Technical Note

Modification of rock mass rating system: Interbedding of strong and weak rock layers

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A B S T R A C T

Rock mass classification systems are the very important part for underground projects and rock mass rating (RMR) is one of the most commonly applied classification systems in numerous civil and mining projects. The type of rock mass consisting of an interbedding of strong and weak layers poses difficulties and uncertainties for determining the RMR. For this, the present paper uses the concept of rock bolt supporting factor (RSF) for modification of RMR system to be used in such rock mass types. The proposed method also demonstrates the importance of rock bolting practice in such rock masses. The geological parameters of the Shemshak Formation of the Alborz Tunnel in Iran are used as case examples for development of the theoretical approach.

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1. Introduction

The very first attempt for rock mass classification utilized in tunnel design was made by Ritter (1879). However, the earliest reference for application of rock mass classification system for tunnel support design purpose was Terzaghi (1946). He proposed a descriptive method to categorize rock mass into seven groups for estimation of rock load on steel sets. Lauffer (1958) suggested that the quality of surrounding rock mass controls the stand-up time of an unsupported tunnel span. In order to obtain a quantitative description of rock mass quality, Deere et al. (1967) introduced rock quality designation (RQD) system. As the first rating system for rock masses, rock structure rating (RSR) was introduced by Wickham et al. (1972). The system uses three parameters, i.e. geological features of rock mass, geometry and groundwater, with regard to joint condition. A two-parameter classification system, i.e. size-strength classification, which is based on rock material strength and discontinuity spacing with regard to opening size, and overburden stress, was developed by Franklin (1970, 1975), New Austrian Tunneling Method (NATM) which was a modification of Lauffer’s classification system uses in situ instrumentation and monitoring techniques interpreting the outcome in a scientific manner (Pacher et al., 1974; Muller, 1978).

Rock mass rating (RMR) system also known as geomechanics classification as one of the most commonly used classification systems consists of six components, i.e. uniaxial compressive strength (UCS) of rock material, spacing of discontinuities, RQD, condition of discontinuities, groundwater condition and joint orientation favorability. Joint orientation favorability is dependent on the engineering application of the structure such as mine, tunnel, slope or foundation. The other five parameters are intrinsic characteristics of rock mass (Bieniawski, 1973, 1989). Rock tunneling quality index or the Q-system was introduced by Barton et al. (1974) which also consists of six parameters, i.e. RQD, number of joint sets \( J_h \), the most unfavorable joint roughness \( J_r \), filling and alteration of the weakest joint set \( J_a \), water inflow \( J_w \) and stress condition (SRF). Eq. (1) represents the Q index where block size in rock mass, roughness and frictional characteristics of joint walls and stress condition are represented by first, second and third quotients, respectively:

\[ Q = \frac{RQD \cdot J_h \cdot J_a \cdot J_w / SRF}{1} \]

The fine-grained sediments which contained high percentage of phyllosilicate minerals were classified by Weaver (1980) based on phyllosilicate and grain size where the term “physil” being an abbreviation of phyllosilicate was introduced for the first time and had no connotation of size. Eq. (2) was proposed by Palmstrom (1982) for

calculation of RQD values for clay-free rock mass where there are no core logs available and discontinuity traces can be seen:

\[ RQD = 115 - 3.3J_v \]  

(2)

where \( J_v \) is the volumetric joint count which is the sum of number of joints per unit length for all discontinuity sets. In order to estimate the UCS of rock mass, Palmström (1995) introduced the rock mass index (RMI). This system consists of two parameters, i.e. UCS of rock material and jointing condition where four parameters, i.e. block volume, joint roughness, joint alteration and joint size, compose the jointing condition. For both weak and hard rock masses, the geological strength index (GSI) was first proposed by Hoek and Brown (1997) after which a chart making classification of rock mass by visual inspection very easy for experts was introduced by Marinos and Hoek (2000). The six qualitative rock classes of the GSI system were mainly adopted from Terzaghi's classification. Most recently, Marinos (2014) classified the flysch of Northern Greece into 11 rock types using a special GSI chart.

Slope mass rating (SMR) system as the most commonly used classification system for slopes based on RMR system was introduced by Romana (1985) and Romana et al. (2003). Some other modifications to SMR or rock classification systems for slope stability were reported by Robertson (1988), Chen (1995), Al-Homoud and Masanat (1998) and Pantelidis (2009). Also, the Kargar slope failure in Iran was examined via analytical and numerical back analyses by Sharifzadeh et al. (2010).

