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Professional paper

THE POINT LOAD TEST, GEOTECHNICAL DATABASE CREATED FROM INVESTIGATIONS FOR INFRASTRUCTURE PROJECTS IN THE REPUBLIC OF MACEDONIA – ANISOTROPY ANALYSIS

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A b s t r a c t: The point load test is one of the most exploited techniques to obtain preliminary information of the strength of the rocks. The paper deals with statistical analysis of large amount of results from the test, obtained for the needs of geotechnical investigations on various structures which are part of the European transport corridors VIII and X in the Republic of Macedonia. Additional number of results have been taken from investigations for other structures. Most of the analyzed rocks had clearly expressed anisotropy. All results are systemized in a GIS database and classified according rock type and belonging in specific geotectonic unit. After that, various analytical regressions with different level of confidence had been established. Effort was made to correlate the values of the point load index parallel and perpendicular to the anisotropy, as well as the values of the point load with the unit weight & unit weight with depth of samples. Most important finding is that some of these correlations, mainly related to the anisotropy of the values of the point load, show high level of correlation and can be suggested for use in preliminary levels of investigations or during control investigations. The use of such correlations is limited in regard of the rock type and the geotectonic unit. Confident correlation for the point load vs. unit weight & unit weight vs. depth of samples was not obtained. Similar analysis is proposed to be done for massive rocks and rocks in frames of specific mineral deposits, where the authors believe it is possible to obtain stronger correlation coefficients also for the two latter correlations.

Key words: point load test; GIS database; statistical analysis; correlations; analytical regressions; limitations

INTRODUCTION

The point load test presents one of the most used index tests in the field of rock mechanics. It serves the purpose of obtaining initial information on the strength of rock samples at the level on. The test can be conducted both in the field and in laboratory. It is performed in the initial phases of geotechnical investigations (when execution of more exact strength determination tests is not yet feasible), but also in phases of detailed or control investigations (with aim to cross check results of more advanced tests). The present paper statistically analyzes large number of point load tests results obtained from various infrastructure projects in the Republic of Macedonia. The main aim is to establish correlations related to anisotropy. In order to create conditions for such an analysis, it was necessary to create appropriate Database in GIS environment.

SOME ASPECTS ON THE DEVELOPMENT OF THE POINT LOAD TEST

The various aspects of the point load test have been investigated by many researchers. In general, the test for determination of the strength index (known in literature as the point load test or point load index test) is relatively simple. For this test portable equipment can be used and no special machining is needed for the sample. It means that core samples as well as lump samples with irregular shape can be tested. However the criteria and corrections for size and shape of the tested samples should be respected. The index test is based on the indirect tests for tensile strength. The disadvantages of those indirect tests are neglected in this case because the tensile strength is not tested but the compression strength.

Broch and Franklin (1972) developed the point load test financed by the Rock Mechanics Project, Imperial College London, with respect to the previous works done for this test and including a large scope of experimental work in order to determine the influence on various factors. According to these authors the irregular shape has small influence on the strength of the sample. However, when conducting this test, as many lumps as possible should be tested in order to obtain an accurate mean value. Also, comparing the mean and median value the authors recommend a minimum number of 10 samples after which it is thought that a small improvement of the results is obtained. In cases when core samples are tested it can be said that the greater the length of the sample the less the influence from that dimension. If the tested samples are short then the plane of failure will intersect any of the ending faces. Broch and Franklin (1972) concluded this after testing a lot of samples from two different types: sandstone and dolerite and determined a minimal length of the sample of $D = 2L$. The authors also recommended correction of the strength index value for a reference value of diameter equal to 50 mm. Furthermore, they inspected the influence of water on the strength of the materials and noticed that even a strong rock material such as granite can reduce its strength. Therefore, it should be pointed out in which state the samples were tested in the presentation of the results for their strength. Also they thoroughly investigated the anisotropy of the materials with respect to the strength and suggest that as many tests should be performed in different directions of the samples.

Broch (1983) conveyed a research for the anisotropy of the materials. According to the author the best results are obtained if a core is drilled perpendicular to the bedding or foliation after which uniaxial compressive test is done and point load tests on the resulting lumps in various directions.

The point load test on irregular samples was developed in Russia by Protodyakonov (1960a, 1960b, 1961, 1963). He determined the strength index by dividing the force of failure by 2/3 power of the volume of the sample, which is approximation of the cross sectional area of the irregular sample. The International Bureau for Rock Mechanics (1964) introduced Protodyakonov's procedure as standard procedure.

In Britain this test was investigated by Hobbs (1963) with special attention on sedimentary rocks. His main critic on the procedure by Protodyakonov was that in the case of samples from laminated rocks the greater axis is mainly the plane of lamination, whereas the test requires to be done parallel to the longest axis and perpendicular to the plane of lamination.

The test on lump samples was also inspected by the authors Diernat and Duffaut (1966), Duffaut (1968), Duffaut and Maury (1970). They especially concentrated on the influence of the size, shape and the orientation of the sample on the results from Protodyakonov's test.

