ONE APPROACH FOR EXTRAPOLATION OF ROCK MASS PARAMETERS IN TUNNELING

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INTRODUCTION

The problem for extrapolation in tunneling and geotechnics is one of the key problems and basis for succesful geotechnical and numerical modelling in the past few decades. The main goal of this problem is how to extrapolate the parameter from zone of testing to the whole area (volume) that is of interes for interaction analyses along tunnel whole lentgh.

The extrapolation methods are mainly developed for design problems at large dams by Kujundžić, 1973 and 1977. This problem is constantly expanded over time, and in this context it is pertinent to mention the works of Kujundžić and Petrović, 1980; Lokin and Čolić 1980, 1990 and 1996; Lokin, Lapčević, Petričević, 1989; Čolić, Manojlović, 1983; Jovanovski, Gapkovski, Petrevski, 1996; Jovanovski and Gapkovski, 1995, 1998; Jovanovski et al., 2000; Jovanovski, Gapkovski, Ilijovski, 2002, 2003, 2004; Ilijovski, Jovanovski, Velevski, 2004; Ilijovski, 2005 etc.

Site testing methods of rock massif deformability and shear strength were developed and perfected by Kujundžić and his colleagues from the Institute "Jaroslav Černi", Belgrade, 1965, 1966, 1974, 1977, 1983.

Contribution to defining deformability and shear strength of rock massif through empirical failure criteria is given by Hoek and Brown, 1980, 1983, 1988. Application of this method to poor quality rocks demanded further changes (Hoek, Wood and Shah, 1992) and even the development of a new classification based on the application of so-called Geological Strength Index (Hoek, Kaiser and Bawden, 1995, Hoek, 1995, Hoek and Brown, 1997, Hoek, Marinos and Benissi, 1998; Marinos and Hoek, 2000, 2001, Hoek, Carranza-Torres, Corkum, 2002; Marinos, V., Marinos, P. and Hoek, 2005, Hoek, Marinos, P. and Marinos, V., 2005; Marinos, P., Hoek, E. and Marinos, V., 2006, Hoek and Diederichs, 2006; etc.). The contributions of Barton and Chobeau, 1994 and Bieniawski, 1993 should also be mentioned.

Classification systems developed in the field of rock mechanics that need to be highlighted are Geomechanical Classification – Rock Mass Rating system (Bieniawski, 1970, 1973, 1974, 1975, 1976, 1979, 1989); RSR - Rock Structure Rating (Wickham, Tiedemam and Skinner, 1972, 1974); Q system - Rock Mass Quality (Barton, Lien and Lunde, 1974); multiparameter classification system, called ERMR (Excavation Rock Mass Rating), which is mainly used for different types of excavation problems, studied by Jovanovski, 2001 etc.

Computers development in recent decades has contributed to the development of numerical calculation method in rock mechanics which enabled new and wider possibilities of stress and deformation calculation. This had significantly stimulated the development of rock mechanics as scientific and technical discipline as well as the wider application of research results into practice.

So, this article describes a methodology that shows how it is possible to integrate all these approaches in a problem for extrapolation of the parameters in tunnelling. The proposed methodology is based on combination of empirical classification rock mass methods, geophysical measurements and direct deformability testing on a field. The analyses are given based on the results from investigations of several tunnels in the Republic of Macedonia, mainly in rocks with poor to fair rock mass quality.

BASIC THEORETICAL SETUP OF AN EXTRAPOLATION PROBLEM

One of limitations in a process of investigations comes from the fact that the total tunnel length can not be completely covered with detailed geological and geotechnical tests. So it is necessary to find an appropiate way to extrapolate the necessary parameters from a smaller volume of the testing zone to the whole volume of the rock mass along the tunnel length.

In order to establish logical procedure for extrapolation, some experiences are presented in the frame of this article.

