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# Tradition of rock mechanics in Macedonia

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## ABSTRACT

More than 70 years have passed since establishing the Chair of Soil Mechanics, Foundation Engineering and Geology at the Technical Faculty in Skopje; exactly 71 years since the application of the radial jack testing method for the very first time in the world, and more than half of century after the Second Congress of International Society for Rock Mechanics, held in Belgrade in 1970. Having this in a mind, as a tribute to these important events, some data about tradition of rock mechanics in Macedonia are presented, as well as contributions of experts from the region of Former Yugoslavia to the development of rock mechanics worldwide. Facts about scientific and teaching tradition, first-time-ever application of rock testing methods, and some rare phenomenons – part of the world geological heritage, are underlined. Beside this, the idea is to ensure applicable engineering politics in the region and to contribute to the promotion of enlarging the rock mechanics community.

## KEYWORDS

Rock Mechanics; Tradition; Development, Rock Engineering.

## 1. INTRODUCTION

Well known fact is that the International Society for Rock Mechanics and Rock Engineering (ISRM) was founded in Salzburg in 1962 as a result of the enlargement of the "Salzburger Kreis". Its foundation is mainly owed to prof. Leopold Müller (1908-1988) who acted as President of the Society till September 1966. The Society organized its first Congress in Lisbon in September 1966. Important fact for the region of Former Yugoslavia (FY) is that the Second Congress took place in 1970 in Belgrade. After that, ISRM World Congresses have taken place at different places, with the purpose to provide a periodic survey of the progress in Rock Mechanics (https://isrm.net).

From the beginning, till today, a numerous scientists and engineers have contributed to establish rock mechanics as a very important discipline for the wider society. In fact, systematic research in development of rock mechanics in the world is related with the post Second World War period, as a part of plans for rehabilitation of industrial capacities and construction of highly demanding structures on or in a rock mass.

Rock mechanics in FY Republics (including the Republic of Macedonia – MKD, as well) have somewhat followed international developments. It was influenced by the necessity to build structures for exploitation of large resources of hydropower, construction of road and railway network, large industrial complexes etc. On the other hand, complex geological and geotechnical conditions influenced ideas to develop some original methods in investigation of large-scale rock mass testing. During the past period, this region has reached the stage which enables comparative knowledge with the world rock mechanics centers. In the most recent years, the idea to promote geotechnics in the region through organizing regional geotechnical conference is also interesting. Having all this in mind, some interesting facts about tradition of rock mechanics in Macedonia and in the region are noted, with an idea to underline once more the importance of rock mechanics and rock engineering in front of scientist and practitioners.

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## 2. ORIGINS OF MACEDONIAN ROCK MECHANICS AS A SCIENTIFIC BRANCH

The origins of geotechnical engineering and rock mechanics in Macedonia date back to the founding of the Technical faculty in Skopje in the academic year 1949/50, when the first students at two departments – civil engineering and architecture, were enrolled. At the same time, the Chair of Soil Mechanics, Foundation Engineering and Geology was formed (now: Chair of Geotechnics). More details can be found in Vitanov et al. (2006) and Jovanovski et al. (2018), while here only the main facts will be noted.

Founder of the Chair was prof. Kiril Žernovski (1897-1972). He studied in Sofia, Zagreb and Graz, and graduated civil engineering at the University of Zagreb in 1927. He was appointed a member of the Parent commission for founding the Technical faculty in Skopje, and he was one of the first three professors elected at the Faculty as an associate professor for the course Foundation engineering. At that time, first assistants were prof. Todor Mitrov (Engineering geology and later Rock mechanics), prof. Boris Šendov (Foundation) and prof. Dimitar Miladinov (Soil mechanics). From the beggining, eng. Blagoja Filipovski also took part in teachning. Later, prof. Naum Gapkovski (Engineering geology and Rock mechanics), prof. Trajko Bogoevski (Soil mechanics), prof. Vasil Vitanov (Foundation engineering), and others continued the tradition of geotechnical engineering at the Faculty of Civil Engineering (FCE) in Skopje (Figure 1).

Figure 1. Founder and members of First and Second Generation of Chair for Soil Mechanics, Foundation Engineering and Geology (later Chair of Geotechnics); upper row, from left to right: prof. Kiril Žernovski, eng. Blagoja Filipovski, prof. Todor Mitrov, prof. Boris Šendov; bottom row, from left to right: prof. Dimitar Miladinov, prof. Naum Gapkovski, prof. Trajko Bogoevski, prof. Vasil Vitanov.

The State Geological Institute was established in 1944. It was one of the first institutions formed with act of the government of Peoples Republic of Macedonia (the name of the country at that time). This Institute has large contribution in the development of geotechnical engineering and rock mechanics in MKD because it performed a lot of detailed investigations for many important structures.

Just a couple of years after the Skopje's 26.7.1963 earthquake with magnitude 6.1, the Institute of Earthquake Engineering and Engineering Seismology (IZIIS) was founded: in 1965. It was the first institute of this kind in Europe, so now it is one of the oldest worldwide. Among the rest, IZIIS works on some topics of rock dynamics.

After a decade, the Faculty of geology and mining was founded in the town of Štip in 1977. That gave additional impulse to the development of geotechnical engineering as interdisciplinary scientific field.

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In 1962, prof. Branislav Kujundžić introduced a subject "Rock mechanics" for the first time in Europe, at the Faculty of geology and mining at the University in Belgrade (Selimović, 2011). As for MKD, very interesting is the fact that in 1967 prof. Mitrov introduced a subject "Geotechnical Engineering" at the FCE, while since the topic was related to rock mechanics, this subject was soon renamed to "Rock mechanics and grouting". In this context, table 1 presents the main data about education of rock mechanics for universities in FY.

Table 1. Introducing rock mechanics at universities in FY (Selimović, 2011).

| University | Discipline | Year | Intoroduced by |
|---|---|---|---|
| University Ss. Cyril and Methodius, Faculty of Civil Engineering – Skopje | Engineering Geology<br>Rock Mechanics and Grouting | 1949<br>1967 | Blagoja Filipovski<br>Prof. Todor Mitrov |
| University in Belgrade, Faculty of Geology and Mining | Rock Mechanics | 1962/63<br>1963/64 | Prof. B. Kujundžić (Geological Department)<br>Prof. M.Antunović-Kobliška (Mining Department) |
| University in Zagreb, Faculty of Civil Engineering | Rock Mechanics in second cycle (Master thesis Programme) | 1963/64 | Prof. B. Kujundžić |
| University in Ljubljana, Faculty of Civil Engineering | Rock Mechanics, as part of Soil Mechanics | 1962 | Prof. I. Sovinc |
| University in Sarajevo, Faculty of Civil Engineering | Rock Mechanics | 1970 | Prof. D. Krsmanović |
| University in Tuzla, Faculty of Mining and Geology | Rock Mechanics | 1964 | Prof. M. Strajher and M. Cvetković |
| University in Mitrovica, Faculty of Metallurgy and Mining | Rock Mechanics | 1976/77 | Prof. P. Milanović |
| University in Prishtina, Faculty of Civil Engineering | Rock Mechanics | 1980 | Prof. N. Dželetović and Dj. Orana |
| University in Mostar, Faculty of Civil Engineering | Rock Mechanics | 1980 | Prof. M. Selimović |

Nowadays, as a discipline, rock mechanics is involved in the teaching programs at many faculties for civil engineering, geology or mining in the region of FY. Details can be found in Selimović (2011).

