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Tel. ++ 389 032 550 575	**Тел. 032 550 575**

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Original scientific paper

RANGE OF ENGINEERING-GEOLOGICAL PROPERTIES FOR SOME CARBONATE ROCK COMPLEXES FROM BALKAN PENINSULA

Milorad Jovanovski[1], Azra Špago[2], Igor Peševski[1]

[1]*Faculty of Civil Engineering, "Ss. Cyril and Methodius" University in Skopje,*
Partizanski odredi 24, MK-1000, Skopje, Republic of Macedonia,
[2]*Faculty of Civil Engineering, "University Djemal Bijedic", Mostar, Bosnia and Herzegovina,*
jovanovski@gf.ukim.edu.mk // Azra.Krvavac@unmo.ba

Abstract: The Carbonate Rock masses are a geological media with extremely complex states and properties, which has a certain influences on the mechanical and hydraulic behavior during construction and exploitation of engineering structures. Practical aspects of the problem analysis arise from the fact that the areas of Bosnia and Herzegovina, Macedonia and the entire Balkans is characterized by presence of wide areas covered with carbonate complexes, where large number of complex engineering structures have been, or shall be constructed in the future. In this context, their engineering-geological modeling is still a practical and scientific challenge**.** The analysis of engineering-geological properties is one of the main steps in forming of analytical and geotechnical models for complex rock structures. This article gives a data about the range for these properties, according to the results from an extensive investigation program. Some original correlations and testing results are given and they are compared with some published relations from the world.

Key words: carbonate rock complexes; GSI classification; deformation modulus; strength properties

INTRODUCTION

It is known, that the large areas of the Balkan Peninsula are covered with Carbonate Rock Complexes with different geological ages, genesis, degree of karstification, weathering and fracture properties. Such conditions, beside phenomenology of their event, are also important from the practical point if view. This comes from the fact that such complexes are often foundational media for construction of large infrastructural projects. So, knowing of engineering-geological properties is one of the main prerequisites for successful design of important structures. The authors were involved in several large projects and had an opportunity to be involved directly in different phases of investigation, design or analyses for dams "Sveta Petka", "Kozjak" and others in R. Macedonia, as well as "Salakovac", "Grabovica" and others in Bosnia and Herzegovina. Also, data from several tunnels designed in carbonate complexes are collected and analyzed. So, numerous data about physical, mechanical, structural and other important geological and tectonically data exist and allow preparing adequate scientific analyses.

Between other usual investigation methods, an adequate geotechnical laboratory and field investigations have been applied in order to define the strength, deformability and shear strength of the rock masses. All the results are used to establish a numerous correlations between rock mass quality and mechanical properties, to modify some known classification methods and to improve methodology of geotechnical modeling for carbonate rock mass complexes (Јовановски, 2001; Špargo, 2010).

RANGE OF VALUES FOR INTACT ROCK STRENGTH PROPERTIES

Although intact rock parts characteristics are obtained from the examination of examples on compressive strength and tension, their practical use in solving engineer's problems is limited, mainly the values of these strengths can be useful parameters that indicate on the quality of rock mass. So it is very often they are used as enter information for classification of rock, or as value for defining some failure criteria.

In order to know interval in which the values of strengths for intact parts of rock mass vary, in this paper we show some results of examination of uniaxial compressive strength σ_{ci} for carbonate rocks from the area in Bosnia and Herzegovina and Republic of Macedonia.

In Table 1 and Table 2, results from testing of uniaxial compressive strength from location of ″Salakovac″ dam on Neretva River, Bosnia and Herzegovina, and ″Sveta Petka″, on Treska River, R. Macedonia are given.

Table 1

Average values of uniaxial compressive strenght σ_{ci} vertical on bedding planes in MPa, samples of limestone for "Salakovac" dam

Condition	Sample					
	1.	2.	3.	4.	5.	6.
Dry	171.5	162.3	152.3	150.6	158.2	153.2
Water logged	164.4	145.4	139.6	135.1	138.3	144.8
Frozen samples	156.4	137.7	127.1	129.2	136.8	143.3

In Table 4. it can be seen that the most frequent values of uniaxial compressive strength for rocks on the location of "Sveta Petka" dam are in diapason from σ_{ci} = 40 – 50 MPa.