Hiramatsu and Oka (1966) proposed their formulation of the test which minimizes the practical issues by expressing the strength as ratio of the force of failure to the square of the distance between the contact points which can be easily determined and measured. According to these authors this formulation exactly corresponds to elastic sphere loaded between two points along a diameter and it is appropriate simplification for irregular samples. Also this method is pretty useful for testing the rock weathering because the samples usually have irregular shape and their machining is not needed, which is not always possible because of their decomposition.

Reichmut (1963, 1968) in USA conveyed an experimental study for the effects of the size and shape of the samples and his formulation was such that the empirical curves fit the experimental results. Then the United States Bureau of Mines used the diametral test as well as other index tests and showed that the test with point loading has the best correlation with the uniaxial compressive strength (correlation coefficient of 0.947).

Based on all these findings, the test was recommended by the ISRM – International Society of Rock Mechanics Commission on Testing Methods, Suggested Method for Determining Point Load Strength as presented in Franklin (1985), as well as in the standard by ASTM (ASTM International) – formerly American Society for Testing and Materials, D 5731-05 Standard test method for determination of the point load index of Rock. Annual book of ASTM standards, vol.04.08 (Current version of the standard from 1995).

According to these standards, in current practice the results of the point load test are obtained as described in the following section.

The main dimensions that should be recorded are the distance between the platen contacts *D* (mm), the width of the lump sample *W* (mm) and the length of the sample *L* (mm). Also the rupture load *P* (N) should be recorded. If the lump does not have a constant width then a mean value should be used for the smallest and the largest width. Then the uncorrected strength index is calculated by $Is = P/De^2$ (MPa) where *De* for irregular samples is $De = 4\ WD/\pi$ (mm²). If the diameter of the specimen is other than 50 mm, then a corrected strength index is obtained by the following expressions: $Is(50) = F \times Is$, where $F = (De/50)^{0.45}$. The mean value is calculated by neglecting the two highest and the two lowest values of all 10 or more samples tested. Furthermore, if the sample has bedding or foliation the Strength Anisotropy Index should be determined as ratio of the mean *Is*(50) values perpendicular and parallel to the planes of weakness. Also the recommendations state that usually the tensile strength is 0.8*Is*(50) and the uniaxial compressive strength is 20–25 times greater than the strength index *Is*(50), however in some cases it can be also 15–50 times greater. Therefore, the correlations should be used very carefully.

Nowadays many researchers investigate the correlations of the point load strength index and other parameters measured with direct tests for particular rock types.

The intention of the paper is to present certain correlations of the point load test results obtained for specific rock types from different geotectonic zones in the Republic of Macedonia (mostly on anisotropic rocks) and suggest if they can be used in various fields or rock engineering.

BRIEF DESCRIPTION OF SOME OF THE STATISTICAL METHODS USED IN THE RESEARCH

Statistics with its methods is a science of data. One of the most important tasks of Statistics is to organize them, with our thinking about them, to analyze them and give interpretation of obtained statistical results. In this section will be presented some of the notations and methods in the Statistics, which are further used.

Let we have a sample distribution with an observed values $x_1, x_2, \ldots, x_n$. The mean of the sample is defined as

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{k} x_i.$$

If the value x_1 occurs n_1 times, the value x_2 occurs n_2 times, …, x_k occurs n_k times, $n = n_1 + n_2 + \ldots + n_k$, then the mean value of the sample is

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{k} (n_i x_i).$$

The variance is the sum of the squared deviations divided by one less than the number of observations:

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n} (x_i - \bar{x})^2 .$$

The standard deviation is the square root of the variance, i.e. $s = \sqrt{s^2}$.

The variance s^2 and especially its square root, the standard deviation s, are common measures of spread about the mean as center. The standard deviation s is zero when there is no spread and gets larger as the spread increases. The mean and the standard deviation are very good descriptions for the symmetric distributions without outliers (individual values that fall outside the overall pattern).

The formal version of the midpoint is the median. The median *M* is the midpoint of a distribution, described as a number satisfying that the half of observations is smaller and the other half are larger than *M*. Let n be the number of observations. To find the median of a distribution the following should be done: Arrange all observations in order of size, from the smallest to the largest; If *n* is odd, the median *M* is the center observation in the ordered list. If *n* is even, the median *M* is midway between the two center observations in the ordered list. It should be noted that the median can be always located in the ordered list of observations by counting up $(n + 1)/2$ observations from the start of the list.

As a remark it can be said that the mean and the median of a roughly symmetric distribution are close together. If the distribution is exactly symmetric, the mean and the median are exactly the same. In a skewed distribution, the mean is usually farther out in the long tail than is the median.

The description of the spread can be improved by introducing the spread of the middle half of the data. The quartiles mark out the middle half. If there is an ordered list of observations, the first quartile lies one quarter of the way up the list. The third quartile lies three quarters of the way up the list. The five number summary of a distribution consists of the smallest observation, the first quartile, the median, the third quartile and the largest observation, written in the order from the smallest one to the largest. This five number summary of a distribution leads to a new graph, the boxplot. A central box spans the quartiles Q_1 and Q_3, a line in the box marks the median *M*. Lines extend from the box out to the smallest and the largest observations.

