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Application of Fuzzy logic to investigate Slope Mass Rating (SMR) in Khoy open-pit mining projects

Mir Akbar Seyed Hamzeh*[1]

[1]*Department of Mining Engineering, Urmia University of Technology, Urmia, Iran*

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ABSTRACT

This study attempts to present the artificial intelligence and fuzzy logic methodology to investigate the stability of jointed rock slopes based on slope mass rating (SMR) in open-pit mining projects in Khoy, West Azerbaijan, Iran. As methodology, the coupled procedure based on SMR and fuzzy logic (named F-SMR) was used to quantification and classification of 25 excavated mine slopes where applied on 6 open-pit mines in Khoy region. For this purpose, the slopes conditions have been evaluated during field surveys and provide the input information for initial SMR model. The fuzzy model has been used to improve the results as well as reduced errors in field evaluations so that it can produce results with higher accuracy. As a result of the presented article, the modified method provides high accurate results in lower evaluating time.

1. Introduction

Slope stability is an important consideration in the management of many types of mining operations or civil engineering projects identified as measurement of how resistant a natural or man-made slope is to fail due to collapse or sliding (Frikha et al., 2017). In open-pit mining, due to the productive blasting vibration, rainfall, transportation of mining machines, excavations and drilling have important effect on the mine slope instabilities (Goel and Singh, 2011). If these triggering factors are combined, they can overcome the rock mass strength and cause the movement and displacement of rock blocks which is considered as failure risk-able mining and the stability condition of mine slopes must be analyzed (Azarafza et al., 2017a). Stability calculations were performed based on empirical or computer-based assessment depending on the evaluation purpose. It can include preliminary studies, linear analysis, numerical modeling, hybrid calculations and high-order solutions (Azarafza et al., 2017c). Meanwhile, to the use of less information empirical approaches due can be appropriate in the initial assessments of stability analysis and provide the possibility of rapid stabilization (Hustrulid et al., 2011). The empirical approaches (known as geomechanical classification systems) attempted to provide the quantitative description for rock mass used to evaluate the stability and suggesting support systems (Goel and Singh, 2011).

Development of empirical classification systems go back to Terzaghi works in 1946 applied on sedimentary rock classification faced with tunneling (Terzaghi, 1946). Cecil (1975) used the Terzaghi's classification system to present the tunnel projects with less calculation requirements. Deere and Deere (1989) used the rock quality designation index, named RQD to rock mass characteristics based on drilling cores. RQD is used in high ranked classification system for description of rock condition and durability factor. Rock Mass Rating (RMR) and Q method were developed by Bieniawski (1989) and Barton et al. (1974) are providing the revolution for empirical classification system for description of rock masses. These classifications were modified upon the time and modified as well. RMR is generally used for all type of evaluations but Q is only used for underground

*** Corresponding author.**
E-mail address: S.mirakbar@gmail.com
B.Sc., Research Assistant.

excavations (Azarafza et al., 2017b). However, the RMR and Q were used by many scholars to develop different classification systems which are lead to quantifying the specific aims in geological engineering, civil projects or mining. In mining engineering some of the important classifications can be described as mining rock mass rating (MRMR) by Laubscher (1977); slope rock mass rating (SRMR) by Robertson (1988); modified-mining rock mass rating (M-MRMR) by Haines et al. (1991); Chinese slope mass rating (CSMR) by Chen (1995); slope mass rating (SMR) by Romana et al. (2003); graphical slope mass rating (GSMR) by Tomás et al. (2012); and slope stability rating (SSR) by Taheri (2013).

In the meantime, SMR due to the flexible utilities on stability assessment, failure mechanism identification and support system suggestion in mining tasks more than other methods. The presented study has attempted to use the coupled SMR classification by fuzzy logic techniques to provide fast and accurate discipline in mining engineering and mine stability analysis.