In general, all extrapolation methods can be based on the assumptions given by Kujundžić (1977):

1. Parallel static and dynamical geophysical testing directly on a field, as a basis to obtain sets of values for deformability and values of longitudinal seismic waves.
2. Determination of values for longitudinal seismic waves for the interaction area with the engineering structure.
3. Forming direct and indirect analytical regression models between modulus of deformation and elasticity (D and E) with values of longitudinal waves (Vp) and dynamic elasticity modulus (Edyn).
4. Extrapolation of the parameters using the formed regression curves from the area of testing to the whole rock mass volume involved in system rock mass-structure interaction.

In general, the Kujundžić methodology can be defined as a Static-Dynamic method of testing and extrapolation of the results.

Improving this methodology, herein the basics of Empirical–Static-Dynamic (ESD) methodology of extrapolation are given. All known methods for defining of deformability and shear strength of rock masses can be used and combined for extrapolation of parameters for the whole area and length of structures. The prerequisite for using this methodology is following:

1. To have enough data for reliable rock mass classification.
2. To have enough testing data for deformability with static tests.
3. Whole interaction of the structure (in this case tunnel) to be covered with geophysical seismic tests.

Such testing must be performed in a manner that will insure reliable data for geotechnical modeling of the natural geological environment of the whole area along the tunnel. Having in mind that too many properties are needed to characterise certain rock mass completely, it is easy to conclude that the claim for uniformity of all or most of the properties cannot be achieved.

So, before some areas are selected, we choose one or few properties for which the uniformity of one area is demanded. We call these areas quasi-homogenous zones and they represent the basic and constitutive elements of geological model.

Inside such zone some conditions or properties are the same in every point, and very different outside it. Each and every zone is determined by space limits and consists, in some way, properties which are important for the study.

It should be noted, that the process of extrapolation is strictly connected and interrelated to the process of geotechnical modelling of the terrain. The complex geotechnical model consists of three basic models (Pavlović, 1995, 1996):

- model of natural geological environment;
- model of engineering activity - geotechnical model in narrow sense (GM);
- model of interaction - model of stress-strain behavior.

One way to show phases during defining of the interaction model is given in Figure 1.

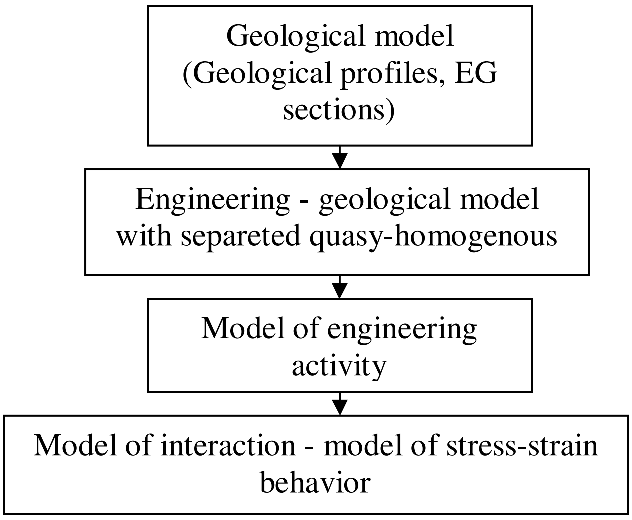

Figure 1. Phases in defining model of interaction

It can be underlined that the model of engineering activity and the model of interaction are final phases of geotechnical modelling.

PRACTICAL EXAMPLES

To illustrate the methodology, in this article, some practical experiences gathered during investigations and design of several tunnels in Republic of Macedonia are presented. The following steps in investigations is used:

1. Collection of data for rock massif test results, particularly laboratory and field test results of strength, deformation, discontinuities and other parameters.
2. Specific laboratory and field testing .
3. Statistical analysis and comparison of data collected from the literature and data collected through research and tests performed for purposes of this article.

Collected data are usually analysed statistically. Only one example for a case of Point Load Strength index parameter, is presented in Figure 2.

