Article Type: Case Study

OPEN ACCESS

Slope mass rating (SMR) application for rock slope stability analysis in Azarshahr, NW of Iran

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Received: 18 July 2024 / Accepted: 20 July 2024 / Published: 25 August 2024

***Abstract*:** The Slope Mass Rating (SMR) system is a widely used method by geoengineers and geologists to assess the stability of rock slopes, such as those found along highways, in mines, or near dams. It helps evaluate the likelihood of slope failure and identify any necessary measures to prevent rock instabilities. In this study, the SMR classification system was applied to analyze the stability of 10 slopes in the Azarshahr province, located in northwest Iran. Each slope underwent a standard geotechnical investigation, including the collection of block samples, which were tested using index rock mechanics methods such as uniaxial compressive strength (UCS), point-load tests, and Schmidt hammer rebound tests. The SMR classification results revealed that the slopes in Azarshahr range from partially stable to completely stable. Potential failures were linked to the development of joints, wedges, or blocks, with varying levels of risk. Where necessary, occasional support systems were recommended to improve stability. These findings offer important insights into the region's slope stability and provide guidance for potential mitigation strategies.

Keywords: Swelling soils, Geotechnical analysis, Soil behavior, Engineering solutions, Soil control methods.

I. INTRODUCTION

Engineering rock mass classification systems are frameworks used by geotechnical engineers and geologists to assess the quality and characteristics of rock masses in various construction projects (Azarafza et al., 2017). These systems help professionals understand the rock's ability to support structures such as tunnels, dams, foundations, or slopes (Tomas et al., 2012). By evaluating different aspects of the rock, like its strength, degree of fracturing, and weathering, engineers can determine whether the rock mass is suitable for construction or if additional support or stabilization measures are required (Tomás et al., 2007).

The purpose of rock mass classification systems is to provide a standardized method for assessing rock conditions. This allows engineers to make informed decisions about the design and safety of engineering projects (Azarafza et al., 2020). Without a clear understanding of the rock's properties, construction could be dangerous or inefficient (Hack et al., 2003). These systems give a common language to describe rock conditions, which is especially important in large, multidisciplinary teams where geologists, engineers, and contractors need to communicate effectively (RK et al., 2011). One of the most widely used classification systems is the Rock Mass Rating (RMR), developed in the 1970s (Bieniawski, 1989). The RMR system evaluates the rock based on six key parameters: uniaxial compressive strength, Rock Quality Designation (RQD), spacing of discontinuities, condition of discontinuities, groundwater conditions, and orientation of discontinuities (Deere & Deere, 1988; Palmström, 2009; Rehman et al., 2018). The values of these parameters are combined to give an overall rating that reflects the quality and stability of the rock mass. This rating helps engineers decide what kind of support is needed during construction, such as whether to use rock bolts or shotcrete to reinforce tunnels (Pantelidis, 2010; Pradhan et al., 2011; Gupte et al., 2013; Aydan et al., 2014).

Another important classification system is the Q-system, which is often used for tunnel design (Palmstrom & Broch, 2006). The Q-system evaluates the rock mass using six different parameters, including the RQD, the number of joint sets (fractures in the rock), the roughness of the joints, and the water conditions (Barton et al., 1974). The final result is a Q-value, which indicates the level of support required. High Q-values mean the rock is strong and stable, while low values indicate that extensive reinforcement will be needed (Singh & Goel, 2011). These classification systems are crucial in geotechnical investigations because they help engineers anticipate potential problems before construction begins (Fereidooni et al., 2015). For example, if the rock mass is highly fractured or contains significant groundwater, it might be more prone to collapse or instability (Singh & Goel, 2011). Understanding this in advance allows engineers to adjust their design, preventing costly delays or even dangerous accidents during construction (Azarafza et al., 2022). By classifying the rock mass early on, projects can proceed with greater confidence in their safety and efficiency.

In addition to guiding design decisions, rock mass classification systems are also valuable in monitoring the performance of rock structures over time (Singh & Goel, 2011). After a tunnel is built, for instance, engineers can continue to use the classification systems to monitor changes in the rock's condition. If cracks appear or the water table rises, they can compare the new conditions to the original classification to determine if additional stabilization measures are needed (Azarafza et al., 2022). Indeed, engineering rock mass classification systems play a fundamental role in ensuring the safety, efficiency, and success of construction projects in challenging environments. By providing a systematic approach to evaluating rock masses, these systems allow engineers to design structures that are both safe and cost-effective, avoiding unforeseen problems and ensuring long-term stability (Vishal et al., 2015).

