DYNAMIC AND STATIC ELASTIC PROPERTIES – LABORATORY INVESTIGATIONS OF METAMORPHITES OF THE "VRANJSKA BANJA" SERIES

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ABSTRACT

Metamorphites of the series "Vranjska banja" built predominantly of high crystallinity schist series, alternately layered double mica, gneiss, leptonite and micaschist. For the construction of the "Prvonek" dam were carried out laboratory investigations of dynamic and static elastic properties on micashist and gneiss samples in the perpendicular and parallel direction to the foliation. These investigations provided monitoring of the rock mass anisotropy properties and greater reliability of the design parameters. As the design of mining and construction facilities becomes more demanding, such investigations are becoming increasingly standard in complicated geological environments.

Key words: *micashist, gneiss, foliation, dynamic properties, static properties*

INTRODUCTION

Rock masses are, as a rule, distinctly anisotropic environments. Rock mass anisotropy is conditioned by mechanical discontinuities (joint systems, stratification, cleavage) or lithological discontinuities, the most important is folation. Anisotropy influence is greatest on the following rock properties: mechanical resistance, elasticity, deformability, water permeability and heat conductivity.

The most common form of anisotropy is anisotropy versus deformability. Investigations on layered rocks have shown that rock masses are generally deformed equally in all directions. The deformation perpendicular to the layers is greater than the deformation in the direction of the layers, the deformations are of the same intensity. The paper presents the results of deformability investigations on rock samples that have pronounced foliation (gneiss and mikashist) in the area of barrier at the dam site "Prvonek".

Dam "Prvonek" separates Banjska river, a right tributary of Juzna Morava, near the Vranjska banja.Storage space and wider cathment area build schist Vranjska Banja series (gneisses, mikashist, ambhibolites and quarzties), they are metamorphosed in the amphibolic facies, previous to Devonian age. Banjska river walley is canyon type, has an asymmetrical profile with distinctive steep left bank, the slope is 45 to 90 degrees, a tilt to the right is 35 degrees. Alluvial valley width is 30 to 60 meters.

The schists cracked due to tectonic disturbances, crack porosity. The alternation is greatest up to a depth of 10 meters. Beneath the altered schists are unlattered crystalline schists that are poorly permable to water. Higher water permeability zones are on the right bank, which represents a rock mass of weaker geomechanical characteristic.

A REVIEW OF THE MOST REPRESENTED LITHOLOGICAL MEMBERS OF VRANJSKA BANJA SERIES

Lithologic members of Vranjska banja series are:

Quartzites occur as lenses, rarely wires in gneisses and micashist. Their thickness is from a few centimeters to several tens of centimeters, rarely over 1 meter. They are milky white. Quartzites are solid rocks with very good mechanical properties. They are not regular lithological members in this area.

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Gneisses are built of grains, medimum size of 2 to 5 millimeters. They are made of feldspar, orthoclase, albite and microcline, muskovite, biotite and quartz. They have extreme schist defined oriented biotite and muscovite leaves. Textures are lepidoblastic, granoblastic and porphyroblastic. There are also fine micro sets and cracks that intersect schist at different angles. It is cleavage of the axial surface and an intermediate cleavage. They are brown in color.

Micaschist are built of biotite, muscovite and quartz. Rarely in this rocks happiness porphyroblastic grenades and kyanite up to a few millimeters. Micaschist have expressed king texture. As with gneiss, in this rocks there are axial surface cleavage and interlayer cleavage, there has been a tectonic transformation along cleavage.Textures are lepidoblastic, less granoblastic and porphyroblastic. When the content of feldspar increase micaschist turns into gneiss.On the field somewhere is gradual transition between the wall and somewhere alternate.Wall thickness grade packages, from several tens of centimeters to over 1 meter, rarely.

Amphibolities occur as lensses or interlayers in gneiss, very rare in micaschist thickness up to a few meters. They are dark green to black. Amphibolities are built by hornblenda and plagioclase. In this wall has a quartz episodes, rare and grenades. Textures are hematoblastic, rare granoblastic and porphyroblastic. Texture is as schist, has mass party of each wall. Tectonic relations are complex, with frequent lateral and vertical transitions.