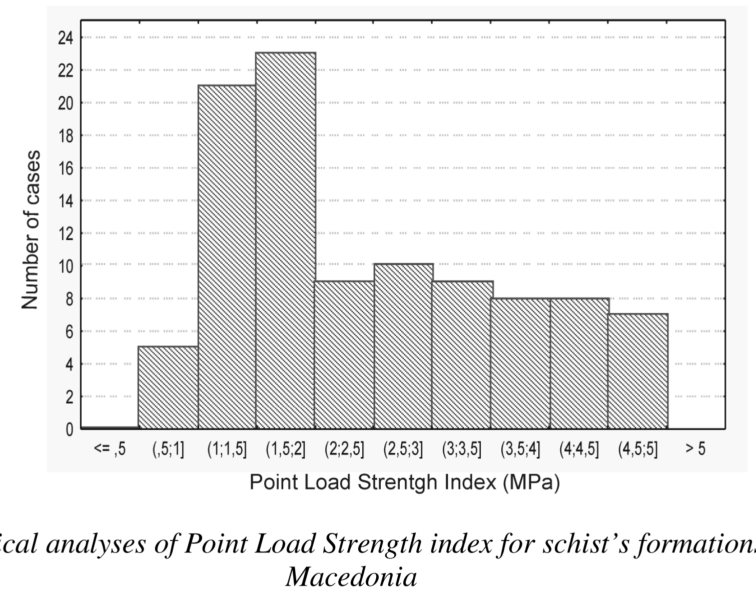

Figure 2. Statistical analyses of Point Load Strength index for schist's formations in Republic of Macedonia

Using all results from geological, geotechnical and geophysical investigations, rock mass quality is defined for all quasihomogenous zones using Rock Mass Rating, Quality index (Q) as well as Geological Strength Index using Hoek GSI classification (Figure 3).

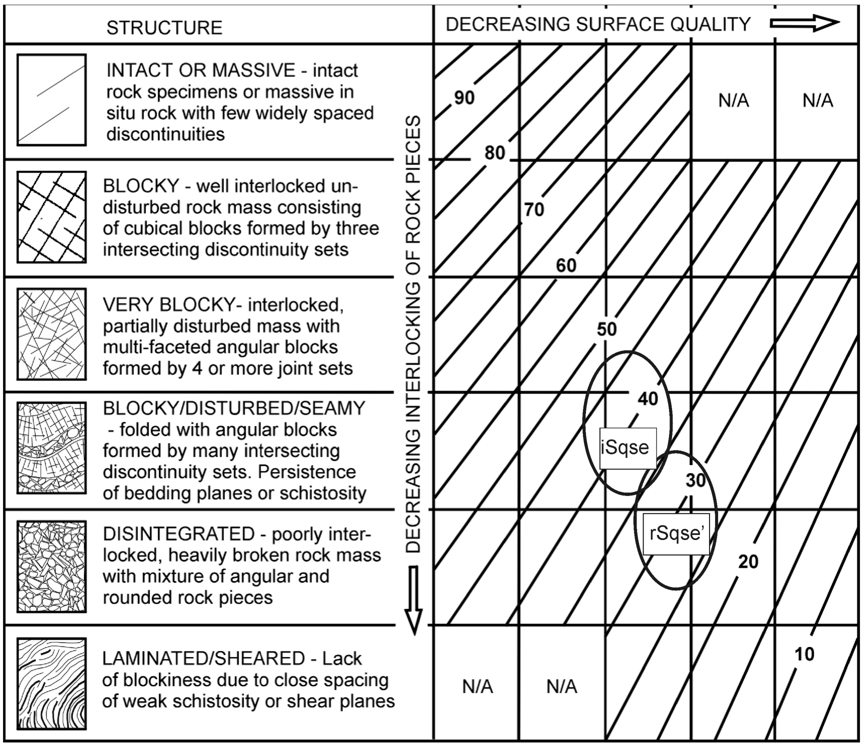

Figure 3. Range of GSI values for different zones of quartz sericitic shists for "Preseka" tunnel

It must be noted, that because of tectonic influences, usually, rock masses in Republic of Macedonia are with poor to fair quality. Some statistical analyses are given in Figure 4 and Figure 5.

