ГЕОФІЗИКА

UDC 550.834

H. Guliyev[1], Dr. Sci. (Phys.-Math.), Prof., Academician of ANAS
Head of department "Tectonophysics and Geomechanics"
E-mail: hatamguliyev@gmail.com, tel.: +994 12 5105617;
Kh. Aghayev[1], PhD (Geol.-Min.)
Leading Researcherof department "Tectonophysics and Geomechanics"
E-mail: khagayev@yahoo.com, tel.: +994 12 5105617;
F. Mehraliyev[2], Director GeoGlobe Ltd
E-mail: fuadmehrali@yahoo.com, tel.: +994 12 4977421;
E. Ahmadova[1], Junior Researcher,
department "Tectonophysics and Geomechanics",
E-mail: ella_ezizova@mail.ru, tel.: +994 12 5105617
[1]Institute of Geology and Geophysics of ANAS
119 H. Javid Ave., Baku, AZ1143, Azerbaijan
[2]GeoGlobe Ltd, 9 M. Muhktarov Str., ap. 5, Baku, AZ1001, Azerbaijan

DETERMINATION OF THE PHYSICAL PROPERTIES OF COMPLEXLY CONSTRUCTED MEDIA USING NEAR-SURFACE CROSSWELL METHOD

(Рекомендовано членом редакційної колегії д-ром фіз.-мат. наук, проф. Б.П. Масловим)

In case when the upper part of the medium has complex geological structure and geodynamic processes occur in it, the necessity of these data increases in projecting of the object under construction.

Purpose. Studying of acoustic, elastic and anisotropic properties of the upper part of section of complicatedly constructed geological media.

Methodology. Seismic observations are conducted in shallow wells in the areas of construction objects located in various seismogeological conditions by NSCW (Near-Surface Cross Well testing) method. Field seismic records are processed. Kinematic and dynamic parameters of pressure and differently polarized shear waves are determined. Thin-layered one-dimensional models of physical properties of the medium are created and interpreted on the basis of nonlinear theory of elastodynamics.

Results. It is determined that the medium with high porous, water saturated rocks and anomalous high reservoir pressure has anomalous low value of velocities and gradient of their increase with depth. When this medium was re-examined after deep piles were built there, the overestimated seismic velocities are obtained, which is explained by a decrease in the section of anomalously high reservoir pressure and, accordingly, the porosity of the rocks after piles were built. When the hollowness is increased in unsaturated pebble rocks, the negative value of Poisson's ratio is obtained on the standard method. Seismic anisotropy related with the direction of the grains packing of the rocks is revealed on velocities of shear waves. The change of property of rocks on depth is manifested clearer on frequencies of waves than on their amplitudes.

Scientific novelty. The elasticity moduli of the 3rd order are determined which are more sensible to variability of nonlinear elastic properties of rocks of the medium than the moduli of the 2nd order. The values of Poisson's ratio are recalculated for one and the same rocks located in different conditions of rock pressure on the basis of nonclassical theory of deformation.

Practical importance. The obtained results can be applied to study the media characterized by complex seismogeological hydrodynamic conditions with clay-sandy rocks of high porosity and water saturation.

Keywords: near-surface cross well, pressure, shear wave, seismic velocity, elastic modulus, anisotropy, saturation, absorption.

Introduction. The earthquakes, landslides, mud volcanoes eruptions are the natural phenomena frequently occurring in Azerbaijan. Here the upper part of the geological section consists of the Quaternary sediments. Here the rocks are mainly clayey, but besides them there are separate beds of sands and shells. The rocks are highly-porous and water-saturated. In some places the sand beds have the abnormal pressure. The groundwater level at the sea cost starts from 2–5 m. The slopes of strata are nearly horizontal. When designing the site of the constructing object with such complex properties, it is necessary to provide its safety from the expected technogenic and natural phenomena. That is why the geological, geotechnical and engineering-geophysical investigations are carried out before the object design in-situ with purpose to get the information regarding the physical-mechanical properties of the upper part of the geological section. Depending upon the solved task the following methods are mainly used in engineering-seismic investigations:

