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Empirical stability classification of steeper slope design in Khoy Open-pit mining projects by using the SMR, Q_{slope} and RMR methods

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ABSTRACT

The presented article tried to utilize the empirical rock mass classifications to rock mass quantification and stability analysis for several open-pit mining projects in Khoy, West-Azerbaijan, NW of Iran. For this purpose, the geomechanical classifications including rock mass rating (RMR), slope mass rating (SMR), and Q_{slope} have been used. The study aim is provide the quick assessment by considering these classifications to appropriate mines design and stability analysis which implemented on 20 open-pit mining cases in Khoy. Based on the results, it has been determined that most slopes are in the generally stable class, but some of the slopes show unstable conditions which stabilization is necessary. In the meantime, one slope is in an unfavorable condition.

1. Introduction

Empirical classification systems are use in rock engineering to quantification of rock characteristics, geo-engineering design and stability analysis which has a quite long background about 19s. But the first practical classification related to Terzaghi's work on steel frame tunnels excavated in sedimentary rocks to support system implementation (Terzaghi, 1946). Lauffer (1958) provide the stand-up time classification based on Terzaghi's classification. Deere and Deere (1989) introduce the rock quality designation (RQD) to rock mass characteristics based on wholesome rate of rock drilling cores which was later widely used in various classifications (Kleinbrod et al., 2019). Rock mass rating (RMR) classification which known as Geomechanics classification was presented by Bieniawski (Bieniawski, 1989) and change the path of empirical classification as well as Q system where presented by Barton and his colleagues (Barton et al., 1974; Barton and Grimstad, 2014). It can be boldly stated that the RMR and Q classifications have caused significant achievements in stability analysis, maintenance system and stabilization of various civil and mining projects in the world. Marinos et al. (2005) have modified the geological strength index (GSI) classification where originally developed by Hoek and his co-workers on 1997 and revise to 2005. Hoek et al. (2013) have illustrated the revised version on GSI in 2013 (Somodi et al., 2018).

Looking at the different geomechanical classifications types of rock mass, it can be said that most of these classifications have been developed for underground analysis and some for surface assessments which mainly originated from RMR, Q or GSI (Azarafza et al., 2017b). In this regard, some of the most important classifications provided that to use in mining purposes can be expressed as follows:

- Mining rock mass rating, MRMR (Laubscher, 1977),
- Simplified rock mass rating, SRMR (Brook and Dharmaratne, 1985),
- Modified-mining rock mass rating, M-MRMR (Haines et al., 1991),
- Chinese slope mass rating, CSMR (Chen, 1995),
- Rock mass number, RMN (Goel et al., 1996),

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- Slope mass rating (Romana et al., 2003),
- Slope stability probability classification (Hack et al., 2003),
- Fuzzy slope mass rating (Daftaribesheli et al., 2011),
- Graphical slope mass rating (Tomás et al., 2012),
- Slope stability rating (Taheri, 2013),
- Q_{slope} (Bar and Barton, 2017).

Meanwhile, the most widely used empirical classifications in Iran which have been applied in various projects included RMR, SMR, and Q_{slope} (Daftaribesheli et al., 2011; Azarafza et al., 2017a; Ahadi-Ravoshti and Farjam Hajiagha, 2018; Bagheri Shendi and Azarafza, 2018; Seyed Hamzeh, 2019). Appropriate and rapid application of these classifications in the primary stability assessments has led to the use of these classifications in this study to assess the stability condition on steeper slope design in mining projects.

2. Material and Methods

2.1. RMR classification

The RMR is a geomechanical classification system for rock structure quantification, developed by Bieniawski from 1972 to 1989 which initially designed for tunnel applications and modified in RMR in 1989 (known as RMR_b or RMR_{89}) and used for all rock mass structures (Bieniawski, 1989). RMR represents the geologic conditions of rock mass with overall comprehensive index of rock mass quality which composed six main parameters contain uniaxial compressive strength (UCS), RQD, discontinuities spacing (DS), discontinuities condition (DC), groundwater conditions (GC) and discontinuities orientation (DO). Each of these parameters is assigned a value corresponding to the rock mass characteristics which are derived from field investigations, and laboratory tests. The sum of the six parameters is the RMR value which lies between 0 and 100 were 0 is the very poor and 100 is very good condition of rock mass (Aksoy, 2008). RMR faced with some difficulties when applied to jointed rock slopes, since the parameter that takes into account the influence of the discontinuities rientation is introduced in detail for dam foundations and tunnels but not for slopes (Pantelidis, 2009), to address this issue, Romana and his colleagues provide the SMR classification system (Romana et al., 2003).