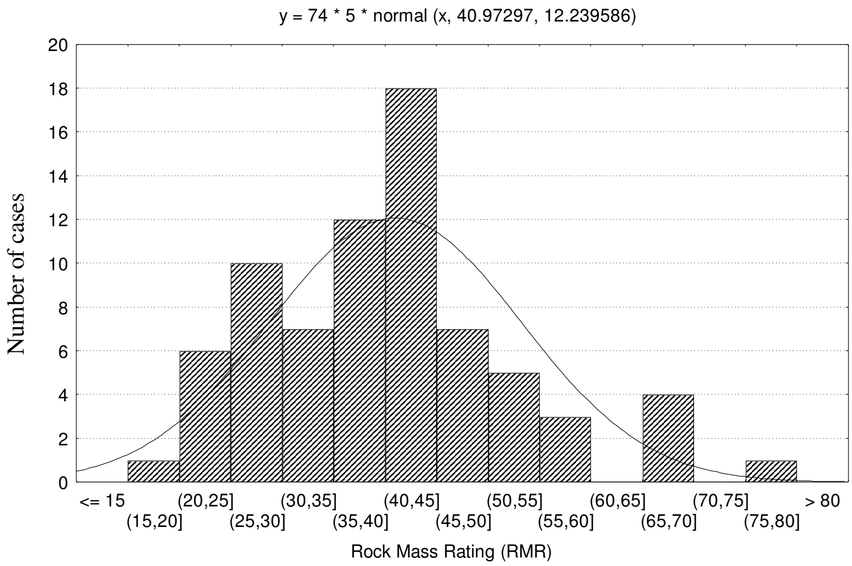

Figure 4. Range of values for Rock Mass Rating (cases for rocks in R. Macedonia)

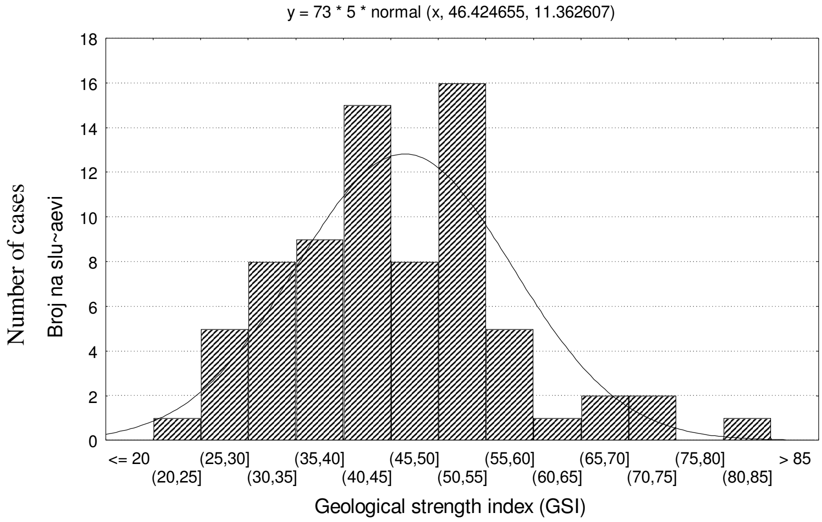

Figure 5. Range of values for Geological Strength Index (cases for rocks in R. Macedonia)

RMR and GSI values were used in order to predict shear strength and deformability parameters of rock massif with a help of Hoek, Carranza-Torres and Corkum, 2002 and Hoek and Diederichs's, 2006 methods.

Beside this, correlations between the quality of rock massif (RMR, GSI and Q indexes), dynamic (Vp and E_{dyn}) and static properties (D and E) of rock masses are expressed using results from the detailed classification of the rock massif around the measuring point with dilatometer testing's. One regression line established for tunnel "Preseka" is presented in Figure 6.

