THE RELATION BETWEEN THE SEISMIC AND GEOMECHANICAL MODELS

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Abstract: The subject of research in this paper is the correlated relations between the seismic and geomechanical characteristics of the medium. A special interest of analysis is made on rocks, which cover a wide area in the Republic of Macedonia, especially in the western part. Field seismic tests are performed at specific locations that define V_p and V_s velocities. At the same locations, geomechanical and engineering-geological research is carried out. Presented dependence between V_p and V_s velocities and geomechanical parameters of the medium: E - Young's modulus of elasticity, G - shearing modulus and ν - Poisson coefficient. Dependences of these paramform V_p and V_s velocities are calculated, or an attempt is made to assess the geomechanical parameters through analysis of seismic speeds. Qualitative assessment is made on the degree of dependence of seismic velocities V_p and V_s with RQD, RMR and Q parameters of carbonate massifs, as well as with φ - angle of internal friction and c - cohesion of material. Model of the rock masses is relatively simpler than the soil model, where significant influence has subsurface water and many other physical phenomena that are not present in the rock masses or their values are negligible. Any geophysical method is based on measurements of certain parameter, for example, gravity measures the force of gravity or appropriate earth acceleration, or geomagnetism measures the intensity of the magnetic field etc. Seismic methods are based on determination of the propagation velocity of longitudinal V_p and transversal V_s wave, or measurement of the velocity of propagation of the elastic waves in the ground. From engineering point of view, of interest is shallow seismic which exploring goes up to more than 100 m. The usage of geophysical methods, especially seismic, has an irreplaceable role in defining geomechanical parameters of the environment. The best results are obtained if geophysical methods are combined with research drilling and laboratory measurements of the taken samples, or geophysical methods define the locations for exploratory drilling. Based on the field research and laboratory testing, the conditions of the terrain as a natural environment are defined, the soil layers are defined according to the depth of the investigated location, ie the possible interactions between the natural environment and the future construction are predicted. In this phase of the research, the geological structure of the terrain was analyzed by defining the basic parameters of the separated lithological members required for the design phase. During the preparation of the work, a database of knowledge from the geological and geotechnical sciences was used, using modern methods of interpretation of data, own experiences from research on a range of objects and standardized methods of research and testing.
Keywords: correlation, seismic velocity, geomechanical parameters, estimation

INTRODUCTION

For the preparation of studies and reports for certain infrastructural facilities it is necessary to know the geomechanical parameters of the environment in which the object is realized. These parameters are the basis for further analysis of the base and dimensions of the object. The normal research procedures begin with geological mapping, making a detailed map with all geologic elements covered in that area. Based on the details of geological surveys and information obtained from them, geophysical surveys are projected. Geophysical profiles are visible changes of the studied physical parameter. Guided by these profiles, an interpretation of the geological profile or schedule of the rocks according to the depth is made. With the synthesis of multiple profiles it is possible to make 2D and 3D maps. Geophysical research is a way to define the location for the research drilling.
The next step is research drilling, laboratory and geomechanical measurements on the spot in the area of extremes, defined by geophysical research. With the results obtained from drilling, reinterpretation is made of geophysical data. The procedure presented is needed knowing that the actual medium is far from homogeneous, or with variable geomechanical parameters. The real medium can generally be divided into stone masses and salts. The rock mass model is relatively simpler than the salt model, where groundwater and other physical phenomena that are not available in the rock masses or their values are negligible.

1. SEISMIC METHODS

Seismic test methods are based on the basic principles of generating elastic waves in a known time interval, resulting in the propagation of seismic waves through the sub-surface structure of the investigative space where through the refractive and reflection process, the feedback signals are recorded on the surface of the terrain determined and

known distance. The elapsed time recorded by the generation of elastic waves, until the first registration of the different elastic waves can be used to determine the nature and geomechanical characteristics of the sub-surface structure of the geological complex. By comparing the known physical and geomechanical characteristics of the geological materials in the investigated environment, the data obtained during the seismic tests enable modeling of the sub-surface structure of the rocky complex.
There are two seismic methods - a refractive method and a reflexive method. A defective refractive method is in the case where a reduced velocity layer of a certain depth can be used in the future. In the area of environmental elasticity, for example for an isotropic homogeneous environment, the dependence of the propagation of seismic (elastic) expressed waves is given.

$$V_p = \sqrt{\frac{\lambda+2\mu}{\rho}} \qquad V_s = \sqrt{\frac{\mu}{\rho}} \tag{1.1}$$

where: λ, μ - Lame coefficient, P - density, V_p - velocity of a longitudinal wave, V_s - velocity of the transverse wave.
The velocities V_p and V_s can be expressed through the Yung elastic module E, the cutting module G and the Poison coefficient ν.

$$V_p = \sqrt{\frac{1}{\rho}\frac{E(1-\nu)}{(1+\nu)(1+2\nu)}} \qquad V_s = \sqrt{\frac{E}{\rho\cdot 2(1+\nu)}} = \sqrt{\frac{G}{\rho}} \tag{2.1}$$

From the expression above, one can see the inner dependence between V_p and V_s speeds of geomechanical parameters.

