THE RESEARCHES OF THE ROCKS PROPERTIES BY THE LABORATORY ACOUSTIC TESTING

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(A kőzettulajdonságok kutatása laboratóriumi akusztikus módszerrel)

The estimation of the mechanical properties of the rocks in laboratory could be done in two ways:

1th - the static method - this involves recording changes of diameters of the rocks sample caused by strain applied.

2end - the dynamic method - this involves the measuring the elastic reaction of the material for dynamic loading factors.

The estimation of the mechanical rocks properties executed in laboratory conditions by using the static method is time-consuming and troublesome - - since a large monolithic sample and subsequent its cutting and polishing is reguired. It is also very often impossible to take a large samples in hardly accesible places or bore wholes. A long procedure of preparation of the samples introduces additional errors to the results, or change the properties of the material. Also the sample can be used only one time for a testing and than is disturbed. So at last time is more satisfactory to use, as much as possible a non-destructive methods for researches the properties of the solid materials. Among of them the great role play the geophysics method and in laboratory conditions the acoustic testing.

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This last method involves the monitoring of the acoustic waves velocity in rocks, under known conditions. It is based on the assumption that the elastic medium reaction is characterised by specific velocity of the acoustic wave propagation - so this velocity depens on the properties of the material.

Main rules of the acoustic method s.c. "going through", lay on measurements of the time necessary for overpassing across the sample the sound impulse, generated from one side and analysed from the other. Such testing is well provide if the dimension of the sample - the way of the wave crossing - is longer than the length of the generated wave. So in laboratory, where the miniaturisation of the sample is very important, the researches are caried with the use of the high-frequency waves: ultrasounds - which make possible a far going reduction of sample size, or directly testing the bore cores.

The acoustic-ultrasound method makes also possible unlimited repeating of the measurements and therefore signicant and rapid increase in their accuracy and further use of non disturbed rock material to the another examinations. So it not suprising that the progress in measurements of geotechnical properties of rocks could be expected with the development of this non-destructive method.

Dynamic-acoustic method make possible to directly measure such elastic properties of the material as an elasticity modulus (E_d) - and Poisson coefficient (ν) from dependences:

$$E_D = \frac{C_1^2 \, \rho_d \, /1+ \; / \; /1-2\nu /}{1 - \nu}$$

$$\nu = \frac{0,5 - /\frac{C_T}{C_L}/^2}{1 - /\frac{C_T}{C_L}/^2}$$

where C_L - longitudinal wave velocity, C_T - transversal waves velocity, and later to determined the other material constances. The above is valid under assumption that the rocks medium is homogenous, infinite, elastic and isotropic.

In geotechnical studies is as well necessary to know the compression and tension strenght, porosity and volume density of a rock material. The latter should be calculated on the empirical way from the correlation between other parameters - especialy often to the longitudinal waves velocity.

But at the case of unhomogenous, muliticomponent rocks material the velocity of the waves propagation depens also on its properties like: mineral composition structure, texture, fracturing, temperature and state of stress.

Waves propagation is quicker in fine grained than in coars grained material and all the planes of foliation, bedding and discontinuity, muffle the waves velocity; and also the differences in values of velocity measured in different directions may be expected. But it means that if the structure and texture are typed very carrefully and is konwn, the various data of rocks properties can be find by the experimental way.

After estimate material constants: E_d i ν , can be fine the coefficient of anisotropy Can as:

$$\frac{\frac{C_x + C_y}{2}}{C_z} \quad \text{or if it is necessary as} \quad \frac{C_x}{C_z} \quad \text{or} \quad \frac{C_y}{C_z} \quad \text{or}$$

in every other programmed directions. During the laboratory acoustic testing of the rocks is very popular looking for the following main relation:

1th the fractures orientation (α) - longitudinal wave velocity (C_L)

2end porosity (p) - longitudinal wave velocity (C_L)

3th compresion strength (R_c) - longitudinal wave velocity (C_L)

For the such studies the samples have to be choosed very carrefully, due to the interesing programme. As an example of the such research may be presented the practical examination have on Oligocene flysch sandstones forming a series very popular in Northern Coupatiens (Fig. 1). The flysch series of sediments are originated in geosynclinal area and are an example of episodic sedimentation. They display repeated sequence from conglomerates through sandstones and siltstones to clays (Fig. 2).

Testing sandstones generally represent upper links of the flysch sequence and macroscopically they are mainly characterized by finaly - layered, random and convoluted textures.

Finely - layered texture is characterized by pararell arromgment of components and a trend of desintegration into thin plates (Fig. 3, 4.)

Random texture is characterised by disorderly arrangment of components, without any privileged direction of grains orientation (Fig. 5, 6).

Convoluted texture is unhomogenous, parallel in some places and with noumerous small foults elsewhere. It is found in corrugated sandstones macroscopically visible numerous forms of current bedding, complex disturbances and several density accented by accumulation of dark minerals, sofor sometimes deposit is built of several forms lens-liker (Fig. 7, 8). From petrography point view all types of sandstones are mostly light-grey sandstones consist of 42% - quartz, 15% - mica, 10% muskovit, 5% - biotyt, 7% feldspar, 5% - plagioclases and the rock's matrix (carbonaceus 25%).

The acoustic testings could be provided at the any shape of the sample: cylindrical or cubic form, but to know all sedimental form and disturbances on it, before testing is abligatory (Fig.9).

The measurements have to be made in three directions, perpendicular one to the another (x, y, z) where the "z" axis is for example perpendicular to the bedding and x, y - parallel to it.

At the presented case, before acoustic testings were executed to the measurements of volume density, unit density, effective porosity of the rocks material. After simply acoustic testing in natural conditions the samples were placed under increasing load for testing the compressions strength and at this time were examinated simultaneus the linear deformations of the samples in all sides and the changes of the waves velocity propagation due to stress increasing. The ultrasound waves velocity of the flyshys sandstones (tab.1) equals 1275 - 6250 m/s for longitudinal waves (C_L) and 1680 - 3390 m/s for transversal (C_T). The lower volue of the transversal wave were strongly muffled. The relation between C_L and porosity (n) is shown on Fig.10. As is clear, waves velocity desreases with the increase of a porosity volue. It may be noted that the highest volues of wave velocity are related to the convoluted sandstones.

Volume density (γ_d) - (C_L) relation as is presented on the Fig.11 is not linear in all directions of the measurements (x, y, z). Due to the computer plotting this relation could be defined as a parabola were $C_L = A\gamma_d^n$ where exg. for the flysches sandstones at the "z" direction, the vqule A = 13, volue n = 6.

The anisotropy is the most visible in the case of thin sandstones - C_{an} rangin from 0,37 - 0,63. It means that the velocity of the wave propagation could be two or more times higher in direction parallel to the bedding than in perpendicular to it. In a case of thick bedded sandstones, in results of their random textures the C_{an} is close to the vqlue 1.

The value of coeficient anisotropy of the corrugated sandstones is varieus - C_{an} rangin from 0,35 - 1,99. So it is evidently resulted by the changeable orientation of the convolute form due to the waves routes (Fig.12). The relation C_{an} to the angle of the inclination of the sedimental layers, is shown at Fig.13.

For practical using is very important to know the relation between compression strength (R_c) and the wave velocity (C_L). Such connection, executed by experimental way, is usualy parabola type as $R_c = a \cdot C_L^n$. General calculation shows that for the flysches sandstones volues a=0,45 and n = 2,9 when the waves velocity is given in km/s (Fig.14). The monitoring the waves velocity under loading is very suitable for observation of the samples destruction.

One may say that the waves are noticing by the wave muffling the broken material at early stage destruction (Fig.15). Therefore, this critical stress value at the visible destruction moment which we are used call as a compression strength, is connected with the disturbed material.

