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# INTERPRETATION OF ROCK MASS BEHAVIOUR VIA “MULTIPLE GRAPH” APPROACH: ADIT P-CP9 OF THE ALBORZ TUNNEL

Saied Mohammad Farouq Hossaini<sup>1</sup>, Mohammad Mohammadi<sup>2</sup>, Mojtaba Askari<sup>3</sup>

**ABSTRACT:** The current paper focuses on the application and advantages of the “multiple graph” approach for interpretation of surrounding rock mass behaviour in underground structures. Behaviour of the Argillitic rock mass surrounding Adit P-CP9 of the Alborz Tunnel was interpreted via the “multiple graph” approach resulting in interestingly accurate prediction. The accuracy of the estimation was later observed in the excavation process and afterwards. The observed results are presented which verifies that the “multiple graph” approach can cope satisfactorily with various geological conditions.

## INTRODUCTION

In construction of underground structures such as tunneling, rock mass classification techniques have been utilized for many years since Terzaghi's (1946) descriptive methodology or Lauffer's (1958) proposal on rock mass quality which controls the stand-up time of an unsupported tunnel span. Other systems such as Rock Quality Designation (RQD) by Deere et al. (1967) were also introduced. Yet, Rock Structure Rating (RSR) was the first system for classifying rock mass (Wickham et al. 1972). Pacher et al. (1974) extended Lauffer's proposal for development of New Austrian Tunneling Method (NATM). However, nowadays the massively used classification systems include Bieniawski's (1973 and 1989) Rock Mass Rating (RMR) system along with the Q-system which was developed by Barton et al. (1974).

Palmstrom (1995) introduced Rock Mass Index (RMI) for the purpose of calculation of rock mass strength as a construction material. The Geological Strength Index (GSI) was proposed by Hoek and Brown (1997) for both weak and strong rock mass types. Later, Marinos and Hoek (2000) developed a chart in order to make the classification of rock mass by visual inspection much easier. Most recently, Marinos (2014) classified flysch rocks of Northern Greece into 11 groups using GSI.

As a result of theoretical study, an intrinsic characteristic of rock mass namely “rock bolting capability of rock mass or Rock bolt Supporting Factor (RSF)” was introduced by Mohammadi et al. (2017) which can be used for calculation of rock bolting efficiency in a given rock mass. Based on the theory, a mathematical definition of rock bolting mechanism was developed. An application of RSF for coping with the discrepancies of the RMR system in rock mass consisting of interbedding of strong and weak rock layers has been introduced by Mohammadi and Hossaini (2017). Some other discrepancies of the RMR system were reported by Gonbadi et al. (2009).

Russo (2008) proposed a “Multiple Graph” approach to be applied for both preliminary assessment of excavation behaviour and selection of support type at the tunnel face. This system is going to be discussed and used for explanation of geomechanical behaviour of argillitic rock mass of the Alborz Tunnel in Iran where a comparison was made between the RMR system and “Multiple Graph” approach.

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### The GDE multiple graph

As a useful tool for both preliminary assessment of the structure behaviour in rock tunneling and selection of support type, the Geodata Engineering (GDE) multiple graph approach has been experienced in many cases (Russo 2008, Russo 2014, Kontrec and Constandinidis 2013, Decman et al. 2013). The graph is composed of four main sections as shown in Figure 1. The properties estimated by the “multiple graph” are presented in Table 1. The first graph is located in the lower right quadrant and the progress is clockwise.