Over time, numerous rock mass classification systems have been developed for various geo-engineering purposes. Among these, certain classification systems have been specifically designed to address rock slope stability (Basahel & Mitri, 2017; Yang et al., 2022). The following are some of the most well-known classification systems specifically developed for rock slope engineering:

- Slope Mass Rating (Romana et al., 2003),
- Chinese Slope Mass Rating (Chen, 1995),
- Slope Stability Probability Classification (Hack, 1998),
- Alternative Rock Mass Classification System (Pantelidis, 2010),
- Q_{slope} (Bar & Barton, 2017).

The presented study primarily focuses on the Slope Mass Rating (SMR) classification system. It aims to utilize this flexible and powerful classification method to evaluate and conduct stability analyses on 10 slope cases in the Azarshahr province, located in the northwest of Iran.

II. Slope Mass Rating

Slope Mass Rating (SMR) is an extension of the widely used RMR system (Bieniawski, 1989), specifically designed for evaluating the stability of slopes. Originally developed by Romana in 1985 (Romana et al., 2001), SMR modifies the basic RMR system to account for factors that influence slope stability, such as the orientation of discontinuities relative to the slope face (Romana et al., 2015). While RMR is a general classification system for rock masses, SMR incorporates additional slope-specific parameters to provide a more detailed analysis of slope stability conditions (Daftaribesheli et al., 2011). The SMR system is based on the core elements of the RMR classification. The RMR system considers parameters such as the strength of the rock, quality of rock discontinuities, groundwater conditions, and the orientation of discontinuities (Azarafza et al., 2022). These parameters are essential for understanding the overall stability of a rock mass, and SMR builds on these to assess the behavior of slopes in particular (Singh & Goel, 2011).

The key feature of SMR is the incorporation of adjustment factors that modify the RMR_{89} (Bieniawski, 1989) value based on slope-specific conditions. The system adjusts the basic RMR value by considering three primary factors: the angle between the slope face and the discontinuity, the relationship between slope and discontinuity dips, and the method of excavation. These adjustments allow SMR to provide a more nuanced evaluation of slope stability compared to RMR (Romana et al., 2003). One of the major adjustments in SMR involves the orientation of discontinuities in the rock mass relative to the slope (Azarafza et al., 2017). This includes both the angle between the slope face and the discontinuity (α) and the dip of the discontinuity relative to the dip of the slope. These factors significantly influence the likelihood of failure along specific planes within the rock mass (Riquelme et al., 2016). For example, a steeper discontinuity angle might indicate a higher risk of planar sliding, making this adjustment crucial for accurate slope stability assessments (Tomás et al., 2007). The SMR system also incorporates a correction factor based on the excavation method used to create the slope (Tomas et al., 2012). Different methods, such as natural erosion or mechanical excavation, can influence the rock's behavior (Romana et al., 2005). Mechanically excavated slopes may be less stable due to the disturbance caused by the excavation process, while naturally formed slopes tend to have better-adjusted stress fields. This factor helps to account for these differences in stability analyses (Azarafza et al., 2017). Figure 1 and Table 1 provide SMR recommendation for stability analysis and support system design for slopes.

As mentioned, the SMR value is calculated using RMR_{89} or RMR_{basic} or RMR_b as follow:

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

where RMR_b is the basic RMR value that is calculated based on Bieniawski (1989) inductions. F_1 is accounts for the relationship between the dip direction of the slope and the discontinuity with a value of 0.15 to 1.0, F_2 represents the relationship between the dip of the slope and the discontinuity with a value of 0.15 to 1.0, F_3 is an adjustment based on the discontinuity conditions (e.g., roughness, infill material) ranging from 0 to -60, and F_4 is a correction factor for the excavation method ranges from -8 to +15 where -8 is selected for a poorly blasted slope and +15 for a natural slope (Romana et al., 2003). This formula provides a comprehensive approach for determining the stability of rock slopes by considering both rock mass properties and slope-specific conditions (Tomas et al., 2012).

$$RMR_b = UCS + RQD + DS + DC + GW \quad (2)$$

$$F_1 = \left(1 - \sin\left|\alpha_j - \alpha_s\right|\right)^2 \quad (3)$$

$$F_2 = \tan^2 \beta_j \quad (4)$$

$$F_3 = \beta_j - \beta_s \quad (5)$$

In this context, UCS is the uniaxial compressive strength, DS is the discontinuity spacing, DC is the discontinuity condition, GW is the groundwater condition, α_j denotes the dip direction of a discontinuity, while α_s refers to the dip direction of a rock slope. Additionally, β_j represents the inclination of the discontinuity, and β_s indicates the dip of the slope. As presented in Table 1, SMR classifies slopes into five different stability categories, ranging from 'completely stable' to 'completely unstable'.

