Statistical Evaluation of Model Rock Compressive Strength at Branisko Exploratory Tunnel Excavation

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Štatistické spracovanie modelovej pevnosti pri razení prieskumnej štôlne Branisko.

Počas razenia východnej časti prieskumnej štôlne Branisko bol na plnoprofilový raziaci stroj Wirth TBII-330-H/M inštalovaný monitorovací a optimalizačný systém WORS, vyvinutý na Ústave geotechniky SAV. Systém umožňoval výpočty v reálnom čase veličín ako špecifická energia rozpojovania a odporučený prítlak raziacej hlavy. Údaje získané monitorovaním boli následne použité ako vstupy do matematického modelu systému IKONA, ktorý umožňoval previesť parametre procesu razenia na parametre horninového masívu. Jednou z takto určovaných veličín bola i modelová tlaková pevnosť horniny, ktorej štatistické hodnotenie je uvedené v článku. Bola skúmaná vhodnosť rôznych rozdelení pravdepodobnosti pre popis modelovej pevnosti v jednotlivých geologických úsekoch prieskumného tunela Branisko. Z analýzy je zrejmé, že pevný celistvý horninový masív najlepšie charakterizuje normálne rozdelenie, zatiaľ čo masív porušený zlomami a diskontinuitami je vhodnejšie popisovať lognormálnym alebo Weibullovým rozdelením.

Kľúčové slová*: razenie tunelov, klasifikačné systémy, pevnosť horninového masívu*

Introduction

In tunnelling there is a great need for geo-data, covering geological, geomechanical, geotechnical and hydrogeological information. The geo-database involves rock types, structural discontinuities and rock material properties in their relation to the designed construction. A proper assessment of results of rock environment requires precise and adequate input values obtained usually by the engineering-geological investigation. Common methods of investigation provide data with a certain time-delay, and the data might not be dense enough (regarding a sufficient number of data for the rock mass characterization).

During the excavation of eastern part of the Branisko exploratory gallery, a unique computer monitoring and optimizing system, called WORS, was installed on the Wirth TBII-330-H/M tunnelling machine. The system was developed at the Institute of Geotechnics, Slovak Academy of Sciences, and has been described in several works (Krupa, 1998). The system provides the optimization of the tunnel boring machine (TBM) operation by scanning the excavation process parameters followed by real-time calculations of the net advance rate, specific disintegration energy and the recommended thrust. TBM driving with the recommended thrust guarantees the excavation with a minimum specific volume disintegration energy.

Using the investigation of the rock-tool interaction, a mathematical model IKONA of the interaction was designed by (Krupa, 1998), determining the rock mass properties such as the model compressive strength, model shear strength and the model RQD index. Long-term research proved good correlations of the IKONA model compressive strength with the strength tests commonly used (uniaxial compressive strength, scleroscopic strength and point load test strength) and approved the model strength for detailed characterization of strength properties of the excavated rock mass.

IKONA - method for real-time continuous determination of rock mass properties

The computer monitoring system recorded the following TBM parameters during the Branisko exploratory gallery excavation: the total thrust force of cutterhead, the cutterhead's torque, the revolutions of the cutterhead and stationing (the distance from the eastern tunnel portal) with 2,03 seconds period for the purpose of the engineering-geological investigation improvement and completion. Monitored parameters enable computations of various excavated rock environment characteristics. One of them is the IKONA model strength of the rock mass σ_{tlH}, which continuously simulates the changes of the rock compressive strength at the tunnel face.

The following equation was derived for the Wirth TB-II-330H/M tunnel boring machine by (Krupa, 1998).

The model strength is defined by a contact pressure of disk into the rock at its disintegration, reduced by the disintegration coefficient C.

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$$\sigma_{tlH} = \frac{1}{10{,}899} \cdot \frac{F}{C \cdot \sqrt{(p + \Delta p)^3}} \qquad [MPa] \tag{1}$$

The C-coefficient (ratio of tangential to normal disk force) models the changes of the rock disintegration mechanism. The details of indirect rock strength determination using the WORS and IKONA systems were described and published in several scientific works (Krupa, 1998) and (Krupa and Lazarova, 2003).