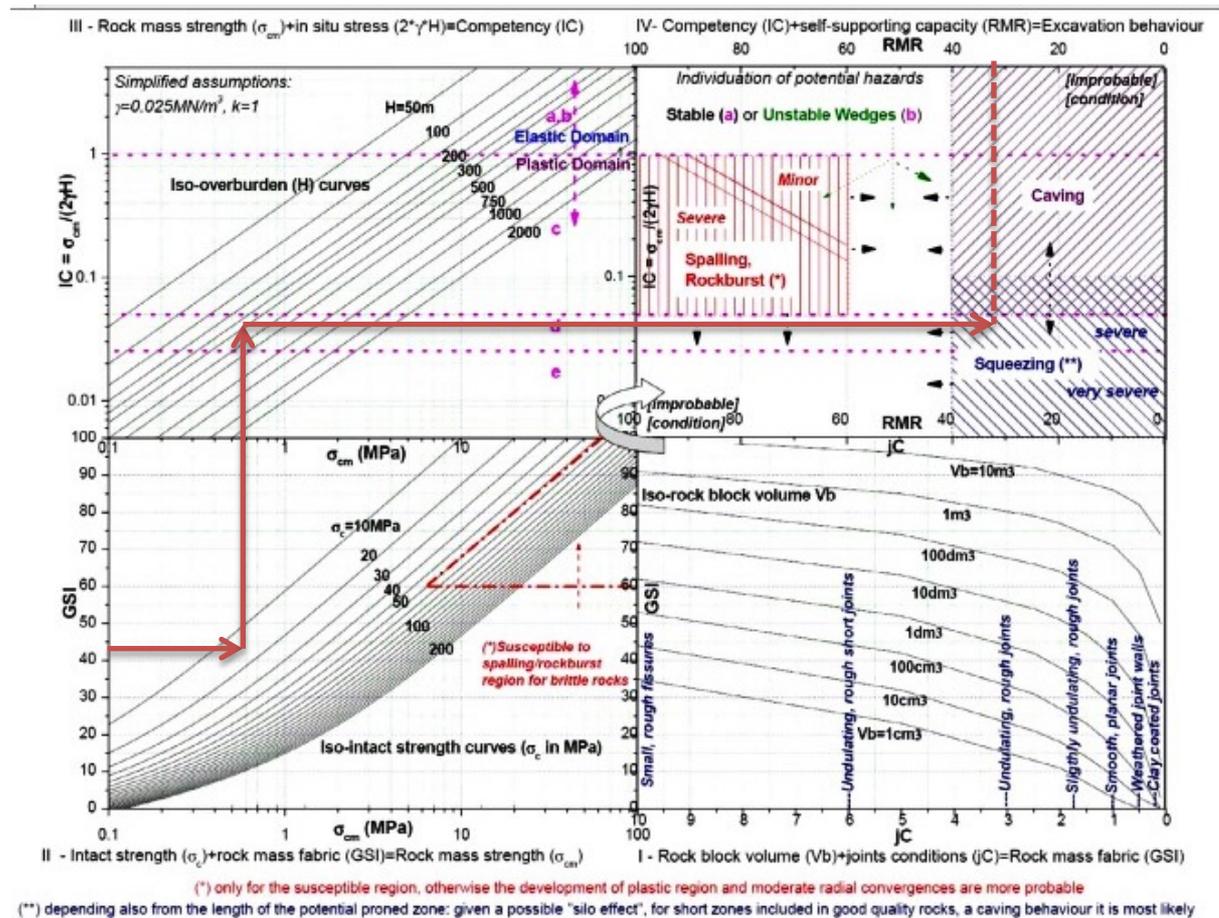


Figure 1: The GDE multiple graph for preliminary assessment of excavation behaviour (Russo, 2014).

Table 1: The properties that are estimated in “multiple graph

<b>Graph 1</b>	<b>Rock block volume + Joint conditions = Rock mass fabric</b>
<b>Graph 2</b>	Rock mass fabric + Strength of intact rock = Rock mass strength
<b>Graph 3</b>	Rock mass strength + In situ stress = Competency
<b>Graph 4</b>	Competency + Self-supporting capacity = Excavation behaviour → Potential hazards)

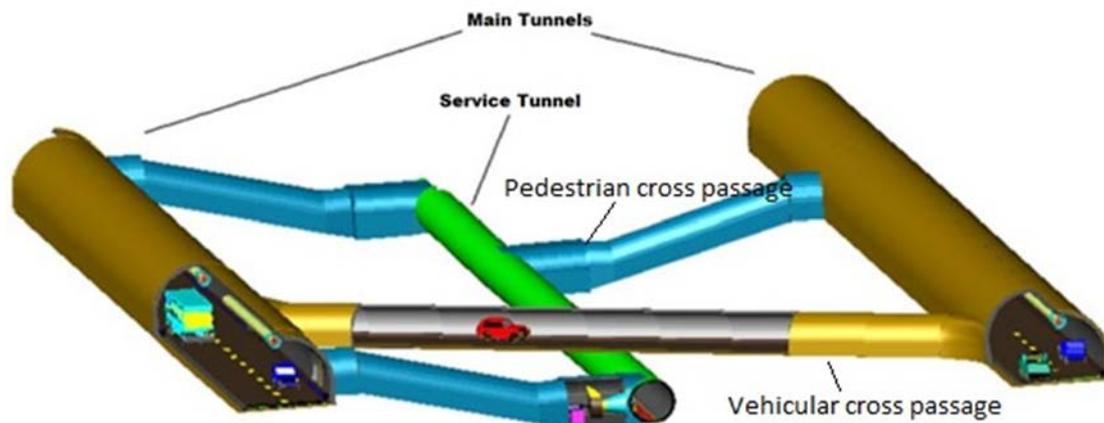
The rock mass fabric (GSI) which can be a scalar function of two components namely rock structure and joint condition, is estimated through graph 1 (lower right quadrant in Figure 1). Then the rock mass fabric (GSI) as well as intact rock strength ( $\sigma_c$ ) is the base for estimation of rock mass strength ( $\sigma_{cm}$ ). The next step is to estimate the rock mass competency or competency index (IC) which is defined as the ratio between rock mass strength and tangential stress ( $\sigma_\theta$ ) on the excavation contour, using rock mass strength ( $\sigma_{cm}$ ) and in situ stress ( $\sigma_e$ ). However, a simplified assumption here has been adopted by considering the ratio

of in situ horizontal and vertical principal stresses ( $k$ ) to be equal to 1. The value of  $IC=1$  separates the behavioral response of the rock mass into elastic and plastic domains. Finally, the excavation behaviour based on Rock mass competency ( $IC$ ) and self-supporting capacity ( $RMR$ ) is estimated via graph IV (upper right quadrant of Figure 1). In the cases that  $GSI$  is already estimated (Russo, 2014).

