Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3
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doi: 10.32075/17ECSMGE-2019-0594

XVII European Conference
ECSMGE 2019 Reykjavik
on Soil Mechanics and Geotechnical Engineering

Determination of deformation modulus from in-situ pressuremeter and dilatometer tests

La détermination du module de déformation basée sur les essais pressiométriques et dilatométriques in situ

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ABSTRACT: Deformation modulus is an important characteristic of rock mass mechanical behaviour. The deformation parameters of rock mass may be obtained by in-situ tests, which is the most reliable and comprehensive method to describe the mechanical behaviour of rock mass. Results of pressuremeter and dilatometer tests from different geological environments are presented in this paper. More than 300 tests were carried out in crystalline igneous, Flysch and carbonate rocks in order to compare two types of in-situ geotechnical tests results. Logging measurements were conducted in each borehole in advance of geotechnical testing in order to choose the best testing section of the borehole. Consequently, the pressuremeter and/or dilatometer tests were performed in selected boreholes. It was observed that the difference between deformation modulus determined by dilatometer and pressuremeter tests could be significant particularly for intact rock with high *RQD.* Correlation for estimating rock deformation parameters–for example in the places without testing borehole –was derived based on analysis of the results from dilatometer and pressuremeter in-situ testing of rocks. Differences in mechanical behaviour of various rock types with diverse degree of jointing were also determined.

RÉSUMÉ: Le module de déformation est une caractéristique importante du comportement mécanique du massif rocheux. Les paramètres de déformation massif rocheux peuvent être obtenus par des essais in situ. Les essais in situ présentent la méthode la plus fiable et la plus complexe pour décrire le comportement mécanique du massif rocheux.. Les résultats des essais pressiométriques et dilatométriques des différents environnements géologiques sont présentés dans cet article. Plus de 300 essais ont été effectués sur des roches ignées cristallines, des roches de Flysch et des roches carbonatées afin de comparer deux types de résultats d'essais géotechniques in situ. Les mesures diagraphiques ont été effectuées dans chaque trou de forage avant les essais géotechniques, ce qui a permis de choisir la meilleure section des essais du trou de forage. En conséquence, les essais au pressiomètre et / ou au dilatomètre ont été effectués dans des trous de forage sélectionnés. Il a été observé que la différence entre le module de déformation déterminée par des tests au dilatomètre et au pressiomètre pourrait être significative, en particulier pour les roches intactes présentant une RQD élevée. La corrélation pour l'estimation des paramètres de déformation de la roche - par exemple dans les endroits sans de trou de forage d´essai- a été dérivée sur la base de l'analyse des résultats d'essais in situ au dilatomètre et au pressiomètre. Les différences dans le comportement mécanique de divers types de roches avec divers degrés de jointement ont également été déterminées.

Keywords: rocks, field testing, dilatometer, pressuremeter

1 INTRODUCTION

The deformation parameters of rock mass are very important geotechnical characteristics describing mechanical behaviour of rocks. These parameters may be obtained by execution of various in-situ tests, which provide most reliable and comprehensive information about the mechanical properties of rock mass (Bieniawski 1978; Goodman 1989; Hoek and Brown 1997). In Slovakia, the most common and widely used in-situ tests in rock environment are pressuremeter and dilatometer tests in boreholes. These tests complement information about geological conditions and also the results of borehole logging and laboratory tests of rock. During the execution of dilatometer and pressuremeter tests, further parameters of rock environment were collected in the field, i.e. macroscopically described degree of weathering or faulting. In the case of using a proper drilling method, it is possible to determine also the value of rock quality designation (*RQD*). This value is one of the most important parameters for rock mass quality evaluation and is widely used in many geotechnical calculations and special evaluations methods for rock environment. In the case of carrying out a relevant number of investigation boreholes, it is possible to do statistical analysis to develop correlation between the in-situ determined value of *RQD* or macroscopically estimated degree of faulting and deformation or strength parameters (Zhang and Einstein 2004, Zhang 2010). The indirect methods can be divided into empirical correlation methods and the equivalent continuum approach (Zhang 2010).