Fuzzy set theory was applied for classification of rock mass by Aydin (2004) as well as Hamidi et al. (2010) using the fuzzy concept for rock mass excavability (RME) classification. Engineering geological assessment or evaluations of different zones around the world has been carried out and reported by various researchers during recent decades (Fookes and Knill, 1969; Doyuran et al., 1993; Yassaghi et al., 2005; Kocbay and Kılıç, 2006; Berhane, 2010). Also, many studies were conducted and aimed at understanding the strength and deformation properties of rock mass, such as strength and deformation measurements for basaltic rocks, discussion on different factors affecting strength of weak sandstones, use of neural networks and empirical equation for intact rock and rock mass, respectively, estimating rock mass strength based on RQD with an empirical relation, and introduction of a modified empirical criterion for determination of strength of transversely anisotropic rocks (Schultz, 1995; Chen and Hu, 2003; Sonmez et al., 2006; Zhang, 2010; Saedi et al., 2013). An extension known as tunneling analyst (TA) was developed in ArcScene 3D GIS by Choi et al. (2009), which could increase the functionality of ArcScene. The TA was applied in Daechong tunneling project in Korea, presenting rational evaluation of different rock mass classes along tunnel alignment. Identifying rock mass composition (RMC), rock type (RT), clay-bearing content (CBC), UCS and tunnel depth (TD) as the major factors affecting tunnel inflow, Zarei et al. (2013) proposed a new tunnel inflow classification (TIC) system for sedimentary rock masses. Data compiled from 33 tunneling projects were used for development of the system which can provide a quantitative measurement and prediction of tunnel inflow.

RMR system has been extended by many researchers in different branches. Some of these extensions or applications, as mentioned by Bieniawski (1989), are mining applications (Laubacher, 1977, 1984), rippability (Weaver, 1975), hard rock mining (Kendorski et al., 1983), coal mining (Unal, 1983; Newman and Bieniawski, 1985), dam foundations (Serafin and Pereira, 1983), tunneling (Gonzalez de Vallejo, 1983), slope stability (Romana, 1985), and Indian coal mines (Venkateswarlu, 1986).

The development of RMR system was reviewed by Aksoy (2008). Most recently, a theoretical study on the difference of rock mass types having the same RMR value with different conditions of parameters used led to introduction to rock bolt supporting factor (RSF) or rock bolting capability of rock mass. The concept can be used for calculation of rock bolting efficiency as well as mathematical explanation of rock bolting mechanism (Mohammadi et al., 2017). This concept is going to be used for modification of the RMR system for Shemshak Formation in the Alborz Tunnel of Iran.

The engineering geological conditions of the Alborz Mountains of Northern Iran are outlined and specific attention is given to the problems related to reservoir construction in varied geological condition, reservoir siltation, tunnels and earthquake activity (Fookes and Knill, 1969). The Shemshak Formation of Alborz Mountain chains has been studied by Fürsich et al. (2005) and the sedimentation and biofacies as well as its evolution were described. Different studies with varied purposes were performed in the Shemshak Formation in recent years (Hassani et al., 2008; Monjezi et al., 2011; Delikordi et al., 2013; Torabi et al., 2013). The capability of the RMR system in prediction of engineering behavior of Shemshak Formation was investigated and discrepancies in the results of the RMR system (and other classification systems) were reported by Gonbadi et al. (2009) where the surrounding rock mass of the Siah Bishe underground excavation project consists of an alternation of strong sandstone and siltstone as well as weak layers of shale, mudstone and coal (Shemshak Formation). Their work resulted in some adjustments based on the dip and thickness of weak layers in the RMR in order to obtain better prediction of rock mass behavior. Later, the incompetency of RMR system in coping with the behavior of rock mass in Shemshak Formation was mentioned by Hossaini et al. (2016). During the excavation of Alborz Tunnel in northern excavation face located in Shemshak Formation, the authors encountered weak layers of argillite with a thickness of less than 1 cm alternated with thick layers of sandstone, leading to difficulties and uncertainties about the rock mass classification procedure. Thus, at first step, the present paper shows the difficulties and uncertainties related to Shemshak Formation as well as all other rock masses which consist of alternation of weak and strong layers. Then the paper introduces a new methodology based on RSF to cope with the uncertainties related to Shemshak Formation, which also demonstrates the importance of rock bolting in such rock mass types.

