IMRAN ATHAR BEG
and
HEMANT KUMAR

Geo-technical investigations and rock mass characterization of quartz biotite chlorite schist of Singhbhum thrust belt

Introduction of new technology and mechanization in underground mine working, driven by increasing need of sustainable usage of mineral resources, yields a chance to exploit untouched resources at greater depth. The design of drives, pillars and other underground structures in hard rockmass such as quartz-biotite-chlorite-schist presents a major challenge to geologists and engineers. The complex structure and the composition of these materials, resulting from the deposition and tectonic history, make it quite difficult to be classified as by the widely used rockmass classification system. The rockmass property of quartz-biotite-chlorite schist of Singhbhum thrust belt has been determined in laboratory of IIT (ISM) Dhanbad. The dynamic and static properties of the rockmass such as uniaxial compressive strength (UCS), modulus of elasticity (E), Poisson's ratio (v) and RMR for this geological formation are determined and presented in this paper. The outcome of the study may be of useful for the design of underground excavation in the mineral rich zone, particularly, in Jaduguda area, East Singhbhum, India. The result of this study may be implemented for excavation design using numerical method (FEM), empirical method and analytical techniques.

Keywords: *deep mining, geo-mining parameters, rockmass characterization, RMR, quartz-biotite-chlorite schist.*

Introduction

The depletion of the mineral resources at shallow depths; deep exploitation becomes the major trend for the future mining activities in the world. Presently, some deep coal mines in China, Germany, England, Japan, Poland and Russia have been exceeded a depth of 1100 m [1]. Due to depletion of near surface and high grade deposits, metal mines are working at deeper levels. Some of the mines in India have already been reached up to a working depth of 1000 m from the surface. Kolar Goldfield (now closed), Hindustan Zinc Limited (HZL), and Uranium Corporation of India Limited (UCIL) mines are working at a depth of more than 1000 m from the surface [2]. In addition, deeper and larger traffic tunnels and hydro-structures are also being constructed, especially in Western China. Also deep tunnel and hydro project in India in the northern part of the country is constructed at deeper levels [3]. Singhbhum thrust belt is the most important mineral rich formation in India which extends approximately 150 km from East to West. The depletion of the ore at shallow depth leads to work at deeper levels. To meet the challenges of the structural design, proper knowledge of physico-mechanical property of rock is essential. In this study geotechnical investigation of the quartz-biotite-chlorite schist of Singhbhum thrust belt was carried out to understand the behaviour of rock and rock mass. The geotechnical properties of rock and rock mass determined in laboratory and other techniques presented in this paper may be the effective tool for the excavation design in rock of Sighbhum thrust belt of Jharkhand state or the design in rock type of similar properties.

Messrs. Imran Athar Beg, M. Tech Scholar and Hemant Kumar, Assistant Professor, Department of Mining Engineering, IIT (ISM) Dhanbad 826 004, India. E-mail addresses: smartimran88@gmail.com and hemantismd@gmail.com

Mine description

The sample of quartz-biotite-chlorite schist of the Singhbhum thrust-belt is collected from Jaduguda underground mine. This section provides detailed description of the mine and sample collection zones for the present study. Jaduguda mine is located in the East-Singhbhum District of Jharkhand and it is one of the oldest metal mine in the country. The present working depth of the mine is approx. 880 m. The mine has been divided vertically in 14 levels of 'level interval'. approximately 65 m.

Geology of the mine

The mine is located on the mylonite shear zone that extends NW-SE. The country rock, both hanging wall and footwall, consists of hard compact granite schist and quartz chlorite/ biotite schist. Chalcopyrite is the predominant copper mineral associated with fewer amounts of pyrite, pyrrhotite and pentlandite. The length of the thrust belt in which mineralization has taken place is about 150 km and its extension is from west to east. Geologically, the thrust belt is constituted by Archean-meta-sediments such as mica-schist, quartzite, phyllites and altered tuffs. The rock types in this zone are broadly classified into two groups: meta-sediments and meta-volcanic. During shearing, the meta-sedimentary rocks are thrust over meta-volcanic rocks. As a result, the meta-volcanic stage of rocks lies below the meta-sedimentary rocks. The thrust contact between these two stages of rocks is severely sheared and brecciated. Mineral occurs in this sheared zone in very finely disseminated form and mainly confined in quartz-biotite-chlorite schist and quartz-biotite-sericite schist (information collected from study mine). The local geology of the case study mine is very consistent, and nearly the same stratigraphy can be found throughout the mine. Still, a detailed analysis of the local geology reveals that even small differences in strength and mineral composition can affect failure modes drastically. Thus, a number of geological base cases, important from a rock mechanics perspective, can be identified. The identified modes of failure can then be linked to the geological variations in the mine in a systematic manner. Mineral occurs in the sheared zone in disseminated form and mainly confined in quartz-biotite-chlorite schist and quartz-biotite-sericite schist. Fig.1 is the geological map of North Singhbhum mobile belt (NSMB), India (modified after Dunn and Dey 1942; Katti et al 2010) showing the distribution of Singhbhum-shear zone in Jharkhand [3].