From the other side, at the first stage of the loading it is noticed the hardening process of the material observed as an erising of the waves velocity. All such observations make clear that for particular sandstones is possible to evaluate the critical velocity value below which material is fractured. It is very interesting also to research the dependences between static and dynamic parrameters - especialy for elasticity modulus. As is know dynamic elasticity modulus volue (E_d) is usually ten times higher than static elasticity modulus (E_{st}). It is specialy observed for the weak rock becouse they are surly fractured or with easy deformable skeleton. It could be clear up also that, in the static testing at the first loading step take place the closing of the fractures and overpacking of the rocks skeleton. It results the characteristic dege nerated two - steps course of the stress -

strain curve (Fig. 16), and two values of the static elasticity modulus (E_{st1} and E_{st2}). The static modulus obtained at the second phase of the loading ($E_{st\,2}$) is similar to the value obtained by the dynamic method:

Practically, many times the measurements of the transversal waves velocity are creating some problems. At one cases the trans versal waves are strongly muffled, at the other their values are very high.

At the first case is very popular to use the simplified formula where

$$C_L = \sqrt{\frac{E}{\gamma_d}}$$

which gives only the approximation to the real modulus value. At the second case, pecular researches are shown that the difficulties at the obtaining the proper values of the transversal waves may combine with the anisotropy of the material.

As is shown at Fig. 17. at the special form of anisotropy, the velocity of analysed, first the quickest transversal wave ($C_{T\ one}$) has to high value, becouse its to short way of propagation, not perpendicular to the way of measurement the longitudinal wave. If $C_{T\ one}$ is to high so

$$\frac{0{,}5 - \left(\frac{C_{T\ one}}{C_L}\right)^2}{1 - \left(\frac{C_{T\ one}}{C_L}\right)^2} < 0$$

and is impossible to ennumarate the Poisson coefficient (Fig. 18).

It such cases it should be considered whether not to applay the velocity value $C_{T\ two} < C_{T\ one}$ which is propagated in horizontal laminated medium at realy perpendicular direction but. It is strongly muffled by the mica laminas, as is shown in an example Fig. 17, 19.

The difference between E_d value estimated with use constant value of the Poisson coefficient (ν) and the ν value being the results of the testing and using $C_{T\ two}$ are not very high. The greatest divergences at C_L and E_d values have been noticed where the laminas were inclinated from horizontal position to 50-60° (Fig. 20 and 21).

All presented studies have been shown that the ultrasonic method of the researches mechanical peoperties of the rocks gives many interesting results.

The interpretation of this results requres carreful analysis which would take into account structural and textural features of the rocks.

Following the conducted tests on the flysches sandstones, it could became clear, the nature of errors and discrepances which take place during determination of parameters of the rocks. If inter-correlation between the survay measurements directions and anisotropy, is not well defined is possible to obtain the data not applicatable from geological point of view. Therefore the acoustic, ultrasound non-destructive methods are very satisfactory and very precise were are analysed with the consideration the specific nature of sedimentary rocks.