2. GEOMECHANICAL PARAMETERS

The geomechanical parameters of a homogeneous isotropic medium are usually defined by Yung's elastic modulus E and the Poison coefficient ν, or the corresponding Lyme coefficient (λ) and (μ)
Table 1 shows the relations between the elastic parameters.

	E	**N**	**k**	**μ**	**λ**
(E, ν)			$\frac{E}{3(1-2\nu)}$	$\frac{E}{2(1+\nu)}$	$\frac{E\nu}{(1+\nu)(1-2\nu)}$
(E, K)		$\frac{3K-E}{6k}$		$\frac{3kE}{9k-E}$	$\frac{3k(3k-E)}{9k-E}$
(E, μ)		$\frac{E-2\mu}{2\mu}$	$\frac{\mu E}{3(3\mu-E)}$		$\frac{\mu(E-2\mu)}{3\mu-E}$
(ν, k)	3k (1 - 2ν)			$\frac{3k(1-2\nu)}{2(1+\nu)}$	$\frac{3k\nu}{1+\nu}$
(ν, μ)	2μ (1 + ν)		$\frac{2\mu(1+\nu)}{3(1-2\nu)}$		$\frac{\mu 2\nu}{1-2\nu}$
(ν, λ)	$\frac{\lambda(1+\nu)(1-2\nu)}{\nu}$		$\frac{\lambda(1+\nu)}{3\nu}$	$\frac{\lambda(1-2\nu)}{2\nu}$	
(k, μ)	$\frac{9k\nu}{3k+\nu}$	$\frac{3k-2\nu}{2(3k+\mu)}$			K - 2μ/3
(k, λ)	$\frac{9k(k-\lambda)}{3k-\lambda}$	$\frac{\lambda}{3k-\lambda}$		3/2 (k - λ)	
(μ, λ)	$\frac{\mu(3\lambda+2\mu)}{\lambda+\mu}$	$\frac{\lambda}{2(\lambda+\mu)}$	λ + (2/3μ)		

Table 1. Dependence between elastic parameters

It should be noted that (μ) is a volume modulus

$$\mu = G = \frac{E}{2(1+\mu)} \tag{3.1}$$

In real terms, rock masses are closer to the model of a homogeneous isotropic elastic medium in relation to salts, so that the relatively small stresses deform out of the elasticity zone. The salts in relation to the rocks behave like a plastic environment, or are easily deformed and come to break. From that perspective, the connection between normal tension and cutting resistance is of particular importance. In general, it is assumed that the relationship between normal tension in any section through the massive salt and the cutting resistance corresponding to the unit area can be described by the formula:

$$s = c + \sigma \cdot \mathrm{tg}\,\varphi \tag{4.1}$$

where: s - cutting force, c - cohesion of salt, σ - tightening, φ - tensioning angle.
Cohesion c is equal to the cutting resistance per unit area if (theta) θ = 0.
For loose clutches, c = 0 and the Coulomb equation is obtained:

$$s = \sigma \cdot \mathrm{tg}\,\varphi \tag{5.1}$$

3. RELATION BETWEEN SEISMIC SPRING AND GEOMECHANICAL PARAMETERS

Here, it is not the task to look for specific dependences between the seismic velocities V_p and V_s and the geomechanical parameters of rocks and saline masses. From a physical point of view, the propagation of seismic waves in an area of elastic relation to the medium, while the salts generally behave as a plastic environment, for example, in a plasticity zone. These theoretical differences of elasticity and plastic relation of the medium and its inhomogeneity reduces the accuracy of geomechanical parameters determination using propagation velocities V_p and V_s in terms of laboratory physical measurements. Cutting in the medium occurs when tangential stress G exceeds the cutting resistance s or when G ≥ s. Knowing that $V_s = \sqrt{\frac{G}{s}}$ и $s = \sigma \cdot \mathrm{tg}\,\varphi$ If in the first equation, instead of tangential stress G, it is replaced with the expression for resistance when cutting s, it is obtained

$$V_s = \sqrt{\frac{\sigma \cdot \mathrm{tg}\,\varphi}{\rho}} \qquad \mathrm{tg}\,\varphi = \frac{\rho V_s^2}{\sigma} \tag{6.1}$$

From the expression it follows that the cutting angle can be determined for a given environment, if we know the density p, the velocity Vs, and the normal tightening τ (tau). If there are no additional stresses, normal cutting can be defined as a geostatic one.
The following tables give the velocities V_p and V_s and geomechanical parameters of the medium of rocks and salts.