- the thick-layer model of the environment is defined by velocity of pressure (V_p) or shear (V_s) seismic waves using therefractionmethod (RM) on the Earth surface by refraction wave travel time curve (*Burger,1992; Burger et al., 2006*);
- the thin-layer models of the upper part of the environment are defined by V_s using the spectral analysis of surface waves (SASW) method *(Antipov and Ofrikhter, 2016; Tokeshi et al., 2013*) and the multichannel analysis of the surface waves (MASW) *(Antipov and Ofrikhter, 2016; Choon et al., 2007; Tokeshi et al., 2013;Yasnickij et al., 2012)* method;
- the method of micro seismic logging (MSL) of the shallow well allows defining the one-dimensional models by V_p and V_s *(Crice, 2011);*
- the NSCW method, applied in the present investigation, is intended to study cross-borehole space *(Aghayev et al., 2012; Moret et al., 2006; Park et al., 2008; Pratt et al., 2008; Taeseo and Paul, 2013; Wadhwa et al., 2005; Yasnickij et al., 2012)*. In this method the observations are carried out in two shallow wells located nearby. In the first well the waves are excited at one depth, but in the second well the waves are recorded consistently at all depths. Then the waves are excited in the first well at the next depth, and they are all recorded at all depths in the second well (tomographic system of observation). The waves recording is performed by the multicomponent seismic receivers.

The MASW, SASWand NSCW methods are mainly applied to study the geological environment of the construction project areas. MSL and RM methods are also widely applied mainly in the seismic survey to define the static corrections. Among these methods the NSCW allows acquiring more detail, precise and comprehensive information regarding the physical properties of the geological environment via P and S waves.

Often the simplified version of the field observations is applied when performing the NSCW actions: only one excitement and one record of the waves is carried out at every depth *(Aghayev et al., 2012).* As a result of the field seismic record processing, the thin-layer one-dimensional models of the environment are defined by V_p, V_s, as well as the Poisson's coefficient (ν) and Young's modulus (E). But the necessity arises to define other moduli of elasticity, anisotropy and absorption by the complex environments *(Bezrodna et al., 2016; Suroso et al., 2017;Thomsen, 2002; Aleksandrov and Prodajvoda, 2000).*

The results of studies of the non-linear physical-mechanical properties of some sedimentary rocks shows that the elasticity moduli of the third order are manifold sensitive to the variability of the environment's elastic properties than the moduli of the second order *(Bezrodna et al., 2016; Guliyev et al., 2016; Aleksandrov et al., 2001; Vyzhva et al., 2005; Kuliev, 2000).*The above mentioned modulus had been used in the present research.

Numerous studies have been carried out to study the anisotropy of the propagation velocity of seismic waves in sedimentary rocks*(Suroso et al., 2017; Thomsen, 2002; Aleksandrov and Prodajvoda, 2000; Dugarov et al., 2011).* The anisotropyis more brightly manifested in the difference of velocities of differently polarized SH and SV shear waves *(Puzyrev et al., 1985).*The seismic wave's absorption is the important property of the environment; it is defined by the amplitudes change of harmonic components of the seismic signal *(Boganik and Gurvich, 2006).*

Objects of research. The article examines the study of geological environments of three sections of building objects using the NSCW method.

The first object (Object_1) locates onshore, 250 m from the Caspian Sea coast, on the flat terrain, 2,3 m over the sea level. Here the groundwater level approximately starts from 2–3 m. The Lower Quaternary sediments lay in the studied interval ((1–28 m) of the geological section. The lithological section consists of the alternation of thin layers of clays and sands. From top and to 30 m deep the clays are characterized as very soft, soft, firm, hard and very hard. The clays are with inclusions of organic matter. Starting from 0.5 m to the groundwater level the water saturation of clays' pores is 16,3–17,4 %. The rocks density starts from 1.86 g/sm? and increases to 2,07 g/sm?.

The second object (object_2) locates onshore, 200 m from the Caspian Sea coastline, at 2,0 m above the sea level. According to samples from wells, here the geological section mainly consists of flat-dipping thin layers of clays, sands and sandstones rocks of the Lower Quaternary sediments. With increasing depth, the clayey rocks and the number of clean clay layers increase. In comparison with object_1, the younger, porous, soft and water-saturated rocks occur here. The present rocks are water-saturated because the site locates at the sea shore. The beds of water-saturated sands, consisting of two layers with abnormal pressure, occur at the depths of approximately 25–50 m. Here the average value of rocks' density is 1,99 g/sm?. At the site of the object, NSCW was observed at depths of 1–83 m. Two years after the numerous large holes were drilled in the direct close from that area and the deep concrete piles were constructed in that holes. After these actions the repeated observations by NSCW were carried out with purpose to control the environment change in this area.