2 LOCALITIES AND GEOLOGICAL CONDITIONS

Results of pressuremeter and dilatometer tests from different geological environments are presented in this paper. Selected rocks consist of wide variety of different rock types. More than 300 tests were carried out in crystalline igneous, flysch and carbonate rocks in order to compare two types of in-situ geotechnical tests results. On the Figure 1, a schematic geological map of Slovakia is presented, with marked localities of rocks testing. Locality A (Kycerka) is situated in north-west part of Slovakia in the flysch belt, locality B (Korbelka and Cebrat) consist of two sites in Velka Fatra mountains in sedimentary rocks, and locality C (Krivan) is located in the south part of Slovakia in Veporic crystalline rock fundament in Slovenske stredohorie mountains.

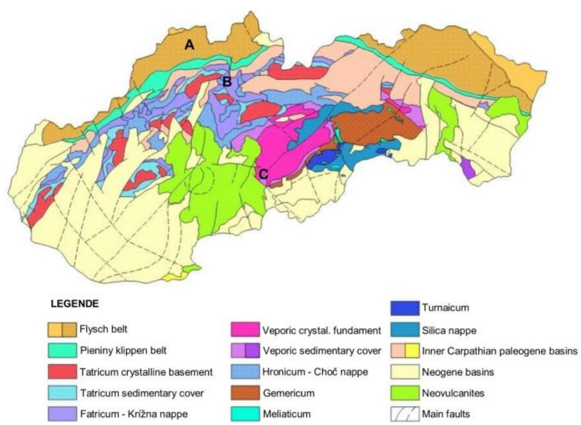

Figure 1. Schematic geological map of Slovakia. A – locality Kycerka, B – locality Korbelka and Cebrat, C – locality Krivan

2.1 Locality A

The locality A (Kycerka) is situated in Flysch Belt. This geological unit consist of sedimentary rock complex, created of few partial nappes. Rocks occuring in this environment are mainly claystones, siltstones and sandstones with various degree of weathering and faulting.

The geological investigation for new railway tunnel Kycerka (4100 m) was realised during 2012. During these works, a number of investigation boreholes were driven to obtain detailed geological and geotechnical information about rock environment in vicinity of the designed tunnel line. Results from 40 pressuremeter tests and 76 dilatometer tests, conducted in the boreholes, have been included into statistical evaluating.

2.2 Locality B

Korbelka and Cebrat are located in valley of river Váh in Velka Fatra mountains. The area is build up of Mesozoic and Paleogene sedimentary rocks. Two main geological units occur in this area – Fatricum (Krizna nappe) and Hronicum (Choc nappe). The Fatricum unit consists of sequences of sedimentary and carbonate rocks, mainly claystones, siltstones, sandstones, limestones and its variations, while the Hronicum unit in the area is explicitly built up of carbonates – dolomites and limestones. The rocks are usually detailed folded and faulted, with various degree of jointing and weathering.

In this part of Slovakia, a new highway D1 will be constructed between Turany and Ruzomberok towns. Three new highway tunnels – Korbelka (5800 m), Havran (2800 m) and Cebrat (3600 m) are planned on this route. The geological investigations for these tunnels were carried out between the years 2013 and 2017. During the ground investigation, 73 of pressuremeter tests and 240 of dilatometer tests were conducted to obtain proper geotechnical parameters of rock environment.

2.3 Locality C

The locality Krivan is formed by Palaeozoic crystalline rocks of southern Veporicum and metamorphic crystalline rocks of Revuca group (perm). Paleozoic crystalline mass of this area consists of wide varying type of granitoids, such as granite, tonalite, granodiorite, diorite, migmatite with bodies of paragneisses or amphibolites. Palaeozoic metamorphic complex consists of slightly metamorphed sandstones and volcanoclastical sediments, or of phylitic schists, phylites, thin layers of volcanogenic material, very sporadic intrusive bodies of acid rhyolite metavolcanoclastics. All these sediments are recrystyalized and schistose due to regional metamorphose.

The geological investigation was carried out for new highway R2 in the section between Krivan and Lucenec during the year 2016. Investigation boreholes were performed for bridge foundation designs on this route. Altogether, 150 dilatometer tests and 120 pressuremeter tests were conducted in crystalline rock massifs.

