Application of Rock Mass Rating system in underground intersections

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Abstract. Rock Mass Rating (RMR) system has been applied in numerous civil and mining engineering projects. However, the applicability of the system in underground intersections has not yet been discussed. By creating an underground intersection, the only parameter of RMR that is affected is joint orientation favorability as the other five parameters (i.e. uniaxial compressive strength of rock material, joint spacing, RQD, groundwater condition and condition of joints) are not structural features but the intrinsic properties of rock mass. The suggested approach is based on considering the minimum rating for joint orientation favorability in the intersections as any set of discontinuity would be parallel or close to parallel with one of the openings in intersection. The application process and usefulness of suggested method is demonstrated by using it in selection of the most suitable location among 5 alternative options for starting a middle excavation face through an adit in the Alborz Tunnel Project. The case example shows that the method can be very helpful and important in practical applications of RMR system.

1. Introduction
The attempt to classify rock mass for construction purpose dates back to Terzaghi’s work [1]. Many other classification systems have been introduced and used including rock quality designation (RQD), rock structure rating (RSR), the Q-system, rock mass rating (RMR) system, geological strength index (GSI) and rock mass index (RMI) [2, 3, 4, 5, 6, 7]. Rock mass rating and the Q-system are mostly used in rock engineering. The RMR system has been subject to many studies in terms of extending it for application in structures in rock such as slopes [8] or using it for defining rock bolting capability of rock mass [9 and 10].

Nowadays, passenger and vehicle adits are commonly used in long tunnels to provide emergency access or exit route [11]. These intersections in underground structures are of crucial importance as the size of the opening increases which consequently can contribute to instability. The stability of intersections was subject to study by many authors. For instance, estimated Hoek-Brown failure criterion parameters for different coal seam lithologies were used for three dimensional finite element analyses to understand the instability and stress distribution around a 4-way coal mine intersection by [12], and in order to control the stability of intersection point in Hebi No. 5 coal mine, countermeasures were applied for support design based on theoretical analysis, geological investigations and numerical modeling [13]. Numerical modeling was also applied for stability assessment of shaft and tunnel intersections by [14]. 75 cases of 3D numerical simulations were done under various tunneling condition namely rock strength, overburden depth, rock mass rating and intersection angle by [11] and a criterion on the intersection angle effect on tunnel behavior as well as three support classes for different geological condition were proposed. In classification procedure, the Q-system deals with the intersection multiplying the Jp parameter by 3 which leads to 3 times decrease of overall Q value [4]. Also, in the Q system there is an excavation support ratio (ESR) which for intersections is defined to be 1 [4, 5]. However, these studies are about measuring the support load that acts on the rock mass on intersection area, and there is no instruction on how to adjust the RMR value.
in underground intersections on site when using it for support determination in order to account for the larger open spans in intersections. Thus, in this paper we suggest a method for determining RMR value in intersections, which is an important adjustment for practical application of RMR. In section 2, an overview of RMR system is given. Section 3 presents the description of the case study in which the proposed method is applied for choosing a safe location for opening a new construction face in between two portals of the tunnel. The proposed method and its application in the Alborz Tunnel is presented in section 4.

2. Rock mass rating (RMR) system
The RMR system has six components and each one of these consisting parameters is assigned with a rating. The components of RMR include uniaxial compressive strength (with rating 0-15), spacing of discontinuities (0-20), rock quality designation (0-20), condition of discontinuities (0-30) and ground water condition (0-15). The sum of the ratings of these parameters yields the basic RMR value and can range from 0 to 100. This range is divided into five classes, i.e. very poor rock (class V, RMR<20), poor rock (class IV, RMR= 21-40), fair rock (class III, RMR= 41-60), good rock (class II, RMR= 61-80) and very good rock (class I, RMR= 81-100) [1].