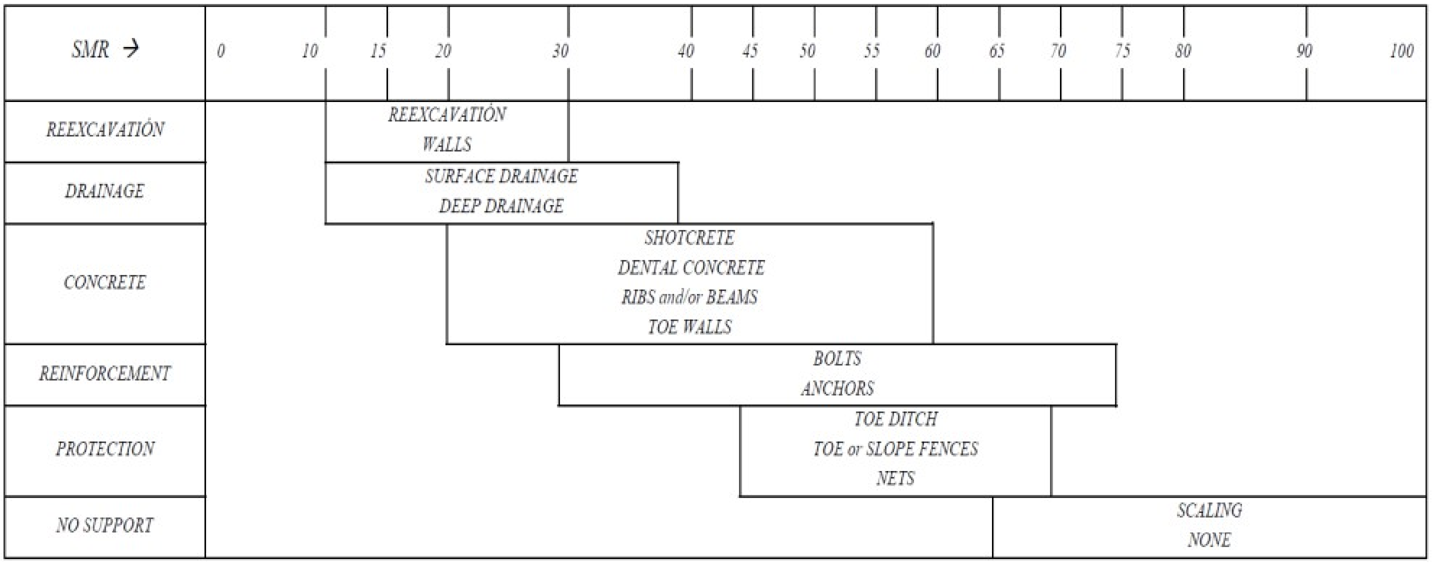

Fig. 1 A recommendation for support systems for slopes based on various SMR value (Romana et al., 2003)

Table 1 SMR Description and recommendations based on failure mechanisms (Romana et al., 2015)

SMR	Classes/Value				
	V	IV	III	II	I
Description	0 – 20	21 – 40	41 – 60	61 – 80	81 – 100
Stability	Very bad	Bad	Normal	Good	Very good
Failures	Completely unstable	Unstable	Partially stable	Stable	Completely stable
Failure probability	Big planar or soil-like	Planar or big wedges	Some joints or many wedges	Some blocks	None

These categories are based on the calculated SMR values (Zheng et al., 2016; Kumar & Pandey, 2021):

- SMR > 80: Very good stability,
- SMR between 60 and 80: Good stability,
- SMR between 40 and 60: Fair stability,
- SMR between 20 and 40: Poor stability,
- SMR < 20: Completely unstable.

These categories help engineers and geologists quickly assess the stability of a slope and determine the need for further analysis or remediation (Kundu et al., 2020; Siddique et al., 2020).