3 FIELD TESTS

In all three localities, a number of different investigation methods were applied: dilatometer and pressuremeter tests, Lugeon tests, borehole logging and, of course, laboratory analysis of rock mechanics.

Dilatometer tests were carried out by PROBEX dilatometer probe, which consist of robust inflatable membrane with the length 475 mm, hydraulic and electrical circuit and electronic datalogger. Hydraulic system can reach load up to 30 MPa. Maximum depth range is about 500 m.

Pressuremeter tests were conducted with standard equipment for Ménard pressuremeter, with inflatable membrane of 10 cm length and two inflatable protection cells. Theoterical load capacity of this probe is 10 MPa and maximum depth range up to 30 m.

Due to a relatively large number of field tests, it was possible to apply statistical methods to analyse the test results. Comparison of the results using dilatometer and pressuremeter testing in similar (comparable) rock environment was analysed, focused on deformation modulus E_{def} and presiometric modulus E_p determination. For selected dilatometer tests result, the modulus of deformation $E_{\mathrm{def\ PR}}$ was derived in lower load range, which corresponds to the common load range of pressuremeter tests with maximum reached limit pressure (within the meaning of pseudo-linear behaviour during pressuremeter test).

4 RESULTS OF TESTS

The number of dilatometric tests is higher than number of pressuremeter tests (Table 1). The main reason for that is shallow depth (up to 30 m) of pressuremeter equipment and therefore less possibility to conduct valid pressuremeter tests due to occurrence of more jointed or weathered rocks in relatively shallow boreholes and higher risk of probe damages. These limitations caused also that lower number of pressuremeter tests were conducted in high quality rock environment, while dilatometer tests seemed to be more general for various geological conditions.

Table 1. Overview of in-situ dilatometer (DMT) and pressuremeter (PMT) tests

Heading	DMT	PMT
Locality A	76	40
Locality B	240	73
Locality C	150	120

4.1 Results of in-situ tests in flysch rock formation

As it was mentioned above, number of valid pressuremeter tests were rather limited in this area, only a small number of tests were conducted in the environment of good or very good quality.

Results from dilatometer tests are shown in the Figure 2. The graph on the left side shows the relation between *RQD* and deformation modulus E_{def} obtained from all valid dilatometric tests, without any deeper statistics. A simple correlation between *RQD* and E_{def} can be obtained using exponential or power fit equation. For the power fit it is possible to use the equation:

$$E_{def} = 0.496 \,.\, RQD^{1.97} \qquad (1)$$

with $R^2 = 0{,}571$.

For the exponential fit the following equation can be used:

$$E_{def} = 57.39 \,.\, 1.05^{\,RQD} \qquad (2)$$

with $R^2 = 0{,}607$.

This relation can be valid only for tests carried out in better rock quality conditions. Analogically, it is possible to use the average load range as an independent variable to express overall deformational and strength hardness (Figure 2 in the middle). The macroscopic degree of faulting (jointing) given by geologist during geological documentation can be also used for regression (Figure 2 right). The relation between *RQD* and E_{defPR} for lower load range from dilatometer tests is presented on the Figure 2 left.