In MKD, the subjects Rock mechanics, Rock improvement and Engineering rock mechanics are part of First, Second and Third Cycle of Studies at the FCE in Skopje. Moreover, at the same Faculty, a separate study programme for Geotechnical engineering exists since 2005 at first and second cycle, while the third cycle of studies were established in 2011. Within the regular international post-graduate and doctoral studies at IZIIS, a flexible sub-directing in the field of soil and rock dynamics, and foundation engineering is foreseen, as well!

## 3. MAIN FACTS ABOUT SCIENTIFIC AND PRACTICAL DEVELOPMENT OF ROCK MECHANICS IN FY

FY was one of the centers for intensive development of rock mechanics and rock engineering. Prof. Kujundžić, who worked both in "Hidroelektroprojekt" and the Institute for development of water resources "Jaroslav Černi" in Belgrade, had the greatest impact: he is one of the world pioneers in rock mechanics, founder of Yugoslavian Society for Rock Mechanics and Underground Works in 1965 and a Vice president of ISRM for Europe from 1970 to 1974. Very important person is also prof. Ervin Nonveiller (Croatia), who particularly contributed to grouting in karst areas. There are a lot of other persons who participated in the development of rock mechanics: the interested reader is referred to Selimović (2011). Having this in mind, below is data about the first ever application of original large-scale tests used in FY (Table 2).

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Table 2. Data about introducing of original large scale testing in the region of FY (Kujundžić, 1970).

| Place | Testing method | Year | Project leader |
|---|---|---|---|
| HPP Jablanica, Bosnia and Hercegovina | Hydraulic strut method (deformability test) | 1947 | R. Sabljak |
| HPP Vinodol, Croatia | Deformability test with test chamber method | 1949 | E. Nonveiller |
| HPP Moste, Slovenia | Deformability test with test chamber method | 1949 | M. Klajdinst |
| HP Vinodol, Croatia | Deformability test with hydraulic jack | 1951 | Kujundžić et al. and E. Nonveiller |
| HPP Mavrovo, Macedonia | Radial jack method | 1951 | Lazarevic and Kujundžić |
| HPP Bajina Basta, Serbia | Large scale field shearing test | 1952 | Kujundžić and Jovanović |
| HPP Buk Bijela, Bosnia and Hercegovina | Double hydraulic jack test | 1954 | Jovanović |
| HPP Bajina Basta, Serbia | Borehole dilatometer test | 1958 | Kujundžić |

It is obvious that the method of radial jack testings invented by the Institute "Jaroslav Černi" was for the very first time in the world applied in Macedonia in 1951 (Fig. 2). It was used during the investigation works for the so called Duf's tunnel of the large Hydro Energy System "Mavrovo".

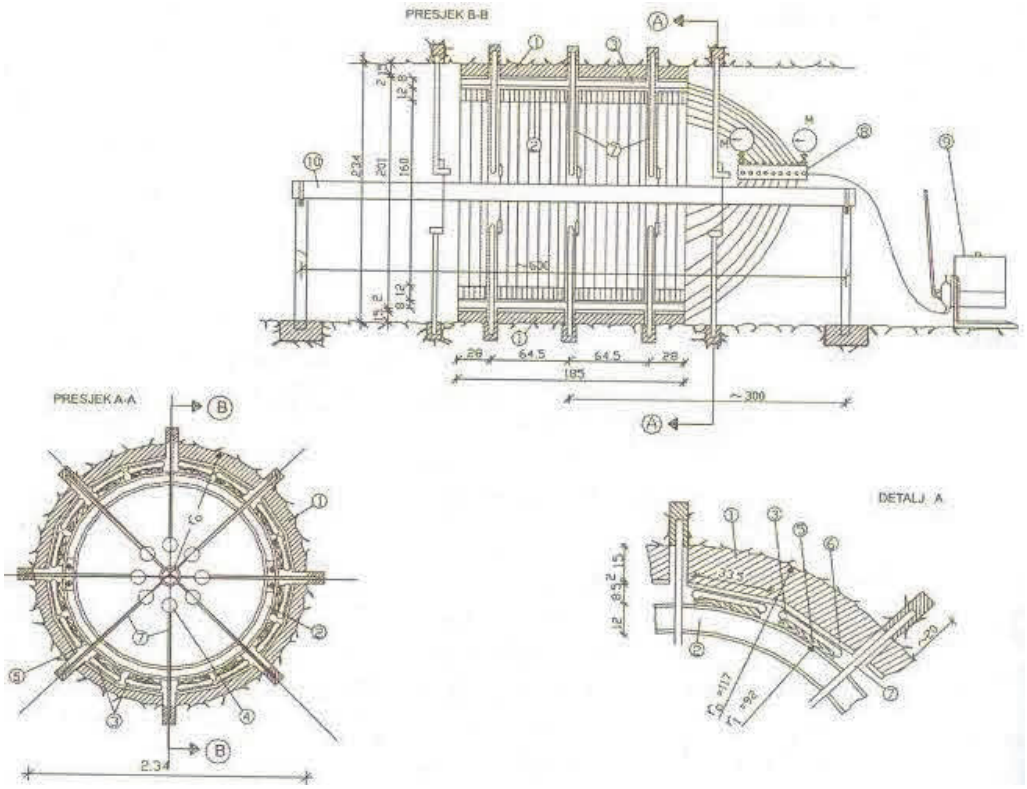
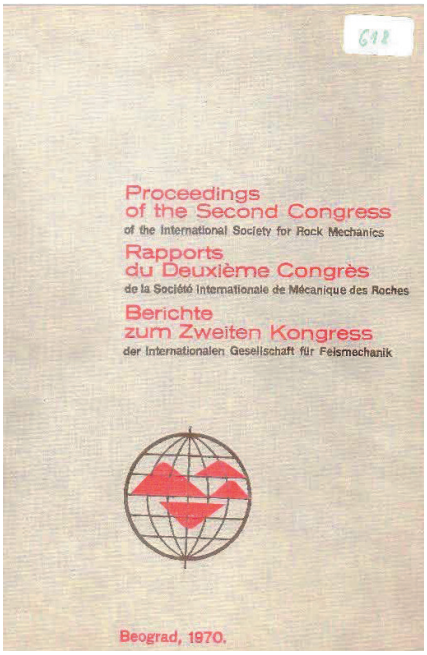


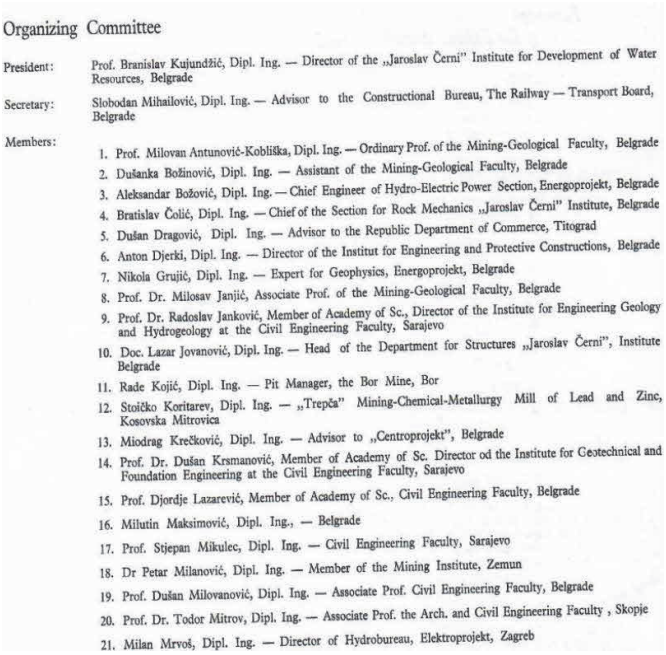

Figure 2. Scheme of the radial flat jack method, first time applied in Mavrovo hydro system tunnel in 1951 (Kujundžić, 1970).