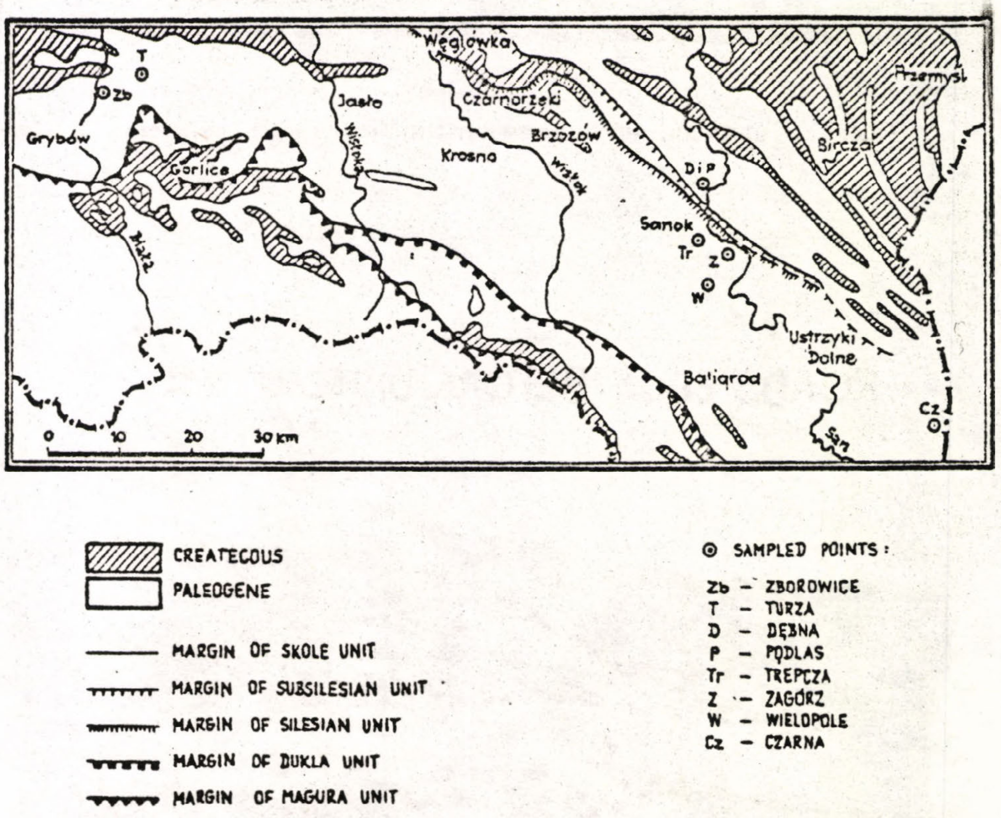


Fig. 1. Location map of studied area

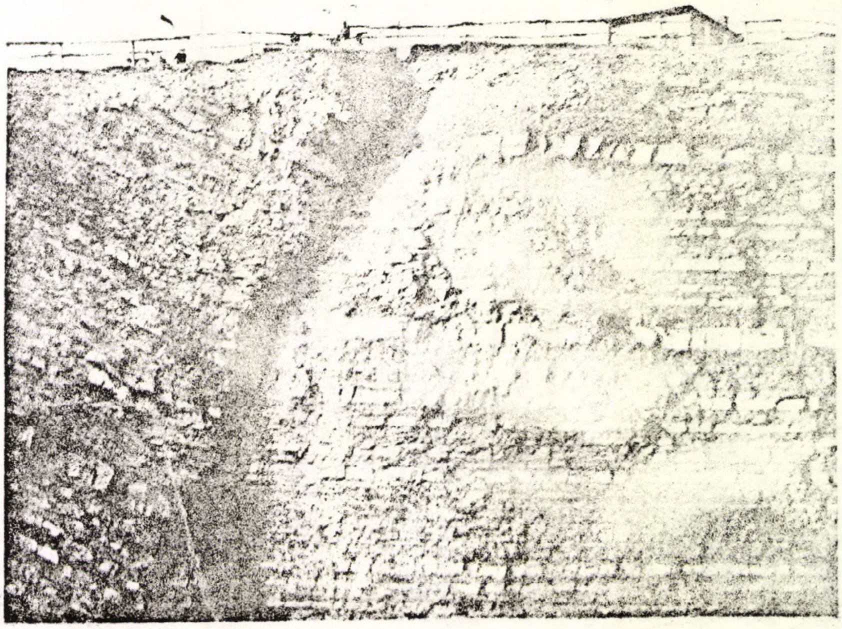


Fig. 2. Repeated sequences on the flysches sediments

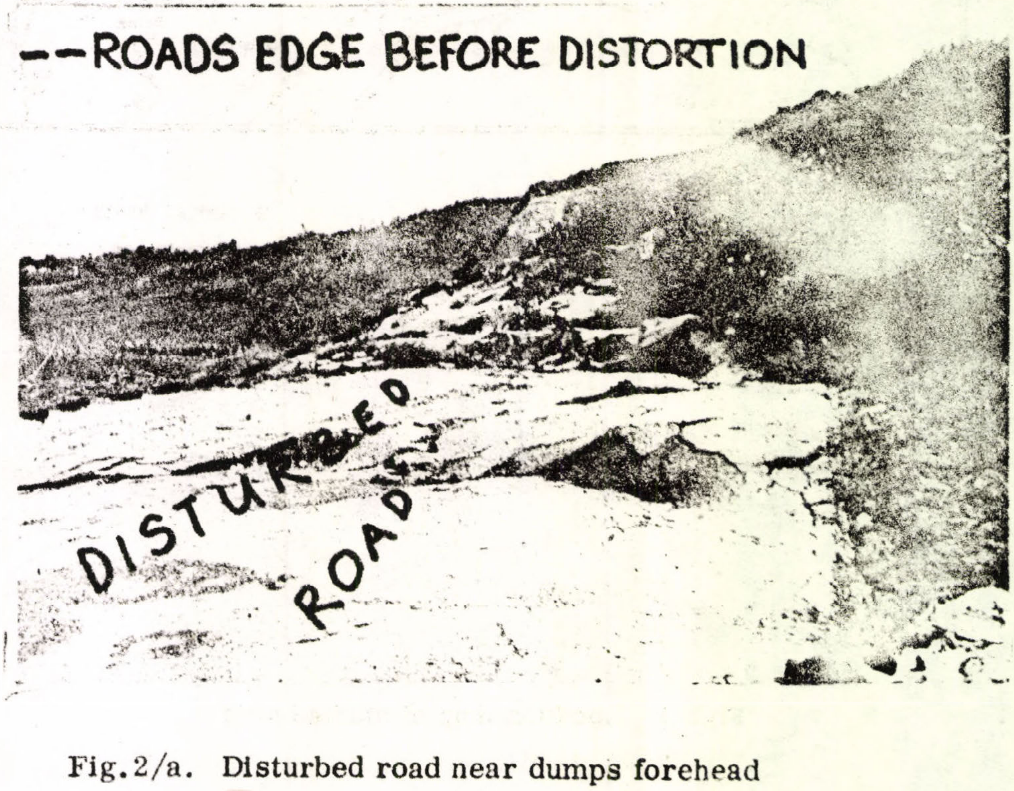


Fig. 2/a. Disturbed road near dumps forehead

Fig. 3. Macroscopic picture of finely layered textures

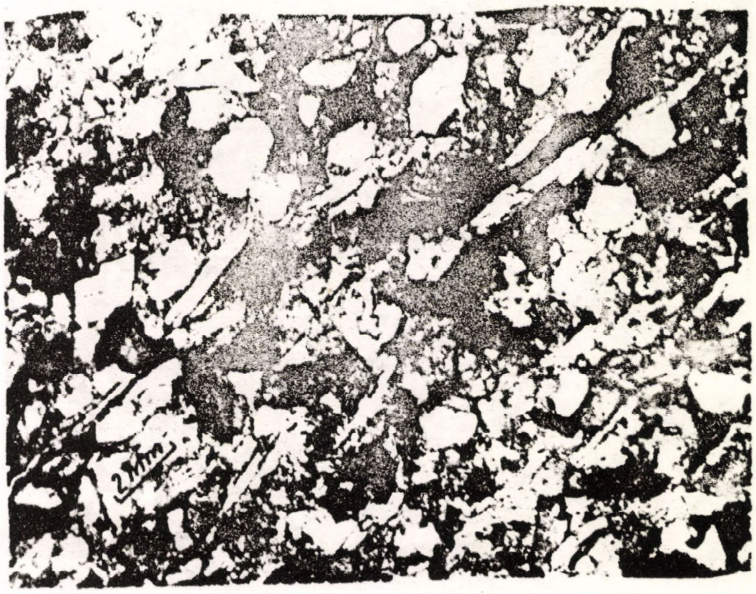


Fig. 4. Microscopic picture of finely layered textures

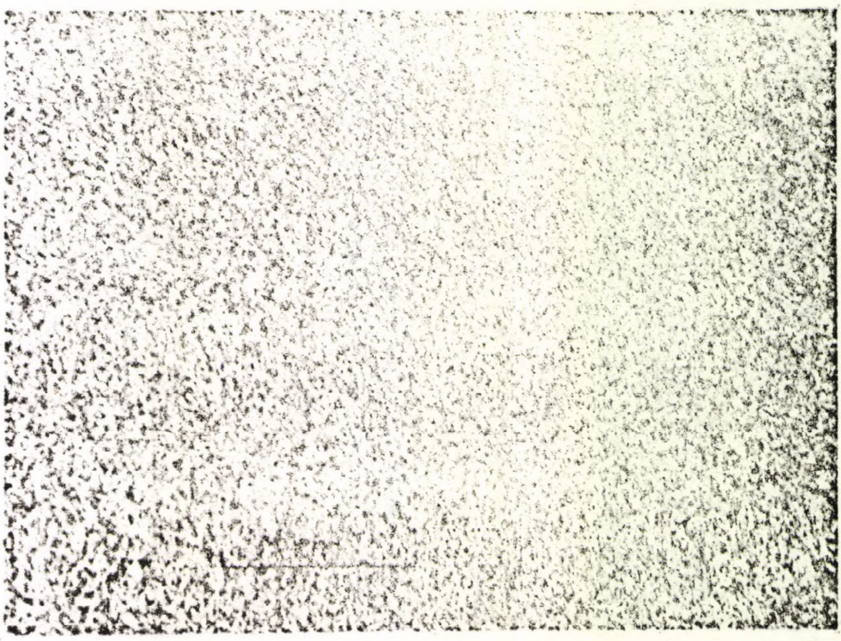


Fig. 5. Macroscopic picture of random texture

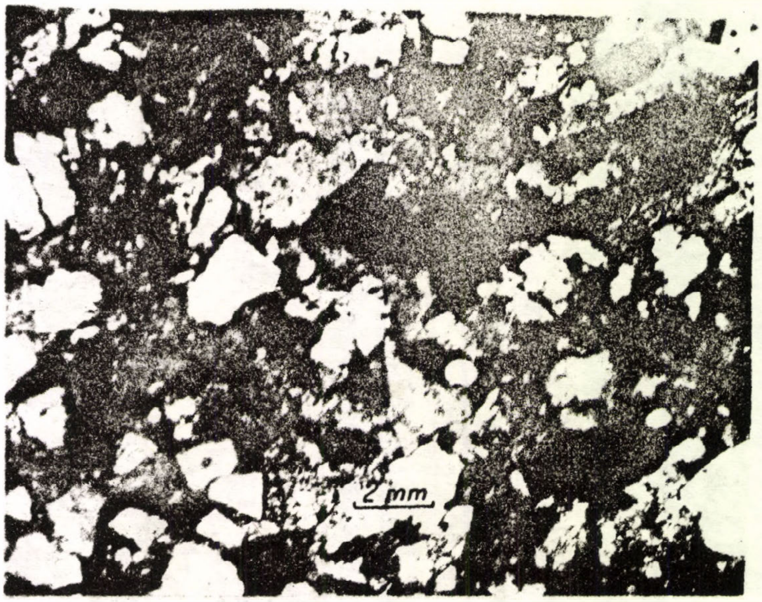


Fig. 6. Microscopic picture of random textures

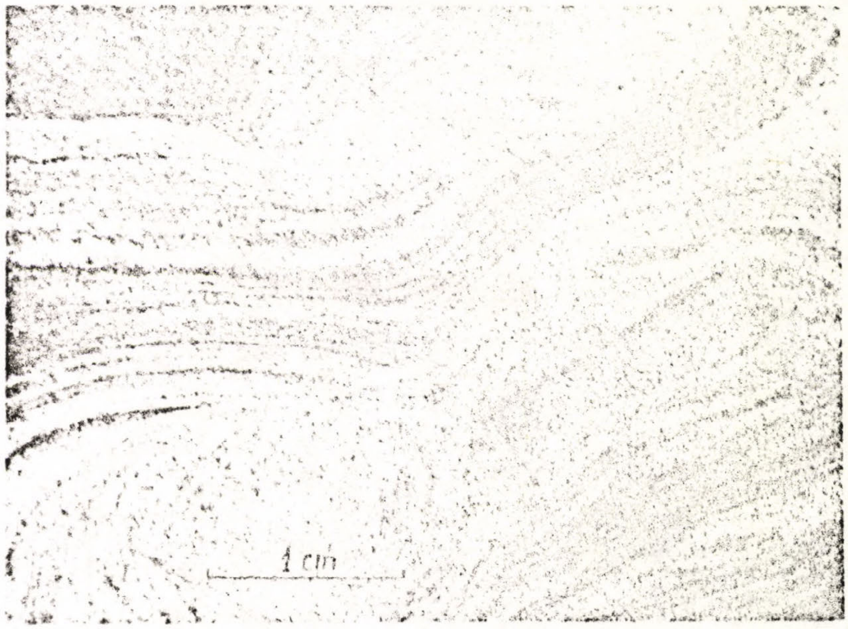


Fig. 7. Macroscopic picture of convaluted texture

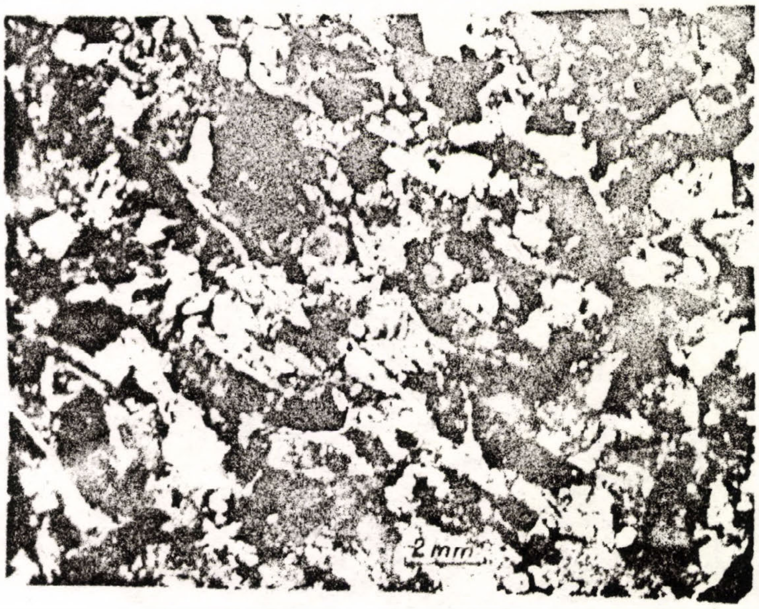


Fig. 8. Microscopic picture of convaluted texture

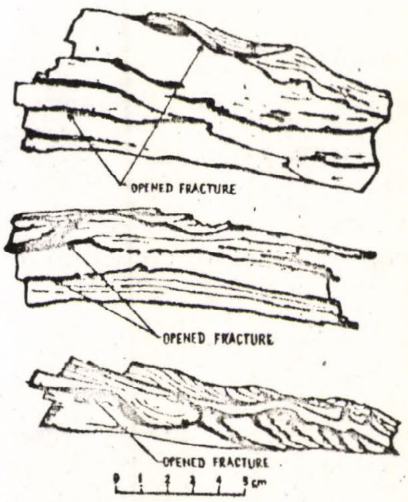
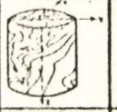
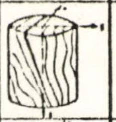
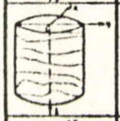
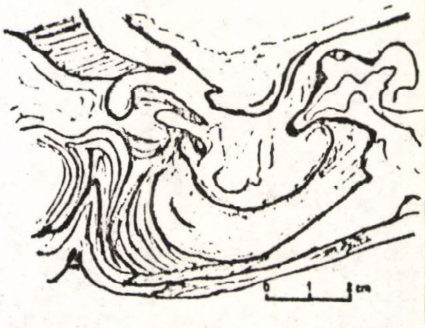
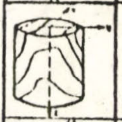
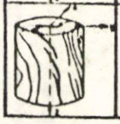