Granodiorites, dacites, quartzites and porphyries are also in this investigation area. Granodiorites dominated. They are gray, massive textures, built of biotite, hornblende, orthoclase, feldspar and quartz. Textures are grainy, sometimes porfyria. Size of minerals is about a few millimeteres. Wall is fresh, just sometimes poor sericitizated and kaolinited. Secretion is plate and parallel which is important for exploitation.

The mechanical characteristic of the Vranjska banja series rocks range from very good (quartzites and granodiorites) to much weaker (gneisses and micaschist). Amphibolities have better mechanical properties of gneiss. They are occur as interlayers and they are not regular members of the lithology in this area. Gneisses have better mechanical properties of micaschist. Micaschist is the weakest, in this rocks there are axial surface cleavage and interlayer cleavage, there has been a tectonic transformation along cleavage. Gneisses and micaschist appear alternately and also have different mechanical properties. Rocks texture is very important, schist, pleating and cleavage too. Schist, pleating and cleavage are predisposed routes of mechanical discontinuity. This is the most important factor of the physical and mechanical properties.

LABORATORY INVESTIGATIONS OF THE SAMPLES ELASTIC PROPERTIES

According to the research investigations on the barrier on the dam site “Prvonek” were allocated eight samples for the second phase of laboratory investigations of physical and mechanical properties. The following parameters of strength and deformability were determined: Compressive Strength perpendicular to and parallel to the foliation, Static Modulus of elasticity and deformation perpendicular to and parallel to the folation, Velocities of longitudinal and transverzal elastic waves perpedicular to and parallel to the foliation, Dynamic Modulus and Poisson Coefficient of dynamic perpedicular and parallel to the foliation and Volumetric weight.

Sampling was done according to the standard SRPS B.B7.110, which determines the method of sampling, for the physical and mechanical properties of the rock material. According to the stated standard the samples are undisturbed. An appropriate number of test bodies was prepared from each undisturbed sample. Test bodies are of different shapes and dimensions, according to the standards for individual investigations of physical and mechanical rock properties. Samples were extracted in the form of blocks of dimensions 200 mm x 200 mm x 200 mm.

Each test body was sketched before investigation to show the direction of foliation. On the same test body more data were collected, velocities of longitudinal, v_p and trasverzal, v_s elastic waves were determined. To determine dynamic properties, the timing of passage of elastic t_p longitudinal and trasverzal t_s waves, used Japanese production company OYO device, type SONIC WIEWER MODEL 5210, with accuracy of reading time of 0.1 microseconds. Dynamic properties were determined in all three directions relative do the foliation, perpendicular to and parallel to the foliation.

In such conditions, with increase load of 10 – 15 daN/cm2, and with the dilatation of the test body in the load direction, the failure force is determined, that is Uniaxial compresssive Strength σ_p. At the same time, dilatation ε_p in percent at the moment of failure was determined. Both parameters were determined in one case perpedilularly to and in the other parallel to the foliation.
Based on the Uniaxial compressive Strength, the test range was defined for the Modulus of deformation E_d and Modulus of elasticity E_e. Triple hysteresis is carried out to determine three levels of static Modulus of elasticity and deformation, deformations were monitored at about on hundred measurements. The third hysteresis should reach of approximately 60% of the minimum compressive strength of the test rock. Based on the vertical dilatations, a graphical and tabular presentation of the relationship σ_p - ε_p and the determined values of Modulus E_d and E_e.
The test results for one sample are given as an example EXAMPLE–3 (VK-3) gneiss. The results are shown in graphs and tables in different directions on the foliation. Figure 1 and tables 1 and 2 show the test results perpendicular to the foliation, and figure 2 and tables 3 and 4, parallel to the foliation.