Details for other contributions of experts from FY in micro seismic tests, seismic refraction method along tunnels, combined static-dynamic rock mass investigations, shearing along joints, model tests, stresses in rock and underground pressure, rock stability problems, tunnel stresses, grouting etc., are presented in Kujundžić (1970). Very important is also the contribution in the field of development of methodology for engineering geological modeling (Kujundžić, 1973).

One of the corner-stones in the development of rock mechanics is surely the Second Congress of ISRM held 21-26.9.1970 in Belgrade (Fig.3). During the Ceremonious opening session, beside by FY

officials, the participants were greeted by the President of ISRM at that time, prof. Manuel Rocha, while prof. Müller, the first president of ISRM, was also present. In total, 963 participants from 44 countries from around the world were registered. The president of the Organizing committee was prof. Kujundžić, while its member was also prof. Mitrov. During the Congress, a new president was elected: dr. L.A. Obert. Curiosity is the fact that several future presidents of ISRM were also present: Edwin T. Brown, Charles Fairhurst, Pierre Habib, Walter Wittke, John A. Franklin and Marc Panet! The impact of this Congress was very high and contributed in establishing the rock mechanics as very important discipline.



Organizing Committee

President: Prof. Branislav Kujundžić, Dipl. Ing. — Director of the „Jaroslav Černi" Institute for Development of Water Resources, Belgrade

Secretary: Slobodan Mihailović, Dipl. Ing. — Advisor to the Constructional Bureau, The Railway — Transport Board, Belgrade

Members:

1. Prof. Milovan Antunović-Kobliška, Dipl. Ing. — Ordinary Prof. of the Mining-Geological Faculty, Belgrade
2. Dušanka Božinović, Dipl. Ing. — Assistant of the Mining-Geological Faculty, Belgrade
3. Aleksandar Božović, Dipl. Ing. — Chief Engineer of Hydro-Electric Power Section, Energoprojekt, Belgrade
4. Bratislav Čolić, Dipl. Ing. — Chief of the Section for Rock Mechanics „Jaroslav Černi" Institute, Belgrade
5. Dušan Dragović, Dipl. Ing. — Advisor to the Republic Department of Commerce, Titograd
6. Anton Djerki, Dipl. Ing. — Director of the Institut for Engineering and Protective Constructions, Belgrade
7. Nikola Grujić, Dipl. Ing. — Expert for Geophysics, Energoprojekt, Belgrade
8. Prof. Dr. Milosav Janjić, Associate Prof. of the Mining-Geological Faculty, Belgrade
9. Prof. Dr. Radoslav Janković, Member of Academy of Sc., Director of the Institute for Engineering Geology and Hydrogeology at the Civil Engineering Faculty, Sarajevo
10. Doc. Lazar Jovanović, Dipl. Ing. — Head of the Department for Structures „Jaroslav Černi", Institute Belgrade
11. Rade Kojić, Dipl. Ing. — Pit Manager, the Bor Mine, Bor
12. Stoičko Koritarev, Dipl. Ing. — „Trepča" Mining-Chemical-Metallurgy Mill of Lead and Zinc, Kosovska Mitrovica
13. Miodrag Krečković, Dipl. Ing. — Advisor to „Centroprojekt", Belgrade
14. Prof. Dr. Dušan Krsmanović, Member of Academy of Sc. Director od the Institute for Geotechnical and Foundation Engineering at the Civil Engineering Faculty, Sarajevo
15. Prof. Djordje Lazarević, Member of Academy of Sc., Civil Engineering Faculty, Belgrade
16. Milutin Maksimović, Dipl. Ing., — Belgrade
17. Prof. Stjepan Mikulec, Dipl. Ing. — Civil Engineering Faculty, Sarajevo
18. Dr Petar Milanović, Dipl. Ing. — Member of the Mining Institute, Zemun
19. Prof. Dušan Milovanović, Dipl. Ing. — Associate Prof. Civil Engineering Faculty, Belgrade
20. Prof. Dr. Todor Mitrov, Dipl. Ing. — Associate Prof. the Arch. and Civil Engineering Faculty , Skopje
21. Milan Mrvoš, Dipl. Ing. — Director of Hydrobureau, Elektroprojekt, Zagreb

Figure 3. Cover page of the Proceedings of the Second ISRM Congress (left), and part of Organizing Committee where prof. Mitrov from FCE is listed under No.20 (Note: No.618 at the cover page is internal number of these Proceedings in the Library of the Chair of Geotechnics at FCE).

## 4. PROFESIONAL ORGANISATIONS RELATED TO MACEDONIAN ROCK MECHANICS

Until 1990, the geotechnical engineering in Macedonia was closely related to FY associations for Soil Mechanics and Foundation Engineering, for Rock Mechanics and Underground Structures and for Engineering Geology. At the sole end of the past century, the preparations for foundation of the Macedonian Association for Geotechnics (MAG) also began. The first assembly to establish MAG was held in 1998: it was officially registered in 1999, while during the XV International Conference for Soil Mechanics and Geotechnical Engineering held in Istanbul in 2001, MAG became a member of the international geotechnical family. In April 2002, MAG was visited by prof. William van Impe, president of ISSMGE at that time. Since then, MAG has been very active as it has organized national symposiums in 2002, 2006, 2010 and 2014. Meanwhile, an International Seminar on Eurocodes 7 & 8 was organized in 2008, with strong support of ISSMGE. For this occasion, the then actual and future presidents of ISSMGE, prof. Pedro Seco Pinto and prof. Roger Frank, were guests of MAG. In June 2018, MAG organized the XVI Danube-European Conference on Geotechnical Engineering (DECGE) in Skopje, with main theme: Geotechnical hazards and risks – Experiences and Practices (Fig. 4). The impressions from that event are still fresh and very positive as it was attended by participants from 44 countries, while during the conference, the boards of ISSMGE and ITA (International Tunneling and Underground Space Association) had their meetings.

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Figure 4. Group photo of participants at XVI DECGE organized by MAG in 2018.

Moreover, all activities of MAG were recognised and awarded with a high level of State Recognition in 2018, when prof. Heinz Brandl from the Technical University in Vienna was awarded by the President of R. Macedonia, prof. Gjorgje Ivanov with Medal of Merits for Macedonia, for development of geotechnics (Fig. 5).

Figure 5. Special State Recognition for development of geotechnics for prof. Heinz Brandl, given by President of R. Macedonia, H. E. prof. Gjorgje Ivanov, in the margins of the XVI DECGE, held in Skopje in 2018 (left: prof. Heinz Brandl; right: H.E. prof. Gjorgje Ivanov, President of RM).