The interquartile range, denoted with *IQR*, is the distance between the first and the third quartiles, i.e. $IQR = Q_3 - Q_1$. Call an observation a suspected outlier if it falls more than 1.5 *IQR* above the third quartile or below the first quartile.

If it is thought that a variable *x* may explain or even cause changes in another variable *y*, then *x* is called an explanatory variable and *y* a response variable.

A scatterplot displays the relationship between two quantitative variables measured on the same individuals. The correlation *r* measures the direction and strength of the linear association between two quantitative variables *x* and *y*.

Suppose that there is a data on variables *x* and *y* for *n* individuals. The values for the first individual are x_1 and y_1, the values for the second individual are x_2 and y_2, and so on. The means and the standard deviations of the two variables are $\bar{x}$ and s_x for the *x* values, $\bar{y}$ and s_y for the *y* values. The correlation *r* between *x* and *y* is

$$r = r = \frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{x_i - \bar{x}}{s_x}\right)\left(\frac{y_i - \bar{y}}{s_y}\right)..$$

Correlation indicates the direction of a linear relationship by its sign. If $r > 0$, there is a positive association, and if $r < 0$, there is negative association. Correlation always satisfies $-1 \leq r \leq 1$ and indicates the strength of a relationship by how close it is to –1 and 1. Perfect correlation, $r = \pm 1$, occurs only when the points on a scatterplot lie exactly on a straight line.

Correlation ignores the distinction between explanatory and response variables. The value of *r* is not resistant, so outliers can greatly change the value of *r*, but this value is not affected by changes in the unit of measurement of either variable.

A regression line summarizes the relationship between two variables, but in a specific sense: one of the variables helps to explain or predict the other one. The linear regression line is a straight line that describes how a response variable y changes as an explanatory variable x changes. When regression line is mentioned here, it is meant on the least-squares regression line of *y* on *x,* i.e. the line that makes the sum of the squares of the vertical distances of the data points from the line as small as possible.

Let we have data on an explanatory variable *x* and a response variable *y* for *n* individuals and let we calculate from the given data the means $\bar{x}$, $\bar{y}$ and the standard deviations s_x, s_y and their correlation *r*. The least-squares regression line is the line $\hat{y} = a + bx$, with slope

$$b = r\frac{s_y}{s_x}$$

and intercept

$$a = \bar{y} - \overline{bx}.$$

With this regression line the predicted response *y* for any *x* is obtained.

In sequel, some useful properties about the least-squares regression are stated.

The distance between explanatory and response variables is essential in regression.

1. There is a close connection between correlation and the slope of the least-squares regression line. The slope and the correlation always have the same sign.

2. The least-squares regression line always passes through the point $(\bar{x}, \bar{y})$, on the graph of *y* against *x*.

3. The correlation *r* describes the strength of a straight line relationship. This description takes a specific form: the square of the correlation, r^2, is the fraction of the variation in the values of *y* that is explained by the least-squares regression of *y* on *x*. The last one, can be briefly written as

$$r^2 = \frac{\text{variation in } \hat{y} \text{ as } x \text{ pulls it along the line}}{\text{total variaton in observed values of } y}.$$

From the last one, it is clear that it can always be found a regression line for any relationship between two quantitative variables, but the usefulness of the line for prediction depends on the strength of the linear relationship. Hence, r^2 is almost as important as the equation of the regression line.

GIS DATABASE OF THE POINT LOAD TEST DATA

The data which is used in this paper is taken from the geotechnical laboratory of the Faculty of Civil Engineering is Skopje. The tested samples have been part of investigation programs conducted for different clients, but mostly in the frames of the design of various structures along the European transport corridors X-8 and X-10. The number of analyzed point load test results is 506, where anisotropic rock samples have been tested in both directions (perpendicular and parallel to anisotropy). Since the data was available only in laboratory sheets, excel sheets or pdf, there was a real need to organize it in a GIS database. So, within the frame of the study a large number of geotechnical reports had to be consulted in order to get familiar with the spatial position of the investigation works. All locations of investigation works were translated to spatial coordinates according to Gauss-Kruger projection. By means of the GIS system, it also information was obtained for the geotectonic unit in which a certain investigation works belong. This was later used in establishing of the analytical correlations.