2.2. SMR classification

SMR system originally was developed and modified by Romana et al. (2003) for geomechanical classification of jointed rock slopes based on RMR_b and several adjustment factors were named F_1 to F_4. These factors describe the rock mass characteristics and discontinuity network properties which are estimated by Romana et al. from 2001 to 2005 (Azarafza et al., 2017a; Seyed Hamzeh, 2019). Romana et al. (2003) was prepared the suitable support system suggestion, stability assessment and failure mechanism probability for slopes based on SMR values. SMR as like as RMR lies between 0 and 100 score which 0 is the very poor and 100 is very good condition of rock slope mass.

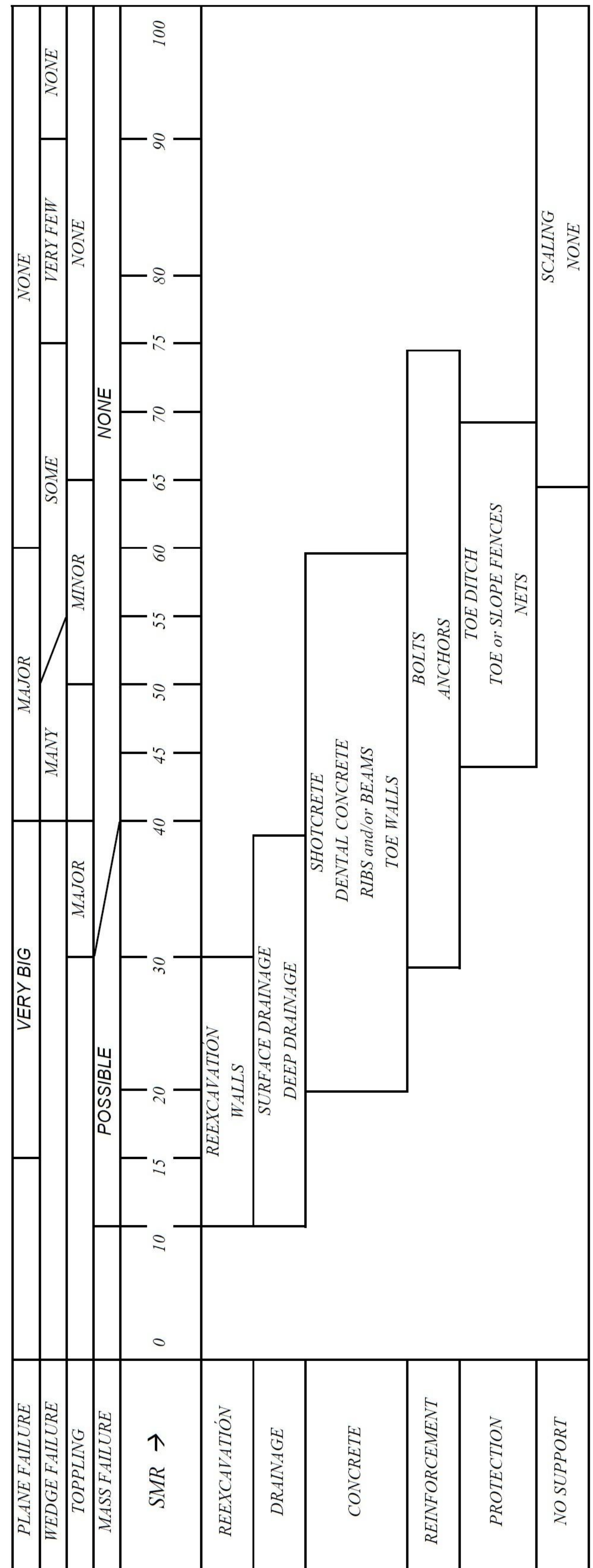

Figure 1. SMR chart for support system and stability assessment (Romana et al., 2003)