DESCRIPTION		S T R U C T U R E S	MEASUREMENTS DIRECTIONS	LONGITUDINAL WAVES VELOCITY m/s			COEFFICIENT ANIZOTROPY C	TRANSVERSAL WAVES VELOCITY C_T m/s	POISSON COEFFICIENT ν	ELASCITY MODULUS E_d MPa 10^4	COMPRESSION STRENGTH R_c MPa
				C_{Lx}	C_{Ly}	C_{Lz}					
GRADUOL AND OVERSTEPPING GROUTH OF MATERIAL IN THE FORM OF CRUSTS - VERTICAL CROSS - SECTION	CONTACTS BETWEEN SUCCESIVE GENERATIONS REPEAT THE SHAPE OF THE PRECEDING ONE			4260	4260	4550	0.94	2440	0.28	435	48.7
				3950	–	4750	–	2630	0.28	477	15.9
				3950	4330	3920	1.13	2640	0.09	409	46.7
	CONTACTS DISCORDANT			4480	4480	4110	1.09	2620	0.15	432	56.5
				2760	3690	3370	0.87	2100	0.25	289	39.0
VERTICAL CROSS - SECTION OF DROP STRUCTURES /SO CALLED „NORMAL"				3980	3980	3720	1.07	2500	0.08	359	51.0
				4560	–	3950	–	2960	0.11	402	42.0
				–	4400	4470	–	2010	0.37	3.07	49.6
COMPLEX PATLERN OF DEFORMATION RESUTING FROM DIFLERED SEDIMENTERYS DIRECTIONS - PLANE CROSS-SECTION.											

Fig. 9. Examples of structures from corrugated sandstones

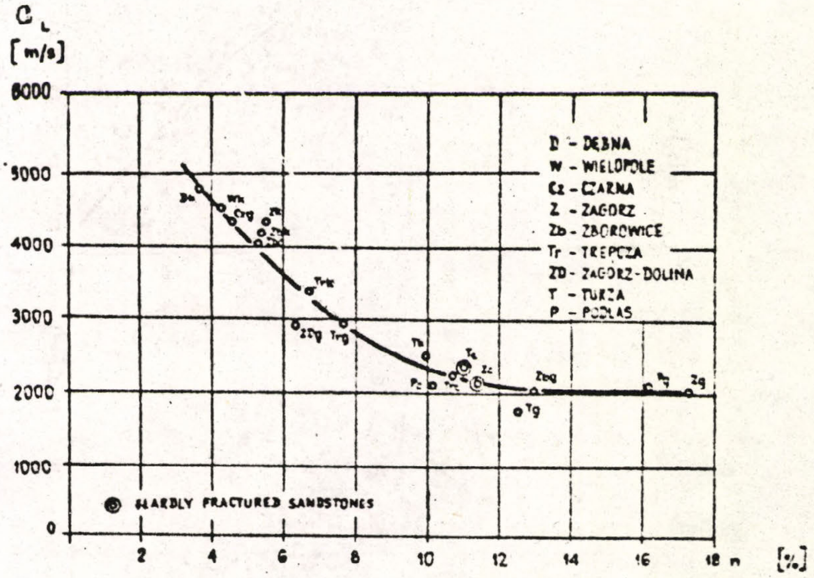


FIG. 10. Dependance of velocity of propagation of longitudinal wave (C_L) on porosity (n)