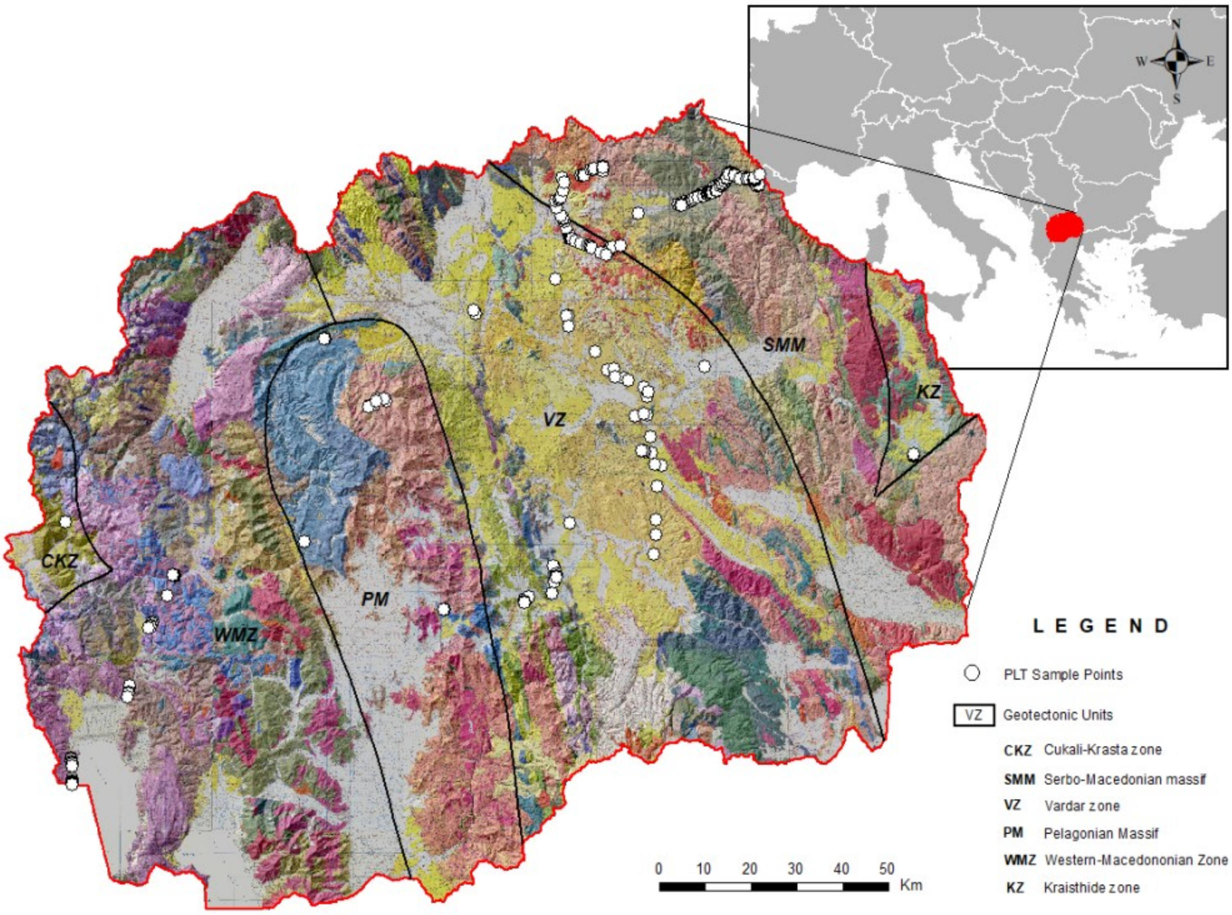

Fig 1. Basic Geological Map of the Republic of Macedonia with locations of point load test samples

ESTABLISHED ANALYTICAL CORRELATIONS

The large amount of data means that many correlations could be established. However, analyzing extensive geotechnical data from vast regions can lead to overgeneralization, hence to wrong conclusions about the intensity of correlations. In order to avoid this, most of the correlations were prepared at the level of particular geotectonic units and according to the rock type. Different statistical values were calculated by means of statistical software. Then, numerous regression dependences from the data were defined, mostly for the values of the point load test in regard to anisotropy. Due to the character of the paper, only some of this data is presented (Figures 2 to 7). Additional correlations were established between the value of the point load index and the unit weight, as well as between the point load value and the depth of tested sample (Figures 8 to 14).

	SJs50N	SJs50P
average	3.28	2.63
min	1.06	0.59
max	5.29	5.15
variance	3.52053	3.76275
median	3.40	3.13

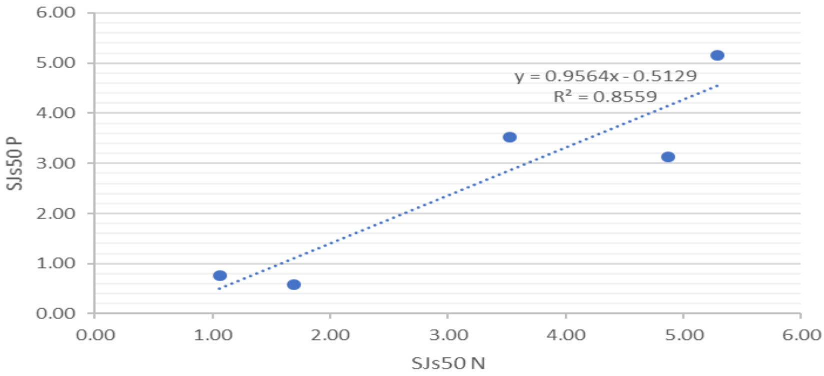

Fig 2. Statistics and correlation of point load test results *Is*(50) perpendicular (*SJs*50*N*) and (*SJs*50*P*) parallel to schistosity for amphibolitic schist from the Kraishtide zone

	SJs50N	SJs50P
average	3.17	1.53
min	1.03	0.63
max	6.81	2.79
variance	4.18	0.64
median	2.47	1.21