The sixth parameter (joint orientation favourability) is not an intrinsic characteristic of rock mass, and its rating must be carried out based on the engineering application of the structure. The ratings for this parameter based on the engineering application of the structure are presented in table 1. The information in table 2 can be used in order to determine the joint orientation favourability with regard to tunnel axis [5].

| Strike and dip orientations of discontinuities | Very favorable | Favorable | Fair | Unfavorable | Very unfavorable |
|------------------------------------------------|----------------|-----------|------|-------------|------------------|
| Tunnels and mines                              | 0              | -2        | -5   | -10         | -12              |
| Ratings                                        | 0              | -2        | -7   | -15         | -25              |
| Slopes                                         | 0              | -5        | -25  | -50         | -60              |

| Strike perpendicular to tunnel axis |
|------------------------------------|----------------|
| Drive with dip                     | Drive against dip |
| Dip: 45-50                         | Dip: 20-45      |
| Very favorable                     | Favorable       |
| Dip: 45-50                         | Fair            |
| Irrespective of strike             | Unfavorable     |

3. The Alborz Tunnel
The Alborz Twin Tunnels with a length of 6387 meters are the longest tunnels located along Tehran-Shomali Freeway in Iran. As shown in figure 1, there is an exploratory service tunnel which is located between the two tunnels. The excavation of this tunnel has already been completed by TMB with a diameter of 5.2 m. The main tunnels are connected to the exploratory service tunnel via access tunnels known as cross passages (figure 1). As the service tunnel is thoroughly excavated, the contractor was planning to start an excavation face in the central parts of the tunnel length by excavating the cross...
passage from service tunnel towards the eastern main tunnel. Since the cross passage was going to be excavated from service tunnel towards the eastern tunnel, the main challenge was the excavation of the intersection between cross passage and main tunnel. During this step, the span would be increased, which meant higher risk of stability problems, especially since there was not large flexibility on installation of primary support due to lack of space. Thus, the choice of location from geological point of view was of prime importance. Since there was five pre-defined cross passage locations based on the tunnel design setting, the choice was narrowed down to five locations. The geological and geomechanical properties of rock mass in these locations was obtained from the geological face mappings during the excavation of service tunnel. The relevant information are presented in table 3.

![Figure (1): Schematic view of Alborz Tunnel setting.](image)

| Location | A | B | C | D | E |
|----------|---|---|---|---|---|
| Lithology | Argillaceous shales | Porferic dyke | Sandstone | Limestone | Sandstone |
| UCS (MPa) | 7-25 | 111-157 | 68-106 | 60-70 | 75-106 |
| RQD (%) | 50-75 | 50-70 | 50-75 | 40-60 | 25-50 |
| Spacing (mm) | 200-600, 60-200 | 200-600 | 60-200, 200-600 | 60-200 | 60-200 |
| Groundwater condition | Dripping | Wet | Wet | Wet to dripping | Damp to wet |
| Joint condition | Open joints (1-5 mm) some empty and some with soft filling, 5-10 m persistence, slightly rough and slightly weathered surfaces | Slightly open joints (0.1-1 mm), empty, 7-10 m persistence, slightly rough and slightly weathered surfaces | Slightly open joints (0.1-1 mm), empty, 10-20 m persistence, slightly rough and moderately weathered surfaces | Continuous open (1-5 mm) joints with slickenside surfaces | Slightly open joints (0.1-1 mm), empty, 3-10 m persistence, smooth and moderately weathered surfaces |
| Joint orientation with regard to tunnel axis | Strike perpendicular to tunnel axis and drive against dip (Dip:60-80): Fair | Strike perpendicular to tunnel axis and drive against dip (Dip:20-45): Unfavorable | Strike perpendicular to tunnel axis and drive with dip (Dip:25-40): Favorable | Strike perpendicular to tunnel axis and drive with dip (Dip:20-45): Favorable | Strike perpendicular to tunnel axis and drive with dip (Dip:55-75): Very favourable |
| RMR | 37-39 | 52 | 47 | 35-40 | 46-50 |
4. Adjustment of RMR for application in the intersections