Meanwhile, MAG founded a National Group for Rock Mechanics in 2017, which became member of the International Association for Rock Mechanics and Rock Engineering (ISRM). The support by Emeritus Prof. Ivan Vrkljan from Croatia and prof. Norikazu Shimizu from Japan must be underlined!


Figure 6. ISRM seminar organized at the FCE in 2017 (from left to right: prof. Milorad Jovanovski – immediate-past president of MAG, prof. Ivan Vrkljan – immediate-past Vice-president of ISRM, prof. Norikazu Shimizu – immediate-past Vice-president of ISRM and asst. prof. Jovan Br. Papić – President of MAG).

Today, the geotechnical engineers in Macedonia participate and contribute to several professional engineering organisations in the country and abroad. MAG is the primary organisation with more than 150 active individual members. According to the national Law for construction, registration of engineers is regulated in the authorised body Chamber of Certified Architects and Certified Engineers of Macedonia (CCACEM), with several divisions: Architecture, Civil engineering, Electrical engineering, Mechanical engineering, Urban planning, Geodesy, Geotechnics, Safety and fire resistance, Environmental engineering, Energy efficiency, Technology and metallurgy and Traffic engineering. It seems that in Europe, MKD is one of the rare countries where geotechnical engineers already have a separate place in professional organizations (Fig. 7).

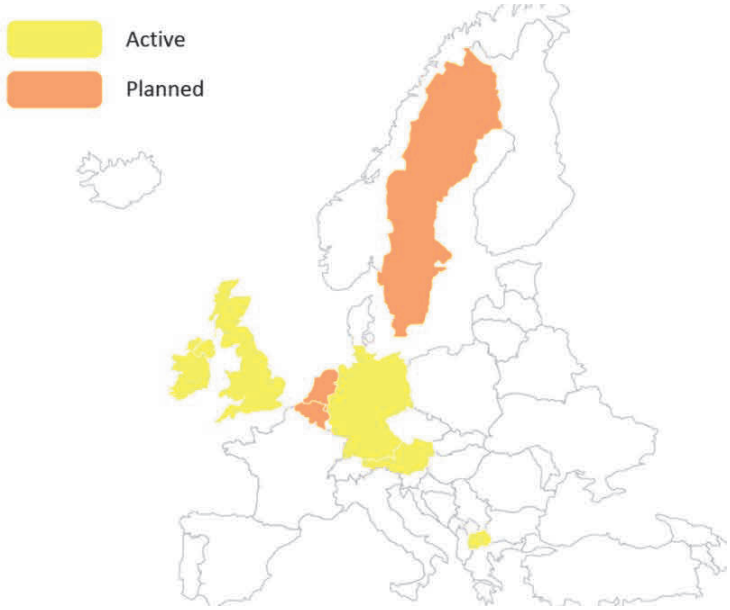


Figure 7. Map with countries in Europe which have professional association that registers engineers in geotechnical engineering (Buggy and Franzen, 2019).

## 5. GEOLOGICAL BACKGROUND TO ROCK MECHANICS PROBLEMS

The geological settings on the territory of MKD are considered to be very complex. The territory of the country is divided in six large geotectonic units which developed during the Proterozoic, Rifej-Cambrian, Caledonian-Hercynian and Alpine orogeny (Figure 8).

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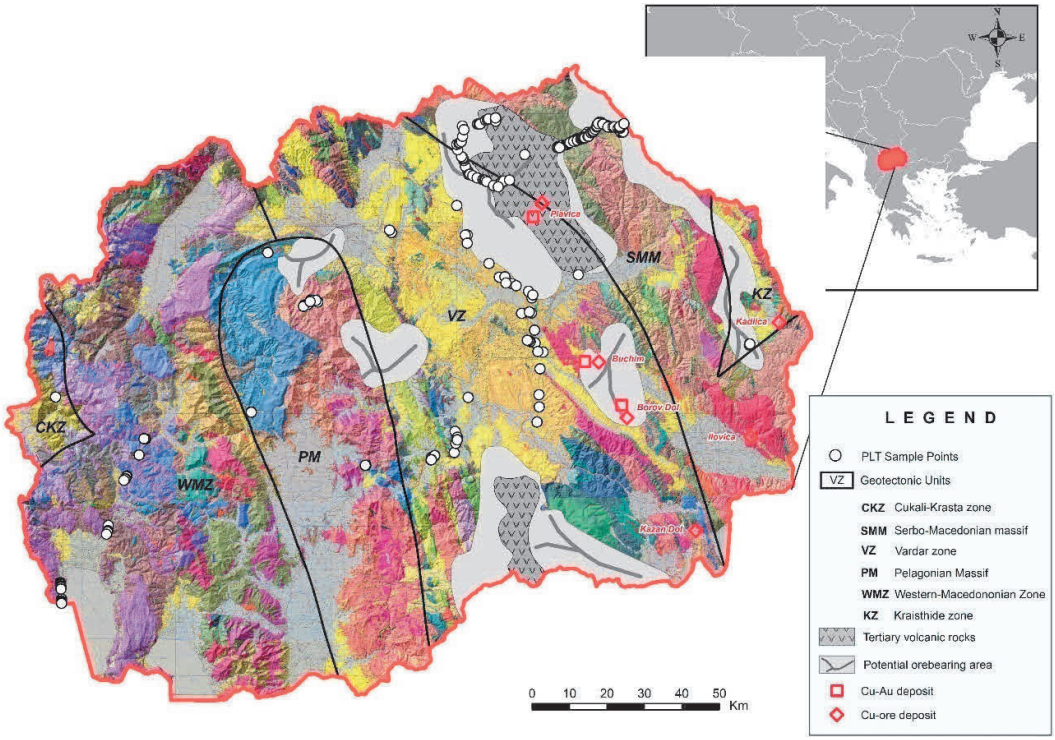


Figure 8. Geotectonic units in Macedonia. White dots represent location of samples from infrastructure projects, red dots present test locations for specific mineral deposit (Peshevski et al., 2019).

The Cukali-Krasta zone is composed mostly of Upper Cretaceous flysch transgressed by Eocene conglomerates. The West-Macedonian zone is represented by very complex tectonics, with a multitude of folded and faulted structures. It is mostly composed of phyllitic low-grade metamorphic complex. Its lower parts are dominated by volcanic sedimentary rocks and its upper part by a terrigene-carbonate formation. The Pelagonian massif is a relic of the Precambrian Earth crust. It is separated by the neighboring tectonic units by deep faults and consists of metamorphic crystalline rocks, gneisses, micaschists, marbles etc. The Vardar zone includes fragments from the Precambrian Earth crust, Paleozoic volcanic-sedimentary complexes, and acidic Mesozoic magmatism. The Serbian-Macedonian massif is characterized by the presence of Precambrian and Rifej-Cambrian complexes. Gneisses and micachsits are prevalent. The Kraishtide zone is consisted of Triassic and other Alpine formations, and also has particular development of the greenschists formation.

Due to the various changes in each stage of geologic development, the rocks exhibit very variable behavior regarding their strength. Figure 8 also shows the approximate spatial distribution of about 1200 samples for Point Load Tests for some infrastructural projects in MKD (Peshevski et al., 2019).

