THE TECHNIQUE FOR EXTRAPOLATION OF ROCK MASS INITIAL PARAMETERS DURING THE CONSTRUCTION OF THE TUNNEL

Nemanja Marinković [1*], Milorad Jovanovski [2], Elefterija Zlatanović [1], Lazar Živković [1]
[1] *Faculty of Civil Engineering and Architecture, University of Niš, Serbia*
[2] *Faculty of Civil Engineering, "Ss. Cyril and Methodius" University in Skopje, MKD*
*E-mail of corresponding author: nemanja.marinkovic@gaf.ni.ac.rs

Abstract: *It is important to perform research to the degree that it is adequate to identify the features of the terrain composition, before, during, and after the building of facilities since predicting the behaviour of rock mass during tunnel construction is a complicated engineering challenge. Engineering research works in laboratories and in the field are of different scope and methodology during testing. In this paper, the established interdependencies of some of the basic parameters obtained during the testing of rock mass are presented: Edyn = f(Vp), Edyn = f(RMR) i Edyn = f(Q). Also, the relations between the engineering systems of rock mass classification and seismic primary waves are derived. RMR = f(Vp), Q = f(Vp). The relations were based on the examination of the rock mass for the construction needs of the tunnel on the Nis-Merdare highway. The results obtained in this study can be applied in environments that have similar lithological and structural characteristics.*
Keywords: *Classification, Extrapolation, Geotechnical model, Physical model, Rock*

Received: 15.08.2022 / Accepted: 19.10.2022.
Published online: 20.12.2022.

Original scientific paper
DOI:10.37023/ee.9.1-2.3

1. INTRODUCTION

Despite the fact that numerical modelling is becoming more prevalent in all aspects of geotechnics, the fundamental conclusions are still reliant on in situ field experiments and laboratory samples. However, the data from several tests do not produce the same conclusions, primarily because one approach differs significantly from the others and also because the material is complicated and heterogeneous. For the designing purposes of underground structures, in addition to the direct application of test results, some of the numerous classifications of rock masses are used regularly. It is necessary to show the granite mass's inherent heterogeneity and the degree of cracking of the rock mass. How to extrapolate the parameters from the test zone to the entire surface (volume), which is important for the investigation of the interaction of the rock mass structure and the object (construction), is one of the fundamental issues. One of the first in Europe who tried to find a solution was Kujundžić (1977) who was working on of extrapolation for the purpose of building large dams, and over time, numerous other authors began to do so.

From a technical point of view, describing the rock mass and its condition during testing is not easy. According to the first classification developed for the needs of tunnel design and construction (Terzaghi 1946), the rock mass was divided into 9 descriptive, ie quantitative categories. However, there was a need to present the classification of rock mass qualitatively (in numbers), and over time, many other classifications have developed, among which the most common in the world: RMR - Rock Mass Rating system (Bieniawski 1973; 1989); RSR - Rock Structure Rating; Q system - Rock Mass Quality (Barton, Lien & Lunde 1974; 1980); RMi - Rock mass index, modified BQ, a multiparameter classification system ERMR - Excavation Rock Mass Rating, as well as increasingly represented GSI - Geological Strength Index (Hoek 1998). The possibilities of integrating approaches for extrapolation of parameters during tunnel construction, which often represent a problem, are presented in this paper The proposed methodology is based on a combination of empirical method, rock mass classification and geophysical measurements in the field. The analyses are based on the results of research on several tunnels in the southern part of Serbia (**Figure 1**). This highway represents a very important road for the further development of the entire western part of the Balkans. According to the Seismic Hazard Maps for the Western Balkans, this area where the highway route is planned is subject to tectonic changes and that is one of the important reasons why the classification should be done in a quality way (Gulerce et al. 2017).

2. METHODS

A highly significant feature of the paperwork for numerous infrastructure projects and geotechnical studies should now include the categorization of rock mass systems as a requirements are to gather. A number of rock mass categorization methods have emerged during the past 50 years, with RMR, Q, and GSI seeing the most widespread application in ordinary routine. A huge variety of studies provide geologists and engineers the chance to evaluate different rock masses. However, for better analysis and comparison, a strong link between these system categories is required. On the basis of statistical analysis of field data, several prominent authors have in the past offered empirical data and a connection between the RMR and Q systems (**Table 1**). Since both of these qualitative classification techniques are based on the examination of a number of factors, it is possible to demonstrate the dependency of the parameters of each approach separately.