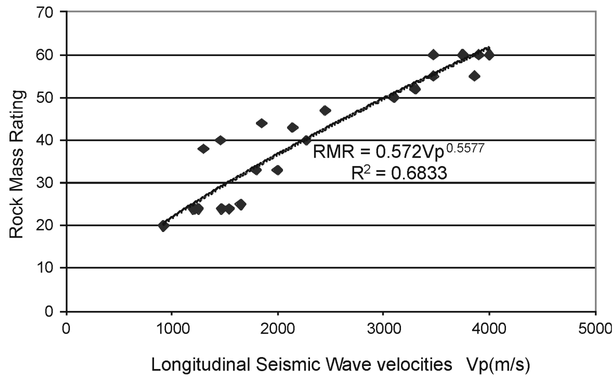

Figure 6. Correlation between rock mass rating (RMR) and longitudinal seismic wave velocities for tunnel Preseka

Some typical deformability diagrams are presented in Figure 7.

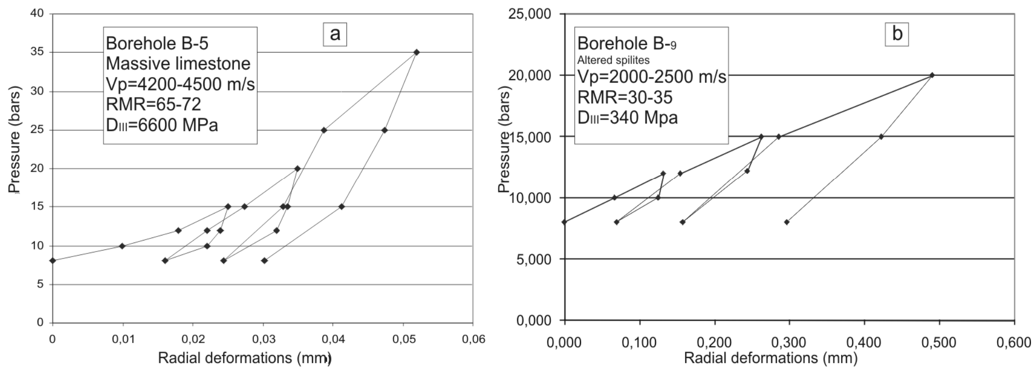

Figure 7. Typical diagrams from dilatometer tests

Finally, based on detailed analyses, a numerous regression models are obtained in order to fulfill the necessary criteria for extrapolation. One regression model between static modulus of deformation (D) and longitudinal seismic waves velocities are shown in Figure 8.

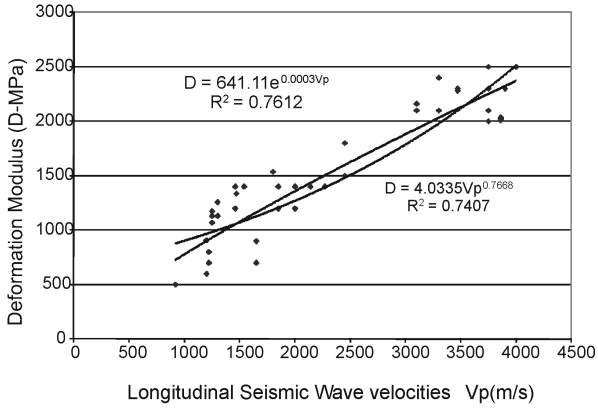

Figure 8. Correlation between Deformation Modulus and longitudinal seismic wave velocities for tunnel "Preseka"

Analyzing all regression models, it is obvious that determination coefficients (r^2) indicate strong connection between examined parameters.

Having such correlations and defined values of seismic waves, for each quasi-homogenous zone along tunnels, it is possible to extrapolate necessary input parameters for numerical analyses (Figures 9 and 10).