These results are under usuall values for carbonate rocks, that can be explained by influence of microscopic deffects made with earlier tectonic influences, although if we look it macroscopicaly, the samples are in fresh state. By parameter of strenght of monoliths, these rocks are medium strong (by Hoek, Brown, 1997).

Beside these results, on Figures 1 and 2, histograms with statistic processed data are presented.

From figures, it can be seen that uniaxial compressive strength of carbonate rock massifs vary in large interval, that can be explained by the influence of crystallization level, decomposition of monolithic parts, strength anisotropy of monolith, different factors of subjective nature etc. Further, results are compared with world's experiences. In this context, with a wider approach, it can be concluded that variations in results are very large, that certainly imply that it is very hard to generalize results from different locations and also indicates of necessity of specific examination for every separate location

Table 2

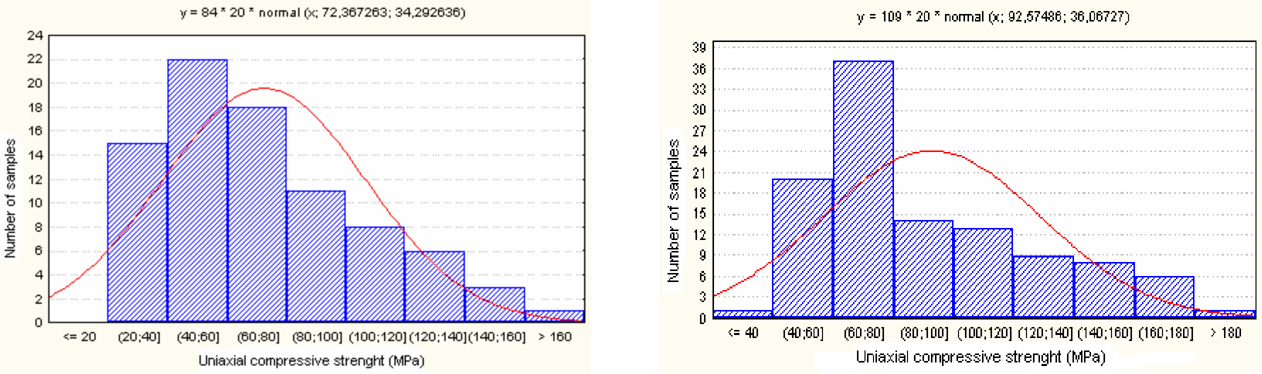
Values of strenght stress σ_{ci} of intact samples from the location of "Sveta Petka" dam

Nr	Drill hole	Depth (m)	Uniaxial compressive strenght σ_{ci} (MPa)
1	DB-8	21.10–21.30	25.78
2	DB-9	25.2–25.40	35.56
3	DB-9	26.5–27.1	45.05
4	DB-9	27.80–28.00	50.84
5	DB-9	28.5–28.7	64.89
6	DB-9	29.40–29.60	62.76
7	DB-9	30.10–30.30	54.45
8	DB-9	73.10–73.3	32.07
9	DB-10	25.10–25.30	27.26
10	DB-10	23.50–23.80	42.35
11	DB-11	33.70–33.90	33.06
12	DIL-2	25.20–25.40	35.12
13	DIL- 2	26.10–26.30	24.91
14	DIL- 2	32.60–32.80	55.88
15	DIL- 2	37.60–37.80	24.91
16	DIL- 2	38.5–38.7	75.96
17	PS-1	32.20–32.40	54.45
18	PS-2	31.60–31.80	41.33
21	PS-2	69.70–69.90	49.47
22	S-3	28.10–28.30	61.28
23	PS-4	25.40–25.60	41.20
24	PS-5	25.40–25.60	33.09
25	S-6	30.40–30.60	42.71
26	DVZ-1	17.30–17.50	26.59
27	DZ-1	28.20–28.40	44.96
29	DR-3	16.10–16.30	38.07