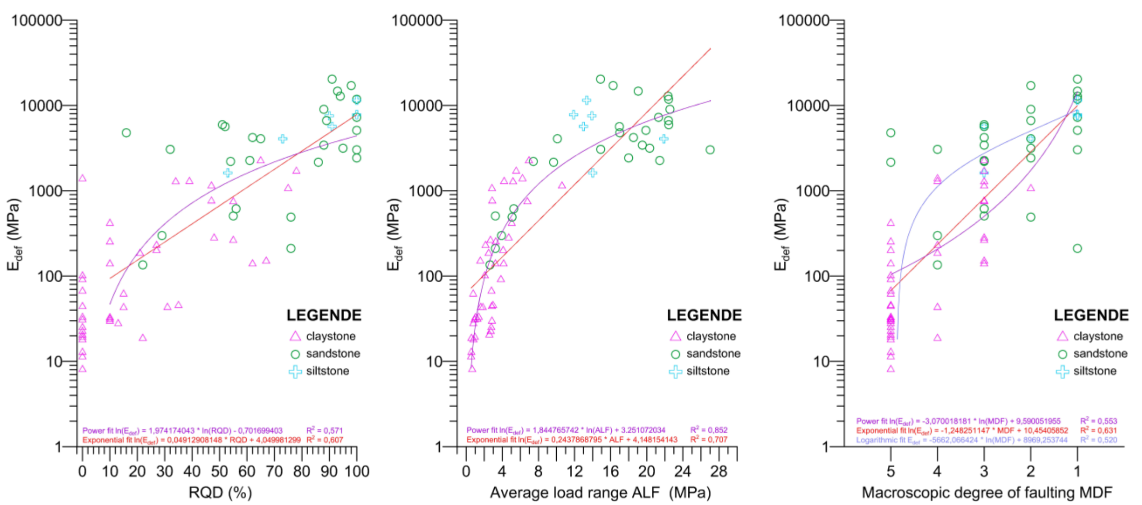

Figure 2. Results of dilatometer tests from flysch rocks. Relation between deformation modulus E_{def} and RQD (left), average load range (middle) or macroscopic degree of faulting (right).

From the pressuremeter tests relations are not so clear due to worse data set. Different relations between *RQD* or degree of faulting and E_{def} could be obtained for distinct rock types, separately for hard rock such as sandstones, and for soft rock such as claystones.

4.2 Results of in-situ tests in Mesozoic sedimentary and carbonate rock formation

Due to larger data set, results from the dilatometer and pressuremeter tests are more reliable than in the case of flysch rock from locality Kycera. On the other hand, there is a higher variability in rock lithology and degree of jointing or faulting.

In the Figure 3 left, the relation between *RQD* and E_{def} for all valid tests and all rock types is shown. Thanks to very brittle behaviour of some rock types (namely dolomites), an evident concentration of test results with high E_{def} at *RQD* level 0% can be seen. A simple correlation between *RQD* and E_{def} (with the RQD ranging between 10% and 100%) can be obtained using exponential or power fit equation. For the power fit, it is possible to use the equation:

$$E_{def} = 5,26 \,.\, RQD^{\,1,53} \tag{3}$$

with $R^2 = 0{,}332$.
For the exponential fit the equation:

$$E_{def} = 187{,}65 \,.\, 1{,}04^{RQD} \tag{4}$$

with $R^2 = 0{,}607$ can be used.

According to the low R^2 coefficients, it is obvious/ it can be crearly seen that this is a very rough estimation and therefore more detailed statistics should be used to obtain better fit.

In the Figure 3 middle, a very interesting relation between average load factor (ALF) and E_{def} can be seen, with relatively clear trends of dependence. In the Figure 3 right, the relation of macroscopic degree of faulting (jointing) and E_{def} is shown, with marked concentration of test results and wide range of E_{def} values on the degree 4 for almost all rock types, but especially for the dolomites.

