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Technical Note

A discussion on the adjustment parameters of the Slope Mass Rating (SMR) system for rock slopes

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ABSTRACT

Rock mass classification systems are common tools used in the design and construction of rock engineering. Numerous classification systems have been developed for rock slopes, of which the Slope Mass Rating (SMR) system is the most popular. Consequently, many rock slope classification systems have been derived from the SMR system. However, these systems are not good at determining the values of the two adjustment parameters F_1 and F_3, implying that the original SMR system may contain theory defects. In this paper, we propose some corrected methods for determining F_1 and F_3 and perform a series of analyses considering the three failure modes of rock slopes: plane, wedge, and toppling failures. The results of the discrepancy analysis from F_1 illustrate that, with respect to each of the aforementioned three failure modes the calculated original SMR index is larger than, or equal to, the real value, and the designed slope is possibly in danger. The results of the discrepancy caused by the F_3 illustrate that for each of the aforementioned three failure modes, the calculated original SMR index is smaller than, or equal to, the real value, and the designed slope might be conservative and not economical.

1. Introduction

A rock mass is a natural geological material; it is also an assemblage of intact rock blocks and discontinuities (e.g., joints, weak bedding planes, weak zones, weak schistosity planes, and faults). Due to the long-term geological processes, the geometrical and mechanical properties of a rock mass are extremely complex. Moreover, its environment is also complex (e.g., the groundwater conditions and in-situ stress both have great variations).

To quantify the complex properties of a rock mass based on past experience (Stille and Palmström, 2003), various taxonomies, usually called rock mass classification systems, have been developed. Those classification systems are of great significance to improving the design and construction of rock mass engineering (Wu and Wang, 2014).

Many classification systems are presented in Table 1. Of them, the Slope Mass Rating (SMR) system (Romana, 1985) is widely used for rock slopes (e.g., Huang and Fan, 1998; Romana et al., 2003; Irigaray et al., 2003; Yilmaz et al., 2012; Siddique et al., 2015; among others). The SMR was derived from the Rock Mass Rating (RMR) system (Bieniawski, 1979). The RMR system was originally created for tunneling applications (Bieniawski, 1979), but the author (Bieniawski, 1989) proposed slope adjustment factors to take into account whether the discontinuities strike and dip are favorable or not to slope failure (Tomás et al., 2007). However, it is not easy in practice to apply the RMR system to slopes, because Bieniawski (1989) only provided five adjustment ratings (0, −5, −25, −50, and −60) with respect to five orientation relationships between the discontinuities and slope face (i.e., very favorable, favorable, fair, unfavorable, and very unfavorable), and furthermore, did not propose a detailed quantitative definition of the five orientation relationships. The SMR system eliminated the aforementioned shortcomings of the RMR system and has become the most important classification for rock slopes. Hence, the SMR system has been used as the basis of many other systems. Chen (1995) developed the Chinese Slope Mass Rating (CSMR) system by adding the discontinuity condition (e.g., faults or intercalated layers, bedding planes, and joints) and slope height to the SMR system. Tomás et al. (2007) modified the SMR system by replacing the discrete classifications of the SMR with continuous functions. Daftaribesheli et al. (2011) addressed the Fuzzy Slope Mass Rating (FSMR) system using a fuzzy set theory to quantify the ambiguous results influenced by the uncertainties of the characteristics of the rock masses. Tomás et al. (2012) built upon their 2007 work and developed a graphical approach for the SMR, based on the stereographic representation of the discontinuities and the slope to obtain the adjustment parameters; this system easily calculates the correction parameters of the SMR in cases where all slopes have the same dip with a different strike, as in linear infrastructure and open pit mining. Singh et al. (2013) described a New Slope Mass Rating (NSMR), incorporating a new parameter, the overburden thickness profile, into the SMR system; this parameter is best suited while

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Table 1
Summary of the existing rock mass classification systems, which was revised on the basis of the list given by Pantelidis (2009).