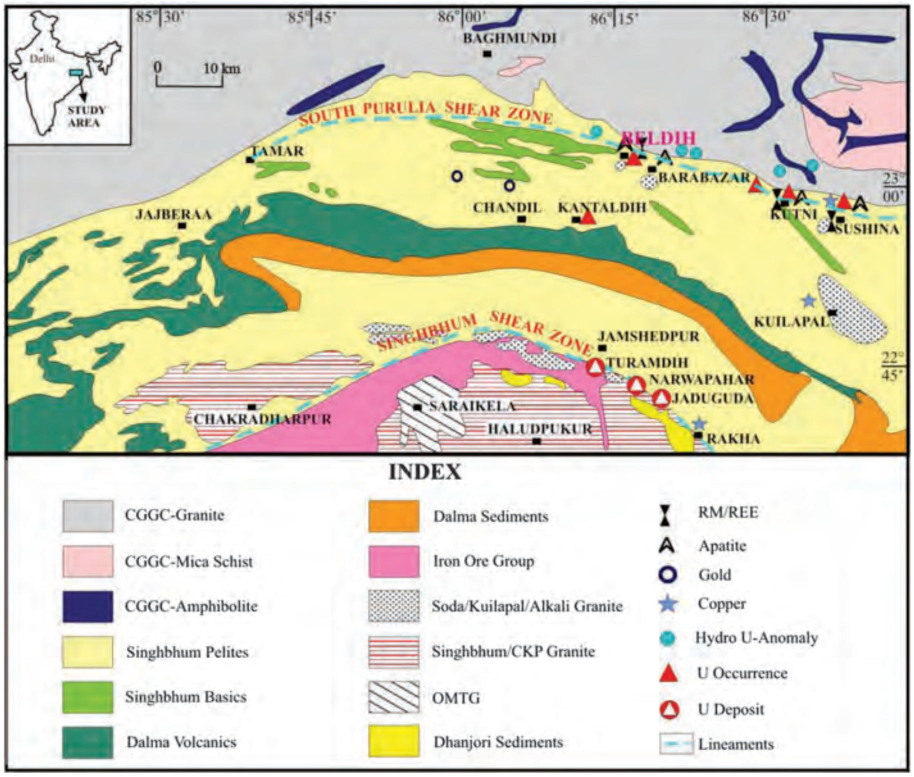


Fig.1 General geological map of NSMB, India (modified after Dunn and Dey 1942; Katti et al. 2010)

TABLE 1: TOTAL NUMBER OF SAMPLES PREPARED FOR LAB TEST

	Sample location	Compressive test	Triaxial test	Tensile test
1.	Hanging wall	07	07	08
2.	Footwall	04	04	05
	Total sample	11	11	13

Location of sample collection

Samples of quartz-biotite chlorite schist rock were collected from Jaduguda mine of UCIL, from different levels comprising hanging wall orebody and footwall lodes. Fig.2 shows the core samples collected from the different locations of the study mine. The core of diameter 54mm was cut in the form of specimen of required length/size for various types of test in the laboratory. Table 1 shows the location and number of sample prepared for laboratory test. Number of sample prepared for compression test, tri-axial test, and tensile test were 11, 11 and 13 respectively.