SMR is widely applied in civil and geotechnical engineering projects, particularly those involving road cuts, open-pit mining, and natural slopes (Salmanfarsi et al., 2020; Rahim et al., 2022). By combining rock mass characteristics with slope-specific parameters, SMR allows for a more precise evaluation of slope stability. It is commonly used to design slope reinforcement systems, assess the need for slope stabilization measures, and predict potential failure mechanisms such as planar, wedge, or toppling failures (Taheri & Tani, 2010; Lai et al., 2016). SMR has been used successfully in various parts of the world for slope stability assessments (Basahel & Mitri, 2017). For example, it has been applied in road construction projects in mountainous areas, open-pit mines, and landslide-prone regions. Studies in Iran, Spain, India, and other countries have demonstrated the effectiveness of SMR in classifying slopes and predicting potential failures (Azarafza et al., 2021). Its flexibility and ease of use have made it a popular tool among geotechnical engineers and researchers. While SMR is a powerful tool for slope stability analysis, it has some limitations. The system relies on field data, which may be difficult to obtain in certain areas or for large projects. Additionally, it assumes that rock mass behavior is primarily influenced by discontinuity orientation and slope geometry, which may not always be the case (Siddique et al., 2020). Ongoing research aims to refine the SMR system and integrate it with modern techniques like numerical modeling and remote sensing to improve its accuracy and applicability in complex geological settings (Salmanfarsi et al., 2020).

III. CASE STUDY

Azarshahr is in the northwest region of Iran within East Azerbaijan Province. This area is characterized by its picturesque landscapes and diverse geological features, which include mountains, valleys, and plains (Ebrahimzadeh et al., 2019). Situated approximately 35 km southeast of Tabriz. The region is easily accessible through well-established road networks, making it an important link between various cities in Iran (Zalooli et al., 2019). The geology of Azarshahr is diverse, comprising various rock types that reflect the complex tectonic history of the region. Predominantly, the area features volcanic and sedimentary rocks formed from ancient geological processes (Rezaee & Alinejad, 2014). The presence of limestone, basalt, and andesite formations is notable, which contributes to the unique geological structure. Additionally, the region's geology is influenced by tectonic activities, including the collision of the Arabian and Eurasian plates, leading to the formation of fault lines and mountainous terrains (Faridi et al., 2017).

The geomorphology of Azarshahr is marked by a range of landforms, including rugged mountains and gently sloping hills. The area's topography has been shaped by both erosion and sedimentation processes, creating a dynamic landscape. The region is home to various valleys and river systems that have carved the terrain over millions of years (Ghazi et al., 2013). The interplay of geological formations and erosional forces has resulted in distinct landforms, such as cliffs, terraces, and alluvial plains, which contribute to the area's natural beauty (Gorgij et al., 2019). Azarshahr experiences a semi-arid climate, characterized by hot, dry summers and cold, snowy winters. The region's climate is influenced by its elevation and geographical location, leading to significant temperature variations throughout the year (Ebrahimzadeh et al., 2019). Precipitation is generally low, with most rainfall occurring in the spring and fall (Rezaee & Alinejad, 2014).

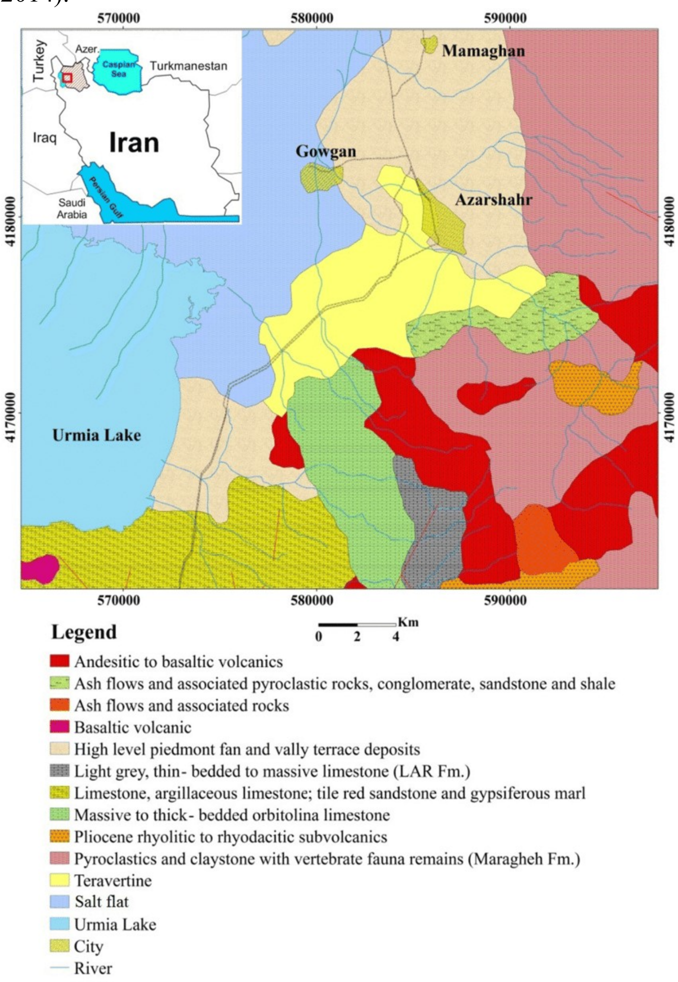

Fig. 2 A location and geological map of Azarshahr (Barzegar et al., 2020)