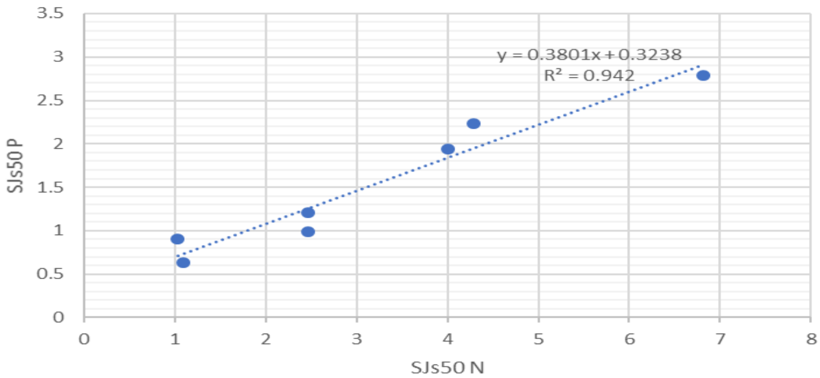

Fig 3. Statistics and correlation of point load test results *Is*(50) perpendicular (*SJs*50*N*) and (*SJs*50*P*) parallel to schistosity for albite quartz muscovite schists from the Serbo-Macedonian massif

	SJs50N	SJs50P
average	3.06	1.45
min	0.91	0.37
max	5.66	3.28
variance	3.22	1.03
median	2.34	1.19

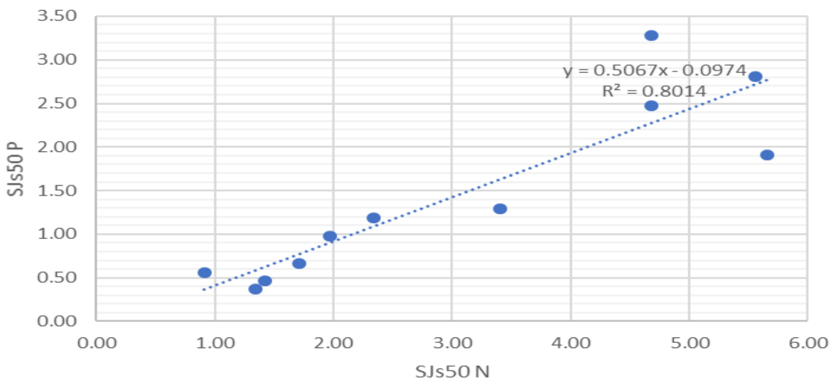

Fig 4. Statistics and correlation of point load test results *Is*(50) perpendicular (*SJs*50*N*) and (*SJs*50*P*) parallel to schistosity for epidote chlorite schists from the Serbo-Macedonian massif

	SJs50N	SJs50P
average	0.83	0.39
min	0.25	0.18
max	1.67	0.61
variance	0.30	0.02
median	0.58	0.40

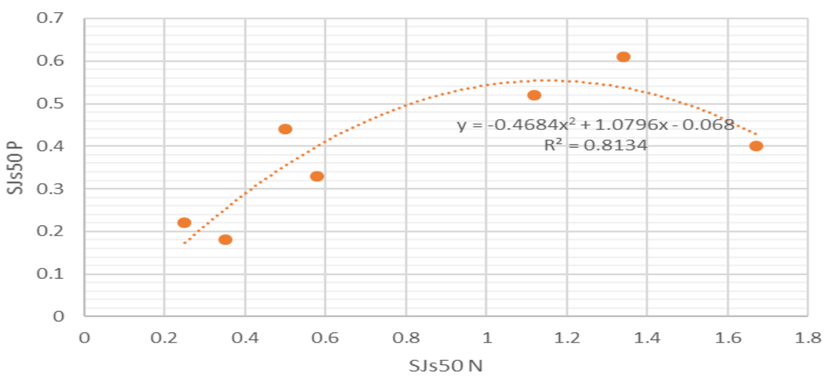

Fig 5. Statistics and correlation of point load test results *Is*(50) perpendicular (*SJs*50*N*) and (*SJs*50*P*) parallel to bedding for marlstones from Vardar zone

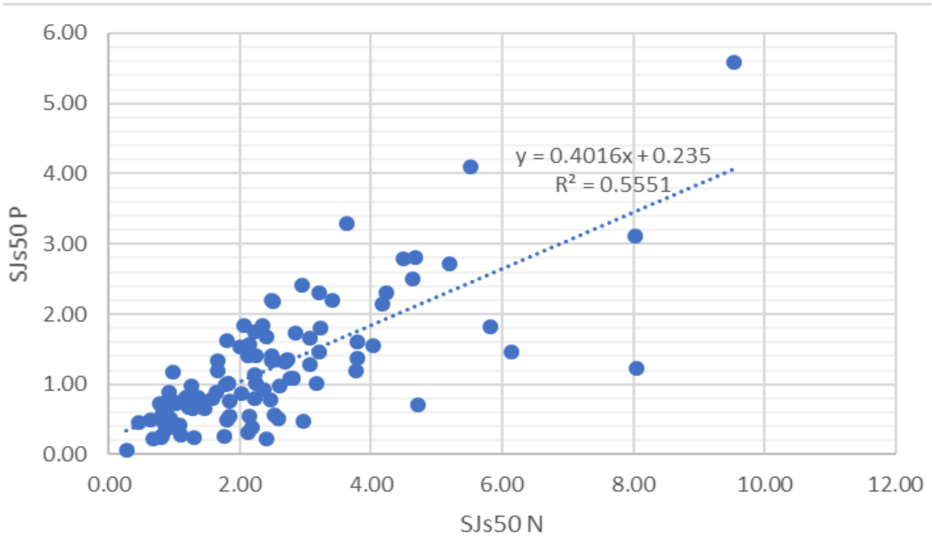

Fig 6. Statistics and correlation of point load test results *Is*(50) perpendicular (*SJs*50*N*) and (*SJs*50*P*) parallel to schistosty for albite epitode chlorite schists from all geotectonic units