Table 3

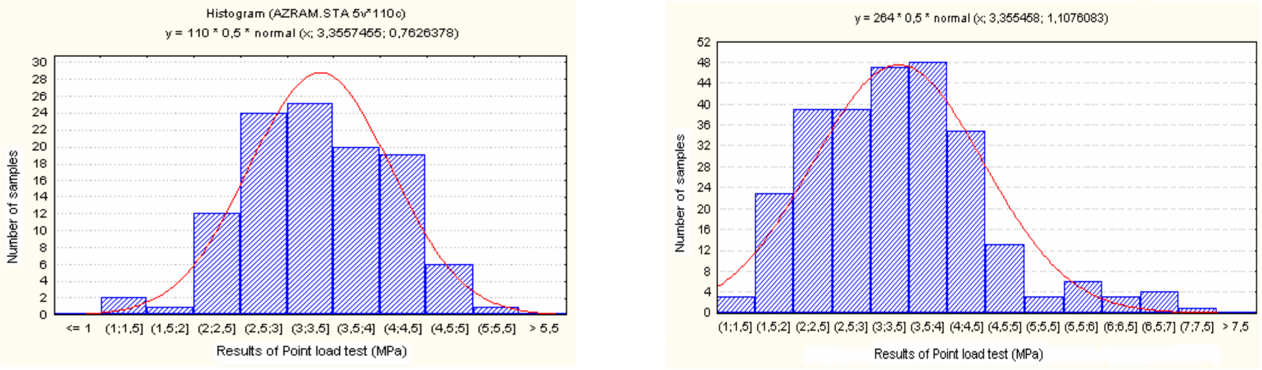
Overview of diapason of variation of values for uniaxial compressive strenght for different types of carbonate rock massifs (Hawkins, 1998)

	Direction of testing	Sample 1 (MPa)	Sample 2 (MPa)	Sample 3 (MPa)	Average (MPa)
Limestone type “Shelly“	Parallel	94	107	115	105
	Vertical	119	139	131	131
	Oblique	109	109	121	113
Crinoids limestone	Parallel	154	157	153	154
	Vertical	169	163	152	161
	Oblique	144	159	179	161
Oolitic limestone	Parallel	118	156	206	179
	Vertical	207	142	156	176
	Oblique	165	141	151	166
Micritic limestone	Parallel	217	225	211	218
	Vertical	222	233	244	233
	Oblique	225	216	235	225
Dolomite	Parallel	227	258	269	251
	Vertical	242	229	248	240
	Oblique	270	259	254	261



a) b)

Fig 1. a) Histogram of distribution of uniaxial compressive strength of intact parts of carbonate rock massifs;
b) Histogram of distribution of uniaxial compressive strength of monolithic samples from the location of dam “Sveta Petka“ (Jovanovski, Krvavac-Špago, Ilijovski, Peševski, 2008)



a) b)

Fig. 2. a) Histogram of distribution of results of Point load test of intact parts of carbonate rock massifs;
b) Histogram of distribution of results of Point load test for samples from the location of dam “Sveta Petka” (Jovanovski, Krvavac-Špago, Ilijovski, Peševski, 2008)

In Table 4, some results from tension strength testing on intact samples of rock from the location on “Sveta Petka” dam, by Brazilian method. Values of tension strength vary, where at lower values are considered for weathered rock variations, and higher values on fresh intact parts. On Figure 3 is given histogram with categories of carbonate rock mass by RMR system from R.Macedonia and Bosnia and Herzegovina.

Table 4

Tests results of tension strenght on monolith by Brasillian method for “Sveta Petka” dam

Num.	Drill hole	Depth m	σ_{t1} MPa	σ_{t2} MPa	σ_{t3} MPa
1.	PS–4	28.60 – 28.80	6.76	9.11	–
2.	S–6	25.60 – 25.90	7.06	11.25	9.52
3.	DB–8	22.60 – 22.90	14.39	15.15	7.56
4.	DM–1	18.30 – 18.50	3.43	0.33	6.79
5.	DM–1	25.10 – 25.30	3.95	7.28	6.30
6.	DZ–1	30.40 – 30.60	3.66	–	3.45