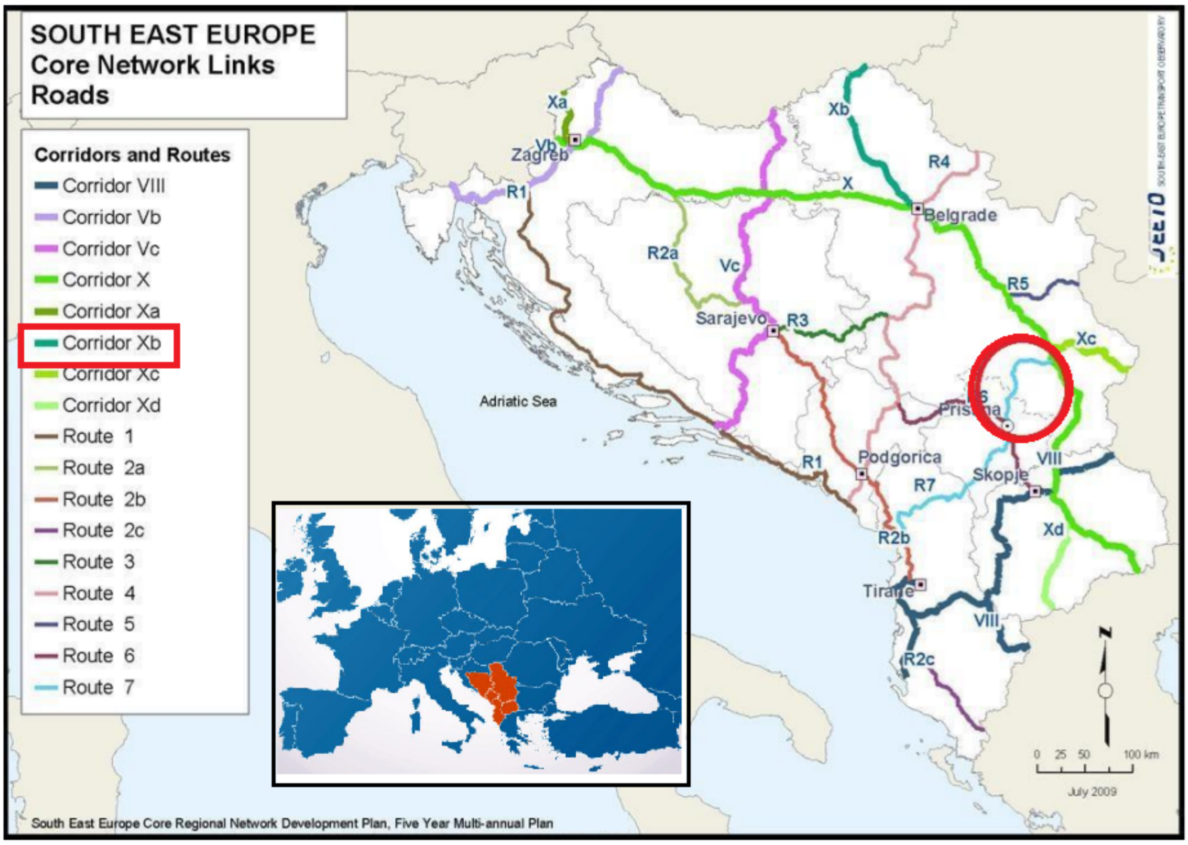

Figure 1. Map of the main road network in the Western Balkans (source SEETO MAP)

Table 1. Equations of existing correlations of RMR and Q methods for rock mass classification (modified according to Sayeed & Khanna)

AUTHORS	CORRELATION
Bieniawski (1976)	RMR = 9 ln Q + 44
Rutledge and Preston (1978)	RMR = 5, 9 ln Q + 43
Moreno (1980)	RMR = 5.4 ln Q + 55.2
Cameron - Clarke and Budavari (1981)	RMR = 51ln Q + 60.8
Abad et al. (1984)	RMR = 10.5 ln Q + 41.8
Jovanovski (2001)	RMR= 9.38 lnQ+45.15

A streamlined technique for classifying rock mass strength is called the Geological Strength Index (GSI). The GSI value is based on an evaluation of the rock mass's structure, the characteristics of the intact rock, the characteristics of the discontinuity surface, as well as the circumstances resulting from the geometry of the intact rock parts and their behavior in response to the rock mass's changing stress state. The interdependencies between the GSI and RMR categorization systems in some of the most significant studies are displayed in **Table 2**.

An alternate approach, or evaluation based on empirical correlations for a variety of characteristics, is frequently utilized when examining the rock mass. This is frequently true for both the categorization that is the focus of this work and for establishing the rock mass deformation modulus, which is crucial information for engineering projects (Khabbazi et al. 2013).

Table 2. Equations of existing correlations of RMR and GSI methods for rock mass classification

AUTHORS	CORRELATION
Hoek and Brown (1997)	RMR_{89} = GSI + 5
Osgoui and Ünal (2005)	RMR_{89} = 20ln(GSI/6)2
Singh and Tamrakar (2013)	RMR_{89} = 1.36GSI + 5.90
Ali et al. (2014)	RMR_{89} = 1.01GSI + 4.95
Zhang et al. (2019)	RMR89 = 0.827GSI + 15.394
Somodi et al. (2021)	GSI = 0.876 RMR_{89} + 0.935