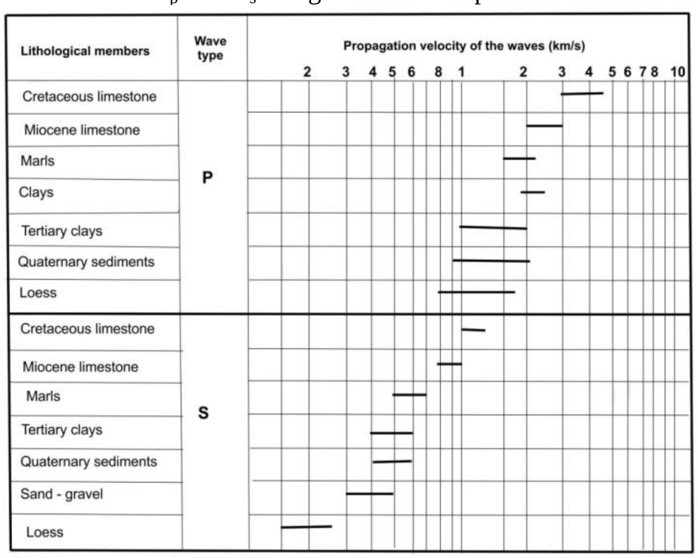

Table 2. Overview of propagation velocity of P and S waves

Rock mass	γ (kN/m^3)	φ (^{o})	c (kN/m^3)
Granite	26.14	30-50	980 to 3000
Quartzite	26.14	30-45	–
Sandstone	19.50	30-45	490 to 1460
Limestone	21.69	30-50	490 to 1460
Porphyrite	25.80	30-40	980 to 3000
Schist	24.00	27-45	240 to 980
Chalk	17.60	30-40	240 to 980

Table 3. Characteristics of some rocks

The advantage of geophysical (seismic) surveys in terms of drilling and geomechanical measurements carried out at the core is that seismic measurements provide relevant data for the entire field of research, while drilling in only one point. It is certain, for the researchers, that the great price difference between these studies is particularly important.

Description	Value φ (°)
Andesite crushed material	31-35
Chalk	35-41
Porphyric crushed material	40
Sandy crushed material	27-38
Crushed schists	37
Crushed clays	10-20
Finely crushed shearing zones	14-22
Crushed cataclastic materials	14-22

Table 4. Values of the angle of internal friction

On the basis of the obtained laboratory results a reinterpretation of the geophysical model of research is carried out. The displayed links between V_p and V_s and geomechanical parameters clearly indicate the possibility of using these methods in defining the geomechanical parameters of the investigative area.

Monolith without cracks Q = 500 RMR = 100	Best quality unchanged cracks Q = 100 RMR = 85	Very good quality cracks on 1 - 3 [m] Q = 10 RMR = 65	Good quality cracks on 0.5 - 1 [m] Q = 1.0 RMR = 44	Bad quality cracks on 30 - 50 [cm] Q = 0.1 RMR = 23	Very bad quality, cracks on 1 - 5 [cm] Q = 0.01 RMR = 3
s = 1	s = 0.01	s = 0.004	s = 0.0001	s = 0.00001	s = 0
Carbonate rocks: dolomite, limestone, marble					
m = 7	m = 3.5	m = 0.7	m = 0.14	m = 0.04	m = 0.007
Clay rocks: slate, clayey shale, sandstone					
m = 10	m = 5	m = 1	m = 0.2	m = 0.05	m = 0.01
Sandy rocks with strong crystals: sandstone, quartzite.					
m = 15	m = 7.5	m = 1.5	m = 0.3	m = 0.08	m = 0.015
Igneous fine-grained rocks: andesite, diabase, rhyolite					
m = 17	m = 8.5	m = 1.7	m = 0.34	m = 0.09	m = 0.017
Igneous coarse-grained rocks: gneiss, granite, gabbro, diorite					
m = 25	m = 12.5	m = 2.5	m = 0.5	m = 0.13	m = 0.025

Table 5. Coefficient of empirical criterion for breaking (according to Hoek and Brown, 1980)

From the values shown in the tables it can be seen that the velocity of seismic waves is in good cooperation with geomechanical paramters, or higher velocities, in general, means areas with greater compactness and cohesion, while smaller values indicate a fragile salt zone or less cohesion.

4. METHODOLOGY OF HOSPITALITY AND TESTING

In the field of a research and testing, a complex methodology of field investigation and laboratory testing is applied.