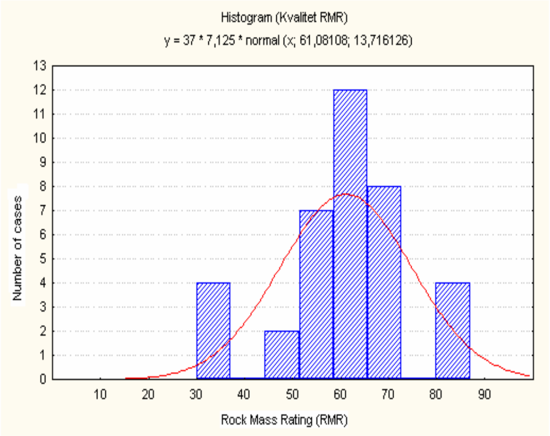


Fig. 3. Histogram with overview of categories of rock mass by RMR system
(Jovanovski, Krvavac-Špago, Ilijovski, Peševski, 2008)

CORRELATIONS AND MODELS FOR PREDICTION OF MODULUS OF DEFORMABILITY OF CARBONATE ROCK MASSES

After collecting, testing and statistical analysis of examined samples, numerous correlations between obtained parameters, as well as creation of analytical models for prediction of other important rock mass parameters, are established.

The most simple correlation that can be established is the one that connects the results from the point load test ($Is_{(50)}$ – Index of point load strength for sample diameter d = 50 mm) and the value of uniaxial compressive strength. For the case of marbles from dam "Sveta Petka" the factor of correlation is 16.832, and for limestone of a round area of Ohrid this factor is 39.508.

When compared with known correlation from for various limestone’s with values 5–27 for the correlation factor it is obvious that the correlation factors for carbonate rock mass of different geological age, mineral structure, weathered and macro and micro structural characteristics vary in large interval. Variation of results again indicates the need of determining of these correlations for every specific location itself. Also important is the scale effect, with the new knowledge that by increasing the size of examined samples, average value of uniaxial strength actually stays unchanged, and only dispersion of results is decreasing i.e. the variation of uniaxial strength.

Further we show the procedure for making analytical models that are used for prediction of possible intervals of modulus of deformation D, cohesion c and friction angle φ, depending on uniaxial compressive strength of intact elements of rock mass. Models are made using software RocLab. On the Figure 4 are shown several examples of analytical models for prediction of possible interval of modulus of deformation D of carbonate rock mass depending on uniaxial compressive strength of intact part of rock mass σ_{ci} for different values of GSI. The GSI classification strongly depends on the uniaxial compressive strength of intact rock as well as the structure of the rock.

For analysis of modulus of Deformation D software RocLab is used (Hoek, Carranza-Torres and Corkum, 2002):

for $\sigma_{ci} \le 100$ MPa →

$$E_{rm} = \left(1 - \frac{D}{2}\right)\sqrt{\frac{\sigma_{ci}}{100}}\,10^{\left(\frac{GSI-10}{40}\right)} \text{MPa}$$

for $\sigma_{ci} > 100$ MPa→

$$E_{rm} = \left(1 - \frac{D}{2}\right)10^{\left(\frac{GSI-10}{40}\right)} \text{MPa}$$

The term modulus of deformation is marked as E_{rm} based on English term and not D as it is the usual case in the literature and in our speaking area, and on the other hand to distinguish it from the term for D (disturbance factor). For deformation modulus D double logarithmic (Power) model of regression is formed which in general form is $D = a \times \sigma_{ci}^{b}$.