It shall be mentioned that there is an old tradition of implementation and exploitation of gold, silver, copper and lead-zinc ores, and monumental stones in Macedonia. This implies that geotechnical methods are, in fact, intuitively used in exploitations. Organized exploitation of those metals and stone existed at time of Ancient Macedonians and before. During the Roman time, the recovery of metal ores and stones substantially increased, which is supported by many marks of mining activity. E.g., relics of panning of gold in the valley of Konska river – Gevgelija from ancient time, mine gates of exploitation in Kratovo-Zletovo, mining area and mine instruments, as well the many ancient statues, busts and columns made from Prilep dolomitic marble in ancient towns of Stibera and Stobi, amphi-theater and statues in ancient town of Heraklea, amphitheatre of Stobi (archaeological location built of limestone) (Fig. 9), amphitheatre from III century B.C. in town Ohrid (built of travertine) etc.

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Figure 9. Statues of Heraklea (left); Old amphitheatre at Stobi (3 Century BC) (right).

From ritual and archaeological aspect, the localities Kokino brdo and Cocev Kamen shall be mentioned (Figure 10).

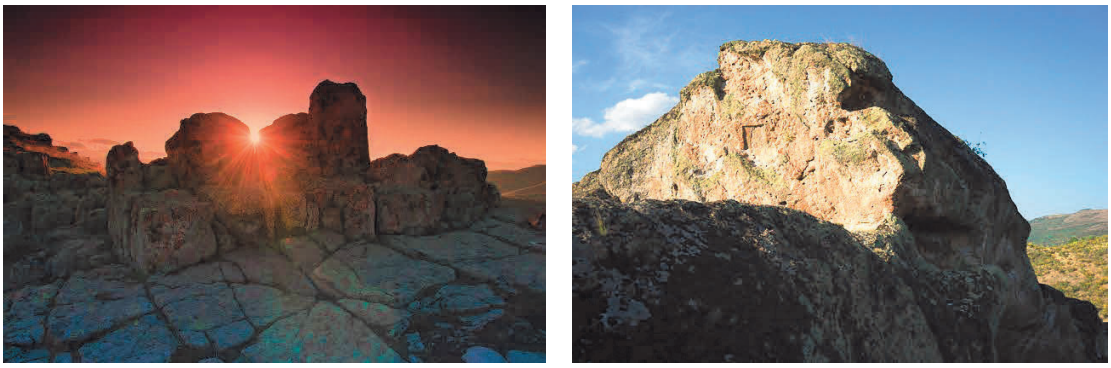

Figure 10. Sunrise at Kokino brdo. (Left)and Cocev Kamen (Right) https://macedonia.for91days.com/the-forgotten-observatory-of-cocev-kamen.

Namely, according to the interpretation, the site of Kokino brdo includes special stone markers used to track the movement of the Sun and Moon on the eastern horizon. It is dated 1800 B.C. and it was mentioned in a poster made by NASA's "Sun-Earth Connection Education Forum" in 2005. In 2009, it was also suggested that the site should be inscribed on the World Heritage Site list.

Cocev kamen is situated in the north-east of MKD and it is a hilltop cave site of volcanic origin near the town of Kratovo (https://en.wikipedia.org/wiki/Cocev_Kamen). Bone fossils discovered near the cave suggest human presence since the Paleolithic, while it is agreed that the site served as a gathering point for sacrificial rituals from the Neolithic, during the Bronze Age, throughout antiquity until the Middle Ages as clarified by an abundance of pottery shards, stone (flint) tools and bone fragments unearthed from the surrounding areas. Debated remains the notion that Cocev Kamen has also been used as an (astronomical) observatory, as there are visible interventions on the stone surface in form of stairs, pools, thrones all around the site, as well as a big cave.

Also, unique and beautiful geomorphological forms and formed reservoirs due to erosion processes or rockfalls can be found: some are presented in Figure 11.

From phenomenological aspect, Macedonian rock art is characterised by diversity and perfection of forms, resulting in the discovery of over 600.000 rock carvings. Macedonia's entire territory is an open-air museum, containing most of the rock carvings that have been discovered and preserved. For example, Macedonian-Italian research expedition discovered an engraved sun symbol resembling the MKD flag in the Kratovo village of Trnovec in 1994 (Figure 12).

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Figure 11. Rock mass form named as “Lady” near city of Prilep in granitic-gneiss complex (upper left); Waterfall near village Rastojca in granitoids (upper right); “Devil wall” in flysch complex near Bogoslovec hill (middle left); “Elephant” near Monastery Treskavec close to the town of Prilep (middle right) and artificial lake created as result of large landslide “Gradot” on river Luda Mara near town Kavadarci (down left and right).

Figure 12. Sun symbol resembling the Macedonian flag in the Kratovo village of Trnovec http://www.macedonia.co.uk.

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There are also a lot of interesting civil engineering structures, and below are mentioned only several which clearly show tradition in construction from Roman time, through Ottoman Empire.

The Stone Bridge crosses the Vardar River in the center of Skopje (Fig. 13). It is considered a symbol of the capital and is the main element of the coat of arms of the city, which in turn is incorporated in the city's flag. The current Stone Bridge was built on Roman foundations under the patronage of Sultan Mehmed II the Conqueror between 1451 and 1469. Throughout the centuries, the Stone Bridge was frequently damaged and repaired, sometimes due to the often earthquakes and floods. Namely, there is historical evidence that it suffered during the great earthquake of 1555 which heavily damaged or destroyed four pillars, which renovations were carried out the same year. However, majority of them stayed stable, including after the last strong earthquake in 1963, partly due to the wooden piles in theirs foundations.

Figure 13. Stone Bridge in Skopje (built in the 6$^{th}$ century or earlier).

Figure 14. Stone bridge Elenski skok on Garska river (16$^{th}$ century) (Nikolovski and Ivanov, 2013).

Other interesting stone bridge structures are also present in MKD, and the details can be found in Nikolovski and Ivanov (2013).

## 6. ACHIEVEMNENTS OF MACEDONIAN ROCK MECHANICS

Taking into consideration especially the political, economic and historical circumstances in Macedonia after the Second World War, with some dose of contentment it could be noted that after modest beginnings, for some ten years only, the geotechnical engineering in Macedonia has experienced a rapid growth. The intensive contacts of the first young geotechnical engineers with the geotechnical centers in FY and worldwide surely contributed appropriately in that direction.

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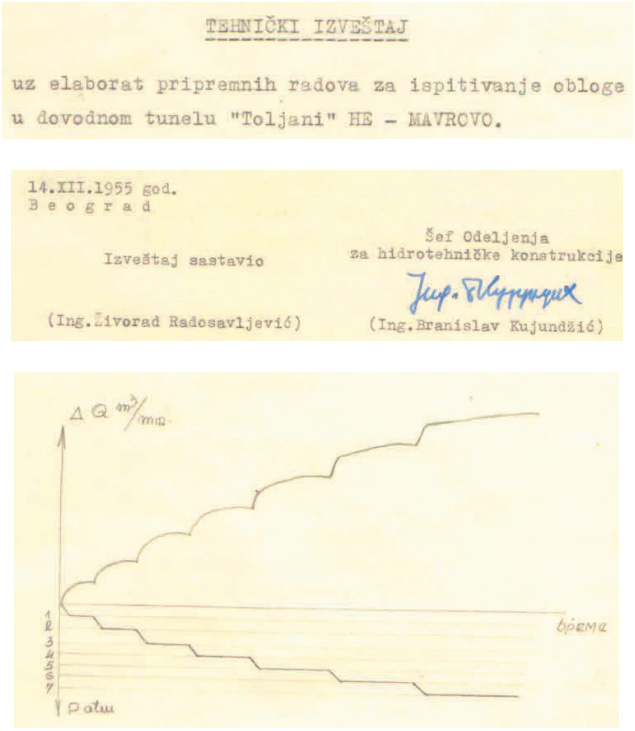
As it was mentioned, the method of radial flat jack test, invented by "Jaroslav Černi" Institute, was for the first time in the world applied in the Republic of Macedonia in 1951. Also, many large scale tests are prepared for large hydropower systems. For example, one of them is the HPP Mavrovo system, so, for historical records, interesting extraction is presented in Figure 15.