Name of the system	Abbreviation	Authors & Data	Application	Comments
–	–	Ritter (1879)	Tunnels	The first attempt for the formalization of an empirical approach to tunnel design
Rock Load	–	Terzaghi (1946)	Tunnels	The earliest reference to the use of rock mass classification for the design of tunnel support
Stand-up Time	–	Lauffer (1958)	Tunnels	Related to the stand-up time of an unsupported tunnel excavation
Rock Quality Designation	RQD	Deere (1963)	General	Component factor of many classification systems
New Austrian Tunneling Method	NATM	Rabcewicz (1964)	Tunnels	Scientifically empirical approach
Rock Structure Rating	RSR	Wickham et al. (1972)	Small tunnels	First rating system for rock masses
Rock Mass Rating	RMR	Bieniawski (1973, 1976, 1979, 1989)	Tunnels and cuttings	A raw rating adjustment for discontinuity orientation for application in slopes was added in the 1979 version of the RMR system
Rock Tunneling Quality Index	Q	Barton et al. (1974)	Tunnels	They are the most commonly used classification systems for tunnels
Size–strength classification	–	Franklin et al. (1974)	General	The method has not been used widely
Mining Rock Mass Rating	MRMR	Laubscher (1977, 1984), and Laubscher and Page (1990)	Mines	Based on RMR (1973)
Engineering–Geological Rock Durability Classification	–	Olivier (1979)	Tunnels	Providing a quantitative appraisal of rock durability
Rock Mass Strength	RMS	Selby (1980, 1982); Moon and Selby (1983)	Cuttings	Based on natural slope data base
Geotechnical Description	–	International Society for Rock Mechanics, ISRM (1981)	General	It is widely used for characterizing the properties of rock masses
Slope Mass Rating	SMR	Romana (1985); Romana et al. (2003)	Cuttings	Based on RMR (1979).The most commonly used classification system for slopes
Slope Rock Mass Rating	SRMR	Robertson (1988)	Cuttings	Based on RMR; the classification is provided for weak altered rock mass materials from drill-hole cores
Index of Rock Mass Basic Quality	BQ	National Standards Compilation Group of People's Republic of China, NSCGPRC's (1995)	General	It is determined by the hardness degree of rock and the intactness index of rock mass
Chinese Slope Mass Rating	CSMR	Chen (1995)	Cuttings	Adjustment factors have been applied to the SMR system for the discontinuity condition and slope height
Geological Strength Index	GSI	Hoek et al. (1995)	General	Based on RMR (1976)
Rock Mass index	RMi	Palmström (1995)	General	Characterizing the strength of the rock mass for construction purposes
Rock Mass Classification Rating	RMCR	Yaşar (1995)	General	Using 12 parameters from laboratory and in situ experiments
Modified Rock Mass Rating	M-RMR	Ünal (1996)	Mines	For weak, stratified, anisotropic and clay bearing rock masses
–	–	Mazzocola and Hudson (1996)	Natural slopes	A rock mass characterization method for the indication of natural slope instabilities
Slope Stability Probability Classification	SSPC	Hack (1996); Hack et al. (2003)	Cuttings	Probabilistic assessment of independently different failure mechanics
Rock Slope Deterioration Assessment	RDA	Nicholson and Hencher (1)997; Nicholson et al. (2000); Nicholson (2002, 2003, 2004)	Cuttings	For shallow, weathering-related breakdown of excavated rock slopes
Geological Strength Index	GSI	Hoek et al. (1998); Marinos and Hoek (2000, 2001); Marinos et al. (2005)	General	For non-structurally controlled failures
Adapted Slope Stability Probability Classification	–	Lindsay et al. (2001)	Cuttings	Based on SSPC
Volcanic Rock Face Safety Rating	VRFSR	Singh and Connolly (2003)	Cuttings (temporary excavations)	For volcanic rock slopes to determine the excavation safety on construction sites
Modified Rock Mass Classification	M-RMR	Şen and Sadagah (2003)	General	Based on RMR (1989)
Falling Rock Hazard Index	FRHI	Singh (2004)	Cuttings (temporary excavations)	Developed for stable excavations to determine the degree of danger to workers.
Modification of Slope Mass Rating	–	Tomás et al. (2007)	Cuttings	Modifying the SMR system by continuous functions
Fuzzy Slope Mass Rating	FSMR	Daftaribesheli et al. (2011)	Cuttings	Based on SMR
New Slope Mass Rating	NSMR	Singh et al. (2013)	Cuttings	Incorporating a new parameter of overburden thickness profile into the SMR system
Rock Mass Quality Rating	RMQR	Aydan et al. (2014)	General	It is used to estimate the geomechanical properties of rock masses

preparing the stability map of mountain areas, where tectonic activity is high.

Though the SMR system has been widely used in practice and has led to the development of numerous classification systems for rock slopes, there are some theoretical defects for determining the parameters F_1 and F_3 in the computational formula of the SMR index given by Romana (1985). Therefore, the primary aim of this study is to correct the determination methods for F_1 and F_3. Note that similar defects exist in the above-mentioned derived classification systems from the SMR system.

2. Review of the SMR system

The SMR index, introduced by Romana (1985), is determined by adding four adjustment factors to the basic RMR proposed by Bieniawski (1979). These factors depend on the discontinuity–slope