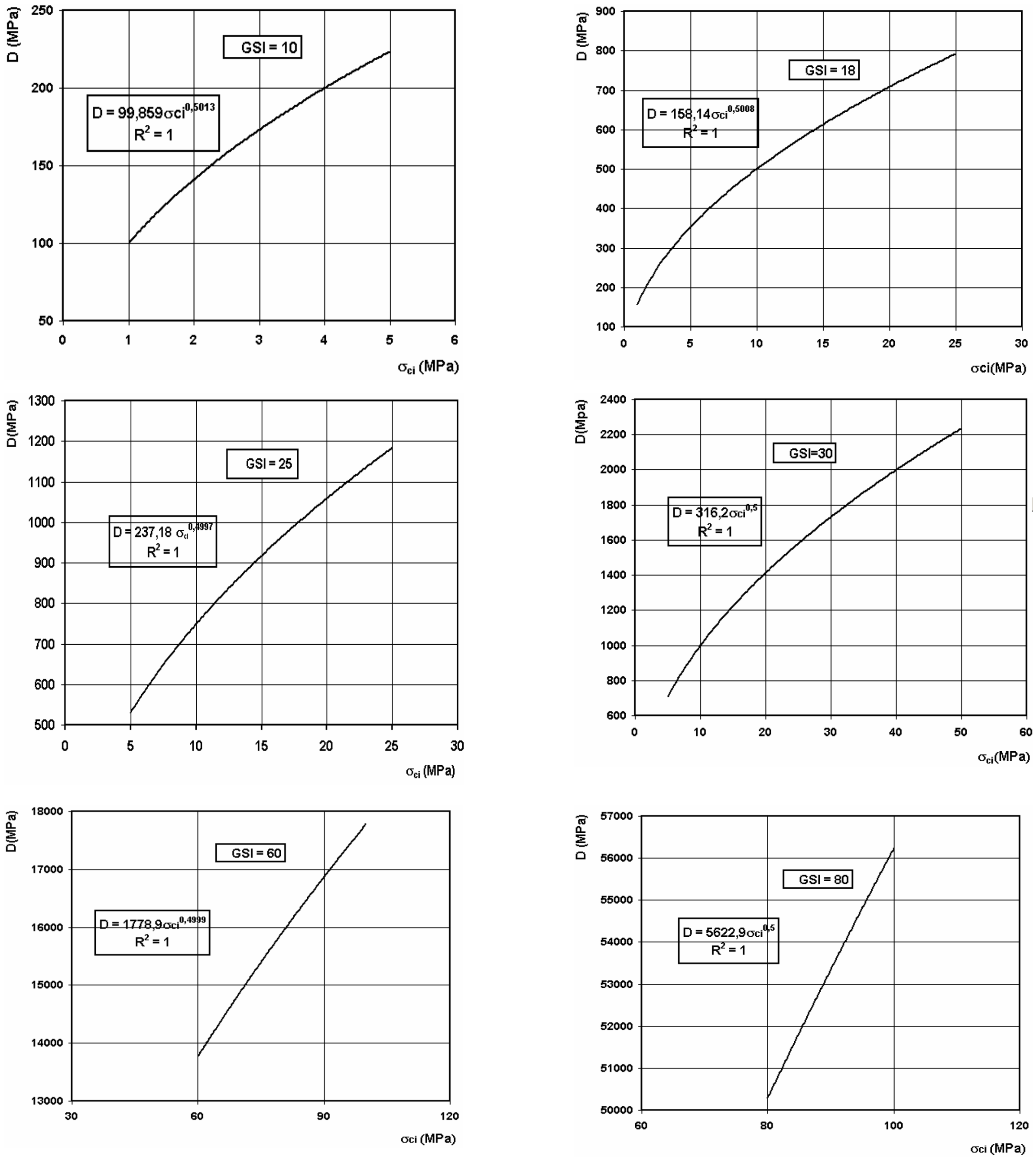


Fig. 4. Analytical models for prediction of possible deformation modulus interval D of carbonate rock mass depending on uniaxial compressive strength of intact part of rock mass σ_{ci} for different values of GSI.

Never version of RocLab software uses term:

$$E_{rm} = E_i \left(0,02 + \frac{1 - D/2}{1 + e^{((60+15D-GSI)/11)}} \right) \text{MPa}$$

The relation is given by Hoek and Diederichs, 2006, and which require knowing of Deformation modulus of intact parts of rock E_i. On Figure 5 is shown model for prediction of deformation modulus D for solid marbles from location of dam "Sveta Petka".