g - thick - bedded sandstones

c - thin - bedded sandstones

k - corrugated sandstones

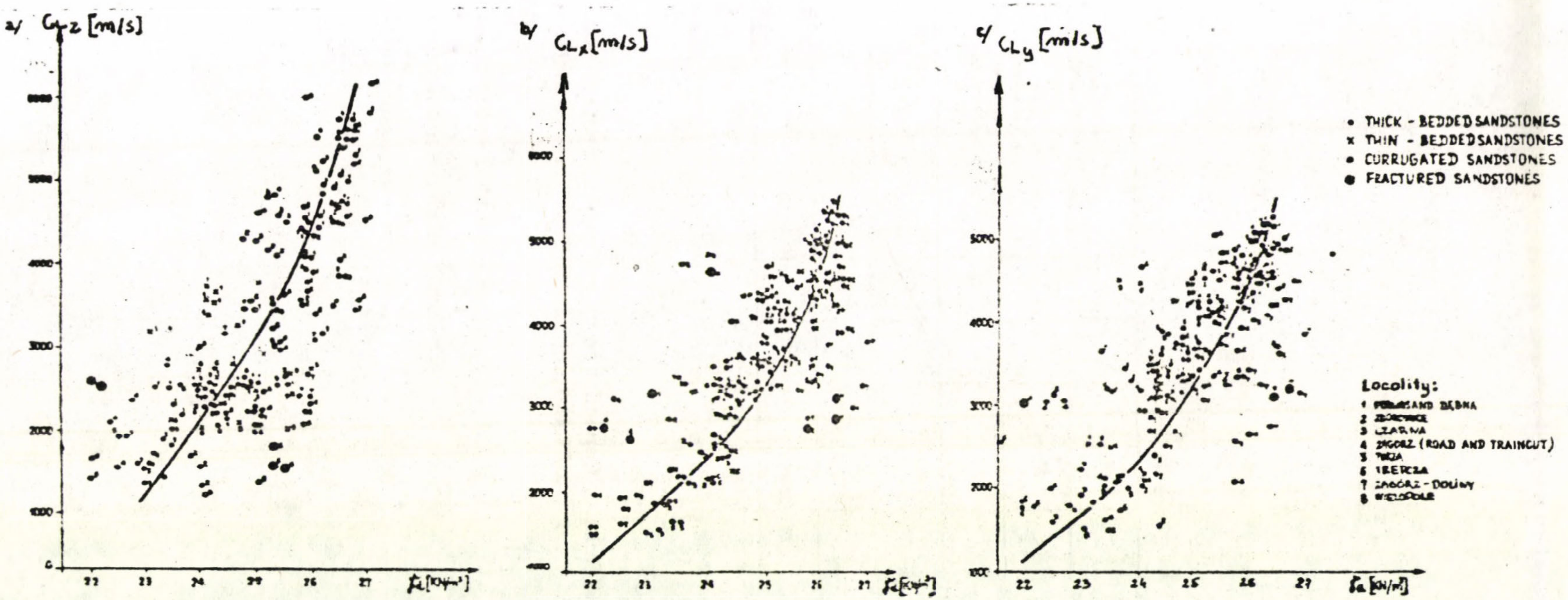


FIG. 11. **Dependance of longitudinal waves yelocity (C_L) on volume density (γ_d) in three directions perpendicular (x, y, z)**

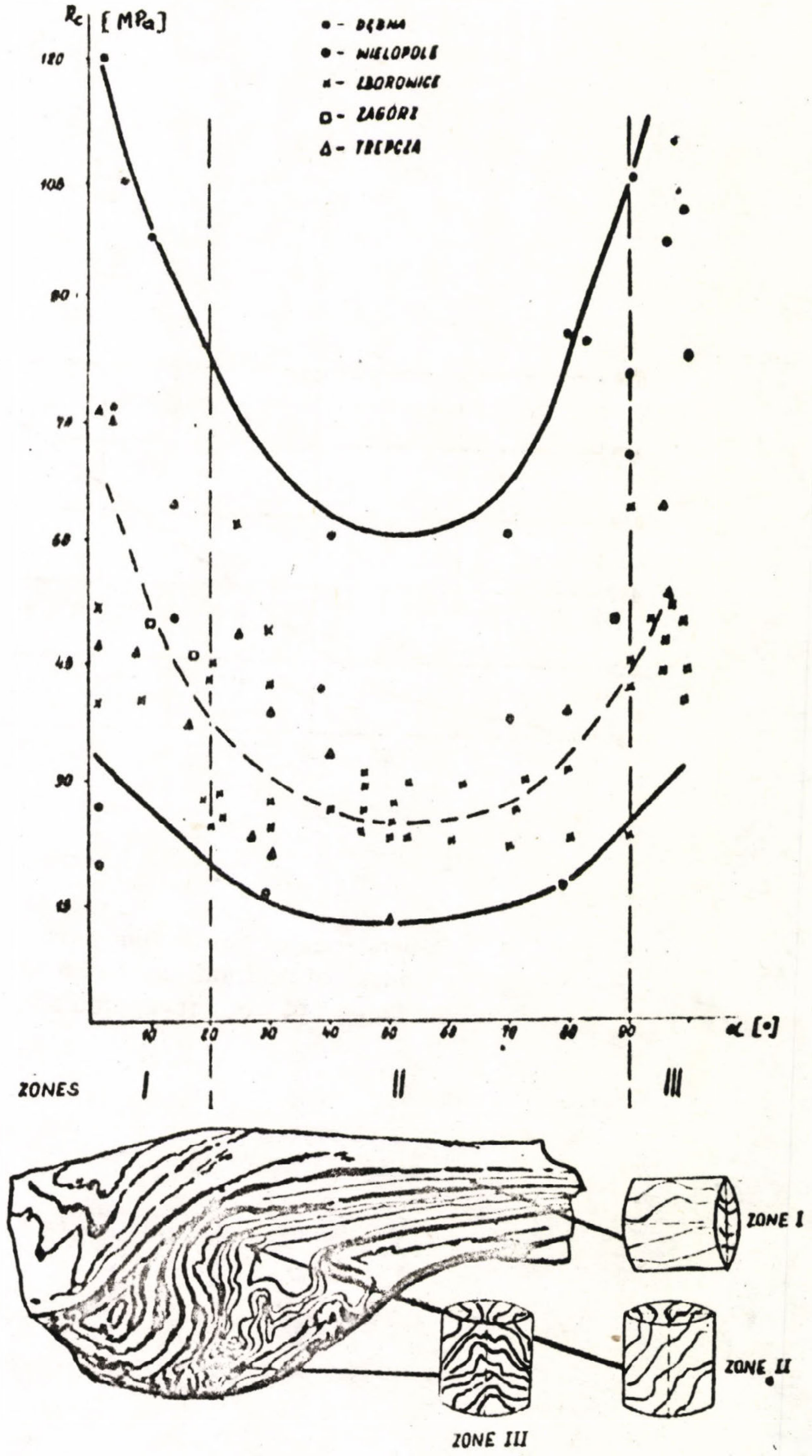


FIG. 12. dependance of sandstones properties on angle of inclination of sedimentary surfaces (α) in corrugated sandstones

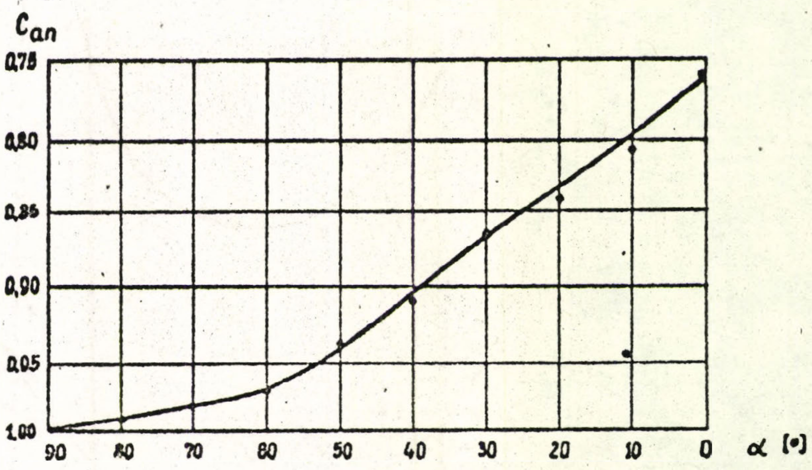


FIG. 13. Dependance of coefficient anisotropy C_{an} on angle of inclination of sedimentary surfaces (α) in corrugated sandstones