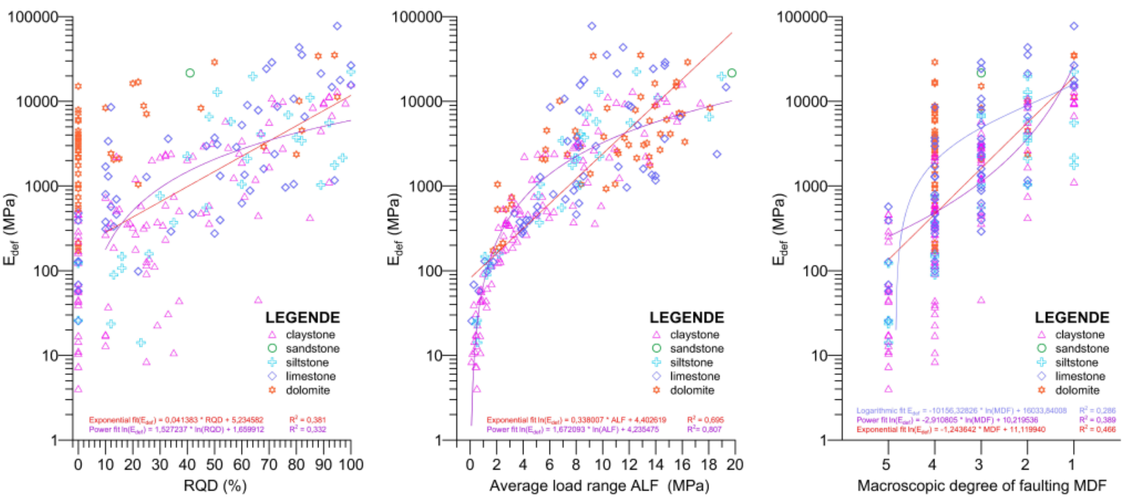

Figure 3. Results of dilatometer tests from Mesozoic sedimentary and carbonate rocks. Relation between deformation modulus E_{def} and RQD (left), average load range (middle) or macroscopic degree of faulting (right).

The relation between *RQD* and E_{defPR} for lower load range obtained from dilatometer tests is presented in the Figure 4 left. The concentration of $E_{def\ PR}$ values at 0% *RQD* is marked. From the further two graphs (on the Figure 4 middle and right) a dependence of *RQD* value or macroscopic degree of faulting respectively and modulus E_p from pressuremeter tests is shown. Thanks to relatively shallow depth range of pressuremeter equipment, the graphs show good data set only for low *RQD* values or high degrees of faulting (jointing) of rocks.

4.3 Results of in-situ tests in Paleozoic crystalline and metamorphic rock formation

Very good data set for both dialtometer and pressuremeter tests was obtained in Paleozoic crystalline rock complex. In spite of relatively wide range of distinct rock types, the results of field tests seem to be very homogeneous.

In the figure 5 left, the relation between *RQD* and E_{def} is shown. Simple regression shows high dependence, which can be expressed by equation:

$$E_{def} = 1{,}25 \ . \ RQD^{2{,}03} \tag{5}$$

for power fit with coefficient of determination $R^2 = 0{,}606$.

For exponential fit, following equation can be used:

$$E_{def} = 150{,}52 \ . \ RQD^{\ 0{,}053} \tag{6}$$

with determination $R^2 = 0{,}610$.

From the graph, a relatively good distribution of results for all rock types can be seen.

Analogically, in the Figure 5 middle and right the relations between average load (ALF) or macroscopic degree of faulting (MDF) and modulus E_{def} are presented. For lower load range a depedence of $E_{def\ PR}$ and *RQD* is on the Figure 6 left. Relation of E_p from pressuremeter test and *RQD* or macroscopical degree of faulting respectively can be seen on Figure 6 middle and right.