With the development of technology, a technique for figuring out a rock mass's propreties has been created that doesn't need excavation and sampling. For the purposes of obtaining these data, geophysical methods and parameters are most often used to obtain the dynamic characteristics of rock masses based on the measured velocities of longitudinal (Vp) and transverse (Vs) seismic waves. it was inevitable that the emergence of new methods led to the creation of new connections between the obtained results. Numerous examples indicate that seismic refraction data in surface layers or deeper cross tomography can be extrapolated using one or more correlations between Q and Vp. At the beginning of the 20th century, based on data from solid rock projects during tunnel construction in several countries, the relationship between RMR, Q and Vp was proposed by several authors (Jovanovski 2001; Barton 2002), where Vp is the propagation speed of longitudinal waves (**Equations 1-4**):

$$\mathrm{RMR} \approx 0.0161\,\mathrm{Vp} + 1.5\ (\mathrm{Vp\ in\ m/s}) \tag{1}$$
$$\mathrm{Vp} \approx 0.545\ln Q + 2.6\ \ (\mathrm{Vp\ in\ km/s}) \tag{2}$$
$$\mathrm{Vp} \approx 3{,}5 + \log Q \quad \text{depth to } 25\mathrm{m}\ (\mathrm{Vp\ in\ km/s}) \tag{3}$$
$$\mathrm{Vp} \approx 5{,}0 + 0{,}5\log Q \quad \text{depth to } 500\mathrm{m}\ \ (\mathrm{Vp\ in\ km/s}) \tag{4}$$

The results obtained by geophysical surveys largely depend on the lithological structure of the terrain. The extrapolation method is mainly based on the following assumptions given by Kujundžić (1977):

1. Parallel static and dynamic testing directly in the field with flat jacks and geophysical methods are needed, as a basis for obtaining sets of values for deformability of rock mass and values of velocity of longitudinal seismic waves.

2. Determining the value of the velocity of longitudinal seismic waves for the area of interaction between the rock mass and the object (tunnel).

3. Formation of direct and indirect analytical connection between the modulus of deformation and elasticity with the values of the velocity of longitudinal waves (Vp) and the modulus of dynamic elasticity (Edyn).

4. Extrapolation of parameters using formed regression curves from the test area to the entire volume of the rock mass involved in the interaction of the rock mass and the object (tunnel).

One of the basic problems in building subterranean structures within a rock mass is determining the rock's strength and deformability for the purposes of study and design. For many different techniques of classifying rock masses, the strength and deformation modulus of the rock mass serve as the fundamental and essential factors. The rock is usually a discontinuous, heterogeneous and anisotropic environment. Therefore, the behavior of the rock mass as a whole cannot be depicted by laboratory testing on core samples or field tests. Representative tests of rock mass strength and deformability by test loads in situ are rarely practically or economically possible. The development of empirical models linking the static modulus of deformation, the dynamic modulus of deformation, and the conditions of rock mass quality went through a number of stages (primarily RMR and Q). **Figure 2** shows a visual illustration of the relationship between the static modulus of deformation and the aforementioned techniques. This study demonstrates the relationship between the dynamic modulus of deformation and the RMR and Q classification systems, as well as the Vp and Vs seismic wave velocities. Also, Barton in his work (Barton 2002) showed that the dynamic modulus can be calculated using the wave velocities Vp and Vs in the classic elastic small strain using the **Equation 5**:

$$E_{dyu} = \gamma V_S^2 \frac{3(V_p/V_s)^2}{(V_p/V_s)^2 - 1} \tag{5}$$

whereby γ - volume weight of wall mass.