The “multiple graph” system gives a prediction of surrounding rock mass behaviour which is going to be applied to understand the behavioral aspects of surrounding Argillitic rock mass of Pedestrian Cross Passage P-CP9 in the Alborz Tunnel of Iran.

### CASE STUDY

the longest ones in the Tehran-North (Shomal) Freeway (TSF) which is the biggest ongoing civil project in the country. The Alborz Tunnels include two main tunnels known as Western and Eastern Tubes as well as an exploratory (Service) tunnel in the middle of the two main ones. There are some adits known as Cross Passages connecting the two tunnels together as well as the two tunnels to the exploratory tunnel. The Cross Passages connecting the main tunnels together are known as Vehicular Cross Passages (V-CP) and the ones connecting the main tunnels to the exploratory tunnel are known as Pedestrian Cross Passages (P-CP). A schematic view of the Alborz Tunneling Complex is presented in Figure 2. The excavation of the exploratory tunnel has been completed with a TBM with a diameter of 5.2 m. The excavation of Main Eastern Tube is ongoing with the drill and blast method. All the Cross Passages were excavated during the excavation of Eastern Tube which is in its final stages.



**Figure 2: A schematic view of the Alborz Tunnel Complex (Technical Report, 2009)**

The surrounding rock mass in the excavation of P-CP9 consisted of tectonised Argillites with low UCS values and a plethora of discontinuities including faults and joint sets. The behaviour of these argillites was checked and properly predicted by the use of “multiple graph” especially as the UCS was low and the properties of rock mass was mainly controlled by intact rock properties rather than the properties of discontinuities. The classification and prediction of behaviour and real rock mass behaviour after excavation are discussed in the next section.

### ROCK MASS CLASSIFICATION IN P-CP9

The P-CP9 has been excavated through tectonised argillites with a diameter of 6 m. The main features of the surrounding rock mass are presented in table 2. Based on the RMR system, the surrounding rock mass belongs to Class IV or Poor Rock ( $RMR: 21-40$ ) where a systematic rock bolt installation along with wire mesh and light to medium steel ribs with spacing of 1.5 m would be enough for supporting the rock. The same has been applied. However, there were many problems in the stability of the structure. Therefore, the aforementioned “multiple graph” system was used for interpretation of rock mass behavior. The process of rock behaviour determination based on the main parameters of surrounding rock mass is shown in Figure 1 with red arrows. As the  $GSI$  of surrounding rock mass was obtained directly through rock mass, there was no need for the first quadrant of “multiple graph” to be compiled. Based on the obtained results, as is apparent in Figure 1, the “multiple

graph” predicts a severe squeezing behaviour for the surrounding rock mass which was accurate based on the observed behaviour of the rock mass.

**Table 1: Main parameters of surrounding rock mass in P-CP9**

UCS (MPa)	GSI	Overburden (m)	RMR
5-25	41	400	33

The squeezing behaviour of rock mass in P-CP9 was observed before the installation of steel ribs. Even after the installation of steel ribs the severe squeezing continued. The squeezing of surrounding rock mass before and after the installation of the steel ribs is shown in Figures 3 and 4 respectively. In Figure 3, the bending of rock bolt plate is evident indicating that the rock bolt is activated properly, however, the squeezing in this Figure is discernable. Even after the installation of steel ribs, the severe squeezing continued up until it caused the yielding of steel ribs as shown in Figure 4.



**Figure 3: Squeezing of surrounding rock mass before installation of steel ribs.**



**Figure 4: Squeezing of surrounding rock mass after installation of steel ribs.**

The facts recorded in this investigation suggest that the “multiple graph” approach can properly predict the behaviour of surrounding rock mass in underground structures. In the case of P-CP9 in the Alborz Tunnel, when the compressive strength of rock material is rather lower than usual, the obvious squeezing of surrounding rock mass was properly estimated whereas the RMR system does not predict the squeezing possibility.

## CONCLUSIONS

The “multiple graph” approach was introduced and used to interpret the behaviour of surrounding rock mass in P-CP9 of the Alborz Tunnel in Iran. After a brief explanation on how to work with the “multiple graph” system, the interpretation of rock mass behaviour was carried out. The method predicted the severe squeezing condition in surrounding rock mass of P-CP9 in the Alborz Tunnel which later was verified by actual observations performed on site where the rock bolt plates bent severely and the steel ribs yielded showing the serious squeezing condition in the surrounding rock mass. The “multiple graph” approach is recommended to be used for interpretation of rock mass behaviour as it copes with the diverse geomechanical condition.

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