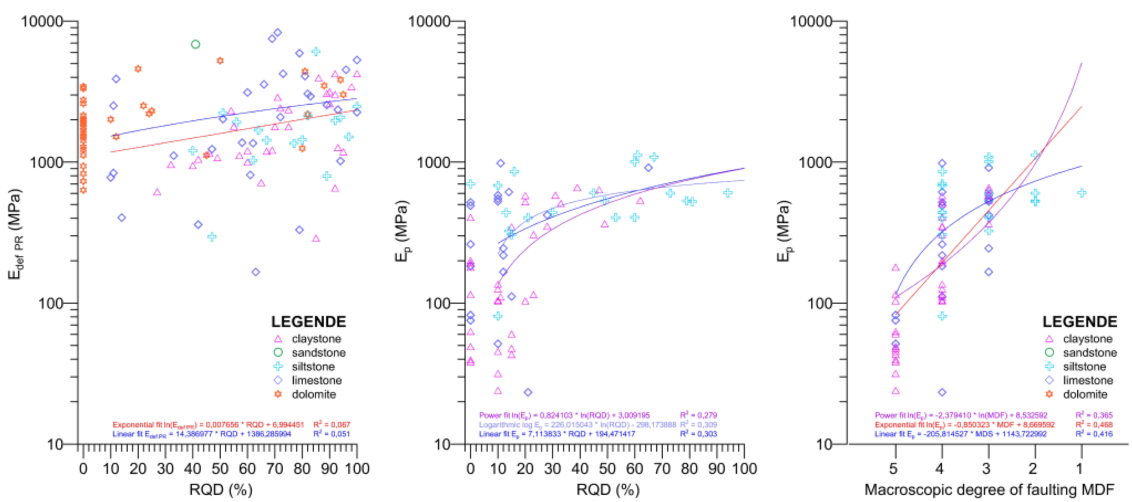

Figure 4. The relation between derived deformation modulus $E_{def\ PR}$ and RQD from dilatometer tests (left) for Mesozoic rocks, relation between pressuremeter modulus E_p and RQD (middle) and relation of macroscopic degree of faulting and E_p (right).

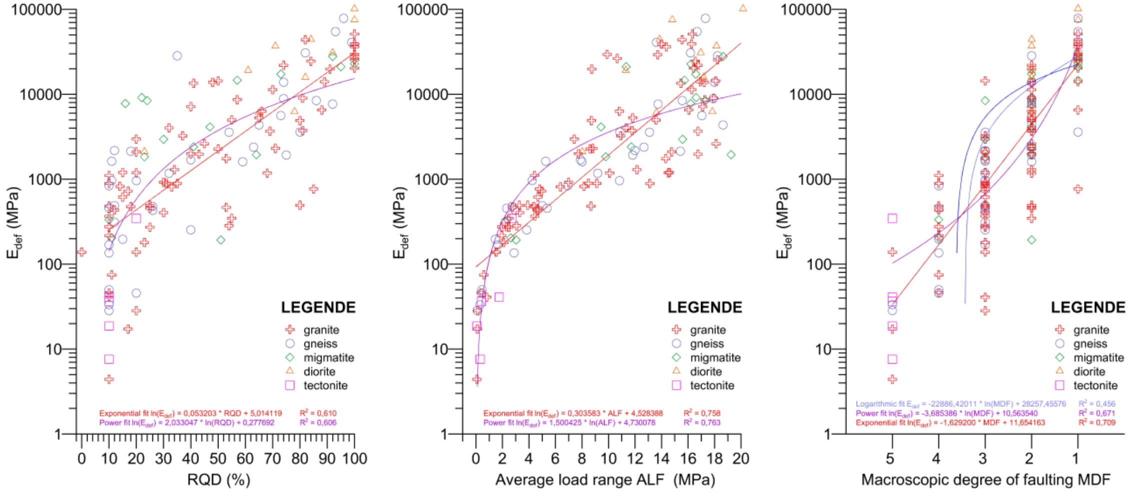

Figure 5. Results of dilatometer tests from Paleozoic crystalline and metamorphic rocks. Relation between deformation modulus E_{def} and RQD (left), average load range (middle) or macroscopic degree of faulting (right).