SMR = $RMR_B + (F_1 \times F_2 \times F_3) + F_4$					
ADJUSTING FACTORS FOR JOINTS (F_1, F_2, F_3)	αj = DIP DIRECTION OF JOINT; αs = DIP DIRECTION OF SLOPE; βj = DIP OF JOINT; βs = DIP OF SLOPE				
	VERY FAVOURABLE	FAVOURABLE	FAIR	UNFAVOURABLE	VERY UNFAVOURABLE
PLANE FAILURE $\|\alpha j-\alpha s\|$ = ; TOPPLING $\|\alpha j-\alpha s-180°\|$ =	> 30°	30° - 20°	20° - 10°	10° - 5°	< 5°
F_1 VALUE	0.15	0.40	0.70	0.85	1.00
RELATIONSHIP	$F_1 = (1- \sin\|\alpha_j-\alpha_s\|)^2$				
$\|\beta j\|$ =	< 20°	20°-30°	30°-35°	35°-45°	>45°
F_2 VALUE PLANE FAILURE	0.15	0.40	0.70	0.85	1.00
F_2 VALUE TOPPLING	1.00				
RELATIONSHIP	$F_2 = tg^2 \beta j$				
PLANE FAILURE $\beta j-\beta s$ =	>10°	10°-0°	0°	0°-(-10°)	<(-10°)
TOPPLING $\beta j+\beta s$ =	< 110°	110°-120°	>120°	-	-
F_3 VALUE	0	-6	-25	-50	-60
RELATIONSHIP	F_3 (BIENIAWSKI ADJUSTMENT RATINGS FOR JOINTS ORIENTATION, 1976)				
F_4 ADJUSTING FACTOR FOR EXCAVATION METHOD	F_4 = EMPIRICAL VALUES FOR METHOD OF EXCAVATION				
	NATURAL SLOPE	PRESPLITTING	SMOOTH BLASTING	BLASTING or MECHANICAL	DEFICIENT BLASTING
F_4 VALUE	+15	+10	+8	0	-8

Figure 2. SMR adjustment factors estimation (Tomás et al., 2007)

The SMR rating is obtained by means of following Eq.:

$$SMR = RMR_b + F_1 \times F_2 \times F_3 + F_4 \qquad (1)$$

where F_1 depends on the parallelism between discontinuity and slope dip direction, F_2 depends on the affective discontinuity in different failures (as regards toppling failure, this parameter takes the value 1.0), F_3 depends on the relationship between slope and discontinuity dips, F_4 is a correction factor that depends on the excavation method used. Figures 1 and 2 are present the SMR chart and adjustment factors estimations.

2.3. Q_{slope} classification

The Q_{slope} classification system was developed by Bar and Barton (2017) were founded based on regular Barton's Q system for slope stability assessments. The main advantage of Q_{slope} is least assumptions were provided fast stability analysis. On the other hand, the less field requirements have caused to estimate quick results by using the Q_{slope} stability chart. The Q_{slope} stability chart is presents in Fig. 3. Mainly, Q_{slope} conducted of the 6 main parameters were 5 of them such as RQD, J_n, J_r, J_a and SRF which is used in classic Q system (Singh and Goel, 2011). The J_{wice} and SRF_{slope} are Q_{slope} parameters were presented in Eq. 2 as follow:

$$Q_{slope} = \frac{RQD}{J_n}\frac{J_r}{J_a}\frac{J_{wice}}{SRF_{slope}} \qquad (2)$$

where, J_n is the number of joint sets, J_r is the joint set roughness, J_a is joint set alteration, J_{wice} is environmental and geological condition number, SRF_{slope} is strength reduction factors for slope condition (Bar and Barton, 2017). Also, Bar and Barton (2016) defined the O-factor which covers the Jr/Ja ratio as the orientation factor. Q_{slope} as same as Q system can range between 0.001 for an exceptionally poor to 1000 for an exceptionally good rock mass.