2. Rock bolt supporting factor

Concept of RSF or rock bolting capability of rock mass was introduced by Mohammadi et al. (2017) and applied for definition of rock bolting mechanism. The theory is based on the difference among varied combinations of parameters used but yielding the same values of RMR. As shown in Tables 1 and 2, the combination of different conditions of parameters led to the same RMR values of 85 and 45, respectively. Thus, what is the difference between rock types mentioned in Table 1 which have the same RMR values of 85? This goes for Table 2 as well, where the same RMR value of 45 is repeated. As discussed by Mohammadi et al. (2017), the difference of such rock masses can be explained benefitting from the concept of RSF. For instance, rock mass states shown in Table 1 have the same RMR value of 85, while the intrinsic characteristic of these rock types, i.e. RSF index (in $x$) which can be calculated from Eq. (3), is different for each case. As stated previously, RSF is the rock bolting efficiency which depends only on joint condition parameter of rock mass, provided that the rock bolt design and implementation are satisfactorily done.
$RSF = \frac{100 - \frac{10r_{co}}{3}}{100}$

(3)

where $r_{co}$ is the overall rating of condition of discontinuities in the RMR system. The value of RSF denotes the efficiency of rock bolting practice and capability of rock mass to be reinforced by rock bolting in different rock types. The more the RSF value is, the more the efficiency of rock bolting process and capability of rock mass to be reinforced are. Eq. (4) is also introduced by Mohammadi et al. (2017) which is a mathematical definition of rock bolting mechanism:

$$RMR_{eq} = RMR + 0.3RSF$$

(4)

3. The Alborz tunnel project

The excavation of Alborz Twin Tunnels with a length of approximately 6.4 km, as the longest tunnels of Tehran-Shomal Freeway Project in Iran, has been going on where the twin tunnels are supported by an exploratory service tunnel in between (Fig. 1). The service tunnel has been excavated with a tunnel boring machine (TBM) with diameter of 5.2 m and excavation of Eastern Tunnel has begun from both ends known as southern and northern excavation faces with drill-and-blast method. The northern excavation face is located in the aforementioned Shemshak Formation where the alternation of strong and weak rock layers makes it difficult and challenging for engineering classification of surrounding rock mass. At approximately 800 m into the Eastern Tunnel from the northern portal, an alternation of strong layers of sandstone with thin weak layers of argillite made the rock mass classification procedure a bit difficult. Table 3 shows the properties of rock layers encountered in the Alborz Eastern Tunnel. It should be noticed that in some parts of the tunnel, thick layers of argillite appeared which was used for determination of UCS of rock by point load test. The input parameters for rock mass classification were obtained by the authors in the field and were used here as case

![Fig. 1. A schematic view of the Alborz twin tunnels (Technical Report, 2009).](image-url)
examples. After that, a theoretical approach based on the RSF concept is proposed to demonstrate the importance of rock bolt implementation in such rock masses. Joint condition for two states of Alborz Tunnel surrounding rock mass is shown in Table 4. The parameters R, VR, Sm, SR, e, Ca and UN represent rough, very rough, smooth, slightly rough, empty, calcite and unweathered, respectively.

As indicated in Table 3, the UCS of rock mass varies from 5 MPa to 118 MPa for argillite and sandstone. If the goal is to calculate the RMR value for this rock mass for support design purposes, it is logical to consider the UCS of argillite which is the critical one. Thus, the UCS for this rock mass would range from 5 MPa to 18 MPa which can be rated 2 (Bieniawski, 1989). The RQD and spacing of discontinuities are correlated and must be considered to be in accordance while rating. The RQD differs from 55% to 75% based on volumetric joint count approach while the range of spacing variation is very wide (from 0.5 cm to 300 cm). The overall rating for RQD and spacing is 21 for both states A and B in Table 4. The groundwater condition for state A is completely dry (dripping) which is 15 and 4, respectively. The joint condition rating for states A and B are 19 (for bedding) and 10 (for joint III), respectively. Thus, the value of critical basic RMR for states A and B would be 57 and 37, respectively. These basic RMR values in the Alborz Tunnel were logical based on the experience of the authors in the Alborz Tunnel, it is possible to assume the weaker rock to be an in.

