 | 8.8 |
| | Max. | 6081.3 | 2.8 | 110.5 | 22 | 12.15 |
| | Min. | 4023.4 | 2.55 | 30.5 | 11.8 | 5.3 |

The rock mass classification results showed that maximum, minimum and mean RMRbasic of rock mass in the study areas are 77.8, 48.4 and 61.65, respectively. Classification results conducted at the mines are presented in Table 4.

**Table 4:** Descriptive statistic results of calculated $RMR_{basic}$ for studying mines

| | Choghart | Chadormalu | Sechahun |
|---|---|---|---|
| **Mean** | 62.5 | 60.4 | 61.9 |
| **Max.** | 77.7 | 67.2 | 75.9 |
| **Min.** | 51.3 | 48.4 | 54.5 |

Due to field surveys to determine $RMR_{basic}$is the time consuming, following equations to estimate this parameter according to the results of the seismic data obtained on fitting different models.

(3) $RMR_{basic} = V_{pf}{}^{0.567}$ $R^2$=0.998

(4) $RMR_{basic} = 718.242VI - 2530.846VI^2 + 2708.967VI^3$ $R^2$=0.99

Where $V_{pf}$ is the longitudinal wave velocity of the rock mass and the VI is velocity index.Using the above relations, after determining $V_{pf}$ and VI by seismic refraction method throughout the mine, we can estimate RMRbasic of the rock mass before any blasting operations. Since the rock mass properties are an important factor affecting the blasting results, in this research in addition to discontinuity properties, parameters such as UCS, UTS, RQD, $V_{pl}$, $V_{pf}$, VI, Young's modulus of intact rock and Schmidt hardness were measured and calculated.However, in cases of deficiency in the database this defect was resolved by fitting the best statistical relationships.

In this regards, the following relations for estimation of UTS and Young's modulus based on the UCS and estimation of Schmidt hardness based on $V_{pl}$were obtained.

(5) $UTS = UCS^{0.442}$ $R^2$=0.946

(6) $E = UCS^{0.629}$ $R^2$=0.991

(7) $R = V_{pl}{}^{0.476}$ $R^2$=1

Where UCS and UTS are uniaxial compressive strength (MPa) and uniaxial tensional strength (MPa), respectively, and E is young' modulus (GPa) and $V_{pf}$ is the longitudinal wave velocity of the rock mass (m/s).

## 6. DISCUSSION AND CONCLUSIONS

We tried to study all rock mass properties influence on blast fragmentation in this research. To this purpose rock mass properties were evaluated in 51 blasting bocks. Statistical analysis of dip, dip direction and spacing data in studying mines indicate that the distribution of dip and dip direction data is normal and distribution of spacing data is exponential. Mainly in all mines, discontinuities have low persistence, open aperture, clay infilling and average spacing. In Choghart and Sechahun mines, discontinuities mainly have undulating and smooth surface and in Chadormalu mine discontinuities mainly have planar and smooth surface. By considering experimental experiments on intact rock samples taken from each blasting blocks in studying mines, averagely UCS, Young's modulus, Brazilian tensile strength, $V_{pf}$, density and hardness were respectively 58.5 MPa, 12.79 GPa, 6.41 MPa, 5273 m/s, 2.77 ton/m$^3$ and 59.1. Implementing the seismic refraction operation in studying areas indicate that mean $V_{pf}$ is in Choghart mine 1265 m/s, in Chadormalu mine 1343 m/s and in Sechahun mine 2134 m/s.

Also, the calculation of VI showed that the average value of this parameter in the Choghart, Chadormalu and Sechahun mines are 0.24, 0.27 and 0.39, respectively.SinceVIhasan inverse relationship to the fracturingdegree of the rock mass, these resultsindicate that thefracture degree in Sechahun mine isless thanChoghart and Chadormalumines. Therefore, the rock massquality of the Sechahun mineisbetter thanthe othertwo mines. Thiscould be due toless Performed blastingoperationsin this minethan theothertwo mines.On the other hand the rock mass classification results showed that the mean $RMR_{basic}$ of rock mass in Choghart, Chadormalu and Sechahun mines are 62.5, 60.4 and 61.9, respectively.Also, statistical analysis of the data led to the development of relations for the estimation of $RMR_{basic}$ based on seismic data.After determining the seismic wave velocity in rock mass and intact rockusing these relationships can quickly be calculated $RMR_{basic}$ and it can be used in the design of optimal blasting operations and slope stabilization. Also, this research has led to the development of relations between UTS, UCS, Young's modulus, Hardness and $V_{pl}$.

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