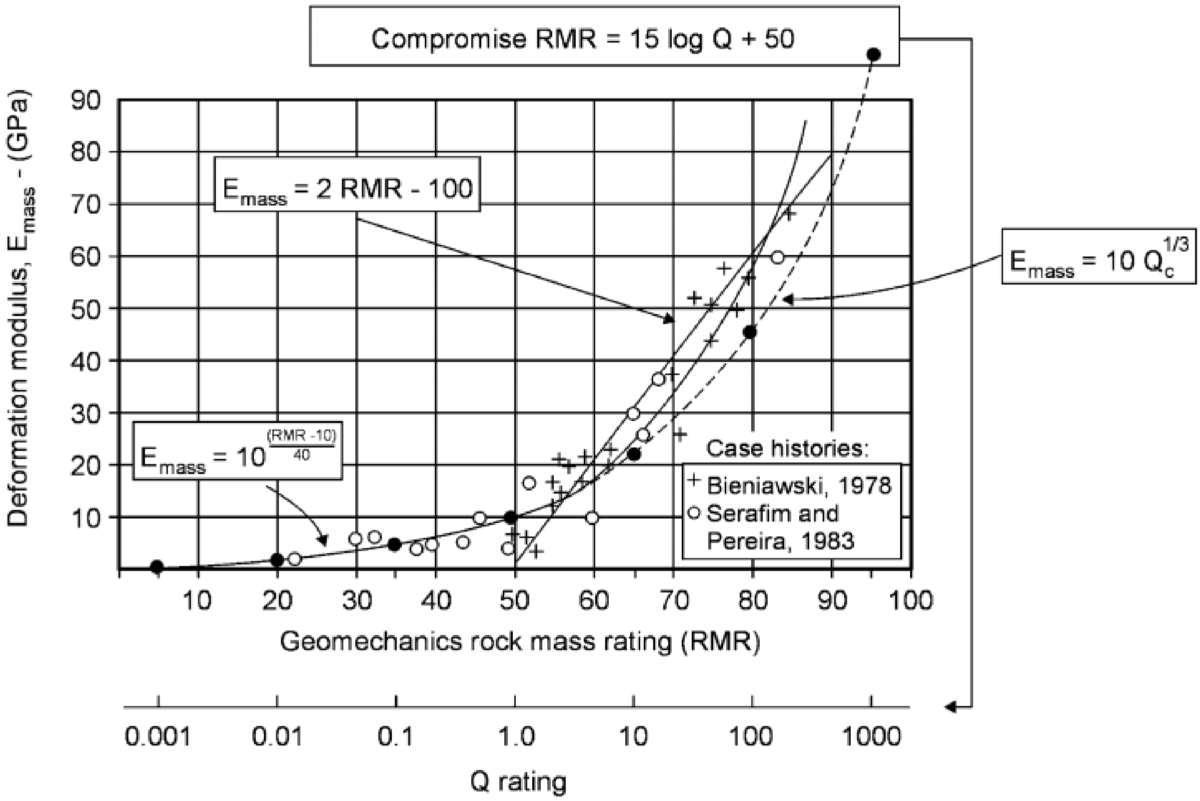

Figure 2. Static deformation modulus Emass; Q and RMR and some empirical inter-relationships (*Barton 2002*)

Based on results from triaxial rock mass tests, the Hoek-Brown rock mass strength criteria is regarded as an empirical criterion. The software programs were created based on the generic Hoek-Brown criteria of fracture, which in a very straightforward manner enables to acquire an accurate assessment of the characteristics of rock mass, both for very excellent and for very weak rock masses. In order to establish geological zones in the next stage of research and model development, the extrapolation problem is primarily created for major constructions by combining static and dynamic testing and the creation of relevant engineering data (EGS and EGM). There are more and more instances when models of rock masses are created by taking into account all geological, geophysical, and geotechnical survey findings and assessing longitudinal elastic wave velocities (Vp), small models, and cross sections by discontinuity characteristics (Nourani et al. 2017).

The proposed methodology can be briefly defined as an empirical-static-dynamic extrapolation methodology. This means that all known methods for determining the deformability and shear strength of rock masses can be used and combined to extrapolate parameters for the whole area. The prerequisite for using this methodology is the following (Zafirovski et al. 2012):

1. To have sufficient data for rock mass classification that are reliable.
2. To have sufficient test data for deformability with static tests.
3. The area of the entire engineering facility (in this case the tunnel) should be covered by geophysical seismic surveys.

Before selecting some test areas, we select one or more properties that will be relevant when compared to other parts. These regions, also known as quasi-homogeneous zones, stand in for the fundamental and defining components of the geological model. Some characteristics or qualities are constant across this zone but can vary greatly outside of it. Spatial restrictions, which are governed by a number of crucially significant characteristics, determine each zone. The tests must be carried out in a way that will provide reliable data for geotechnical modeling of the natural geological environment of the whole area along the tunnel. Given that a significant number of characteristics are required for the characterisation of a particular rock mass, it is simple to draw the conclusion that information on the uniformity of the whole working environment may be acquired with just a limited (insufficient) number of tests and samples. It should be noted that the process of extrapolation is interrelated with the process of geotechnical terrain modeling. Obviously, the models must meet two requirements: to simulate real terrain conditions as best they can, but to be as simple as possible (Pavlović, 1996).

3. RESULTS AND DISCUSSION

Based on the mentioned methods and comparisons, in this paper, the data collected during the testing for the needs of the construction of several tunnels designed along the Nis-Merdare highway are processed. For the purpose of processing the parameters, the following methodology is used (Zafirovski et al. 2012):

1. Collection of data from the results of massive rock tests (laboratory and field tests) - results of strength, deformation, discontinuity and other parameters.
2. Specific laboratory and field tests for specific purposes.
3. Statistical analysis and comparison of data collected from the literature and data collected by research and tests performed for the purposes of this article.

All the results of geological, geotechnical and geophysical investigations were used to establish a physical model through RMR, Q and GSI classification. The exception is the Božurna tunnel, where the terrain is predominantly marly clay, where correlations were made according to other parameters because RMR classification could not be done, except for one small segment (Rakić et al. 2017a; 2017b). **Figure 3** shows the correlation of RMR and Q classification on tunnels in these areas.