2. SMR classification system

The slope mass rating or SMR system originally was developed and modified by Romana et al. (2003) for geo-mechanical classification of jointed rock slopes. The SMR equation was derived on RMR and several adjustment factors in presented as Eq. 1.

$$SMR = RMR + \left[F_1 \cdot F_2 \cdot F_3\right] + F_4 \qquad (1)$$

where RMR is Bieniawski's classification, F_1 to F_4 are represented the SMR index factors to describe rock mass and discontinuity network properties. RMR is divided on 5 main parameters concluded uniaxial compressive strength (UCS), RQD, discontinuity spacing, discontinuity condition, and groundwater condition. The sixth parameter of RMR, which has not been shown herein is the correction based on discontinuity orientation. The adjustment factors are estimated by Romana et al. (2001, 2003, 2005) as following Eqs.

$$F_1 = \left[1 - \sin\left|\alpha_{\text{joint}} - \alpha_{\text{slope}}\right|\right]^2 \qquad (2)$$

$$F_2 = \tan^2 \beta_{\text{joint}} \qquad (3)$$

$$F_3 = \beta_{\text{joint}} - \beta_{\text{slope}} \qquad (4)$$

where α_{joint} is dip direction of discontinuity, α_{slope} is dip direction of slope surface, β_{joint} is dip of discontinuity inclination, β_{slope} is dip of slope surface inclination. F_4 is experimental excavation method. Romana and his colleagues provide the empirical values for adjustment factors. Romana et al. (2003) was preparing the support system for slope based on SMR values. Figure 1 presented the suggested chart for support system design for jointed slope instability reinforcements. Also, Table 1 presents the stability evaluations based on SMR value.

Table 1. Description of SMR values (Azarafza et al., 2017a)

SMR class	Description	Stability	Failure	Support
Ia Ib	Very good	Completely stable	None	None
IIa IIb	Good	Stable	Some blocks	Occasional
IIIa IIIb	Fair	Partially stable	Some joints	Systematic
IVa IVb	Bad	Unstable	Planar and Wedges	Important
Va Vb	Very Bad	Completely unstable	Massive	Excavation

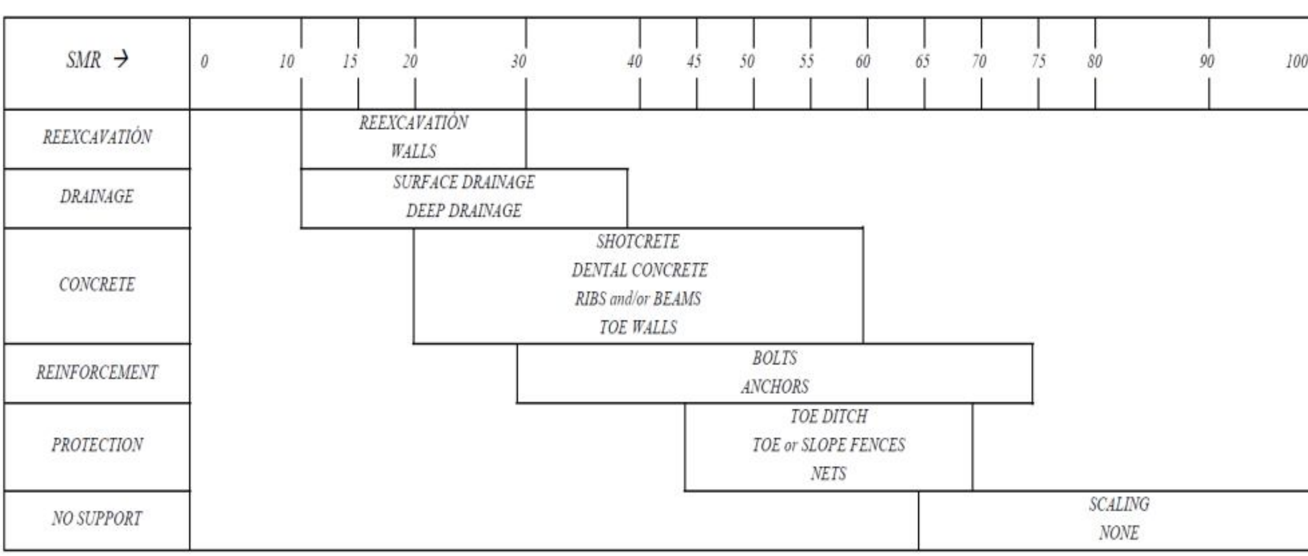

Figure 1. SMR suggested chart for support system design (Romana et al., 2003)

3. Material and Methods

This study attempts to use the fuzzy logic based SMR classification approach of estimate the rock mass characteristics as well as stability condition of rock slopes in mining projects. In this regard, the 25 excavated mine slopes, applied on 6 open-pit mines in Khoy region were selected as evaluation cores. These slopes are investigated and obtained the rock slope conditions were obtained by field measurements. As first stage of assessment, all field requirements for SMR classification was conducted in open-pit mines and data were gathered instead of statistical analysis input to the fuzzy logic interface to evaluate the SMR value with a high accuracy.