The Q-system was adjusted for use in intersections by multiplying the parameter related to number of joints, i.e. $J_n$, by 3. The parameter $J_n$, together with RQD value, in the Q-system is representative of block size. It is logical to use the quotient of RQD representing the block size to adjust it for application in intersections as in intersections it is the geometry of the tunnel that changes, not the characteristics of surrounding rock mass. The same notion should be considered when adjusting RMR for applications in underground intersections. Thus, in intersections, it is the parameter that is related to engineering structure (i.e. joint orientation with regard to tunnel axis) that should be the focus of attention. The other parameters, i.e. uniaxial compressive strength of intact rock, rock quality designation, spacing of discontinuities, condition of discontinuities and groundwater condition, are the intrinsic properties of rock mass. The effect of joint orientation with regard to tunnel axis in intersections is due to the fact that there are two openings in two different directions in each intersection. Thus, the most critical orientation must be considered while assessing the RMR value in intersections.

As an example, in location A of table 3 the joint strike is perpendicular to main tunnel axis. As the intersection angle in the Alborz Tunnel is 90 degrees, strike of the same joint set will be parallel to the axis of cross passage. As the joint dip is not affected (60-80 degrees), from table 2 (strike parallel to tunnel axis and dip 60-80) the joint orientation with regard to cross passage axis would be “very unfavorable” acquiring the rating of -12. Thus, in case of excavating an intersection with angle of 90 degrees, the joint orientation parameter will change from “fair” to “very unfavorable” the rating of which would decrease from -5 to -12. Accordingly, in case of opening an intersection in location A, the overall value of RMR would be decreased by 7 points to be ranging 30–32. In location B, the joint orientation with regard to axis of main tunnel is “unfavourable” with a rating of -10. Later, by excavating a cross passage, the joint orientation with regard to the axis of cross passage would be “fair” with a rating of -5. Accordingly, in assessment of RMR value in the location of intersection B, it is the original rating, i.e. -10, that should be used since it is the critical one. Thus, in this case the adjusted RMR value would be the same as when there was no intersection at the location (given the current strike of main tunnel axis). Thus the critical one, would be the latter and must be used for RMR. Therefore, in this case the adjusted RMR value would be the same as the previous one.

This procedure has been done for other locations and the obtained results are shown in table 4. As it is obvious, the best possible choice for middle excavation face (creating the intersection) would be location B. the most noticeable change occurred in location E where the RMR value was decreased 12 points. This is very important to compare the RMR values in locations B and E where there is approximately no difference between the rock mass types in these two locations (see table 3). However, after calculating the adjusted RMR for intersection (see table 4) it is revealed that location E is not a suitable choice for creating an intersection. The proposed method can be used for adjusting the RMR values in underground intersections.

Later, during the completion of all cross passages, it was observed that in argillaceous shales, i.e. location A, the contractor experienced problems with regard to tunnel stability in the intersection at location A. The construction of the tunnel in other parts where there was no intersections in the same rock mass proved to be less problematic. It means that the Adjusted RMR values for intersection should have been taken seriously by the contractor and can help preventing unwanted instability problems in any future tunnelling project.

5. Discussion
It must be noticed that the parameters of basic RMR can and may have an effect on the stability of tunnel in the location of intersections, especially since the size of opening in intersections can be considered to be larger than other parts of tunnel section. This effect has been investigated for example by [11, 12, 13, 14]. However, the suggested adjustment has the benefit of applicability from practical point of view with no need for extra measurements. The method has also proved to be helpful during the construction of Alborz Tunnel.

The angle of intersection is of particular importance for the adjustment. According to table 2, the tunnel axis would be either perpendicular or parallel to the joint strike. The angle between the two openings in intersection (in Alborz Tunnel this angle is 90 degrees) can be of prime importance for adjusting the RMR value for intersections, and practically the angle between the discontinuity strike with two openings should be checked separately in order to choose the critical one. In cases where the dip of the discontinuities are less than 20 degrees, the adjustment would not make any difference (see table 2).