The third object (object_3) locates far from the seashore. The rocks of the studied environment mainly consist of pebble soils with sandy loam and sandy fillers. The pebbles are large in size. The space between the rocks particles is empty enough. In object the groundwater level starts approximately from 16 m. Up to this depth the particles of young and non-cemented rocks have the good contact. After the depth of 16 m the rocks' water saturation is approximately 15 %. Here the average value of the rocks density is 2,20 g/sm? Here observations by NSCW were carried out at a depth interval of 1–20 m.

Method of study. *Acquisition method.* The seismic observations were carried out by NSCW method *(Aghayev et al., 2012; Park et al., 2008; Dejneko et al., 2017; Oshkin et al., 2016)* with application of "Geotomographie" devices *(www.crosswellinstruments.de).* At the same time two wells with equal depths in some tens meters were used. A plastic pipe was put down into every well, and the annular space was filled with cement grout. The pipe position along every well bore was determined by inclinometer. The distance between the wells was 8–10 m. In accordance with observation system the source shot-point was lowered down into the first well, but the seismic waves' receiver – into the second well.

In the first well, the P wave, SH and SV types of S waves were simultaneously excited.In the second well they were received by three-component XYZ seismic receivers. In the course of study, not tomographic *(Wadhwa et al., 2005)* but simple system of observations was used located at the same depth with excitation source and receiver *(Aghayev et al., 2012).* The devices in well were directed according to compass reading. In the receiving well the Y component was directed towards the well of waves' exciting. Observation at each depth was repeated 10 times and the records were summarized.In each depth, the waves were excited separately by strikes in the right and left directions.The mentioned process was repeated after raising of the excitation source equipment for 1 m. At the strokes to the left and right directions the first P wave is got with similar polarity, but S wave – with direct and reverse polarity *(Crice, 2011; Parket al., 2008).* Such observation allows choosing between P and S waves because the polarity of S wave differs from the noise.

The duration of seismic record is 64 msec, but the discretization – 0,021 msec.

Processing of seismic data. Field seismic records were processedby "GEOPRESS" *(Guliyev et al., 2010)* software package. As a result of test the graph and optimal values of processing parameters were selected. The main procedures of processing graph *(Aghayev, 2012; Gheslagni and Santamarina, 1998; Dejneko et al., 2017)* are the following:

1. bringing of seismic records to processing format;
2. calculation coordinate of each observation points in well;
3. visualizing and editing of seismic records;
4. summarizing of seismic records on right and left directions to select P and S waves and subtracting from each other;
5. calculation of complete vector records from XY component records;
6. definition of frequency spectrum and the leading frequencies of P and S waves;
7. application in necessary of zero phase frequency bandpass filters to seismic records;
8. definition of polarization parameters of P and S waves;
9. determination of the 1st and 2nd phase time, amplitudes of P and S wave signals in different seismic attribute records;
10. calculation of layer velocities of propagation P and S waves in the medium;
11. correction of wave time and velocities on depths at which signal/noise ratio is low;
12. calculation of Poisson, Young and other ratio of elasticity modulus;

13. calculation of values of the seismic anisotropy by the time difference of fast and slow shear waves;

14. calculation of values of the seismic waves' absorption by their amplitudes.

The seismograms of P and S waves, obtained after the processing of the field seismic records, are given in fig. 1 as an example for object_1.