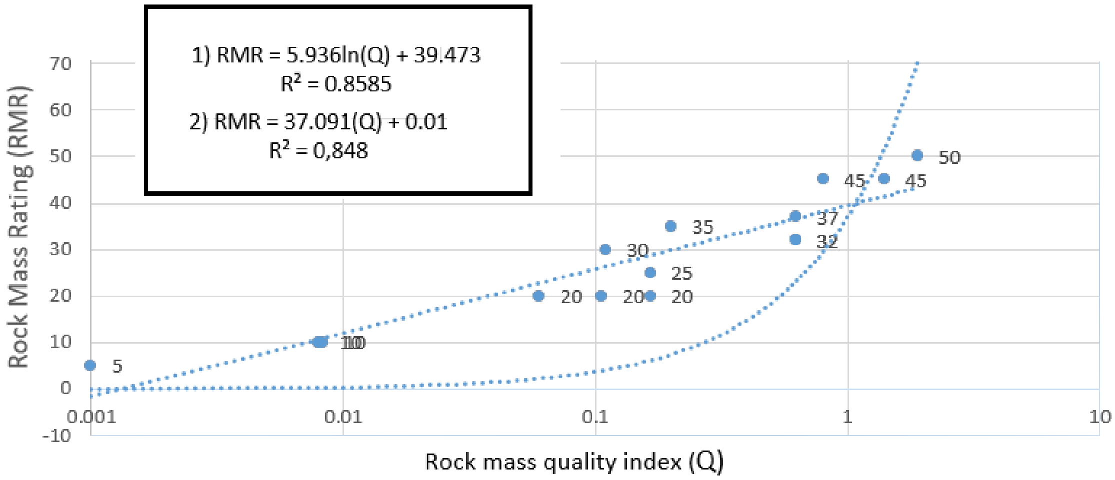

Figure 3. Correlations between rock mass rating (RMR) and Rock mass quality index (Q): 1) Logarithmic, 2) Linear

Various physical models defined by GSI values based on the HB method (Hoek & Brown 2018) were used for analytical models and prediction of shear strength and deformability parameters of rock mass. The GSI value is also used to classify terrain as a working environment (Chaniotis et al. 2017). Some typical GSI values for the main lithological types along the analyzed cross section in the Bozurna and Visnik tunnels are given in **Figure 4**.

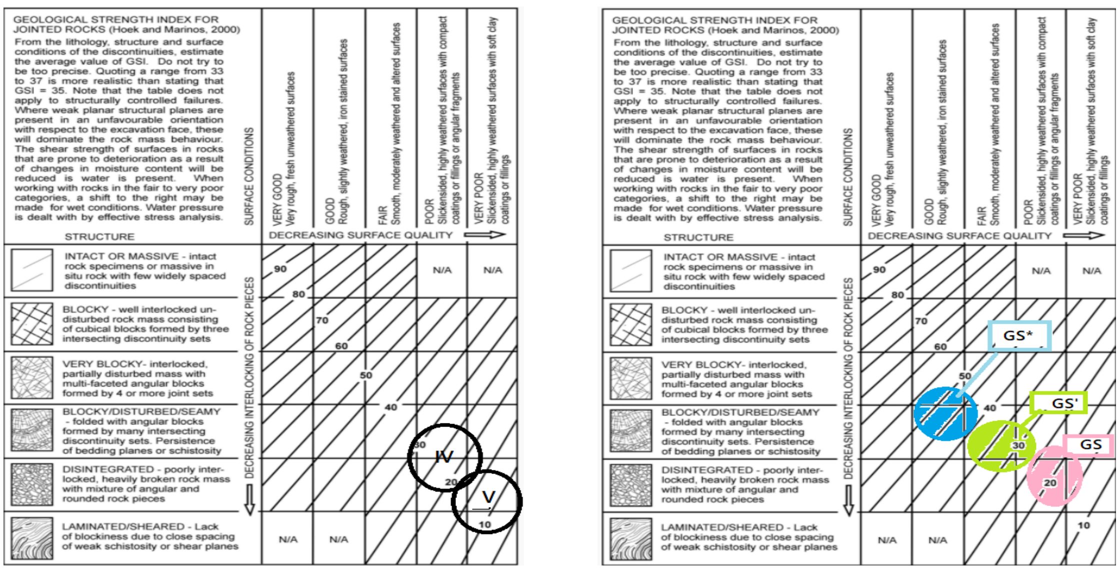

Figure 4. Range of GSI values for different zones of tunnel Bozurna and tunnel Visnik

Figure 5 and **Figure 6** illustrate regression models between longitudinal elastic wave velocities and rock mass quality as determined by the RMR and Q systems. For the tunnels in this segment, zones may be categorized as follows based on the average value of longitudinal elastic wave velocities (results do not apply for the Bozurna tunnel):
- Surface layer with values: Vp < 200-750 m/s, Vs < 80-280 m/s 1 to 4 meters thick;
- Subsurface zone, which would correspond to the decomposed altered rock masses to the level of soil debris with values: Vp < 800-1580 m/s i Vs = 300-590 m/s, 8 to 11 meters thick;
- Quite degraded gneisses with values: Vp = 1600-1900 m/s; Vs = 600-700 m/s
- Degraded cracked gneisses with values: Vp = 1900-2200 m/s; Vs = 700-800 m/s.
By examining the data, it can be shown that the base rock mass does not have a high longitudinal wave propagation velocity up to the test depth. Other classifications of rock masses and the expected conditions for tunnel construction can be implicitly determined based on the known relationships between the quality of the rock mass and Vp (Barton et al. 2002; Jovanovski 2001).