Laboratory tests performed

To carry out the excavation and support design etc., the geotechnical data required are compressive strength, tensile strength, and modulus of elasticity, Poisson's ratio, cohesion, angle of internal friction and density of the rock. The various tests are conducted to find out the above parameters of the sample collected from the mine areas. The tests conducted in the laboratory are as follows:

- P and S-wave (for dynamic constants)
- Uniaxial compressive strength (for static constants and compressive strength)
- Tensile strength test
- Triaxial test (for angle of internal friction and cohesion)

P AND S-WAVE TEST

This test is a non-destructive test in which samples having L/D ratio of 0.5 to 1.0 are taken into account i.e., tensile test samples, as per the ISRM standards [4]. This test involves the transmission and receiving of Primary (P) wave and Secondary (S) wave through the sample with the help of sonic viewer machine. Fig,3(a-c) shows the laboratory set-up for the determination of dynamic constant by using the P and S wave through the samples. Reading is noted down from the computer screen. The unit of measurement of the velocity of propagation of the waves is in km/sec. Dynamic constant are determined by using the formulas as follows:

$$\text{Poisson's ratio}\,(\text{v}) = \frac{1-2\left(\frac{v_s}{v_p}\right)^2}{2-2\left(\frac{v_s}{v_p}\right)^2} \quad \ldots \quad (1)$$

$$\text{Modulus of rigidity}\,(\text{G}) = \rho v_s^{\,2}\,\left(\text{kgf}/\text{cm}^2\right) \quad \ldots \quad (2)$$

$$\text{Young's modulus}\,(\text{E}) = 2(1+v)G\,\left(\text{kgf}/\text{cm}^2\right) \quad \ldots \quad (3)$$

$$\text{Bulk modulus}\,(\text{K}) = \frac{E}{3(1-2v)}\left(\text{kgf}/\text{cm}^2\right) \quad \ldots \quad (4)$$

Tables 2 and 3 show the various dynamic constant determined by using above formulae.

Uniaxial compressive strength test

UCS test is conducted as per the ISRM standard [4] to determine the compressive strength and deformability of rock samples. The following formulae are used to determine the compressive strength, modulus of elasticity, modulus of rigidity and volume elasticity:

$$\text{Uniaxial compressive strength} = \frac{\text{Breaking load}}{\text{Area}}\,(\text{Mpa}) \quad \ldots \quad (5)$$

$$\text{Poisson's ratio}\,(\text{v}) = \frac{\text{Lateral strain}}{\text{Axial strain}} \quad \ldots \quad (6)$$

$$\text{Modulus of elasticity}\,(\text{E}) = \frac{\text{Stress}}{\text{Strain} \bullet \text{area}}\left(\text{N}/\text{mm}^2\right) \quad \ldots \quad (7)$$

$$\text{Modulus of rigidity}\,(\text{G}) = \frac{E}{2(1+v)}\left(\text{N}/\text{mm}^2\right) \quad \ldots \quad (8)$$

$$\text{Volume elasticity}\,(\text{K}) = \frac{E}{1-2v}\left(\text{N}/\text{mm}^2\right) \quad \ldots \quad (9)$$

Fig.4 (a) and 4(b) show the rock specimen for UCS testing along with the strain gauge fitting for determination of lateral and axial strain on the rock sample. Fig.4(c) shows the universal testing machine during applying load on the specimen. Fig.5(a) and (b) show different mode of failure after applying the load and breaking the rock specimen in the laboratory.

Fig.2 Sample of quartz-biotite chlorite schist rock from Jaduguda mine UCIL

Tensile strength test

This test is intended to measure the uniaxial tensile strength of rock specimen indirectly by the Brazilian test, in accordance with "suggested method for determining tensile strength of rock materials" by Z. T. Bieniawski, L. Hawkes [4]. Figs.6(a-b) show that rock specimen of footwall and hanging wall rock samples taken from Jaduguda mines. Fig. 6(c) shows the specimen is loaded in the testing machine and Figs.6(d-f) show the different failure mode after breaking the specimen in the laboratory test. The tensile strength of the rock specimen is determined by the following formula:

$$\sigma_t = \frac{0.636P}{D * t}\,(\text{Mpa}) \quad \ldots \quad (10)$$

where, σ_t = Tensile strength (Mpa)

P = Breaking load at failure (N)

D = Dia. of test specimen (mm)

t = thickness of test specimen measured at the centre (mm)

Tri-axial test

This test is intended to measure the strength of cylindrical rock specimen subjected to tri-axial compression. This provides the values necessary to determine the strength envelope and from this the value of the

TABLE 2: PROPERTIES OF OREBODY, HANGING WALL AND FOOTWALL ROCK MATERIALS (BASED ON LAB TEST CONDUCTED)