Analyses

The part of the Branisko exploratory gallery excavated by TBM from the eastern portal of total length 2160 m (stationing 136,0 to 2295.65 m) was divided during the engineering-geological investigation into 42 quasi-homogeneous geological sections followed with the classification by various classifying systems. The model strength values were calculated for every 2,03 seconds of the tunnel excavation which means that it covers the rock mass millimeter by millimeter (according to the tunnelling net advance rate). For the purposes of further computations, thoese values of instant model strength were averaged in the manner that one averaged value covers approx. 25 cm of excavated rock mass. Out of the process, 5036 averaged values were obtained for 2130 meters of the rock mass excavated by the Wirth TBM. Such an amount of data forms an ample database for a further evaluation and provides a continuous information on excavated rock environment properties. The averaged IKONA model strength values from particular geological sections have been subjected to the detailed statistical analysis using description statistics, distributional fitting and comparison.

Probability distribution of a variable gives the likelihood that a particular value or range of values will be observed. The continuous probability distribution gives the probability of a range of values (an interval) of a continuous variable. The height of the probability distribution indicates the relative likelihood of certain values. The distributions cover the characters of observed data. Probability distributions are typically defined in terms of the probability density function. There is a number of probability functions used in various applications, (NIST/SEMATECH, 2004).

The histograms of absolute frequencies of model compressive strength have been fitted to various statistical distributions. Their usability for characterization of geological sections with various qualities has been tested by several goodness-of-fit tests (Chi-square, Kolmogorov-Smirnov, Anderson-Darling) using the BestFit, Palisade Software. The first tests results showed that three distributions passed the goodness-of-fit tests, namely the normal, lognormal and Weibull distributions. These distributions describe calculated values of the model compressive strength in a best way.

The normal (Gaussian) distribution is the most common type of distribution and many random variables correspond to it. It is generally used for probability studies in geotechnical engineering if there are no major reasons for use of another distribution. The lognormal distribution is useful when describing multiplicative mechanisms that tend to result in variables which are lognormally distributed, as opposed to the normally distributed variables resulting from additive mechanisms. The weibull distribution is used for the interpretation of devices lifetime or for the test results such as point load tests on the rock core in which a few very high values may occur (Hoek ,2000).

Tab. 1. Description statistics for the model compressive strength in the classes of RQD and QTS classification systems
Tab. 1. Popisná štatistika modelovej tlakovej pevnosti v jednotlivých triedach klasifikačných systémov RQD a QTS

Model strength of rock mass in geological sections with rock quality classes [MPa]					
	using RQD			using QTS	
Rock quality class	**B - good**	**C - fair**	**D - poor**	**B - good**	**C - bad**
Number of data	725	3691	620	1911	2915
Minimum	40,94	1,54	2,70	1,54	1,85
Maximum	271,02	343	235,62	324,06	343
Mean	138,26	94,13	52,28	121,76	79,64
Modus	140,62	66,47	57,39	78,06	57,39
Median	136,43	86,43	46,34	120,08	71,62
Standard deviation	39,15	48,31	34	48,08	45,43
Variance	1530,42	2333,41	1154,1	2310,91	2063,23
Skewness	0,57	1,06	1,57	0,52	1,23
Kurtosis	3,67	4,69	7,27	3,76	5,39

Model compressive strength values taken from particular geological sections classified by the engineering-geological survey of the Branisko exploratory gallery were subjected to a deeper analysis. Instant model compressive strength values were averaged in a manner mentioned above for the purposes of further calculations. As the model strength provides complex information on the rock mass strength, obtained averaged values have then been divided to classes of selected classification systems RQD and QTS. Only three from five classes of the RQD system and 2 from 5 classes of the QTS system were present in the Branisko exploratory gallery rock mass. The data have been evaluated by statistical procedures using several statistical software tools available via Internet. The results exhibit various strength rock properties in compared classes of RQD and QTS. High kurtosis values for every dataset (from 3,67 to 7,27) have proved high accuracy of measured values.