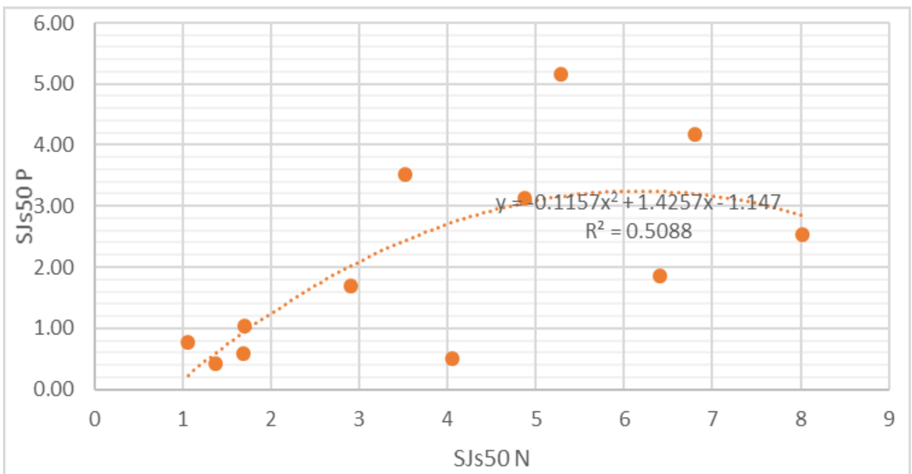

Fig 7. Statistics and correlation of point load test results *Is*(50) perpendicular (*SJs*50*N*) and (*SJs*50*P*) parallel to schistosty for amphibolitic schists from all geotectonic units

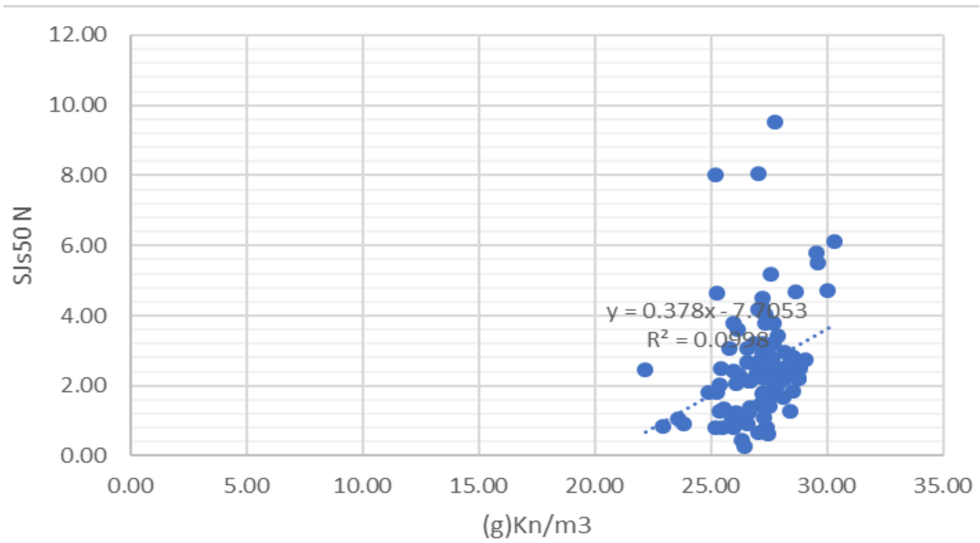

Fig 8. Correlation of point load test results *Is*(50) with unit weight for albite epidote chlorite schists

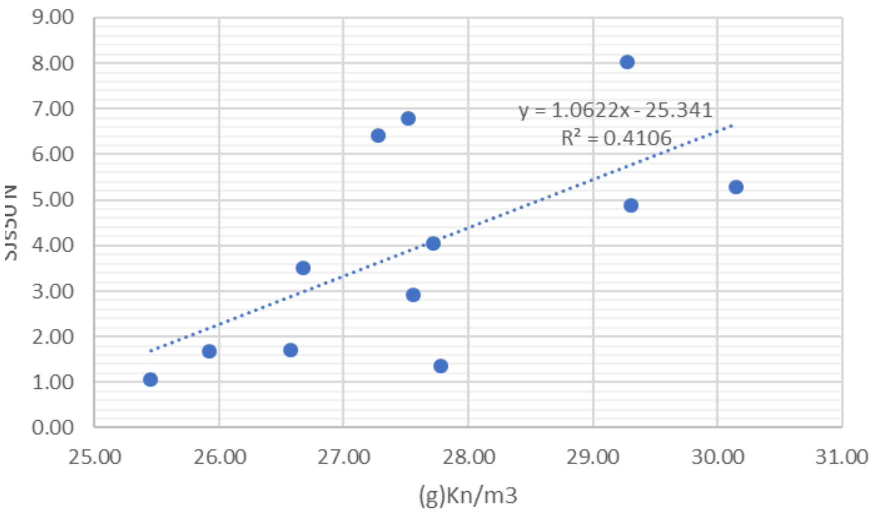

Fig 9. Correlation of point load test results *Is*(50) with unit weight for amphibolitic schists