TEHNIČKI IZVEŠTAJ

uz elaborat pripremnih radova za ispitivanje obloge u dovodnom tunelu "Toljani" HE – MAVROVO.

14.XII.1955 god.
Beograd

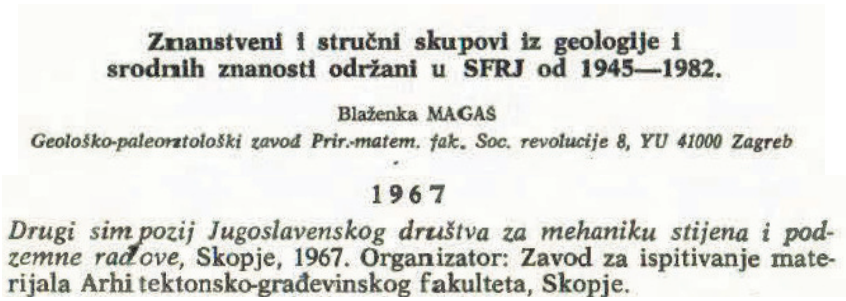
Izveštaj sastavio
(Ing.Živorad Radosavljević)

Šef Odeljenja
za hidrotehničke konstrukcije
(Ing.Branislav Kujundžić)



Figure 15. Original crops from Report of deformability and permeability tests with test chamber methods applied on a Toljane tunnel in 1955 (with a kind permission of the staff from HEC Mavrovo): Title of Report (up), Original signature of prof. B. Kujundžić (middle), Results from testing program (bottom).

It interesting to note that the Second Yugoslav Symposium for Rock Mechanics and Underground Structures was organized in Skopje in 1967 (Fig. 16).


**Znanstveni i stručni skupovi iz geologije i srodnih znanosti održani u SFRJ od 1945—1982.**

Blaženka MAGAŠ
*Geološko-paleontološki zavod Prir.-matem. fak. Soc. revolucije 8, YU 41000 Zagreb*

**1967**

***Drugi simpozij Jugoslavenskog društva za mehaniku stijena i podzemne radove*, Skopje, 1967. Organizator: Zavod za ispitivanje materijala Arhitektonsko-građevinskog fakulteta, Skopje.**

Figure 16. Excerpt from "Geološki vijesnik" (Geological Gazette) 37, Zagreb 1984: title page for Scientific meetings in SFRY in the period 1945-1982 (up); Crop for year 1967, the Symposium held in Skopje (bottom).

It is good to note that prof. Naum Gapkovski, who worked on almost all important rock mechanics problems and challenges for many hydraulic structures, was also one of the persons involved in the first phases of large scale and other investigations at the profile for arch dam "Mratinje" on a river Piva and "Bijeli Brijeg" on river Tara in Montenegro, in a period 1967-1968: at that time, he was employed in the company "Geosonda" from Belgrade.

In the period from 1951 to 1988, a lot of dam profiles were investigated in details. Among the rest, large scale rock mechanics tests were applied, usually in cooperation by the Institute and with staff from the Chair of Geotechnics of FCE. Just to illustrate the interesting historical records, some originals from Reports or Design books are presented in below.

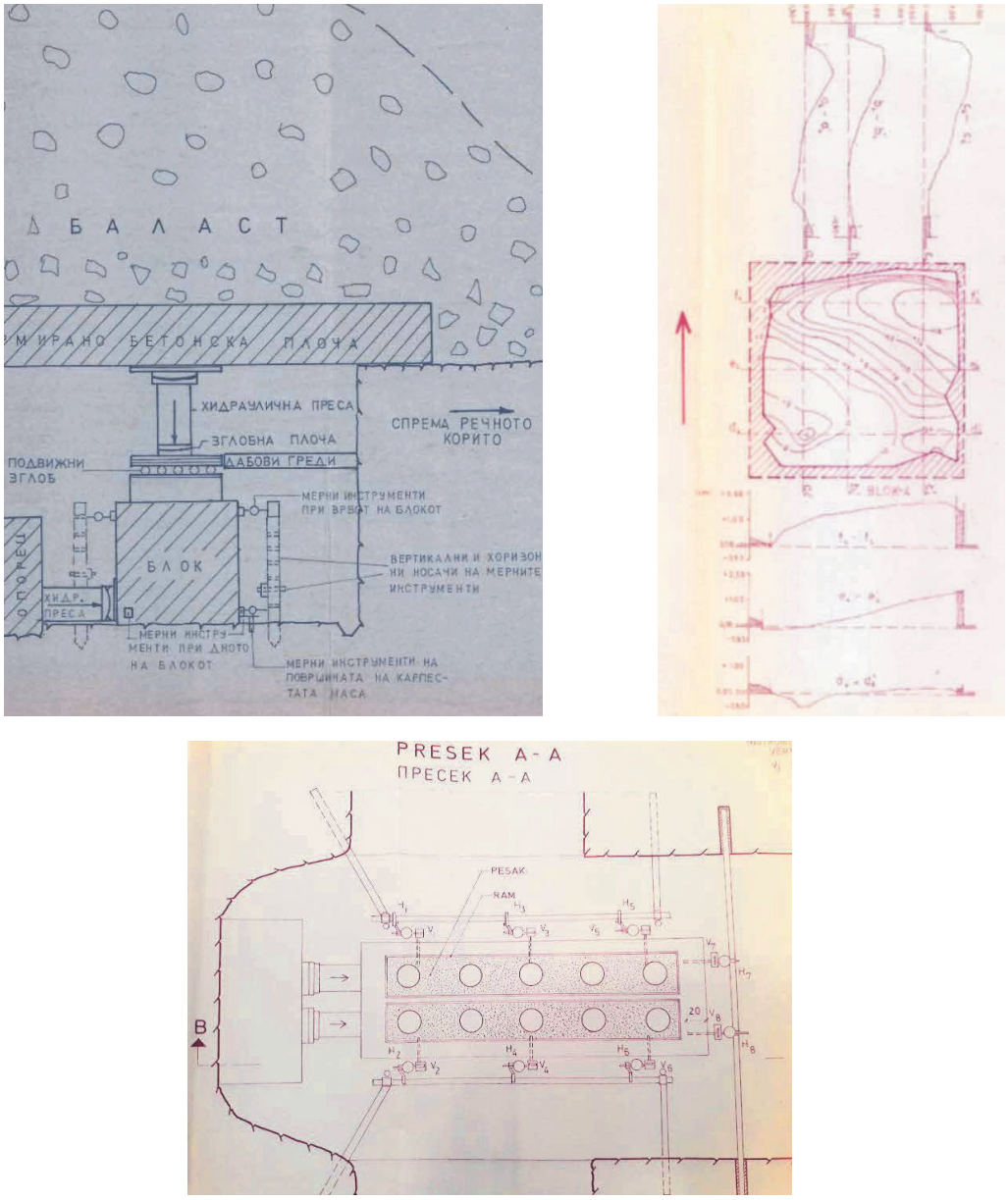



Figure 17. Some originals from large scale deformability and shear strength tests in MKD: Non typical disposition of block deformability tests near surface for dam “Otinje” prepared by Chair of Geotechnics, FCE (up, left); A sketch of roughness plan and profiles of roughness after shearing of block for a dam “Galište” prepared by FCE and Institute “Jaroslav Cerni” (up, right); Large shear block with dimensions 3*1 m test on a profile for dam “Veles” (down) (Source: Library of Chair of Geotehnics at FCE).