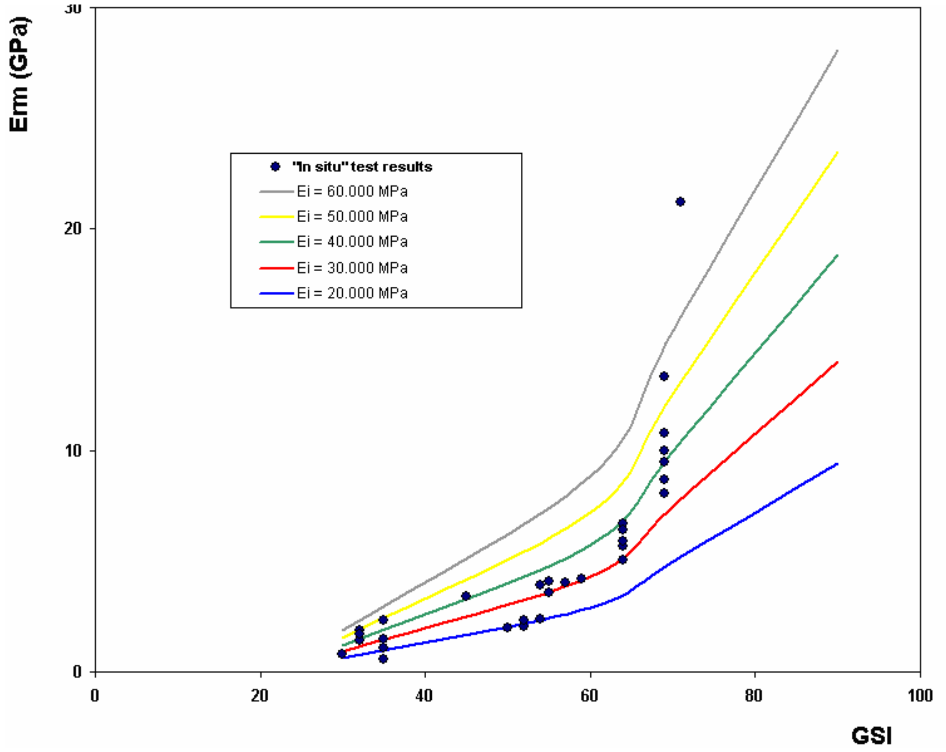
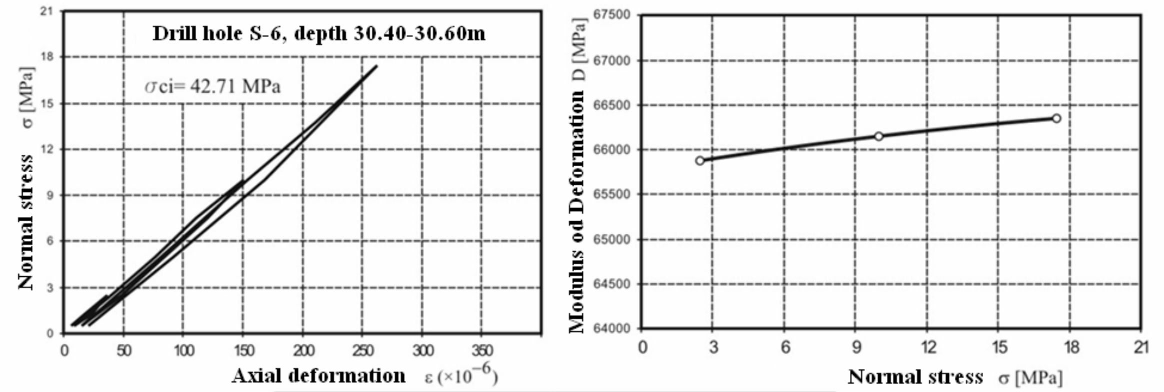


Fig. 5. Comparison of values for rock mass modulus of deformation E_{rm} estimated by Hoek and Diederichs (2006) for deformation modulus of intact parts of rock mass E_i = 20.000 MPa, E_i = 30.000 MPa, E_i = 40.000 MPa, E_i = 50.000 MPa and E_i = 60.000 MPa and disturbance factor D_f = 0, 8 with values of deformation modulus by field investigation through hydraulic flat jack