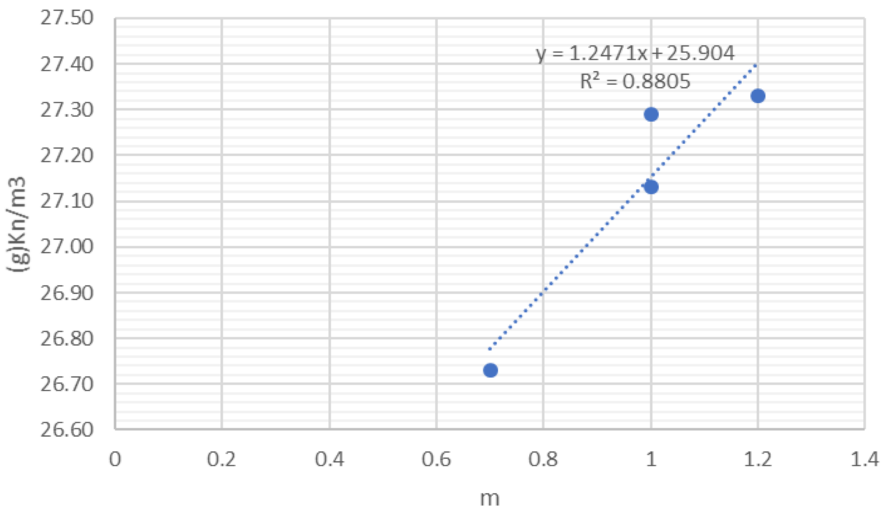

Fig 10. Correlation of unit weight of samples tested for point load strength with the depth of sample. Quartz-graphitic schists from Čukali–Krasta zone

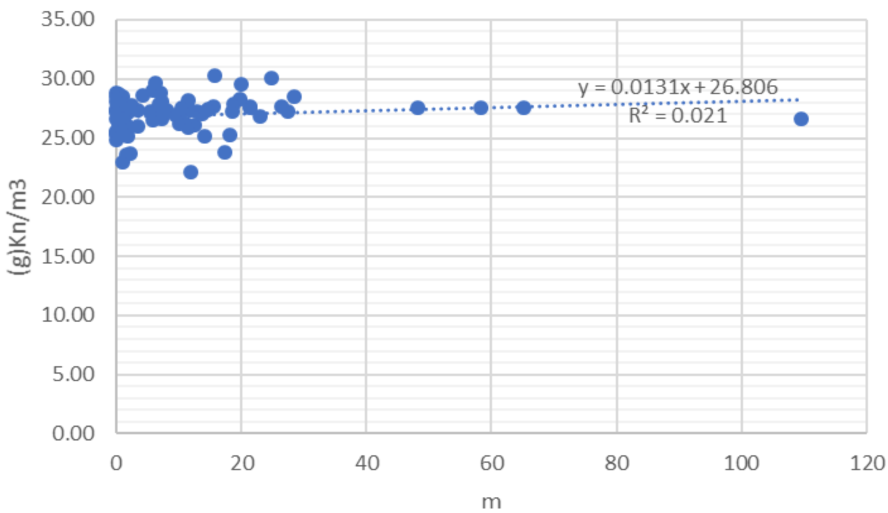

Fig 11. Correlation of unit weight of samples tested for point load strength with the depth of sample. Albite epidote chlorite schists from the Serbo-Macedonian massif