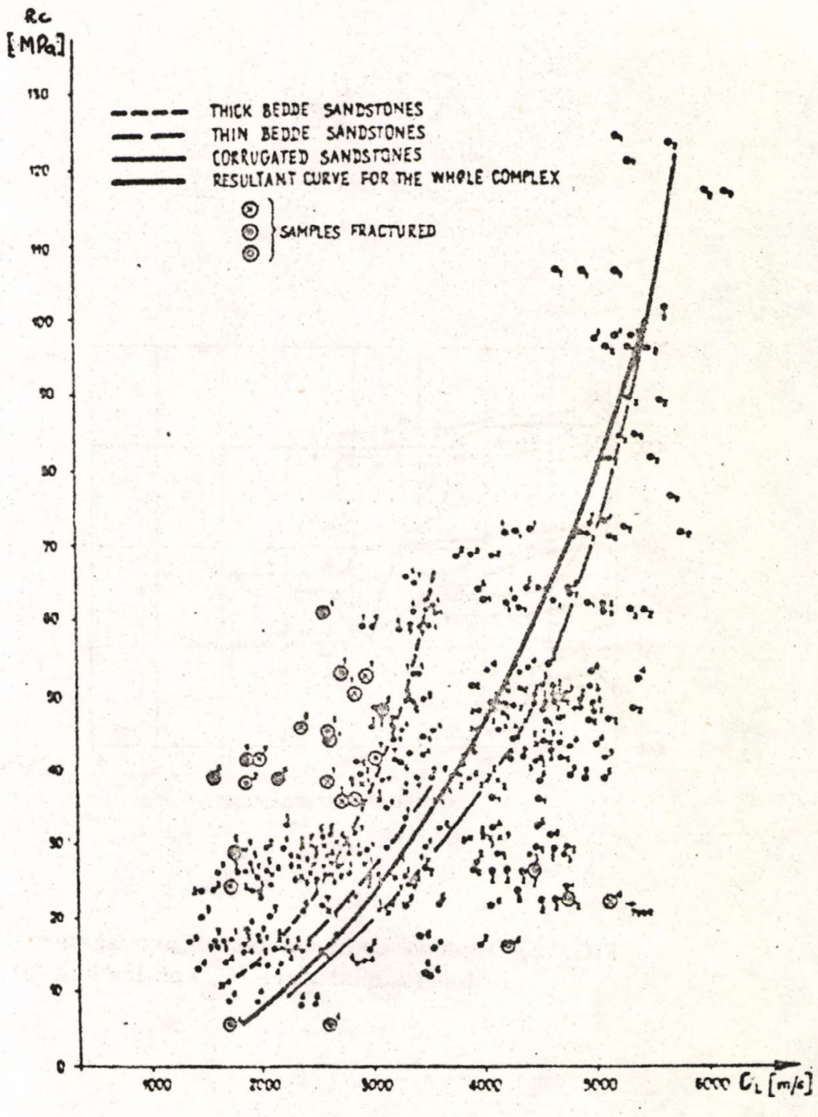


FIG. 14. Dependance of strength to compression (R_c) on velocity of propagation of longitudinal wave (C_L).

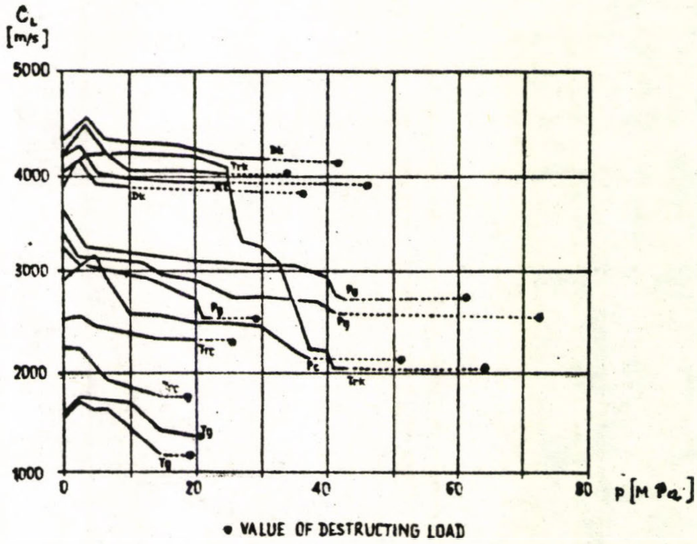


FIG. 15. Dependance of velocity of propagation of longitudinal wave (C_L) on loading (p)

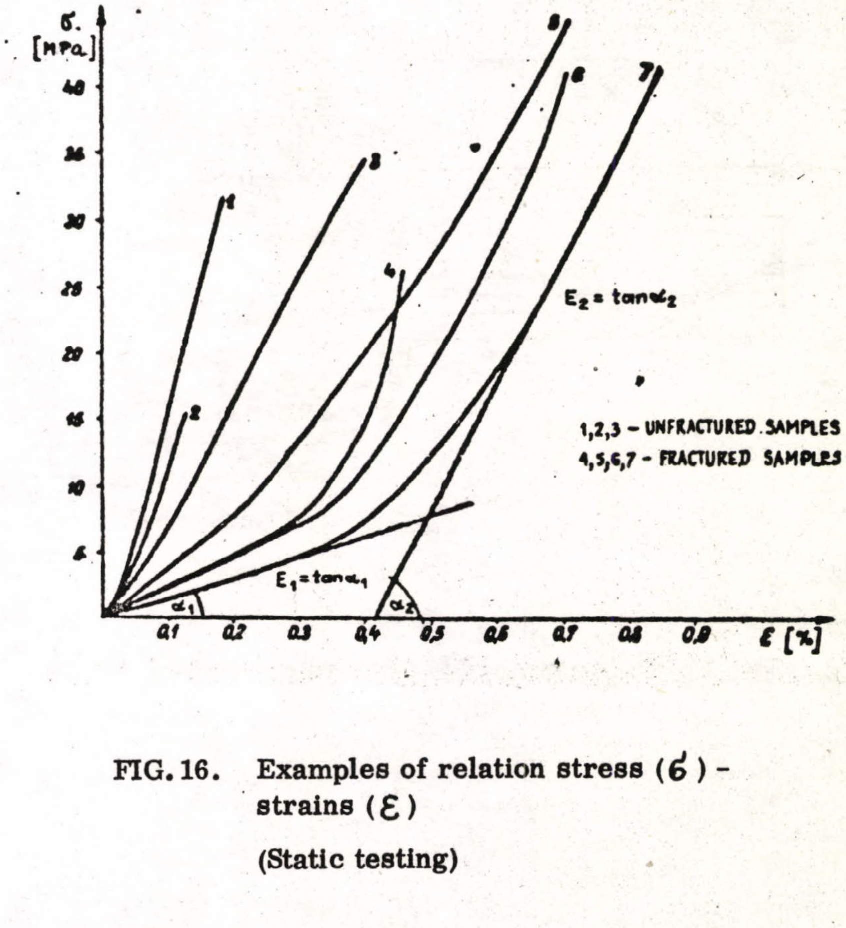


FIG. 16. Examples of relation stress (σ) - strains (ε)

(Static testing)

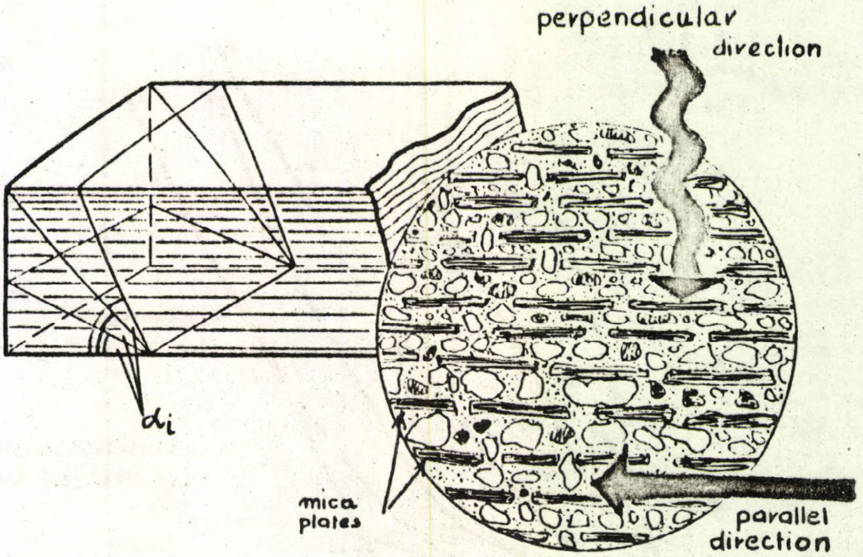


FIG. 17. Dependance of waves velocity of the forme of anisotropy (α_i)