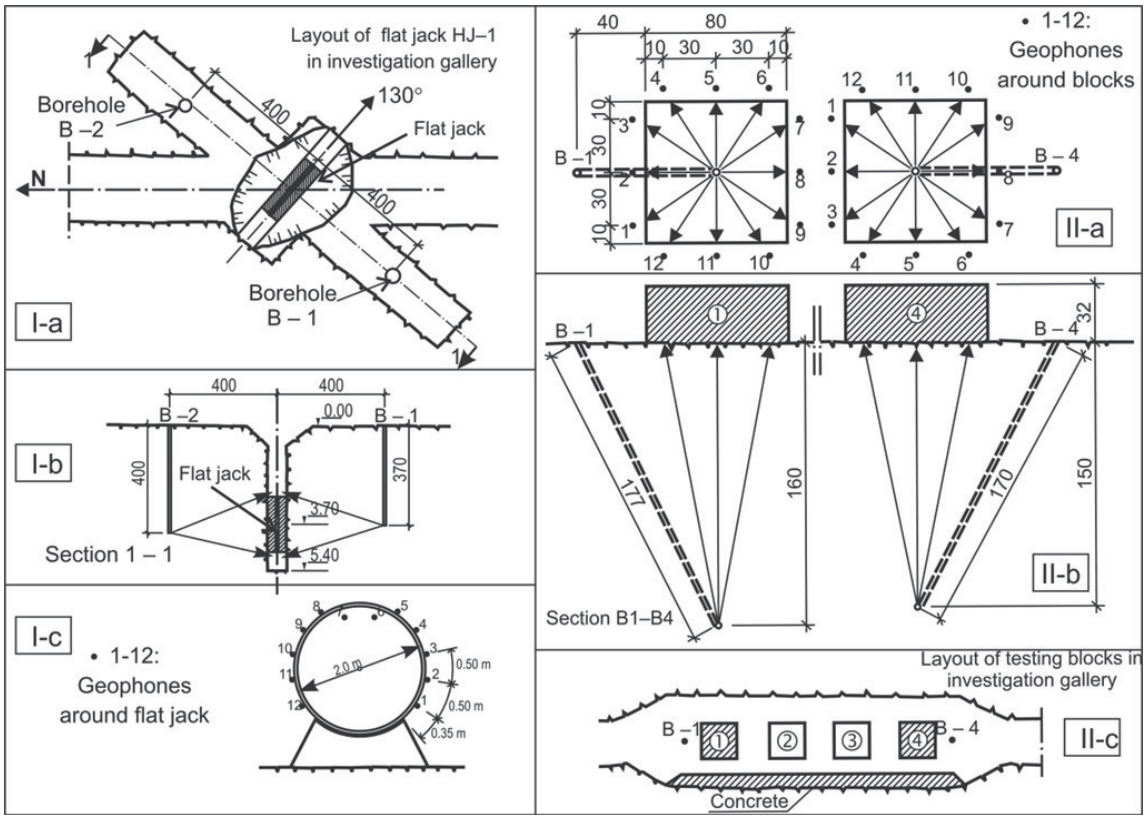



Figure 18. Disposition of parallel static and dynamic deformability tests at the profile for arch dam "Sveta Petka" on river Treska in a cooperation of FCE, Civil Engineering Institute "Macedonia" and Institute "Jaroslav Černi"; (Jovanovski et al., 2018).

So, the level of application of the last achievements of geotechnical engineering and rock mechanics in MKD could be appraised from good and appropriate, up to quite formal. For the most of the capital civil engineering structures financed out of state funds and sources, the investigations, design, construction, control, monitoring and utilization and maintenance are respected, but not equally in all phases. It could be said that, in general, technical standards, regulations and codes as well as other legal acts, are followed, and, when necessary, also an expert knowledge from the country and abroad is applied. Similar situation is in the field of geological investigations, mining engineering, as well as in the area of geotechnical hazards. However, despite obvious difficulties, some impressive structures are constructed and complex geotechnical problems are solved using geotechnical knowledge and specific test methods in an appropriate manner. Some examples are given in the following pictures.

In Figure 19, one interesting apparatus for rock fill testing is presented. The original version is with dimensions 1,50 x 1,50 x 0,60 m, but it was modified to dimensions 1,00 x 1,00 x 0,60 m in order to make conditions for appliance of higher normal stresses. The shear surface is horizontal (it is positioned in the middle between the lower and the upper frame of the shear box), the normal stress is achieved with 4 vertical presses from 1000 kN, and the horizontal load (shear stress) is achieved with two inclined hydraulical presses mounted under an angle of around 11° in relation to the horizontal plain. The lower frame is static, while the upper frame is moving over it, enabled by rollers which help to restrict unwanted resistance from any kind.

Beside numerous tests for many rockfill dams, embankments and very high retaining walls with this apparatus, some interesting direct shear between the interfaces surfaces for the dam "Kozjak on river Treska are applied. Namely, with such disposition, interfaces of bedrock (marbleized limestone)-rockfill; bedrock-filter material and bedrock-clay, are tested (Papic et al., 2011).

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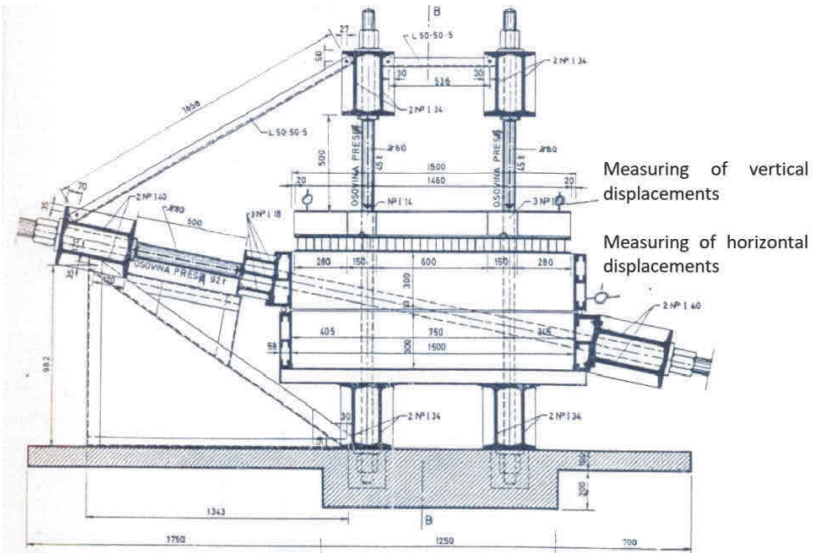


Figure 19. Direct shear box 1,00 x 1,00 x 0,60 m applied during the testing of rockfill or interfaces of different materials (Papic et al., 2011).