Properties	Orebody		Hanging wall		Footwall	
	Range	Average value	Range	Average value	Range	Average value
UCS (MPa)	40.7-102.2	72.0	41.71-171.31	100.0	28.49-93.68	75.0
Tensile Strength, σ_t (MPa)	7.06-11.36	9.29	6.403-16.89	10.65	6.29-11.79	8.57
Young's Modulus, E_i (GPa)	-	77.15	68.76-100.56	82.229	56.49-92.61	74.70
Poisson.s ratio, η	-	0.1583	0.13-0.16	0.1399	0.13-0.28	0.1768
Angle of internal friction, ϕ_m	-	$40^0 42'38''$	-	$38^0 51'36''$	-	$42^0 33'40''$
Cohesion (MPa)	-	15.75	-	9.82	-	15.259
Rock material constant, m_i	-	14	-	14	-	14
Density (t/m^3)	2.67-3.09	2.79	2.67-2.868	2.797	2.697-3.16	2.93

(a) Sample with transducer (b) Sonic viewer machine (c) Graph on the machine

Fig.3(a-c) Laboratory setup for determination of dynamic constants by P & S wave

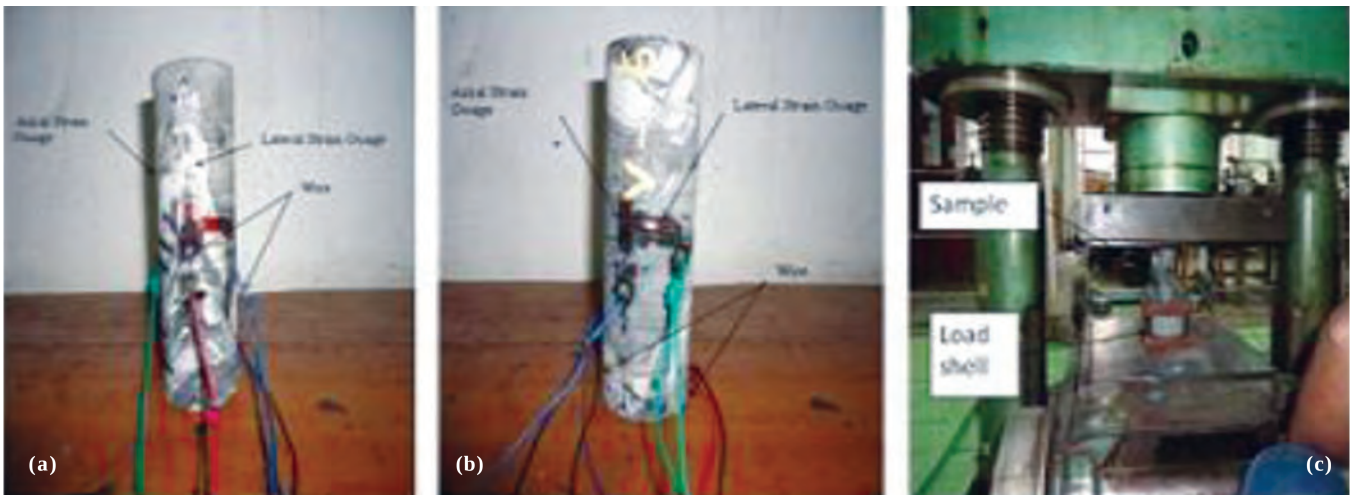


Fig.4 (a) Front side of sample with strain gauge arrangement (b) back side of sample (c) Universal testing machine with sample

angle of internal friction (ϕ) and the apparent cohesion (c). Strength envelope, angle of internal friction and cohesion may be calculated, in accordance with the suggested method for determining the strength of rock materials in tri-axial compression [4]. The test results are shown in Figs.7 and 8.

Formula used to determine ϕ, c and compressive strength are:

$$\phi = \arcsin \frac{m-1}{m+1} \quad \dots (11)$$

Table 3: Rock mass classification for orebody (Bieniawski, 1976)

Parameter	Description	Rating
UCS (Mpa), σ_{ci}	40.7-102.2	4-12
Rock quality designation RQD	40% to 75%	8-13
Spacing of joints	15-25 cm	10
Condition of joints	Slightly rough-planar/undulating joint surfaces, joints separation <1 mm, hard/soft joint wall rock	12-20
Groundwater	Dry	15
RMR	49-70	

$$c = b\frac{1-\sin\phi}{2\cos\phi} \quad \text{... (12)}$$

$$\text{Compressive strength} = \frac{\text{Breaking load}}{\text{Area of specimen}}(\text{Mpa}) \quad \text{... (13)}$$

where,

m = gradient of line.

b = intercept on Y-axis.