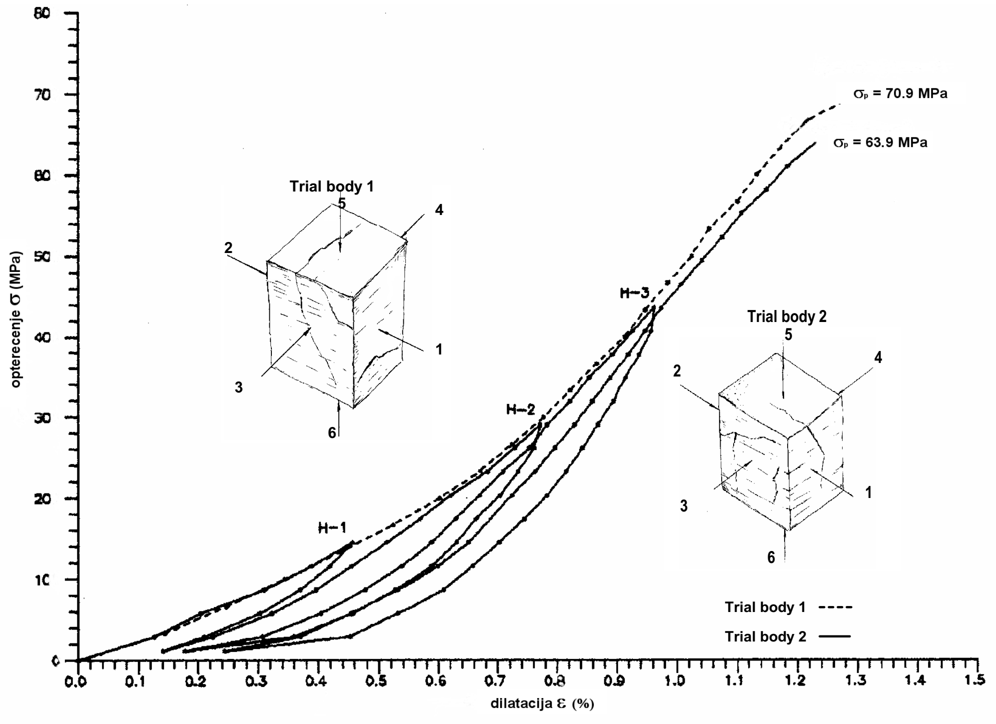

Figure 1.Sample VK-3, left bank, perpendicular to folation, gneiss.
Relatioship Dilatation ε (%) – Load σ (MPa) (Mining and Geology Faculty, 1992)

Table 1. Dynamic properties, perpendicular to foliation, gneiss, sample VK-3.

Trial body mark	Mark direction	γ kN/m3	V_p m/s	V_s m/s	E_{dyn} MPa	μ_{dyn}
1	Parallel (1-2)	26.12	3 879	1 697	20 790	0.38
	Parallel (3-4)		4 608	2 127	32 250	0.36
	Perpendicular (5-6)		2 550	1 355	12 500	0.30
2	Parallel (1-2)	26.12	3 844	1 708	20 990	0.38
	Parallel (3-4)		3 500	2 000	26 280	0.26
	Perpendicular (5-6)		2 424	1 429	13 160	0.23

Table 2. Static properties trial body 2, load direction 5-6, gneiss, perpedicular to foliation, sample VK-3.

σ (MPa)	Hysteresis	Static elasticity Modulus (MPa)	
σ=15	H-1	E_e=4 375	E_d=3 333
σ=29.5	H-2	E_e=4 750	E_d=3 851
σ=44	H-3	E_e=5 811	E_d=4 574