The main problem here is the movement of sandstone blocks having weak layers of argillite in between which lead to low shear strength of discontinuity surfaces. This is the reason for some problems encountered in such rock mass types. As previously mentioned, some of these problems were discussed by Gonbadi et al. (2009) and Hossaini et al. (2016). The next section is going to present a new approach based on the RSF concept which can cope with difficulties related to these kinds of rock masses. Also, the new approach demonstrates the importance of rock bolting in such rock mass types.

4. Proposed classification technique

As discussed previously, the RSF is an indicator of rock bolting capability of a given rock mass, showing the rock bolting efficiency in different rock mass conditions. Its value ranges from 0% to 100%, where the value of 100% denotes the highest capability of rock mass to be reinforced by rock bolting. Here, in order to employ the concept of RSF for rock mass classification, a brief introduction to joint condition rating in the RMR system is presented.

The joint condition parameter in the RMR system has five components, i.e. discontinuity length (persistence), separation (aperture), roughness, infilling material and weathering condition. The ratings for these components are shown in Table 5. However, some conditions are mutually exclusive. For instance, in the presence of infilling material, the roughness of discontinuity surface may be irrelevant as its effect will be overshadowed in the presence of infilling material. In such cases, Table 6 should be used directly (Bieniawski, 1989).

As the thickness of weaker rock layer (argillite in Alborz Tunnel) is very low with regard to the strong rock layer (sandstone in Alborz Tunnel), it is possible to assume the weaker rock to be an infilling material. This simple assumption is the base of new proposed method for classification of such rock mass types. Assuming the weaker layer as infilling material, the rating for joint condition must be carried out directly from Table 6 which assumes the rating of 0 when the separation (thickness of weaker layer) is more than 5 mm. The other parameters of basic RMR will not change except for UCS of rock material which in this case is UCS of sandstone.

### Table 3

Properties of rock types encountered in northern excavation face of the Alborz Tunnel.

<table>
<thead>
<tr>
<th>Rock type</th>
<th>Thickness of bedding (cm)</th>
<th>UCS (MPa)</th>
<th>Number of point load tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td>18–190</td>
<td>69</td>
<td>118</td>
</tr>
<tr>
<td>Argilite</td>
<td>0.5–1</td>
<td>5</td>
<td>18</td>
</tr>
</tbody>
</table>

### Table 4

Joint condition and orientation for two states of Alborz Tunnel surrounding rock mass.

<table>
<thead>
<tr>
<th>State</th>
<th>Discontinuity set</th>
<th>Persistence Value (m)</th>
<th>Rating</th>
<th>Aperture Value (mm)</th>
<th>Rating</th>
<th>Roughness Condition</th>
<th>Rating</th>
<th>Infilling Condition</th>
<th>Rating</th>
<th>Weathering Condition</th>
<th>Rating</th>
<th>Overall rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Bedding</td>
<td>Joint I</td>
<td>10–20</td>
<td>1</td>
<td>1.2</td>
<td>1</td>
<td>R</td>
<td>5</td>
<td>e</td>
<td>6</td>
<td>UN</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>Joint II</td>
<td>1–2</td>
<td>4</td>
<td>0.5</td>
<td>4</td>
<td>Sm</td>
<td>1</td>
<td>e</td>
<td>6</td>
<td>UN</td>
<td>6</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Joint III</td>
<td>2–3</td>
<td>4</td>
<td>1.5</td>
<td>1</td>
<td>SR</td>
<td>3</td>
<td>e</td>
<td>6</td>
<td>UN</td>
<td>6</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>B Bedding</td>
<td>Joint I</td>
<td>10–20</td>
<td>1</td>
<td>1.5</td>
<td>1</td>
<td>SR</td>
<td>3</td>
<td>e</td>
<td>6</td>
<td>UN</td>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>Joint II</td>
<td>3</td>
<td>4</td>
<td>0.5</td>
<td>4</td>
<td>VR</td>
<td>6</td>
<td>e</td>
<td>6</td>
<td>UN</td>
<td>6</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Joint III</td>
<td>8–10</td>
<td>–</td>
<td>4</td>
<td>–</td>
<td>R</td>
<td>–</td>
<td>Ca</td>
<td>–</td>
<td>UN</td>
<td>–</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

### Table 5

Guidelines for classification of discontinuity condition (after Bieniawski, 1989).