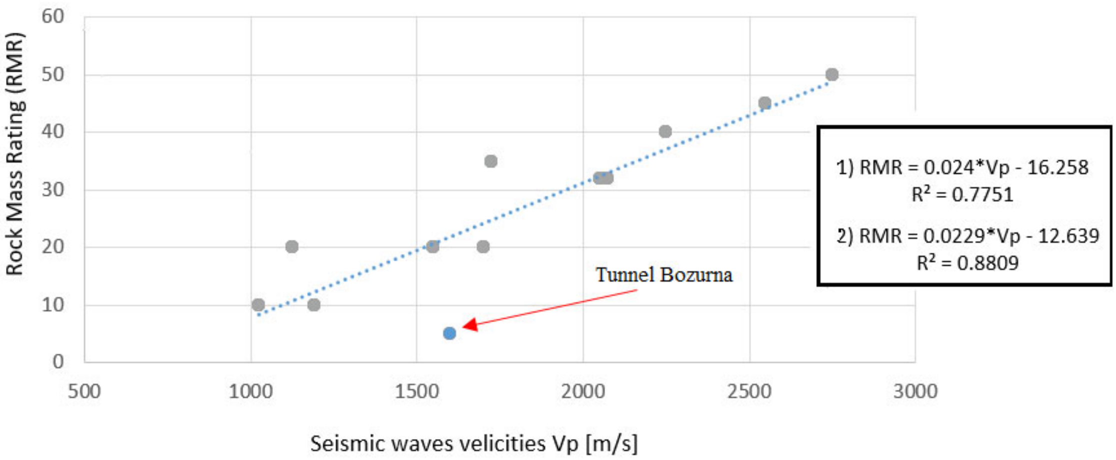

Figure 5. Correlations between rock mass rating (RMR) and longitudinal seismic wave velicities(Vp): 1) All Tunnels 2) All Tunnels without Bozurnain in marls and soil rock types

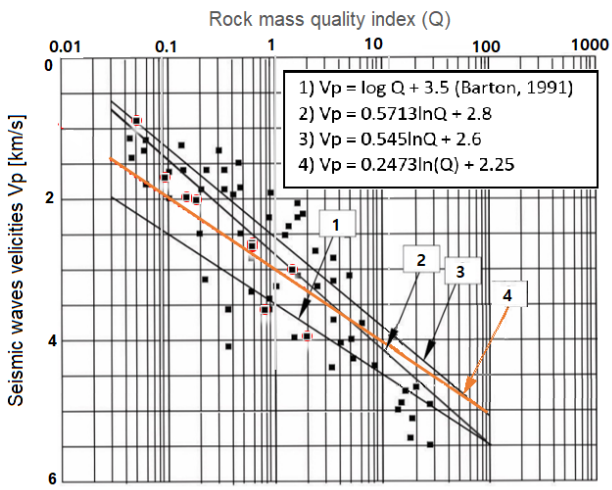

Figure 6. Correlative dependences between rock mass quality index (Q) and longitudinal seismic wave velocities (Vp)): 1) for areas from Norway, 2) more areas than Macedonia, 3) tunnels from the highway Demir Kapija - Smokvica (Jovanovski 2001), 4) tunnels from the highway Niš-Priština

The fact that the wave velocity Vs findings decrease with increasing values suggests that this approach is not the most accurate in high pressure areas and that the results for these regions are widely dispersed. **Figure 7** and **Figure 8** show a few regression models between the dynamic modulus of elasticity and values derived from the categorization systems RMR and Q, as well as the basis of the velocity of longitudinal elastic waves.

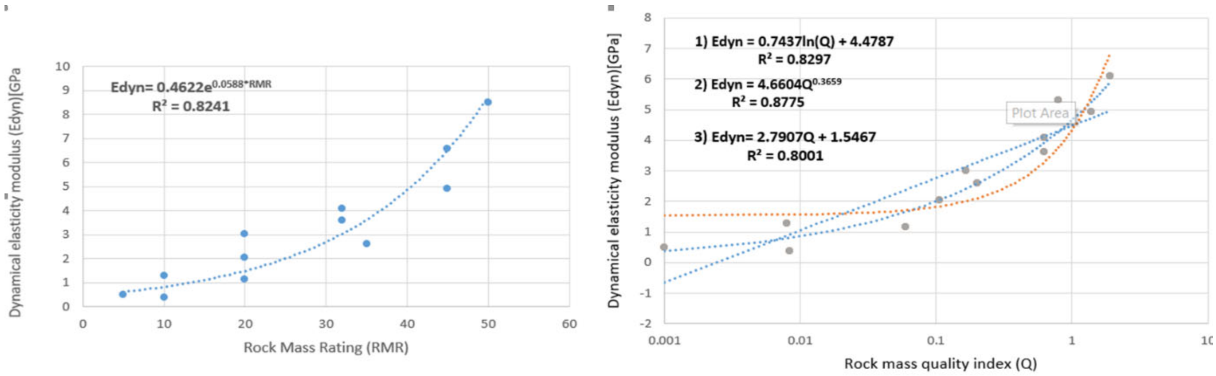

Figure 7. Correlative dependences between: (left) quality of rock mass by RMR and dynamical elasticity modulus (Edyn) and (right) Rock mass quality index (Q) and Edyn