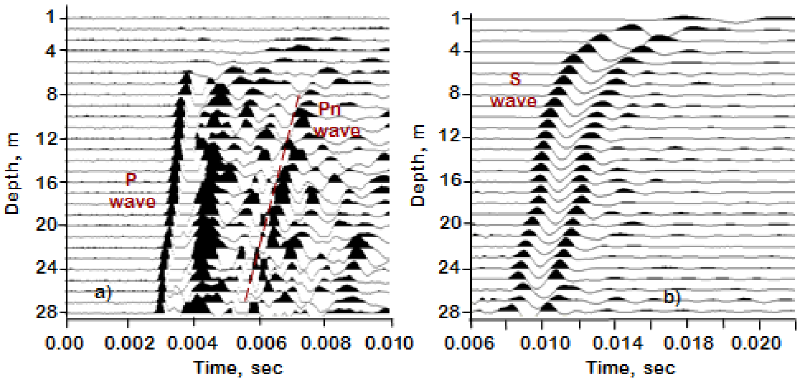

Fig. 1. NSCW seismograms after processing of Object_1:
a – pressure wave; b – shear wave

Here the first P and S waves are steadily traced on which their kinematic and dynamic parameters were defined. The precision of S wave times is approximately two times higher than by P wave. The changes of waves parameters depending upon the observation depth are recorded in the seismograms. Various unwanted energies are observed in the seismogram by P wave (fig. 1, a). The regular unwanted signal defined as P_N has double arrival time and low apparent velocity than P wave. Probably, the P_N is multiple P wave.

Definition of the physical properties of the environment. The thin-layer one-dimensional models of the environment were defined by V_p, V_s, ν, E, n_1, n_2, a, b and c as a result of the seismic records processing. Here n_1, n_2 – are combined, but*a*, *b*and *c* are the elasticity moduli of the third order *(Guliyev et al., 2016; Aleksandrov et al., 2001)*. The values of moduli of the third order were calculated by the non-classic theory of deformation *(Vyzhva et al., 2005; Kuliev, 2000)* considering the geostatic pressure in the environment. Values of moduli n_1, n_2, a, b and c are corresponded to the conditions of atmosphere pressure. The data on velocities of the pressure and shear waves SH, SV, rocks density and geostatic pressure for every depths were used for moduli calculations.

The time rate of the seismic waves was studied by their rate spectrum and band filters of thedifferent ranges. The amplitudes of time phases, "visible time rate", calculated by time phases of the wave signal, were used to get the precise data regarding the waves. The time rate of waves and amplitude values, related with depth change, were defined. The processing results were interpreted according to the accepted technique *(Aghayev et al., 2012; Suroso et al., 2017; Wadhwa et al., 2005; Oshkin et al., 2016).*

Results and discussions. The results of studies are given for three objects mentioned above. For the first object (object_1) the results are complete, for the rest two ones they are partial. The results are discussed individually for each object and by the physical parameters of the environment.

The properties of the rocks seismic velocities for Object_1. According to P and S waves, with increase of depth, the layers velocities increase gradually by small variations (fig. 2, a). The most velocity gradient is observed at the depth of 1–6 m and by V_p. It is related with gradual increase of saturation of the rocks with groundwater. In the following depths the velocity change is related with porosity, density, lithology of the rocks and, according to P, with water-saturation changes. Unlike the V_p which characterizes the solid and liquid part of the skeleton, V_s doesn't practically depend upon the rock saturation *(Garotta, 2000)* and describes only the solid part of the rock skeleton. The quantity and hardness of contacts between the rocks grains strongly influences the V_s. Therefore, V_s more accurately characterizes the strength of the rock.

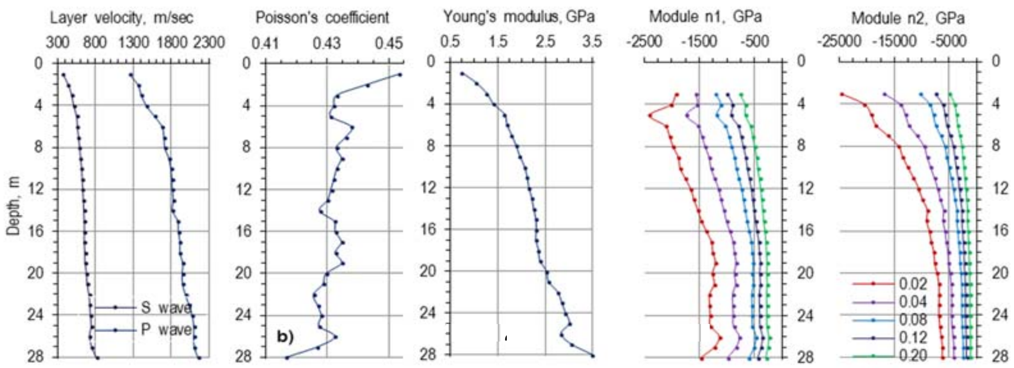

Fig. 2. The graphs of dependences of the seismic velocities and elasticity moduli values upon the depth for Object_1:
a – layer velocity for pressure and shear waves; b – by ν; c – by E; d – by n_1; e – by n_2

According to depth interval 1–28 m the correlation 0,974 of intermediate dependence between V_p and V_s was approximated by the linear function (fig. 3) coefficient.

$$V_s = -0{,}1328 + 0{,}4195V_p$$

This equation is correct within the velocity values given in fig. 2, a.