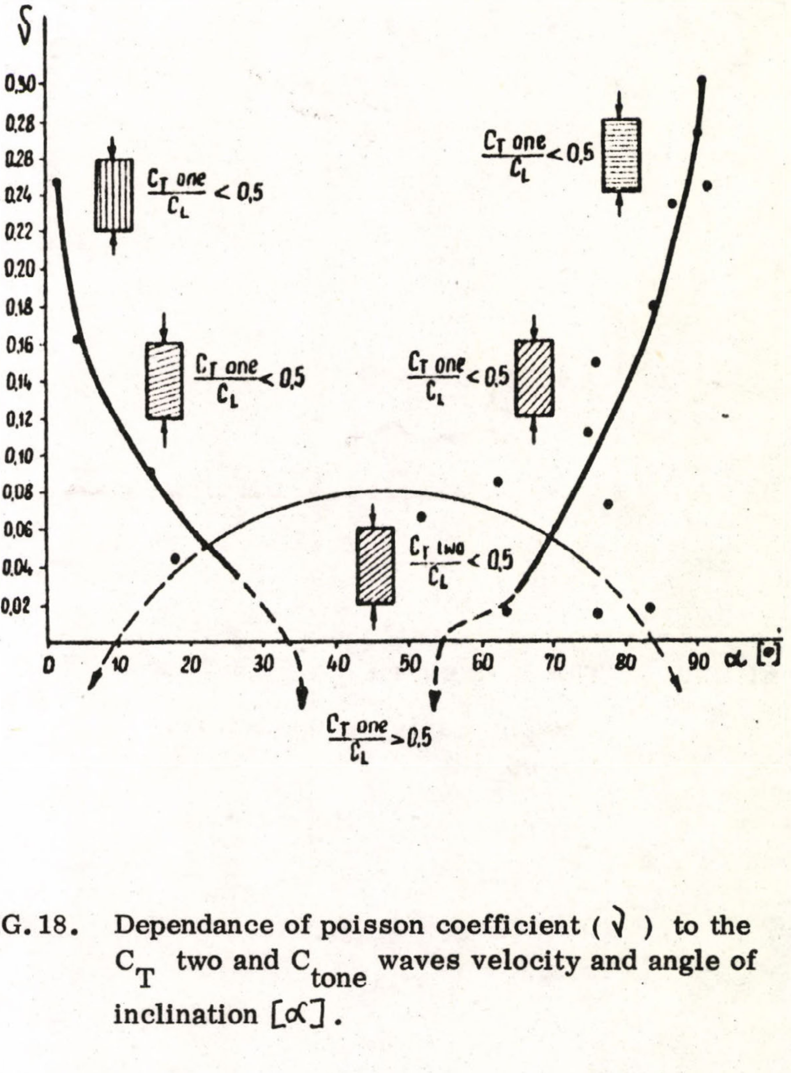


FIG. 18. Dependance of poisson coefficient (ν) to the C_T two and C_{tone} waves velocity and angle of inclination $[\alpha]$.

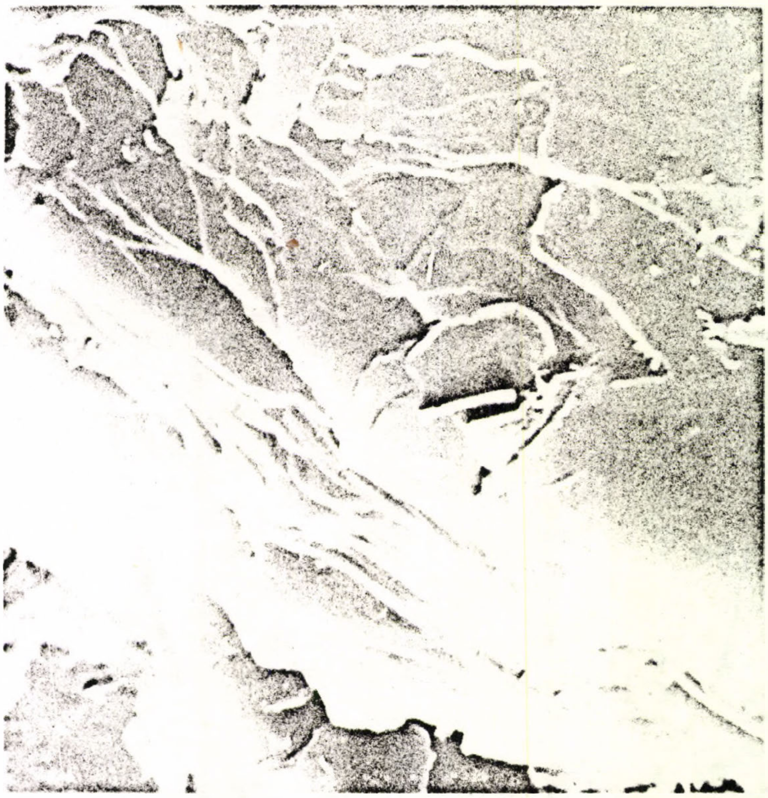


FIG. 19. The mica plates

- Scoming microscop picture.
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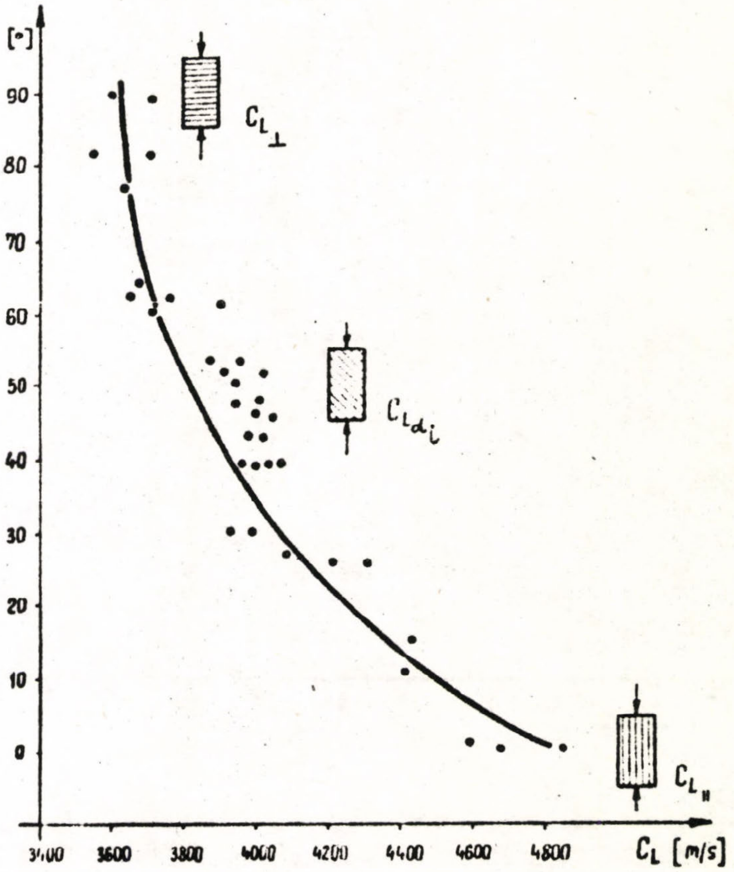

FIG. 20. Depandance of C_L velocity due to the angle of inclination (α)