| Location | Joint orientation favorability with regard to main tunnel (rating) | Joint orientation with regard to cross passage (rating) | RMR value prior to adjustment for intersections | Adjusted RMR value for intersection |
|----------|--------------------------------------------------|--------------------------------------------------|---------------------------------------------|----------------------------------|
| A        | Fair (-5)                                        | Very unfavorable (-12)                           | 37-39                                       | 30 - 32                          |
| B        | Unfavorable (-10)                                | Fair (-5)                                       | 52                                          | 52                               |
| C        | Favourable (-2)                                  | Fair (-5)                                       | 47                                          | 44                               |
| D        | Favourable (-2)                                  | Fair (-5)                                       | 35-40                                       | 32 - 37                          |
| E        | Very favorable (0)                                | Very unfavorable (-12)                          | 46-50                                       | 34 -38                           |

6. Conclusions
Rock mass rating system has been very useful in design and construction of underground structures. For the design of underground intersections some researchers used numerical simulation to better account for the required support system for the intersection. However, there is no practical way to adjust the RMR system for application in intersections like that of the Q-system. Therefore, the present paper suggests a practical approach for adjusting RMR values to be used in intersections on site. The suggested adjustment is based on the orientation of dominant discontinuity set with regard to tunnel axis, where in case of an intersection the most critical orientation must be used. The data from the Alborz Tunnel was used to demonstrate practical application of the proposed method. The adjusted RMR values in Alborz Tunnel were used for selection of the best location for opening intersection for a new excavation face. The method proved to be very helpful from practical point of view during the excavation of Alborz Tunnel.

References
[1] Terzaghi K, 1946 Rock Defects and Loads on Tunnel Supports. Rock tunnelling with steel supports.
[2] Deere DU, Hendron AJ, Patton FD and Cording EJ, 1966 Design of surface and near-surface construction in rock. *The 8th US symposium on rock mechanics (USRMS)* Jan 1. American Rock Mechanics Association.

[3] Wickham GE, Tiedemann H and Skinner EH, 1972 Support determinations based on geologic predictions. *N. Am rap. excav & tunn. conf proc* Jun (1).

[4] Barton N, Lien R, Lunde J, 1974 Engineering classification of rock masses for the design of tunnel support. *Rock mech.* Dec., 6 (4): 189-236.

[5] Bieniawski ZT, 1989 *Engineering Rock Mass Classifications: a Complete Manual for Engineers and Geologists in Mining, civil, and Petroleum Engineering.* (New York: John Wiley & Sons)

[6] Palmstrom A, 1995 Characterizing the strength of rock masses for use in design of underground structures. *Int. conf. in des. and const. of underg. struc.*, Feb; 23 (10).

[7] Hoek, E, 1994 Strength of rock and rock masses, *ISRM News J.*, 2 (2), 4-16.

[8] Romana M, 1985 New adjustment ratings for application of Bieniawski classification to slopes. *Proc. of the int. symp. on role of rock mech.*, Zacatecas, Mexico Sep; 49-53.

[9] Mohammadi M, Hossaini MF and Bagloo H, 2017 Rock bolt supporting factor: rock bolting capability of rock mass. *Bull. of eng. Geo. and the envi.* Feb 1; 76 (1): 231-9.

[10] Mohammadi M and Hossaini MF, 2017 Modification of rock mass rating system: interbedding of strong and weak rock layers. *J. of rock m. and geot. Eng.* Dec 1; 9 (6): 1165-70.

[11] Hsiao FY, Wang C L and Chern J C, 2009 Numerical simulation of rock deformation for support design in tunnel intersection area. *Tunn. and underg. sp. Tech.*, 24 (1), 14-21.

[12] Chugh Y P, Abbasi B, 2011 A numerical analysis of a four-way coal mine intersection with primary and secondary supports. *12th ISRM cong. int. Soc. for rock mech.*, Jan, Beijing, China.

[13] Hai-He J I N G, Yuan S H E N, 2011 Study on and application of support for deep soft rock at (E0,0E) intersection point in Hebi No. 5 coal mine. *Tun. Const.*, 31 (1), 331

[14] Aksoy, C O, Onargan T, Kucuk K, Genis M and Guney A, 2009 Numerical modeling for the umbrella arch application at the shaft and tunnel intersection. *ISRM int. symp. on rock mech. -SINOROCK 2009.* International Society for Rock Mechanics. Jan.