Elastic properties of the rocks for Object_1. The value of ν differentiates strongly with depth increase and changes with great gradient (fig. 2, b). As the water-saturation influences upon V_p and V_s in different ways *(Burger, 1992; Burger et al., 2006; Puzyrev et al., 1985; Garotta, 2000),* this coefficient cannot completely describe the elasticity properties of the rock matrix particles. Accordng to Young's modulus, the graph is multiply differentiated and the changes of the rocks elasticity properties reflect there more substantively (fig. 2, c). It is related with differences of formulae of the elasticity moduli calculation and with more stable change of V_s with depth than V_p has. In the present research the moduli n_1 and n_2 were used to study the elasticity of the environment's rocks and the jointing simulation (ξ) by disk-shaped fractures *(Maslov et al., 2000).* It is assumed that the change of ξ characterizes the rock porosity change. Testing n_1 and n_2 was carried out for various values of ξ (0,02÷0,20) and depth of observation. An increase in ξ corresponds to an increase in the porosity of the rock. The values of n_1 and n_2 are calculated taking into account the geostatic pressure at each depth of observation. The graphs from fig. 2, d,e show that at equal value of ξ the values of anddecrease with the depth grow. This is due to the increase in the values of the velocities and density of rocks in depth. The results of the calculations show (fig. 2, d, e) that as the porosity increases, the absolute value of n_1, n_2 and accordingly the elasticity of the rocks decreases. The value of changes within wider range than by n_1 (fig. 2, d, e). With an increase in ξ, the gradient of the variation of and decreases with depth. With the same value of ξ, with increasing depth the values of n_1 and n_2 decrease. This is due to the increase in the difference in the rock pressure. These changes show the possibility of predicting the variability of rock porosity with the use of the above modules.

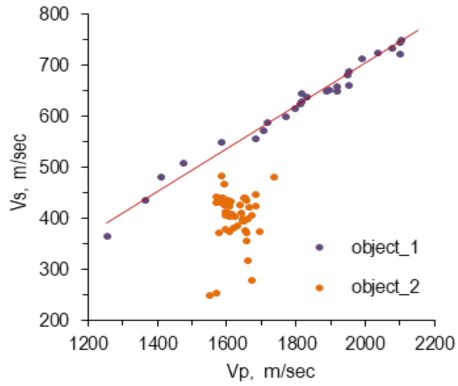

Fig. 3. Dependency between pressure and shear wave velocities

The difference between the maximum and minimum values of each elasticity modulus is determined. It was obtained that the differential by moduli ν, E, n_1 and n_2 (at ξ = 0,20) is 9 %, 127 %, 122 % and 184 % accordingly. It points to the great range of n_1 and n_2 change and their high sensitivity to variability of the rocks' elastic properties than moduli of the second order. The moduli and can be applied when forecasting the rocks' porosity.

The values of moduli a, b, c and ν by the classic and non-classic theory of deformations for object_1 and object_3 are given in table 1.