Table 2 Geological description for studied slopes

Slope ID	Geo-formation	Lithology
SMR1	Travertine	Its composition mainly consists of minerals like calcite and aragonite, along with various types of calcium carbonate, and may occasionally include small quantities of organic matter.
SMR2	Travertine	
SMR3	Travertine	
SMR4	Travertine	
SMR5	Travertine	
SMR6	Travertine	
SMR7	Travertine	
SMR8	Travertine	
SMR9	Travertine	
SMR10	Travertine	

Table 3 Geotechnical parameters for studied slopes

Parameter	Unit	Value (average)
Density	kN/m^3	25.16
UCS	MPa	41.43
RQD	-	57
Point-load index	-	2.12
Friction angle	Degree	32
Cohesion	kN/m^2	120
Schmidt index	-	28

Table 4 Geomechanical investigation results for studied slopes

Discontinuity type	Dip	Dip direction
	Degree	Degree
Joint set 1	53	182
Joint set 2	40	098
Joint set 3	55	115
Joint set 4	73	317
Bedding plane	69	288

The location and geological maps of the study area are shown in Figure 2. The study discussed here focused on applying the SMR classification to analyze the stability of ten slopes in Azarshahr province, located in northwest Iran. Each slope underwent a standard geotechnical investigation, during which slope block samples were collected. These samples were then tested using various index rock mechanics tests, including uniaxial compressive strength, UCS (ASTM D7012), point-load (ASTM D5731), and Schmidt hammer rebound (ASTM C805) tests.

IV. Results and Discussion

A field survey was conducted during the summer in the Azarshahr region, and the results of the geomechanical investigations are presented in Tables 2 to 4. These tables contain the data used for SMR stability calculations for the selected slope cases. Additionally, Tables 5 and 6 summarize the results of the SMR stability analysis, providing estimates of the stability for the slopes under study. According to the SMR classification, the slopes fall into categories ranging from partially stable to completely stable, as outlined in Table 1. Based on the SMR analysis, potential slope failures could occur due to the formation of joints, wedges, or individual blocks. In such cases, the likelihood of slope failure varies, and occasional support systems may be recommended to stabilize the slopes and prevent instability.

Table 5 The SMR classification results for studied slopes

Slope ID	RMR_b	F_1	F_2	F_3	F_4	SMR	Class
SMR1	53	0.15	1.00	0.00	10	64.15	II
SMR2	62	0.20	1.00	0.00	10	73.20	II
SMR3	65	0.15	1.00	0.00	10	76.15	II
SMR4	48	0.70	1.00	0.00	10	59.70	III
SMR5	63	0.15	1.00	0.00	10	74.15	II
SMR6	52	0.70	1.00	0.00	10	63.70	II
SMR7	65	0.15	1.00	0.00	10	76.15	II
SMR8	63	0.20	1.00	0.00	10	74.20	II
SMR9	63	0.20	1.00	0.00	10	74.20	II
SMR10	65	0.20	1.00	0.00	10	76.40	II

V. Conclusion

This study applied the Slope Mass Rating (SMR) system to evaluate the stability of ten rock slopes in the Azarshahr province of northwest Iran. Through a comprehensive geotechnical investigation, including rock mechanics tests like UCS, point-load tests, and Schmidt hammer rebound tests, we assessed the stability conditions of the slopes. The results indicated that the slopes range from partially stable to completely stable, with potential failure mechanisms involving the formation of joints, wedges, or blocks. In cases where instability risks were identified, occasional support systems were recommended to enhance slope stability. The findings provide critical insights for slope management in the region and serve as a foundation for future stability assessments and mitigation efforts. So, the application of the SMR system proved to be an effective tool for understanding the behavior of rock slopes in the area, supporting safe infrastructure development and risk management strategies.

Acknowledgment

We extend our thanks to the reviewers for their meticulous attention to detail and constructive suggestions that greatly improved the quality of this manuscript. Your contributions have been instrumental in shaping this work.

Authors' contributions

Naser Abbasi and Elmira Fakor conducted the main data analysis, contributed to the data collection, preprocessing, and interpretation, and were responsible for drafting the initial manuscript. Mahdi Nikbakht assisted in the development of the methodology and performed validation checks, provided supervision, conceptual guidance, and critical revision of the manuscript. All authors read and approved the final manuscript.

Conflict of interest

The authors have not disclosed any competing interests.

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