Fuzzy logic is originally introduced by Zadeh in 1965 and his colleagues to estimate the series of truth degrees sets named fuzzy sets. Fuzzy logic provides the logical propositions between two values containing uncertain quantities. Fuzzy set theory or fuzzy logic is specified sets whose elements have degrees of membership. These memberships represent the degree of correctness or inaccuracy (truth or falsity) where a covered uncertainty in classic sets. In fuzzy logic methodology, all sets consist of fuzzy sets with functions on which all evaluation and inference operations are performed. These steps are classified as fuzzification, fuzzy inference core and defuzzification process. In processing stages, the rules are provide in rule center and applied on fuzzy controlling/fuzzy inference system named FIS core (Zimmermann, 2001). Mamdani method is the most usable FIS in slope stability analysis (Rafiee et al., 2016) which is used in this study too. MATLAB software (Niemiec, 2017) was has been used as programming language for implement of fuzzy model in slope stability analysis. Figure 2 presents the graphical representation for input characteristics which is same as SMR classification parameters. The purpose of using these parameters is to prepare an optimal model for SMR classification. It should be noted that all the rules are defined on the basis of fuzzy logic is according to the 'IF→THEN' structures.

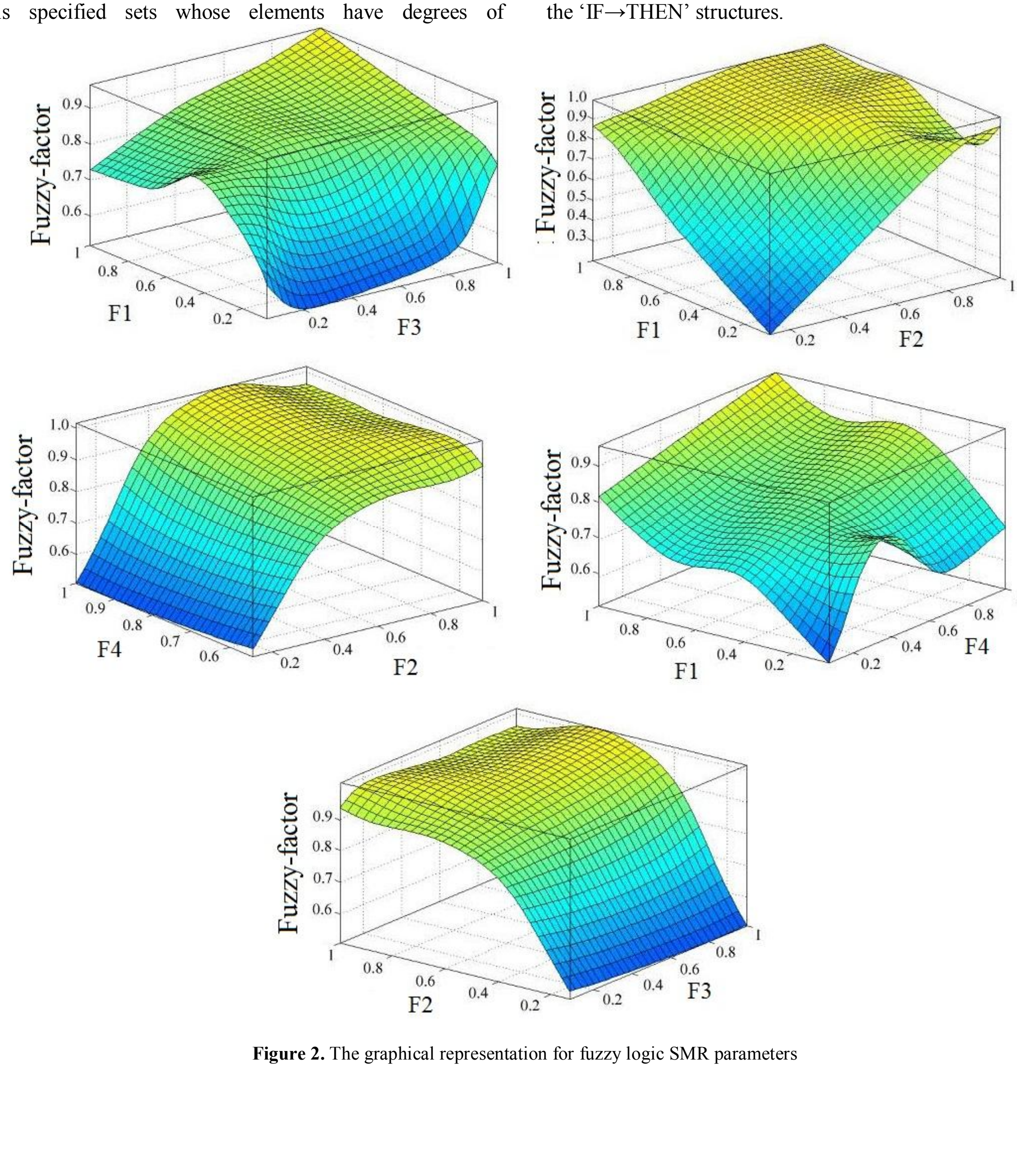

Figure 2. The graphical representation for fuzzy logic SMR parameters

4. Results and Discussions

A total of 25 cases were used to analyze the stability in Khoy region located in West-Azerbaijan, northwest of Iran. These slopes, selected from 6 different open-pit mining project required investigating about the stability and providing appropriate stabilization methods. According to the field investigations, most slopes composed by limestone to granite ore geo-units were excavated as mineral ore which are very useful in the construction industry. However, by the application of fuzzy logic on estimated data from field survey, the modified SMR is evaluated by the fuzzy model is presented in Table 2. As seen in this table, the results of the presented model provide high accuracy in less evaluating time which is capable of quake decisions.

Table 2. SMR evaluation for studied cases

Case	Fuzzy SMR	SMR class	Stability	Support