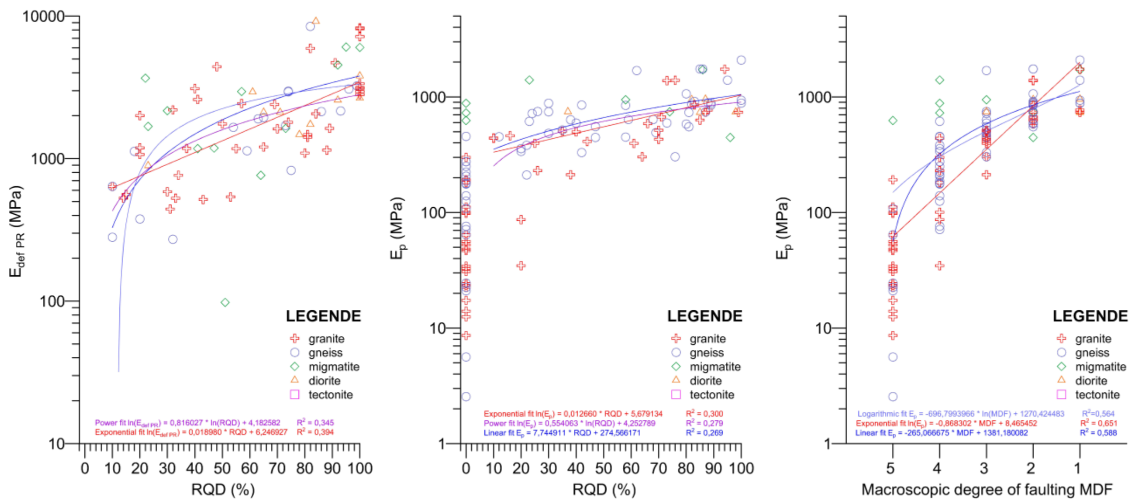

Figure 6. The relation between derived deformation modulus $E_{def\ PR}$ and RQD from dilatometer tests (left) for Paleozoic crystalline and metamorphic, relation between pressuremeter modulus E_p and RQD (middle) and relation of macroscopic degree of faulting and E_p (right).

Due to rock environment character in Paleozoic crystalline and metamorphic complex with relatively good balanced occurrence of all engineering geological types of rocks, all degrees of faulting (jointing) or whole *RQD* range are covered with pressuremeter or dilatometer test results.

5 CONCLUSIONS

The geomechanical properties of rock masses can be determined through direct or indirect investigations. The direct methods include in-situ tests on field rock masses. Results of deformation modulus determination by dilatometer and pressuremeter tests were analysed for sedimentary, carbonate, crystalline and metamorphic rocks.

It was observed that the difference between deformation modulus determined by dilatometer and pressuremeter tests could be significant especially for intact rock with high *RQD*. Dilatometer tests seemed to be more general for various geological conditions. The main reason is less possibility to conduct valid pressuremeter tests due to occurrence of more jointed or weathered rocks in relatively shallow boreholes and higher risk of probe damages.

Empirical equations for indirect estimation of the deformation modulus are simple and may be cost-effective in many engineering applications. Although various empirical methods have been developed, they come in many forms and are scattered in different sources (Zavacky et al., 2017, Zhang, 2017). In the cases, where an adequate set of rock strength tests is not available, an indirect approach can be used, for example using of average load value for each test as an independent variable.

Presented correlations are based on *RQD* or macroscopically evaluated degrees of faulting MDF). This could be used in inaccessible places, where no drilling rig can be installed, therefore no field testing can be provided. Correlations developed locally for a particular geological setting tend to have relatively small variation, as opposed to the relatively large variation for those developed based on global data that may involve many different geological settings (Phoon and Kulhawy, 1999; Zhang et al., 2004).

6 ACKNOWLEDGEMENTS

This paper was supported by Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic, VEGA, grant project No. 1/0842/18.

7 REFERENCES

Bieniawski, Z. T. (1978). Determining rock mass deformability: Experience from case histories. *Int. J. Rock Mech. Min. Sci*. Geomech. Abstr., 15, 237–247.

Goodman, Richard, E. (1989). *Introduction to rock mechanics*. John &Sons, New York

Hoek and Brown (1997). Practical estimates of rock mass strength. I*nt J Rock Mech Min Sci* 34(8):1165–1186

Phoon, K.K., Kulhawy, F.H. (1999). Evaluation of geotechnical property variability.*Canadian Geotechnical Journal* 36 (4), 625–639

Závacký, M., Štefaňák, J., Horák, V., Miča, L. (2017). Statistical Estimate of Uniaxial Compressive Strength of Rock Based on Shore Hardness. *Procedia Engineering,* 191: 248-255

Zhang L., Einstein HH (2004). Using RQD to estimate the deformation modulus of rock masses. *Int. J Rock Mech Min Sci* 41: 337-341

Zhang, L.M., Tang, W.H., Zhang, L.L., Zheng, J.G. (2004). Reducing uncertainty of prediction from empirical correlations. *Journal of Geotechnical and Geoenvironmental Engineering* 130 (5), 526–534

Zhang.L, (2010). Method for Estimating the Deformability of Heavily Jointed Rock Masses. *J. Geotech. Geoenviron. Eng*., 136(9): 1242-1250

Zhang L., (2017). Evaluation of rock mass deformability using empirical methods – A review. *Underground Space* 2, 1–15