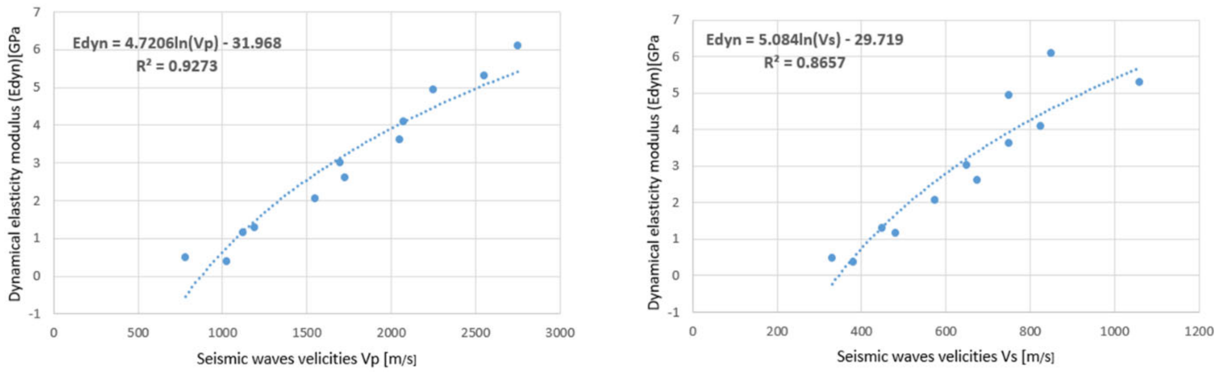

Figure 8. Correlative dependences between (left) seismic wave velocities (Vp) and dynamical elasticity modulus (Edyn) and (right) seismic wave velocities (Vs) and Edyn

When all tunnels are taken into consideration and the models are reviewed, it is discovered that the studied parameters have a significant link, as shown by the coefficients of determination (R2). Lower values of RMR and Vp refer to the category of very weak to weak rock masses (RMR = 10-30 RMR and Vp mainly from 1000-1800 m/s). Degraded and cracked gneiss corresponds to the value of the class of parameters in the range of RMR = 30–40 and Vp of 2100–2900 m/s, whereas higher evaluation values were achieved in the event of excellent rock mass. With such correlations and known seismic wave values, it is possible to extrapolate the input parameters using the empirical-static-dynamic methodology approach of parameter combination in order to carry out numerical analyses for each quasi-homogeneous zone throughout the tunnel.

4. CONCLUSIONS

In the creation of geotechnical models, the empirical-static-dynamic approach for data extrapolation is described. The suggested approach has to be examined in the interim for potential applicability at other sites and other facilities in other geological contexts in order to verify. However, considering that it is virtually difficult to finish researching this scientific subject in a single publication, this also creates prospects for more study. The phases of study and design must coincide with the modeling process. In the beginning, simpler methods are frequently applied. The outcomes of this kind of first models for complex things may point to the need for new data and permit reinterpretation of current data, both of which have an impact on the model's improvement or generate fresh concepts for novel models. We might infer from the foregoing that there are many of possibilities for more study in this area. The goal is to validate and enhance the methods described in this article for different types of building structures as well as for rock mass during the construction of tunnels.

***Acknowledgments**:* The authors gratefully acknowledge the support of the Science Fund of the Republic of Serbia in the scope of the scientific-research project "A New Concept in Improvement of Geotehnical Properties of Ground - Chemical Electrokinetic Tretment of Soil (ElectroSoil)", Grant No. 7742530.
Funding information: No external funding received.

5. REFERENCES

Ali W, Mohammad N and Tahir M (2014) Rock mass characterization for diversion tunnels at Diamer Basha dam, Pakistan - A design perspective. International Journal of Scientific Engineering and Technology, 3, 1292–1296.

Barton N (2002) Some new Q-value correlations to assist in site characterisation and tunnel design. International Journal of Rock Mechanics & Mining Sciences, 39, 185-216. doi: 10.1016/S1365-1609(02)00011-4

Barton N, Lien R, and Lunde, J (1974) Engineering classification of rock masses for the design of rock support. Rock Mechanics, 6 (4), 189-236. doi.org/10.1007/BF01239496

Barton N, Loset R, Lien R, and Lunde J (1980) Application of Q-system in design decisions concerning dimensions and appropriate support for underground installations. In: En Begman M (ed) Subsurface Space. Pergamon: New York, 2, 553-561.