There were absurd results from three number of sample due the presence of weak planes (intrusion of molybdenum) in the sample/specimen rock and hence the values are discarded in plotting (Fig.8).

Geo-technical study and rock mass characterization

Engineering properties of rocks (dynamic and static) have been determined using samples obtained from hanging wall and footwall of different locations of the study mine. Bieniawski RMR classification system is incorporated for determination of RMR of orebody, hanging wall and footwall [5]. The properties of the rock sample are provided in Table 2.

Joint survey and GSI of orebody, hanging wall and footwall rock mass

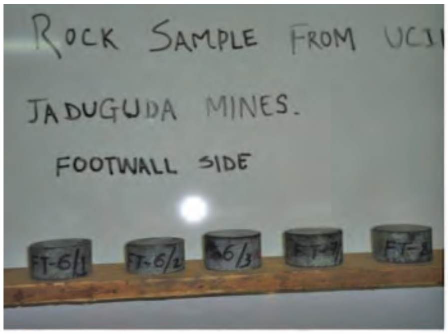
Geo-technical study of the case study mine includes the joint survey of drives, drifts and openings of various levels of mine. The results of the survey suggest that the foliation planes are the dominant planar feature in the mine. Since these planes do not show any abrupt anisotropy, they do not affect the stability. There are three sets of joint planes present in the rocks.

(i) Joint set 1: The most prominent joint set which is nearly parallel to foliation strike but having dip 35^0 to 55^0 towards SW (i.e. opposite to the ore lode). A few of them are nearly vertical joints.

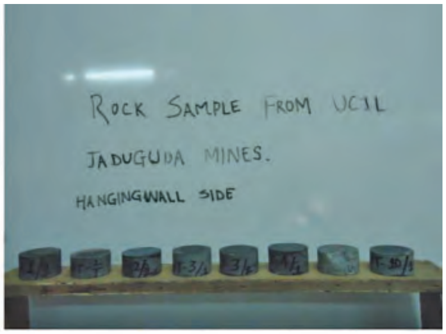
(ii) Joint set 2: The second set of joints is the dip joint which is vertical or having dip 35^0 to 55^0 towards NW or SE.

Fig.5(a) Failure occurred during UCS testing in footwall sample

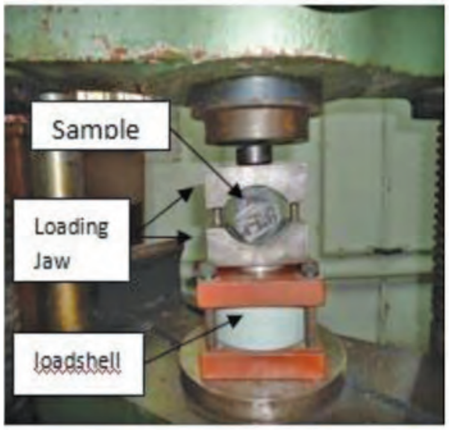
Fig.5(b) Failure occurred during UCS testing in hanging wall sample



(a) Footwall sample for tensile strength test



(b) Hanging wall sample for tensile strength test



(c) Sample for tensile strength test in UTM

(d) Sample showing failure

(e) Hanging wall samples showing failure.

(f) Footwall sample showing failure.

Fig.6(a-f) Tensile strength test of the rock specimen

(iii) Joint set 3: The third set of joints is not so prominent joint and seldom occurs at places. The spacing of joints generally lies between 15 cm to 25 cm, and the joint separation has been found less than 1 mm in orebody as well as in hanging wall and footwall. In general, joints are dry with few exceptional wet conditions, slightly rough-planar and undulating joint surfaces.

Geological strength index (GSI)

GSI is a practical system, depends on the visual impression of the rock structure, lithology and surface condition of discontinuities for estimation. This method is more realistic in quoting a range of the values rather to become more precise [6]. GSI for orebody rockmass, hanging wall and footwall have been estimated, for the analysis of joints, water condition and weather-ability of the rockmass. Geotechnical study of the mine shows that the GSI value for orebody, hanging wall and footwall approximately varies between 42 to 75, 55 to 70 and 50 to 70 respectively.