The presented article was providing the comprehensive study on open-pit mining in Khoy County, West-Azerbaijan province, Iran on 20 cases of slopes. The RMR, SMR and Q_{slope} were performed to evaluate the parallel stability assessment. For this purpose, first by conducting field survey, the classification requirements are prepared and RQD was calculated based on the jointing system (Palmstrom, 2005). Then calculations and classifications are performed.

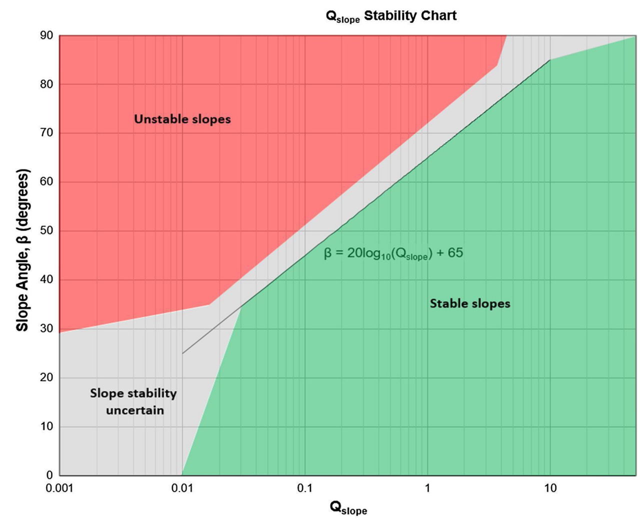

Figure 3. Q_{slope} stability chart (Bar and Barton, 2017)

3. Results and Discussions

The main aim of the study is providing the fast and acceptable path to primary stability analysis and suggestion the support system for 20 steeper slopes in open-pit mining. For this purpose, empirical methodology was used based on standard instructions introduced in the main references. In order to implement and classify, field studies have been done and the geotechnical properties of the rock mass are evaluated in the each mines. During the field survey, the rock mass characteristics, discontinuities feature and RQD are estimated. Then, by using engineering relations and experience judgments, RMR, SMR, and Q_{slope} values are obtained. Table 1 is illustrated the evaluate results of studied cases.

Table 1. The results of the studied cases

Case	RMR	SMR	Q_{slope}	Stability	Support
1	60	73	0.83	Stable	None
2	55	63	0.70	Generally stable	Needed
3	53	60	0.70	Generally stable	Needed
4	45	57	0.63	Generally stable	Needed
5	60	73	0.83	Stable	None
6	35	43	0.52	Unstable	Necessary
7	43	55	0.60	Generally stable	Needed
8	43	55	0.60	Generally stable	Needed
9	40	50	0.58	Partially unstable	Necessary
10	60	73	0.83	Stable	None
11	38	49	0.55	Partially unstable	Necessary
12	38	49	0.55	Partially unstable	Necessary
13	43	55	0.60	Generally stable	Needed
14	55	65	0.65	Generally stable	Needed
15	53	63	0.70	Generally stable	Needed
16	53	60	0.70	Generally stable	Needed
17	55	63	0.70	Generally stable	Needed
18	60	70	0.80	Stable	None
19	60	73	0.83	Stable	None
20	55	65	0.65	Generally stable	Needed

4. Conclusion

The empirical methods application in open-pit mining for quantification of rock mass and providing rapid stability assessments is common procedure in mine design, civil and geotechnical projects which has a quite long background. Although empirical methods has developed for different purposes, but in mining activities, applied methods (for both surface and underground excavations) can be illustrated as RMR, SMR, Q and Q_{slope}. The presented study tried to utilize the RMR, SMR and Q_{slope} classifications to provide the comprehensive stability analysis and support system for 20 cases of open-pit steeper slopes located in Khoy County. Based on the results, it has been determined that most slopes are in the generally stable class, but some of the slopes show unstable conditions which stabilization is necessary. In the meantime, one slope is in an unfavorable condition.

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