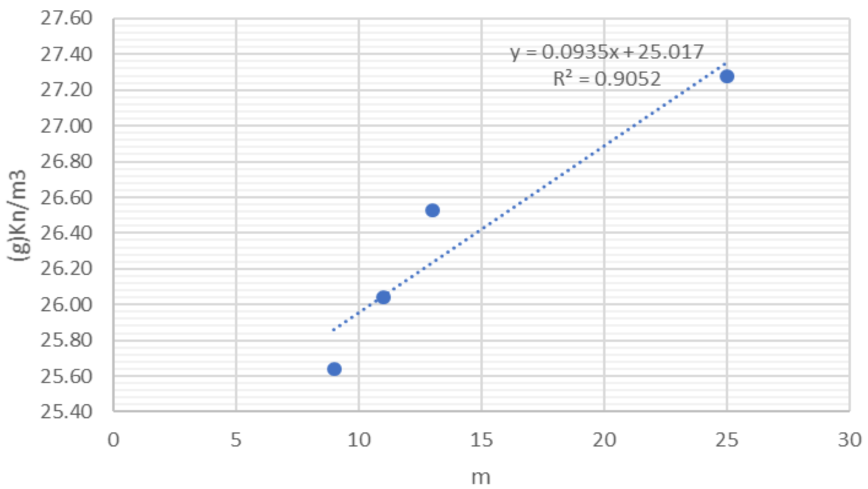

Fig 12. Correlation of unit weight with the depth of sample. Carbonate schists

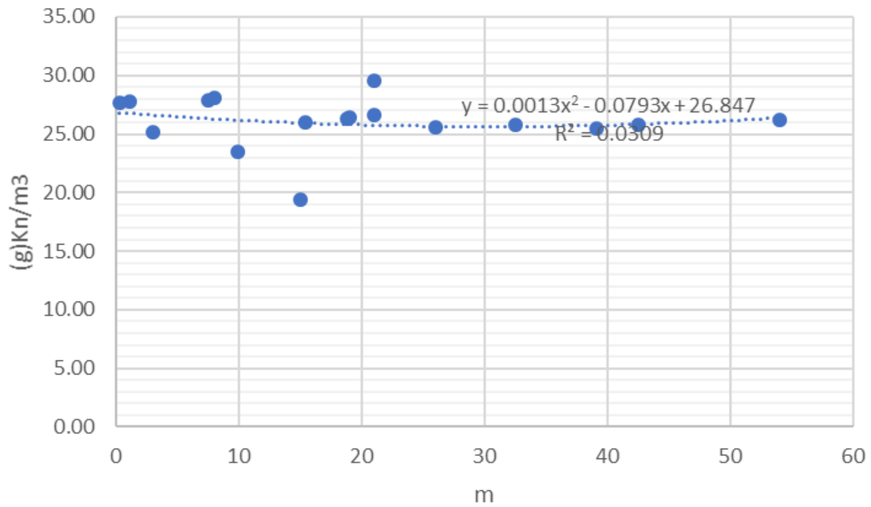

Fig 13. Correlation of unit weight with the depth of sample. Limestone

CONCLUSIONS

Established regression dependences show that it is possible to find acceptable correlation of the value of the point load index for anisotropic rock masses. The strongest square correlation r^2 is found for the albite quartz muscovite schists from the Serbo-Macedonian massif. However, any value of r^2 above 0.7 is considered strong and can be accepted for prognosis of the dependence parameter. In the particular case study this was achieved only at the level of specific geotectonic unit, while analyzing all available data in one pool gave less strong correlations (r^2~0.5). This means that based on this database it is not possible to establish regression equations which will be applicable for the entire territory. Extension of the database might lead to another conclusion. Therefore, it is suggested that the obtained regression equations are used only in preliminary phase of studies and during control geotechnical investigations, and only at the level of specific rock type and geotectonic unit.

Regression dependences between the point load value and unit weight, as well as unit weight and depth of sample have a wide range of the r^2, which in some instances are very high and in others very low. Therefore it was concluded that these two parameters cannot be correlated with confidence. Such type of correlations might be possible for massive rock masses and rock masses in frames of specific mineral deposits, which can be subject on another study.

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Р е з и м е

ИНДЕКС НА ТОЧКЕСТА ЈАКОСТ, ГЕОТЕХНИЧКА БАЗА НА ПОДАТОЦИ СОЗДАДЕНА ОД ИСТРАЖУВАЊА ЗА ИНФРАСТРУКТУРНИ ОБЈЕКТИ ВО РЕПУБЛИКА МАКЕДОНИЈА, СО АКЦЕНТ НА АНАЛИЗАТА НА АНИЗОТРОПИЈАТА

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Опитот за определување точкеста јакост е еден од најкористените методи за добивање прелиминарни информации за јакоста на карпите. Во трудот се прикажани статистички анализи на голем број резултати од опитот, добиени за потребите на геотехнички истражувања на различни објекти кои се дел од европските транспортни коридори VIII и X во Република Македонија. Дополнителен број резултати се преземени од истражувања за други објекти. Повеќето од карпите кои се анализирани имаат јасно изразена анизотропија. Сите резултати се систематизирани во GIS-база на податоци и класифицирани според типот на карпа и припаѓањето на конкретна геотектонска единица. Воспоставени се различни аналитички регресии со различно ниво на доверливост. Направен е напор да се поврзат вредностите на индексот на точкеста јакост паралелно и нормално на анизотропијата, како и вредностите од точкеста јакост со волуменската тежина и волуменската тежина со длабината на примероците. Најважниот заклучок е дека некои од овие корелации, главно поврзани со анизотропијата на вредностите на точкестата јакост, покажуваат високо ниво на поврзаност и може да се предложат за користење во почетна фаза на истражувања или за време на контролни истражувања. Употребата на вакви корелации е ограничена од аспект на типот на карпа и геотектонската единица. Доверлива корелација за точкеста јакост со волуменска тежина и за волуменска тежина со длабина на примероци не е добиена. Се предлага слична анализа за масивни карпи во рамките на конкретни лежишта на минерални суровини, за која авторите сметаат дека овозможува да се добијат подобри корелациони коефициенти и за последните две корелации