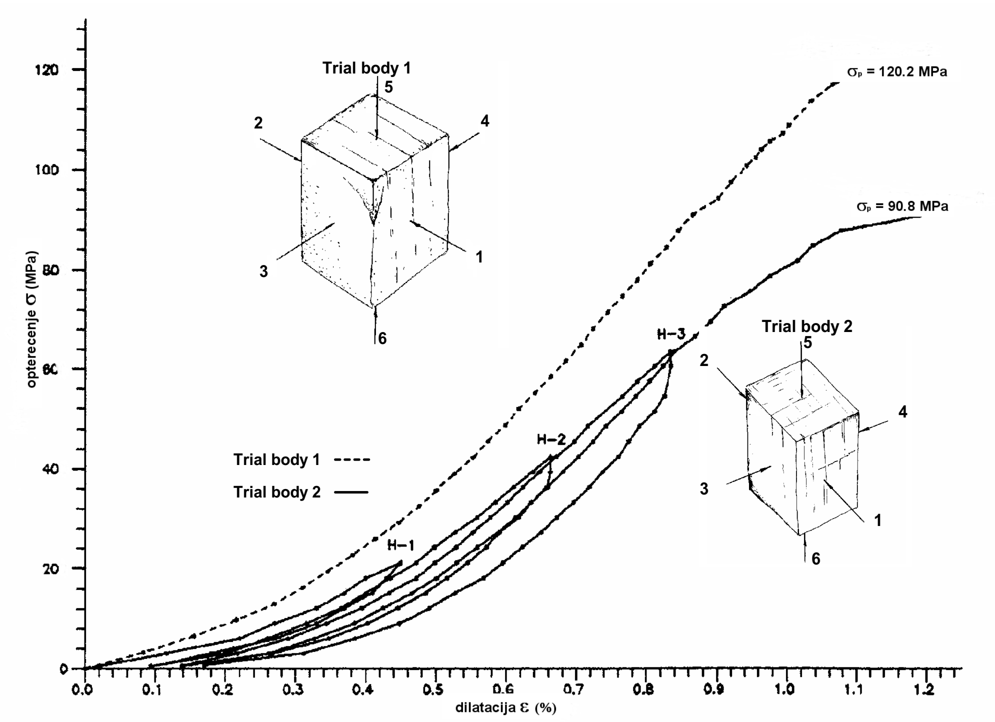

Figure 2.Sample VK-3, left bank, parallel to foliation, gneiss.
Relationship Dilatation ε (%) – Load σ (MPa) (Mining and Geology Faculty, 1992)

Table 3. Dynamic properties, parallel to foliation, gneiss, sample VK-3.

Trial body mark	Mark direction	γ kN/m³	V_p m/s	V_s m/s	E_{dyn} MPa	μ_{dyn}
1	Parallel (1-2)	26.12	4 583	1 222	11 400	0.46
	Perpendicular (3-4)		2 545	1 400	13 140	0.28
	Parallel (5-6)		4 889	2 316	37 980	0.36
2	Parallel (1-2)	26.12	3 733	1 273	12 140	0.43
	Perpendicular (3-4)		2 458	1 341	12 100	0.29
	Parallel (5-6)		3 864	1 635	19 420	0.39

Table 4. Static properties trial body 2, load direction 5-6, gneiss, paralllel to foliation, sample VK-3.

σ (MPa)	Hysteresis	Static elasticity Modulus (MPa)	
σ=21	H-1	E_e=5 845	E_d=4 825
σ=44	H-2	E_e=8 413	E_d=6 835
σ=64	H-3	E_e=10 805	E_d=7 589

In tables 5 and 6, the average values of static elastic and dynamic properties of gneiss samples are given, from the left bank, perpendicular to the foliation. In tables 7 and 8, the average values of static elastic and dynamic properties are givne, from the left bank, parallel to the foliation.

Table 5.Average values of static properties of gneiss samples, left bank, perpendicular to foliation.