Figure 20 presents the oldest arch dam in Macedonia – "Matka", on the river Treska, dated from 1938 and designed by academician Miladin Pećinar, as a case of successful rock and dam engineering. In 2021, the Skopje City Council adopted the initiative to name a street after him.

Examples of more recent structures are given in Figures 21 to 24.

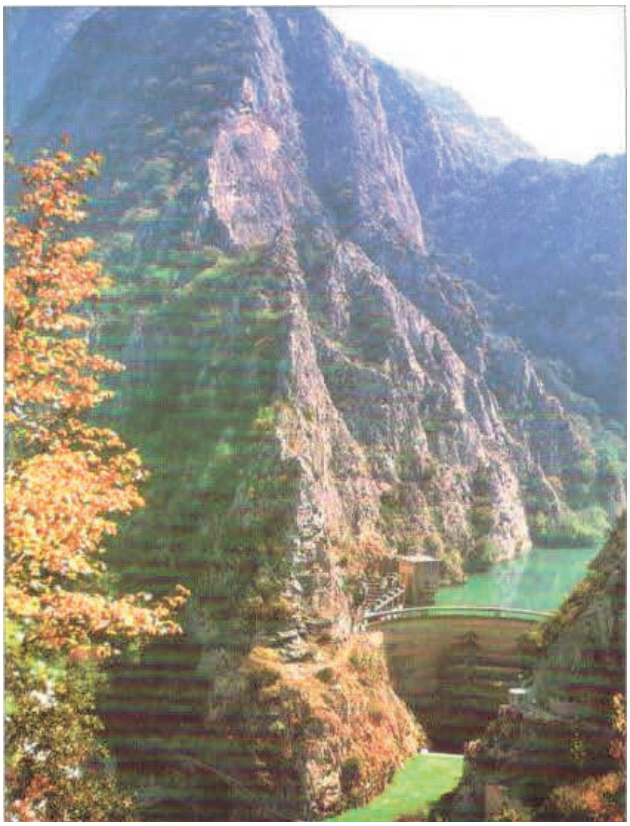

Figure 20. Arch dam "Matka" on Treska river, constructed in 1938 (https://mk.wikipedia.org/wiki/HE Matka).

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Figure 21. Arch dam "Sveta Petka" on the river Treska (construction completed in 2012) (https://mk.wikipedia.org/wiki/HEC Sveta Petka).

Figure 22. Bridge over the lake "Kozjak", nearby the dam Kozjak at Treska river (Nikolovski and Ivanov, 2013).

Figure 23. High cuts in metamorphic rocks at highway from Kicevo to Ohrid in a phase of construction.

Figure 24. Some structures at highway E-75, section from Demir kapija to Smokvica (cut is in diabases with a height of about 70 meters).

During the last 25 years, the efforts to collect and to analyze rock mass parameters in systematic way are present, so some of the results are presented in the following figures.

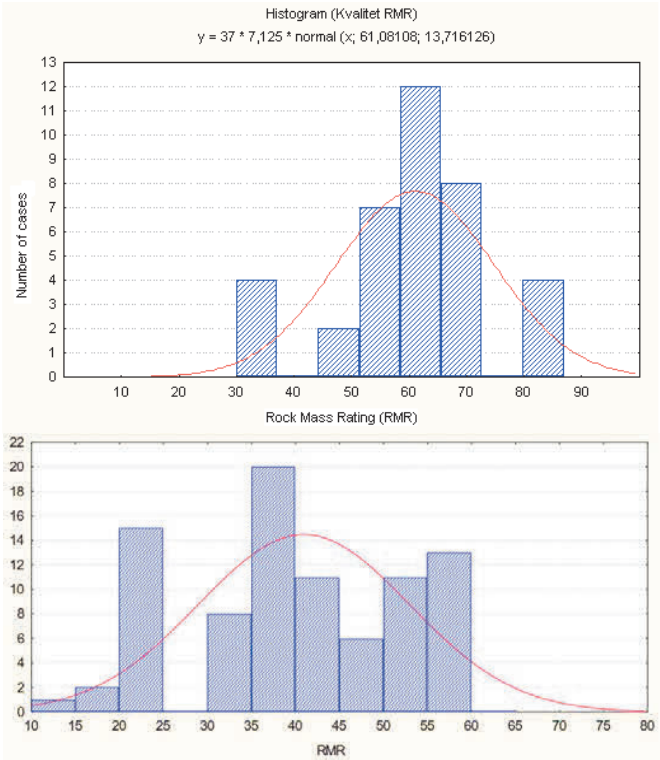


Figure 25. Up: Histograms of Rock Mass Rating for carbonate rocks for some dams from Balkan region (Jovanovski et al., 2010); Bottom: for schist rock mass complexes from MKD (Nikolov and Jovanovski, 2010).

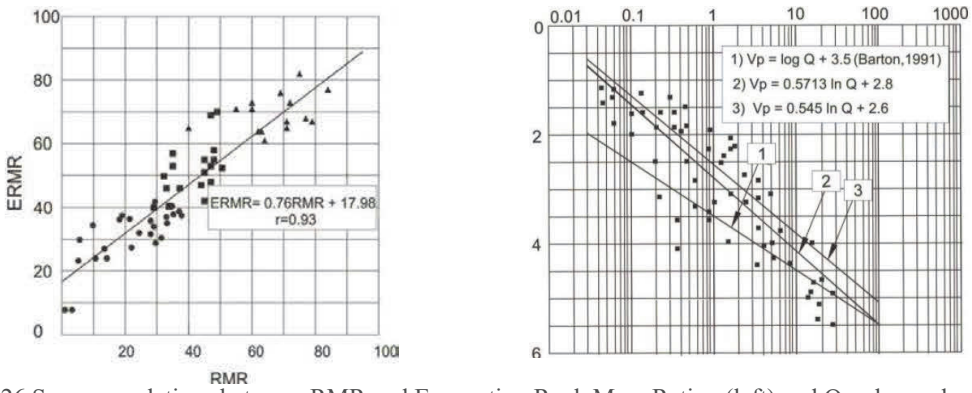


Figure 26.Some correlations between RMR and Excavation Rock Mass Rating (left) and Q-value and values of longitudinal seismic waves (in km/s) for different regions.

It can be underlined that a lot of young researchers are active in the last period in all ISRM activities, which fact is very important for further development and following the trends in rock mechanics. Methods for microseismic tests, combined empirical-static-dynamic methodology for extrapolation, shearing along joints, model tests of contacts and BIM-rocks, development of original rock mass classification systems, problems for rock stability problems, tunnels, grouting, risk analyses etc. are field of permanent occupation of researches.

## INSTEAD OF CONCLUSION

The article makes an attempt to overview several aspects of rock mechanics in MKD as a significant field in civil and mining engineering. It is obvious that it is not possible to demonstrate the entire activities of the experts from FY and MKD, although some of the explained methods are certainly

interesting, as well as contributions to the general idea for development of rock mechanics. Based on the motto that the tradition is a challenge to innovation, the aim is to cause as large as possible interest within the young researchers for whom geotechnical engineering is life determination, to establish close cooperation and to ensure applicable engineering politics in the region and to contribute to larger rock mechanics community in future.

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