On monolithic samples taken from different depth of bore hole on the dam location we have got modulus of deformation by lab deformability test. This value of deformation modulus varies in wide interval from 20,000 to 85,000 MPa. So in that way deformation modulus were valued by Hoek and Diederichs, 2006, for values of deformation modulus of intact parts of rock mass E_i = 20,000 MPa, E_i = 30,000 MPa, E_i = 40,000 MPa, E_i = 50,000 MPa and E_i = 60,000 MPa. From the Figure 6, it can be seen that results obtained with *in situ* investigation of deformation modulus with hydraulic flat jack mainly match with those valued by term from Hoek and Diederichs (2006).



Modulus of deformation D [MPa]		Modulus of elasticity E [MPa]	
I cycle	65869.38	I cycle	70518.98
II cycle	66137.14	II cycle	70041.91
III cycle	66341.10	III cycle	70179.01

Fig. 6. Results of Deformability tests on the samples form dam "Sveta Petka" in three cycled for sample S-6 (a)

In case when we are not able to use values for deformation modulus of intact parts of rock mass E_i or to be able to prepare undisturbed samples for measuring values of E_i, and we do have lab defined values of uniaxial compressive strength of intact parts of rock mass σ_{ci} then we use term:

$$E_i = MR \cdot \sigma_{ci}$$

where *MR* is relation between deformation modulus of rock mass and modulus of intact rock mass E_{rm}/E_i, which is different depending of the type of the rock.

Model formed by last two terms for carbonate complex of dam "Sveta Petka" is given on Figure 7 (Average value of uniaxial compressive strength $\sigma_{ci} = 44$ MPa, disturbance factor $D_f = 0.8$, which are values for dam "Sveta Petka", value of MR as relation between deformation modulus of rock mass and modulus of intact part of rock mass $E_{rm}/E_i = 850$ – value for marble) and is showing good overlapping with curve which is gotten by extrapolation of the investigation results on the location of dam "Sveta Petka". The same procedure is done for the cases of dams Grabovica and Salakovac.

From Figure 7 it can be seen, that there exist well correspondence between formed correlative dependences for deformation modulus *D* and quality of rock mass *RMR* form location of "Salakovac" dam, "Sveta Petka" dam and correlations given by Jovanovski, Gapkovski, and Ilijoski, 2002. Also curve form the location of "Grabovica" dam is approaching these curves by increasing values of *RMR*. On the other hand, term gotten by Serrafim and Perreira, 1998, some higher values of deformation modulus *D* for equal value of *RMR*. Analytical models formed by term of Hoek, Carranza-Torres, Corkum, 2002, and Hoek and Diederichs, 2006, show well correspondence with curve formed by extrapolation of „in situ“ gotten results on the location for "Sveta Petka" dam.