#1	Stable block	IIb	Stable	None
#2	Local unstable	IIIb	Partially stable	Important
#3	Local unstable	IIIa	Partially stable	Important
#4	Local unstable	IIIb	Partially stable	Important
#5	Stable block	IIb	Stable	None
#6	Local unstable	IIIb	Partially stable	Important
#7	Unstable	IVa	Unstable	Required
#8	Local unstable	IIIa	Partially stable	Important
#9	Local unstable	IIIa	Partially stable	Important
#10	Local unstable	IIIb	Partially stable	Important
#11	Stable block	IIb	Stable	None
#12	Unstable	IVa	Unstable	Required
#13	Unstable	IVa	Unstable	Required
#14	Unstable	IVa	Unstable	Required
#15	Stable block	IIb	Stable	None
#16	Stable block	IIb	Stable	None
#17	Local unstable	IIIa	Partially stable	Important
#18	Local unstable	IIIb	Partially stable	Important
#19	Local unstable	IIIb	Partially stable	Important
#20	Local unstable	IIIa	Partially stable	Important
#21	Unstable	IVb	Unstable	Required
#22	Unstable	IVa	Unstable	Required
#23	Local unstable	IIIb	Partially stable	Important
#24	Unstable	IVa	Unstable	Required
#25	Stable block	IIa	Stable	None

5. Conclusion

The application of empirical methods of investigates of slope stabilities which are one of the oldest evaluation methods still used today due to its low assumptions and fast evaluation. This article has used the SMR classification system and fuzzy logic procedures as empirical-computer based assessment to provide fast technique to estimate the stability and design support systems for stabilizing of rock slopes in mining projects. In this regard, 25 cases of jointed rock slopes related to 6 open-pit mines are selected to analysis of the stability located in West-Azerbaijan, northwest of Iran. In fuzzy logic methodology, all sets consist of fuzzy sets with functions on which all evaluation and inference operations are performed. These steps are classified as fuzzification, fuzzy inference core and defuzzification process of implemented on MATLAB software. For this purpose, the slope conditions have been evaluated during field surveys and provide input information for initial SMR model. The fuzzy model has been used to improve the results as well as reduce errors in field evaluations so that it can produce results with higher accuracy. As the results of the article, the modified method has provided highly accurate results in less evaluating time.

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