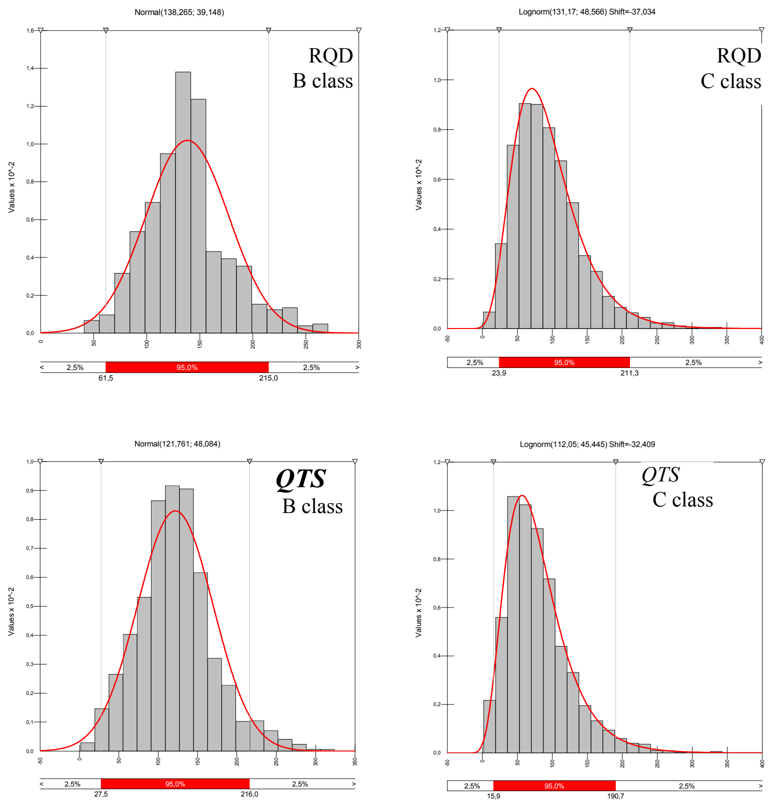

Fig. 1. Histograms of frequency distributions of model rock compressive strength in the classification systems RQD and QTS.
a) RQD – B class (good rock),
b) RQD – C class (fair rock),
c) RQD – D class (poor rock),
d) QTS – B class (good rock),
e) QTS – C class C (bad rock).

Obr. 1. Histogramy rozdelenia modelovej tlakovej pevnosti v triedach klasifikačných systémov RQD a QTS.
a) RQD – trieda B (dobrá hornina),
b) RQD – trieda C (obstojná hornina),
c) RQD – trieda D (slabá hornina),
d) QTS – trieda B (dorbá hornina)
e) QTS – trieda C (zlá hornina)

Conclusions

The geological sections of higher rock strength (B classes of both classification systems) have shown a normal distribution of model rock strength. The histograms of model rock compressive strength from more jointed and worse quality sections exhibit a tendency to skew left, which underlines more a frequent presence of lower strength values with several extremely high values. Those histograms have fitted the lognormal and Weibull distributions best. An obvious transition from the normal distribution in sections classified by both RQD and QTS systems as "good" to the Weibull and lognormal distributions in sections classified as worse ones, inheres probably in the different mechanism of the rock disintegration by the cutterhead. The disintegration mechanism may change when moving from strong tough rocks to the jointed rock mass.

Such procedures of fitting histograms into distributions have been carried out for the data of every geological section. Due to a small space, the graphic results are not presented, but the results were the same, i. e. stronger rock mass corresponds to the normal distribution and weaker to the lognormal, Weibull or even exponential distributions.

Out of available monitored and calculated model rock strength data analyses it has arisen that the stronger rock mass may be described better by the normal distribution, while the jointed rock mass may be described better by the Weibull or lognormal distribution.

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