Bieniawski ZT (1989). Engineering rock mass classifications. New York: John Wiley & Sons.

Chaniotis N, Saroglou H and Tsiambaos G (2017) Excavatability of rockmasses intunnelling, 7th International Symposium on Tunnels and Underground Structuresin SEE 2017, Zagreb, Croatia, May 3-5.

Gülerce ZG, Šalić R, Kuka N, Markušić S, Mihaljević J, ... Kovačević, S. (2017) Seismic Hazard Maps for the Western Balkan. Environmental Engineering - Inženjerstvo okoliša, 4 (1), 7-17.

Hoek E and Brown ET (2018) The Hoek-Brown failure criterion and GSI – 2018 edition. Journal of Rock Mechanics and Geotechnical Engineering. doi:10.1016/j.jrmge.2018.08.001

Hoek E and Diederichs MS (2006) Empirical estimation of rock mass modulus. International Journal of Rock Mechanics and Mining Sciences, 43, 203-215. doi.org/10.1016/j.ijrmms.2005.06.005

Hoek E, Marinos P and Benissi M (1998) Applicability of the geological strength index (GSI) classification for very weak and sheared rock masses. The case of the Athens Schist Formation. Bulletin of Engineering Geology and the Environment, 57(2), 151–160. doi:10.1007/s100640050031

Hoek E and Bray JW (1989) Rock slope engineering. Institute of Mining and Metallurgy, London, UK. Google Scholar.

Jovanovski M (2001) Methodology for deteremination of rock masses as a working media, Doctoral thesis, University Ss. Cyril and Methodius, Faculty of Civil Engienering, Skoplje.

Khabbazi A, Ghafoori M, Lashkaripour GR and Cheshomi A (2013) Estimation of the rock mass deformation modulus using a rock classification system. Geomechanics and Geoengineering, 8(1), 46–52. doi:10.1080/17486025.2012.695089

Kujundžić B (1977) Osnovi mehanike stena (I). SGIJT, Beograd.

Nourani MH, Moghadder MT and Safari M (2017) Classification and assessment of rock mass parameters in Choghart iron mine using P-wave velocity. Journal of Rock Mechanics and Geotechnical Engineering, 9(2), 318-328. doi:10.1016/j.jrmge.2016.11.006

Osgoui R and Ünal E (2005) Rock reinforcement design for unstable tunnels originally excavated in very poor rock mass. In: Erdem and Solak (eds.): Underground Space Use. Analysis of the Past and Lessons for the Future – Taylor & Francis Group, 291-296. doi:10.1201/noe0415374521.ch44

Pavlović N (1996) O metodologiji geotehničkog modeliranja. In: The International Conference: Trends in the Development of Geotechnics, 239-248.

Rakić D, Berisavljević Z, Basarić I, Lazić M, Stevanović M (2017a) Opšti geotehnički uslovi izgradnje autoputa E-80 Niš – Merdare, Deonica: Niš – Pločnik - I Deo. Zbornik radova sedmog naučno-stručnog međunarodnog savetovanja - Geotehnički aspekti građevinarstva, 75-82.

Rakić D, Berisavljević Z, Basarić I, Lazić M, Stevanović M (2017b) Opšti geotehnički uslovi izgradnje autoputa E-80 Niš – Merdare, Deonica: Niš – Pločnik - II Deo. Zbornik radova sedmog naučno-stručnog međunarodnog savetovanja - Geotehnički aspekti građevinarstva, 83-92.

Sayeed I and Khanna R (2015) Empirical correlation between RMR and Q systems of rock mass classification derived from LesserHimalayan and Central crystalline rocks. In Proceedings of the International Conference on "Engineering Geology in NewMillenium", New Delhi, India, 27–29.

Singh JL and Tamrakar NK (2013) Rock mass rating and Geological Strength Index of rock masses of Thopal-Malekhu River areas, central Nepal lesser Himalaya. Bulletin of the Department of Geology, 16, 29-42. doi:10.3126/bdg.v16i0.8882

Somodi G, Bar N, Kovács L, Arrieta M, Török Á and Vásárhelyi B (2021) Study of Rock Mass Rating (RMR) and Geological Strength Index (GSI) Correlations in Granite, Siltstone, Sandstone and Quartzite Rock Masses. Appl. Sci.11, 33-51. https://doi.org/10.3390/app11083351

Terzaghi K (1946) Rock Defects and Loads on Tunnel Supports. In: Proctor, R.V. and White, T.L., Eds., Rock Tunneling with Steel Supports, Commercial Shearing and Stamping Company, Youngstown.

Zafirovski Z, Peševski I and Papić J (2012) Methodology for extrapolation of rock mass deformability parameters in tunneling. Facta universitatis: Architecture and Civil Engineering, 10(3), 235-244.

Zhang Q, Huang X, Zhu H, and Li J (2019) Quantitative assessments of the correlations between rock mass rating (RMR) and geological strength index (GSI) Tunnelling and Underground Space Technology, 83, 73–81. doi:10.1016/j.tust.2018.09.015