<table>
<thead>
<tr>
<th>Discontinuity length (persistence/continuity)</th>
<th>Separation (aperture)</th>
<th>Roughness</th>
<th>Infilling (gouge)</th>
<th>Weathering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value (m)</td>
<td>Rating</td>
<td>Value (mm)</td>
<td>Rating</td>
<td>Condition</td>
</tr>
<tr>
<td>&lt;1</td>
<td>6</td>
<td>1</td>
<td>6</td>
<td>Very rough</td>
</tr>
<tr>
<td>1–3</td>
<td>4</td>
<td>0.1–1</td>
<td>4</td>
<td>Rough</td>
</tr>
<tr>
<td>3–10</td>
<td>2</td>
<td>0.1–1</td>
<td>4</td>
<td>Slightly rough</td>
</tr>
<tr>
<td>10–20</td>
<td>1</td>
<td>1–5</td>
<td>1</td>
<td>Smooth</td>
</tr>
</tbody>
</table>

instead of argillite, since argillite is treated as infilling material. Thus, assuming the average rating of 9 for UCS of sandstone, the basic RMR value for states A and B in Table 4 would be 45 and 34, respectively. The classification outcomes in case of using conventional and proposed methods are compared in Table 7. As can be seen, the proposed method gives more conservative result than the critical RMR which can be a tool to cope with the discrepancy and difficulties mentioned by Gonbadi et al. (2009) and Hossaini et al. (2016). This method was successfully used in the Alborz Tunnel northern excavation face for classification purposes by the authors.

5. Discussion

The important feature in Table 7 is the difference between the obtained RMR values in both states. The lower the rating of joint condition in the critical RMR, the lower the difference between the obtained RMR values. In fact, in the proposed method, the joint condition and UCS ratings are different from those of conventional method. Therefore, assuming \( r \) and \( r_{co} \) to be ratings for UCS and joint condition, respectively, in conventional method as well as \( R \) to be rating for UCS in the proposed method, the difference between RMR values in conventional and proposed methods will be expressed as

\[
RMR_c - RMR_n = r_{co} - (R - r)
\]

(5)

where \( RMR_c \) and \( RMR_n \) are the obtained values of RMR by conventional and proposed methods, respectively. Eq. (5) can be rewritten as

\[
RMR_c - RMR_n = r_{co} + r - R
\]

(6)

The difference between RMR values obtained through conventional and proposed methods can be discussed in three states, i.e. \( RMR_c > RMR_n \), \( RMR_c = RMR_n \) and \( RMR_c < RMR_n \). These three states are going to be discussed separately:

(1) State 1: \( RMR_c > RMR_n \)

If we assume \( f(x) = r_{co} + r - R \), then under the condition \( RMR_c > RMR_n \), the value of \( f(x) \) will be positive. Thus, \( f(x) > 0 \), then \( r_{co} + r > R \).

(2) State 2: \( RMR_c = RMR_n \)

In this case, \( f(x) = 0 \), therefore, \( r_{co} + r = R \).

(3) State 3: \( RMR_c < RMR_n \)

Hence, \( f(x) < 0 \), then, \( r_{co} + r < R \).

Only in State 3, the proposed method yields RMR values more than that of conventional method. However, in practical cases as shown about the Alborz Tunnel in Table 7, State 3 seldom occurs. Also, for State 3 to occur in practical cases, it is necessary for joint condition rating to be very low which is similar to the condition of proposed method assuming the value of 0 for joint condition rating. Overall, in cases with condition of State 3, the proposed method should not be applied.

As mentioned previously, Eq. (3) shows the rock bolting capability of rock mass or the rock bolting efficiency in a given rock mass. The rock bolting efficiency based on conventional and proposed methods are computed and compared in Table 8. The RSR values in the proposed method are 100% (Eq. (3)) in all cases as it assumes the rating of 0 for condition of discontinuities. Therefore, the importance of rock bolting practice in such types of rock masses is demonstrated by the presented method.

6. Concluding remarks

The difficulties of using rock mass classification systems where rock mass consists of an alternation of strong and weak layers such as the Shemshak Formation of Alborz Tunnel in Iran are shown and then using RSF, a new methodology is proposed for such rock masses classification. The proposed methodology can cope with discrepancies in results of rock mass classification systems in such rock mass types as well as demonstrating the importance of rock bolting practice. The geological parameters of Alborz tunnel are used as case examples while developing the theory.

Conflict of interest

The authors wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

References


