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Technical Note

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

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ABSTRACT

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.

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_n), 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:

$$Q = (RQD/J_n)(J_r/J_a)(J_w/SRF) \tag{1}$$

The fine-grained sediments which contained high percentage of phyllosilicate minerals were classified by Weaver (1980) based on physils 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

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

$$RQD = 115 - 3.3J_v \tag{2}$$

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, Palmstrom (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 Kilic, 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; Saeidi 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 Daecheong 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 (Laubscher, 1977, 1984), rippability (Weaver, 1975), hard rock mining (Kendorski et al., 1983), coal mining (Unal, 1983; Newman and Bieniawski, 1985), dam foundations (Serafim 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; Dehkordi 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 %) 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.

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