Rock mass rating (RMR) of orebody, hanging wall and footwall

Bieniawski (1976) RMR [5] of rock mass is determined by using the data collected from the case study mine and the laboratory analysis done in IIT (ISM) Dhanbad. From Table3, 4 and 5 it can be seen that the ranges of RMR of orebody, hanging wall and footwall may be given as (49-70), (49-70) and (49-65) respectively.

Conclusion

The geo-technical investigation of the rock mass in the laboratory provides vital information about the RMR, GSI as well as design parameters of rock structures such as in situ pillars, tunnels, and others rock supports. The assessed values such as RMR, Uniaxial compressive strength (UCS), modulus of elasticity (E), Poisson's ratio (v) and density, can be used as preliminary input parameters and considered as basis for numerical modelling. This investigation provided an updated and comprehensive record of the discontinuities, UCS, tensile strength, modulus of rigidity, poisons ratio, angle of internal friction, cohesion as well as the groundwater condition of the rocks of Jaduguda area. Overall this study provides basic information of the geological structure and engineering properties of the rock mass that are required to meet the challenges during site investigation, tunnel and cavern design, and excavation and support installation. These parameters are used as an input

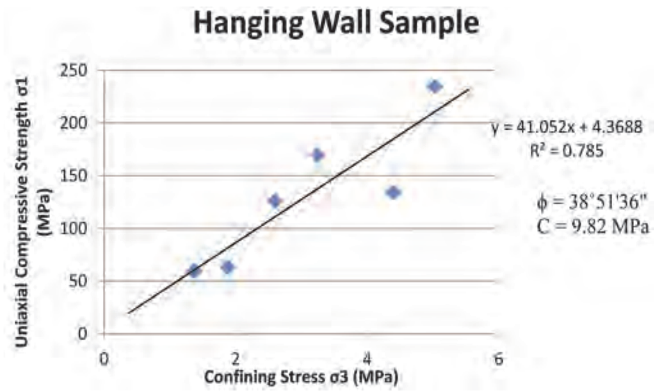


Fig.7 Tri-axial test result of hanging wall samples

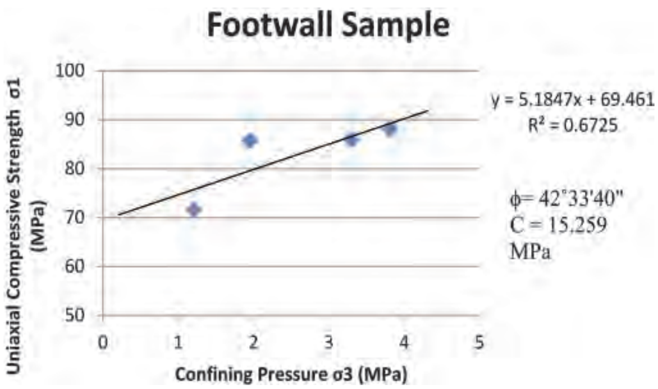


Fig.8 Triaxial test result of foot wall samples

TABLE 4: ROCK MASS CLASSIFICATION FOR HANGING WALL ROCK (BIENIAWSKI 1976)

Parameter	Description	Rating
UCS (Mpa), σ_{ci}	41.71- 171.31	4-12
Rock quality designation RQD	50 % to 75%	8-13
Spacing of joints	15-25 cm	10
Condition of joints	Slightly rough-planar/undulating joint surfaces, joints separation <1 mm, hard/soft joint wall rock	12-20
Groundwater	Dry	15
RMR		49-70

TABLE 5 ROCK MASS CLASSIFICATION FOR FOOTWALL ROCK (BIENIAWSKI 1976)

Parameter	Description	Rating
UCS (Mpa), σ_{ci}	28.49-93.68	4-7
Rock quality designation RQD	40% to 75%	8-13
Spacing of joints	15-25 cm	10
Condition of joints	Slightly rough-planar/undulating joint surfaces, joints separation <1 mm, hard/soft joint wall rock	12-20
Groundwater	Dry	15
RMR		49-65

parameter in the numerical modelling, pillar design and excavation design. The parameters provided in this study are considered for the analysis purpose for hard rockmass of Singhbhum-thrust belt. In this study laboratory and field investigations of quartz-biotite-chlorite-schist rock has been carried out. Another important parameter, in situ stress is to be determined in the mine site to get better results for future design purposes.

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