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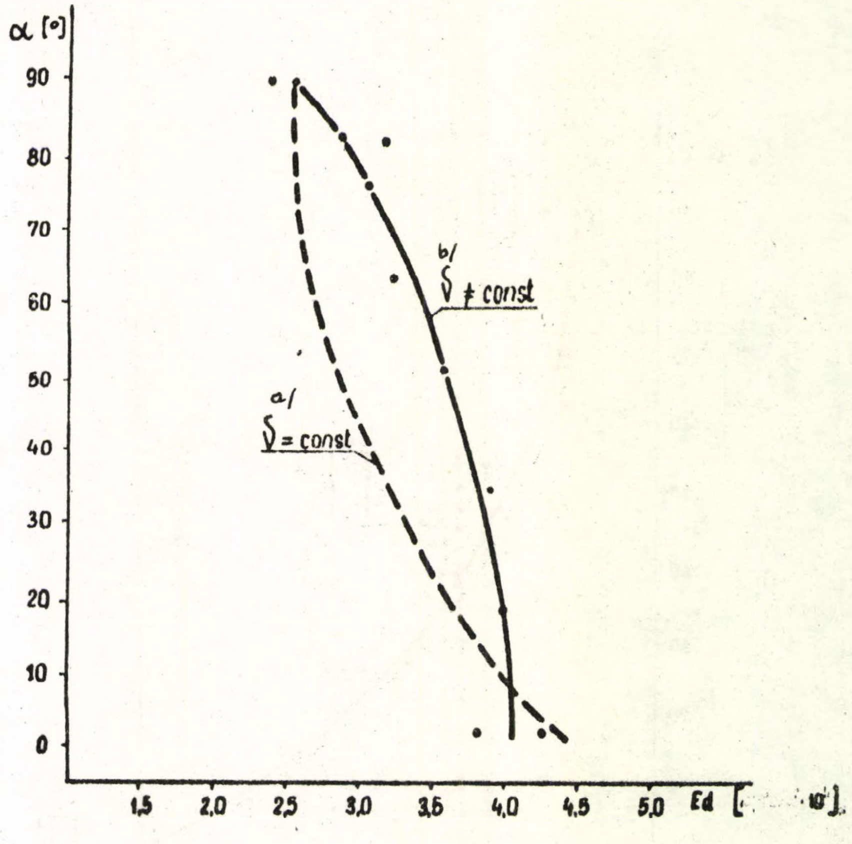

FIG. 21. Relation between angle of inclination (α) and dynamic modulus value (E_d)

a) ν - value given constance = 0, 25

b) ν - value given from real measurements for every angle

TABLE 1. TESTING RESULTS

SERIES	LOCALITY		DYNAMIC TESTING								STATIC			
			LONGITUDINAL WAVE C_L [m/s]			ACUSTIC ANISOTROPY COEFFICIENT G_{an}	TRANSWERSAL WAVE G_T [m/s]	ELASTICITY MODULUS $E_d \cdot 10^4$ (MEDIUM) [MPa]	POISSON COEFFICIENT ν	C_L (MEDIUM) [m/s]	COMPRESION STRENGTH (MEDIUM) [MPa]	ELASTICITY MODULUS $E_{st} \cdot 10^4$ [MPa] (MEDIUM)		POISSON COEFFICIENT ν
			z	x	y							E_1	E_2	
MIDDLE BEDS	PODLAS	g	2240 - 2670 2590	3160 - 3510 3265	3130 - 3680 3330	0.73 - 1.20 0.99	2510 - 2720	3.1	0.02	3205	42.9	0.25	1.43	0.27
		c	2680 - 3570 3081	2890 - 3510 3221	2250 - 3610 3070	0.76 - 1.02 0.98	—	—	—	3124	40.0	0.40	1.10	—
	DĘBNA	s	3850 - 5840 4928	3700 - 5390 4800	4330 - 5240 4727	0.56 - 1.11 0.68	2010 - 3230	4.50	0.07 - 0.30	4831	65.1	4.20	4.20	0.33
	CZARNA	g	3500 - 4910 4507	3330 - 4880 4257	4090 - 5560 4604	0.82 - 1.26 1.04	2100 - 3200	5.35	0.13 - 0.18	4435	58.4	0.44	4.60	0.08
LOWER BEDS	MIELOPOLE	s	4300 - 6250 4608	—	—	—	2030 - 3200	5.30	0.13	—	80.8	0.50	6.20	—
	ZAGÓRZ (train cut)	s	2000 - 5170 4086	4310 - 5170 4702	2680 - 5340 4336	0.39 - 1.12 0.92	2820 - 3390	1.35	0.14	4375	48.7	0.46	0.56	0.42
	ZAGÓRZ	g	1250 - 2830 2105	1000 - 3110 2306	755 - 3080 2191	0.57 - 1.74 1.03	—	—	—	2201	11.8	0.11	0.29	—
		c	7980	2130	2070	0.92 - 0.97 0.94	—	—	—	2060	41.3	—	—	—
	TREPCZA	g	2550 - 2760 2655	2580 - 3260 2515	3290	0.83 - 0.98 0.88	1680 - 2320	0.79	0.02	2986	38.7	0.25	0.73	0.48
		c	2060 - 2320 2287	2120 - 2520 2330	2140 - 2520 2360	0.89 - 0.98 0.97	—	—	—	2316	25.3	0.12	0.58	—
		s	1470 - 4550 2720	2780 - 5000 2520	2080 - 5100 3821	0.35 - 1.99 0.70	2240 - 2980	0.9	0.12 - 0.25	3454	36.1	0.32	1.00	0.05
	TURZA	g	4453 - 2080 1711	2470 - 2600 1734	1745	0.73 - 1.38 0.99	—	—	—	1777	24.4	0.10	0.60	—
		c	1783 - 2910 2428	4100 - 4760 4472	3900 - 4890 4469	0.37 - 0.68 0.55	2520 - 2760	0.63	0.26	3789	26.4	0.14	0.50	—
		s	2200 - 2700 2460	2470 - 2600 2686	2390 - 2930 2586	0.85 - 1.13 1.00	—	—	—	2592	37.8	—	—	—
	ZAGÓRZ - DOLINY	g	1400 - 3370 2515	2100 - 4100 2568	2250 - 3750 3042	0.71 - 0.72 0.72	—	—	—	2987	46.5	0.40	0.66	0.14
	ZBOROWICE	g	1275 - 1750 1657	1810 - 2630 2258	2000 - 2700 2095	0.65 - 1.63 0.98	—	—	—	2003	32.9	0.75	1.50	0.29
		c	4000	4030	4100	0.98 - 0.99 0.98	2320	3.4	0.24	4043	38.0	0.90	2.10	0.20
		s	2670 - 5280 4250	2950 - 5290 4196	2220 - 5030 3726	0.87 - 1.13 0.89	2100 - 2840	3.7	0.09 - 0.29	4184	42.3	0.12	2.20	0.06

σ-thick-bedoe sandstones, c-thin-bedoe sandstones, c-corrugated sandstones

Kivonat a "KŐZETTULAJDONSÁGOK KUTATÁSA LABORATÓRIUMI AKUSZTIKUS MÓDSZEREKKEL" c. előadásból

Joanna Pininska

A kőzet mechanikai tulajdonságai sztatikus és dinamikus módszerekkel egyaránt vizsgálhatók, de a roncsolásmentes dinamikus vizsgálatoknak - mint például az akusztikus módszereknek - sok az előnyük.

Az akusztikus sajátságok fontos tulajdonsága, hogy a jól mérhető terjedési sebesség hü anyagjellemző: ha a longitudinális és transzverzális hullámok sebességét (c_1, c_{tr}) egyaránt megmérjük, akkor számitható a rugalmassági modulus és a Poisson tényező is, feltételezve, hogy a kőzet homogén, rugalmas, izotróp és végtelen.

A hullámterjedés azonban az e feltételeknek meg nem felelő kőzetekben is jellemző, de függ a kőzet sajátságaitól (pl. ásványos összetétel, szövet, tagoltság, hőmérséklet és feszültségi állapot). A terjedés sebesebb a finomszemü, mint a durvább szemü kőzetekben, és jelentősen befolyásolják értékét a rétegződési, palássági vagy tagoltsági felületek. Igy a sebesség irányfüggő is lehet és igy az anizotrópiai tényezőt is meg lehet határozni.

A dolgozat egy kárpáti flis homokkő-területen végzett vizsgálatok eredményét mutatja be. A homokkövet először általánosan ismerteti, majd közli az anizotrópiai és összefüggés-vizsgálatok módszereit, három egymásra merőleges irányban végzett sebességmérés alapján. A 10. ábrán a porozitás - longitudinális sebesség összefüggéseit figyelhetjük meg, a testsürüség - longitudinális sebesség összefüggései a három térirányban különbözők. A nyomószilárdság és az ultrahang-sebesség parabolikus összefüggéseinek be-

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mutatása után (14. ábra) a terhelés nagyságának hatását vizsgálja a sebességekre (15. ábra).

A dolgozat foglalkozik még a transzverzális hullámok mérési problémáival, ismertetve a második beérkezéshez tartozó sebesség-értékek alkalmazását is.

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