Field investigative works

The following investigative procedures apply for the preparation of research:

- Drilling of investigative holes;
- Mapping the holes;
- Taking the optimal number of samples from the soil materials;

In field investigations, drilling of investigative holes with a maximum depth of 8.00 m' to 16.00 m' is carried out in conjunction with the type of construction. Investigative cavities are performed in order to perform macroscopic identification of soil materials in depth, to determine their spatial layout, to take the necessary number of samples for laboratory tests and to identify all aspects that would contribute to a more complete definition of the terrain as a natural construction.

5. LABORATORY RESEARCH

After the geomechanical mapping of the discovered materials in siu and taking representative samples of them, and in order to confirm the field identification and classification, as well as to define the physic-mechanical characteristics of the materials present at the investigated location, the following laboratory tests are carried out over disordered and semimorted samples:

- Determination of natural humidity, natural volume weight, the boundaries of consistency, granulometric composition, Direct shear test, the modulus of compressibility.

The results of the performed geomechanical investigations are displayed through appropriate diagrams, numerical and tabular.

6. GEOMECHANICAL CONDITIONS

According to the conducted field investigations and laboratory classification and identification tests at the subject's location, generally according to the USC system it can be concluded that the location contains the following materials:

- H - Humus;
- GP - Gravel and sand, medium granular with minimum presence of fine particles, gravel is 50% with grain size up to Ø70mm;
- GFs - Dusty gravel and sand, with the presence of gravel grains with rounded edges with a maximum diameter of grain Ø100mm, medium compact;
- L_p - Piocene lake sediments, pavement, well-compacted and consolidated, in alternating layers of laporous intermediate plastic dusty clay, with intermediates of medium-sized dusty sand;

Given the characteristics of the represented lithological units, their physical mechanical parameters are determined according to the data from the performed laboratory researches. In addition to the classification of the materials, the following tables (tables 6 and 7) show the obtained geomechanical parameters from the special laboratory tests.

Investigation duplex	**Depth**	**Type of material**	**Humidity (%)**	**Volume weight $\gamma[\mathrm{kN/m^3}]$**	**Angle of internal friction $\varphi[°]$**	**Cohesion c[kPa]**
1	2	3	4	5	6	7
D – 1	2,80-3,10	GP	7.25	22.39	30.15	0.00
D - 1	7,50-7,80	Lp	16.74	17.81	19.95	21.80

Table 6 Results of direct smear tests

Investigation duplex	**Depth**	**Type of material**	**Humidity (%)**	**Volume weight $\gamma[\mathrm{kN/m^3}]$**	**Module of stiffness Mv $[\mathrm{kN/m^2}]$**	
					p=100-200	**p=100-400**
1	2	3	4	5	6	7
Д-1	7,70-8,00	Lp	15.71	17.85	10224	23087

Table 7 Results of the tests of deformability

The modulus of compressibility for the materials is estimated on the basis of the laboratory tests of the homologous experiment, whereby values are obtained that vary within the limits of Mv = 10224 - 23087 [kPa].

In addition to the criterion of scrap on the soil, the criterion of permissible and steady descents must also be met, which in turn depends on the deformation characteristics of the soil layers to the depth to which the additional load of the structure has an impact. On the basis of the adopted physical and mechanical characteristics of the materials in which the structures will be based, a calculation of the limit and permissible payload on the natural foundation. The calculation is performed according to the theory of Terzaghi and EC7, where the form of:

- Terzaghi $\sigma_{gr} = k_1\, c\, N_c + k_2\, \gamma' D_f\, N_q + k_3\, \gamma'' B\, N_\gamma$
- 3N Formula $\sigma_{gr} = c\, N_c\, s_c\, d_c + \gamma_1\, D_f\, N_q\, s_q\, d_q + 0.5\, \gamma_2\, B\, N_\gamma\, s_\gamma\, d_\gamma$

Where: D_f - effective depth of foundation, B - width of the foundation, c - cohesion of the material, φ - angle of internal friction, ϒ - volume weight, Nc, Nq, Nϒ - load factors (Terzaghi, Hansen, Mayerhof, Eurocode 7) sc, sq, sϒ, k1, k2, k3 - factors of form, ic, iq, iϒ - factors of torsion, dc, dq, dϒ - factors of depth.

CONCLUSION

The usage of geophysical methods, especially seismic, has an irreplaceable role in defining geomechanical parameters of the environment. The best results are obtained if geophysical methods are combined with exploratory drilling and laboratory measurements of the sampled or geophysical methods define the exploration drilling sites. On the basis of the obtained laboratory results a reinterpretation of the geophysical model of research is carried out. The displayed links between V_p and V_s and geomechanical parameters clearly indicate the possibility of using these methods in defining the geomechanical parameters of the investigative area.

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