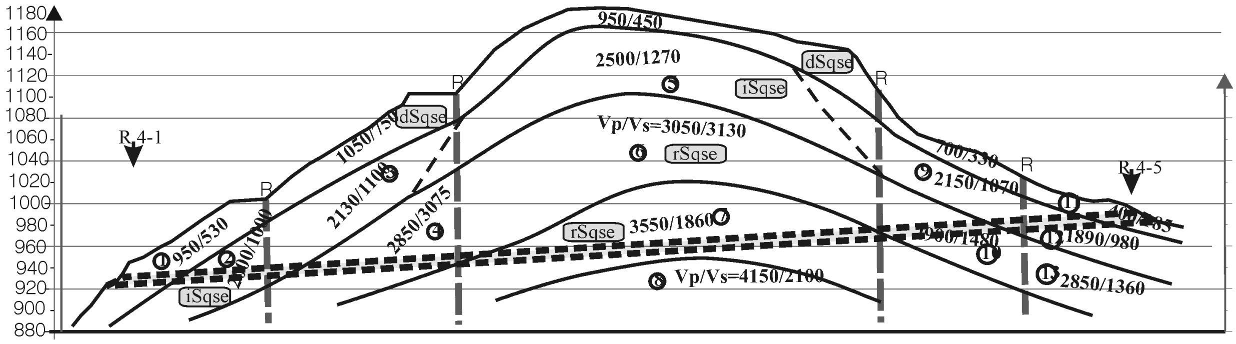

Figure 9. Simplified Engineering Geological Section per seismic wave velocities for tunnel "Preseka" in R. Macedonia

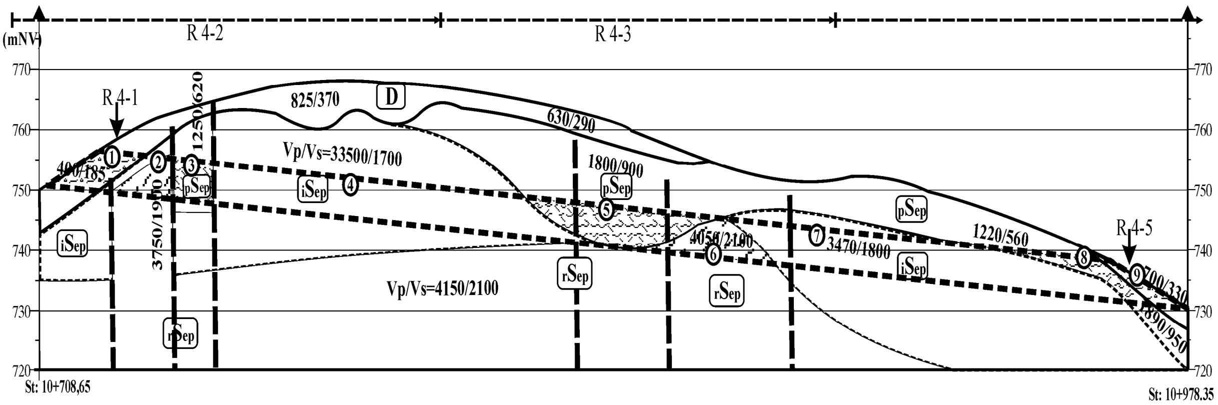

Figure 10. Simplified Engineering Geological Section per seismic wave velocities

In fact, the figures illustrate two EGM models per parameter of velocities of longitudinal elastic waves (V_p for cases of tunnel "Preseka" and Tunnel No 4, designed in an areas of Traffic Corridor 8 in R. Macedonia.

CONCLUSIONS

The presented Empirical–Static–Dynamic method for data extrapolation can be very useful tool in preparation of geotechnical models for further analyses in tunneling. Because of its verification, the suggested methodology must be critically re-examined meanwhile in terms of possibilities to apply it in other locations and other facilities in different geological media.

However, it will open doors and possibilities for further researches, considering that it is practically impossible to exhaust this scientific theme with only one paper. Analytical models for prognosis of possible intervals of deformation modulus *D* are useful as input data in numerical analysis for relatively shallow tunnels.

Also, the process of modelling must be harmonized with research and design phases. It is common to use simpler approaches in initial phases, which meet current quality and quantity of available data. Results of such kind of initial models of complex facilities can indicate the need for new data and they enable re-interpretation of existing data, what, in the other hand, influences the improvement of models or leads to new ideas for new model types.

Based on the aforementioned, we can conclude that there are many unlimited possibilities for further research in this area. The purpose is to improve and confirm the methodologies suggested in this article, yet not only when it comes to tunnelling but also for other types of structures.

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