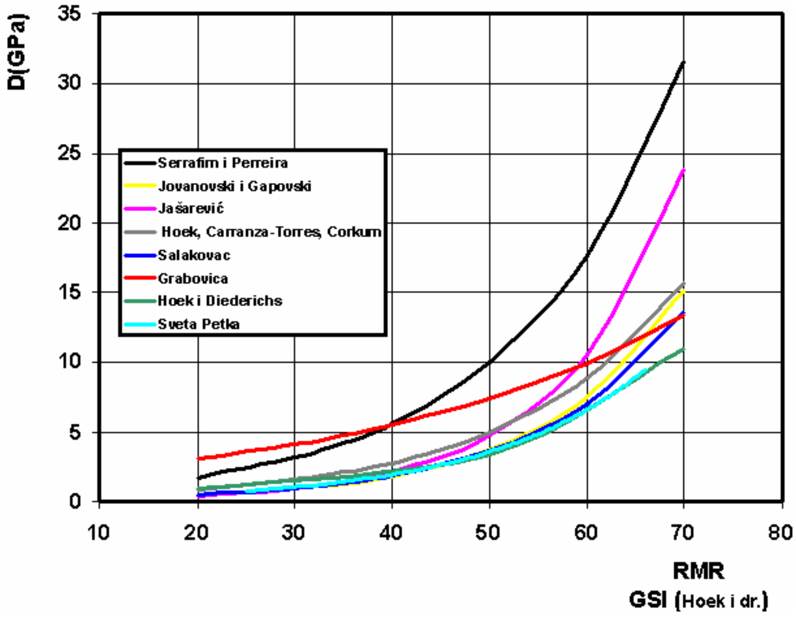


Fig. 7. Comparison of correlative dependences between quality of rock mass *RMR* (GSI) and deformation modulus *D* from the location on "Salakovac" dam $D = 0.1369 \times e^{0.0657RMR}$ (GPa), "Grabovica" dam $D = 1.6963xe^{0.0295RMR}$ (GPa) and "Sveta Petka" $D = 0.1104 \times e^{0.0703RMR}$ dam with correlative dependences formed by Jovanovski and Gapovski $D = 1.69^{-6}\ RMR^{3,9}$ (GPa), then Hoek, Carranza-Torres and Corkum (2002) and Hoek and Diederichs (2006) (average value of uniaxial compressive strenght $\sigma_{ci} = 44$ MPa, distrubance factor value $D_f = 0.8$, which are values of the "Sveta Petka" dam, value of MR relation between deformation modulus of rock mass and modulus of intact part of rock mass $E_{rm} / E_i = 850$ – values for marbles).

CONCLUSIONS

Range of values for strength and deformability parameter of Carbonate rocks are analyzed in this paper. Based on these analyses, some correlations analytical models are formed for obtaining the Modulus of Deformation of carbonate masses through the cases of dam sites "Sveta Petka", "Salakovac" and "Grabovica". After executed analysis it can be concluded that beside large variations in values, the trend of the correlation curves remains the same for all analyzed cases. However, because of the specific nature of the carbonate rock masses, and the different degree of karstification, folding and fracturing of each location, these analytical models stand only for the subject terrain.

The forming of a universal analytical model is not possible because of these reasons, so given analyses can be used for other structures for lower stages of design, while for larger projects, the adequate testing shall be prepared.

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Резиме

ДИЈАПАЗОН НА ВРЕДНОСТИ НА ИНЖЕНЕРСКО-ГЕОЛОШКИ КАРАКТЕРИСТИКИ НА НЕКОИ КАРБОНАТНИ КАРПЕСТИ КОМПЛЕКСИ ОД БАЛКАНСКИОТ ПОЛУСТРОВ

Милорад Јовановски[1], Азра Шпаго[2], Игор Пешевски[1]

[1]Градежен факултет, Универзитет „Св. Кирил и Методиј“ во Скопје,
Партизански одреди 24, МК-1000, Скопје, Република Македонија
[2]Градежен факултет, Универзитет „Џемаил Биједиќ“,
Мостар, Република Босна и Херцеговина
jovanovski@gf.ukim.edu.mk // Azra.Krvavac@unmo.ba

Клучни зборови: карбонатни карпи; класификација GSI; модул на деформација; јакостни својства

Карбонатните карпести маси се геолошка средина со екстремно сложени својства и состојби кои имаат и директно влијание врз механичкото и хидрауличкото однесување при изведба и експлоатација на инженерски објекти градени врз нив. Практичните аспекти за анализа на овој проблем произлегуваат од фактот, што големи пространства во Босна и Херцеговина, Македонија и целиот Балкански полустров се карактеризираат со присуство на вакви комплески, каде се изведени или се планираат за изведба голем број инфраструктурни капитални објекти. Во овој контекст, инженерскогеолошкото моделирање на овие средини е сеуште голем предизвик од научен и практичен аспект. Анализата на инженерско-геолошките својства е еден од најзначајните чекори во припремата на аналитички и геотехнички модели за вака комплексни карпести маси. Така, во овој труд се прикажани одредени дијапазони на варирање на некои инженерско-геолошки својства, а врз основа на резултати од испитување според опширна програма за истражување. Основните аспекти се потенцирани во овој труд, а резултатите можат да послужат како основа за идни анализи. Покрај другото, прикажани се некои оригинални корелации кои се споредени со воспоставени корелации во светот.