Rock type and sample mark	**σ_p MPa**	**Static properties**		
		σ_1 E_e E_d MPa	**σ_2 E_e E_d MPa**	**σ_3 E_e E_d MPa**
Sample-2 VK-2 gneiss	52 53.2	σ_1=7.5 E_e=1530 E_d=1290	σ_2=15 E_e=2070 E_d=1740	σ_3=23 E_e=2630 E_d=2130
Sample-3 VK-3 gneiss	**70.9** **63.9**	**σ_1=15** **E_e=4590** **E_d=3180**	**σ_2=29.5** **E_e=4890** **E_d=3766**	**σ_3=44** **E_e=8570** **E_d=4520**
Sample-5 VS-2 gneiss	64.1 44.6	σ_1=14 E_e=3560 E_d=2220	σ_2=26 E_e=3710 E_d=2720	σ_3=40 E_e=5180 E_d=3260
Sample-6 ZK-1 gneiss	44.2 26.7	σ_1=9 E_e=2440 E_d=1720	σ_2=18.5 E_e=3840 E_d=1830	σ_3=- E_e=- E_d=-

Table 6.Average values of dynamic properties of gneiss samples, left bank, perpendicular to foliation.

Rock type and sample mark	**V_p m/s**	**V_s m/s**	**E_{dyn} MPa**	**μ_{dyn}**
Sample-2 VK-2 gneiss	2636	1480	14 050	0.22
Sample-3 VK-3 gneiss	**2494**	**1381**	**12 720**	**0.28**
Sample-5 VS-2 gneiss	2626	1606	14 740	0.20
Sample-6 ZK-1 gneiss	1634	1134	7 080	0.15

Table 7.Average values of static properties of gneiss samples, left bank, parallel to foliation.

Rock type and sample mark	**σ_p MPa**	**Static properties**		
		σ_1 E_e E_d MPa	**σ_2 E_e E_d MPa**	**σ_3 E_e E_d MPa**
Sample-2 VK-2 gneiss	71.4 62.2	σ_1=8 E_e=3070 E_d=2560	σ_2=18 E_e=3740 E_d=2890	σ_3=27.5 E_e=3070 E_d=2560
Sample-3 VK-3 gneiss	**120.2** **90.6**	**σ_1=21** **E_e=10580** **E_d=7180**	**σ_2=44** **E_e=8010** **E_d=6390**	**σ_3=64** **E_e=10580** **E_d=7180**
Sample-5 VS-2 gneiss	96.2 45.4	σ_1=16 E_e=5040 E_d=3110	σ_2=32 E_e=5460 E_d=3390	σ_3=- E_e=5040 E_d=3110
Sample-6 ZK-1 gneiss	45.9 75.4	σ_1=9.5 E_e=2270 E_d=1460	σ_2=18 E_e=3100 E_d=1970	σ_3=28.5 E_e=2270 E_d=1460

Table 8. Average values of dynamic properties of gneiss samples, left bank, parallel to foliation.

Rock type and sample mark	**V_p m/s**	**V_s m/s**	**E_{dyn} MPa**	**μ_{dyn}**
Sample-2 VK-2 gneiss	4347	1641.5	20 215	0.36
Sample-3 VK-3 gneiss	**4736**	**1769**	**24 690**	**0.38**
Sample-5 VS-2 gneiss	2246	2069	28 890	0.28
Sample-6 ZK-1 gneiss	2582	1747.5	8 100	0.30

CONCLUSION

This paper presents the results of the dynamic and static deformable properties of gneiss samples investigations, isolated during the second phase of the research. Gneisses represent a rock mass with significantly better mechanical characteristics than micaschist. The importance of providing foliation can be seen on the profiles of the left and right banks. The left bank is steeper and has a more favorable strike of foliation. The right bank has a milder slope and very unfavorable foliation strike. These properties of rock masses have caused significant changes in the geometry of the barried dam site.
The investigations aimed to select reliable parameters for the development of a geotechnical model. In such an anisotropic rock mass such as the lithological members of the Vranjska banja series, it was very important to define the folation influence on the examination parameters. The advantage of dynamic tests, which do not lead to the destruction of test bodies, was used, so they were later used to determine static parameters.
These investigations were a combination of theoretical and practical knowledge about the rock mass properties in which lithological discontinuities are expressed. Mining and construction facilities are becoming more demanding and complicated. The choice of reliable parameters enables safety and economy of construction and operation of mining and construction facilities.

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