Table 1

The values of elastic properties of rocks of the environment

object_1						object_3					
depth m	a ×10× GPa	b ×10× GPa	c ×10× GPa	ν of classic	ν of no classic	depth m	a ×10× GPa	b × 10× GPa	c × 10× GPa	ν of classic	ν of no classic
5	–213	253	–801	0,431	0,432	5	1863	–2782	8358	0,160	0,177
6	–98	74	–248	0,438	0,432	6	–2782	4193	–12583	–0,081	0,177
7	–136	150	–472	0,436	0,432	7	–3747	5621	–16893	0,069	0,177
8	–98	106	–340	0,433	0,432	8	–953	1435	–4322	0,052	0,177
9	–149	180	–560	0,435	0,432	9	–360	545	–1643	0,086	0,177
10	–61	54	–184	0,433	0,432	10	–1190	1786	–5368	0,113	0,177
11	–61	58	–194	0,432	0,432	11	–546	820	–2470	0,120	0,177
12	–90	105	–331	0,431	0,432	12	–210	318	–957	0,078	0,177
13	–111	138	–432	0,430	0,432	13	503	–755	2252	0,185	0,177
14	–174	235	–721	0,428	0,432	14	–824	1233	–3710	0,155	0,177
15	–173	230	–703	0,432	0,432	15	73	–109	322	0,142	0,177
16	–166	221	–676	0,433	0,432	16	–2023	3033	–9107	0,009	0,177
17	–147	193	–589	0,435	0,432	17	525	–792	2365	0,265	0,177
18	–133	174	–535	0,433	0,432	18	5	–40	112	0,417	0,177
19	–125	161	–495	0,435	0,432	19	–168	222	–669	0,422	0,177
20	–156	210	–641	0,430	0,432	20	–488	694	–2088	0,428	0,177
middle	–131	159	–495	0,433	0,432	middle	–645	964	–2900	0,164	0,177

As a result of comparing the following had been discovered:

- the dispersion of values a, b, c and ν for object_1 is significantly lower than for object_3;

• the difference of ν values average by depth by the classic and non-classic theory for object_1 and object_3 is +0,14 % and –7,49 % accordingly;

• the difference of ν values by classic and non-classic theory for separate depths is greater for object_3 than for object_1;

• the negative values of ν were obtained by the non-classic theory of deformation for object_3 for the depths 1–3 m and 6 m.

For every object the application of non-classic theory allowed to get the equal values of by ν all depths of observations. It is necessary to mention that when calculating ν values by the non-classic theory it is proposed that in the studied depths the rocks have a similar lithological composition but different values of the rock pressure.

Anisotropy properties of the rocks for Object_1. In all studied objects the shear waves of SH and SV type are traced in the seismic records (fig. 4, a). These waves have the equal frequency spectrum but different arrival time to seismic receiver. In the seismic records the high-velocity SH wave are traced in the horizontal components, but in the vertical components – the low-velocity SV wave *(Taeseo and Paul, 2013; Karpov et al., 2014; Puzyrev et al., 1985).* The time differences of these waves change by depth accordingly, 1,0 ms in an average. These differences make it possible to determine the rock anisotropy from the seismic velocity *(Suroso et al., 2017; Thomsen, 2002)* (fig. 4, b). In the horizontal direction the wave width covers the rocks particles, but in the vertical direction it travels with great velocity *(Dugarov et al., 2011; Karpov et al., 2014; Puzyrev et al.,1985).*Due to direction of the covered particles of the rocks of the observed seismic anisotropy the sites to study had been accepted considering the following properties:

1. according to well data from the sites, the rocks layers occur approximately in the horizontal direction;

2. the rocks of the site have no microfractures due to the softness, great porosity and low pressure at the occurrence places;

3. the anisotropy is observed by sand, clayey sands, and clay beds containing the organic matter.

The anisotropy values change within 5–25 % and are observed at the depth interval 14–28 m maximum (fig. 4, b). Similar results with various values of the anisotropy were obtained in all studied objects. All these prove once more that in spite of the presence of isotrope in the pure clay, it (clay) has the properties of the seismic anisotropy, related with direction of packing of the rocks particles with pure and mixed sands *(Puzyrev et al.,1985).*

Absorption proerties of the rocks for Object_1. It is known that the variability of the frequency of the detected signal depends on the factors *(Puzyrev et al.,1985; Garotta, 2000; Boganik and Gurvich, 2006)*: the greater the hardness of the rock in the medium, the greater the frequency of the excited signal and the less the signal absorption in the medium between the source and the receiver; the higher the frequency of the hormone signal, the greater its absorption *(Boganik and Gurvich, 2006).*The influence of these factors cannot be separated when determining the absorption from data with a simple NSCW observation system. Therefore, the absorbing property of the medium, determined from the data used, is a priori information.

An increase of visible frequency of seismic signal with a depth is mainly observed on seismograms (fig. 1, a, b) and on charts (fig. 4, c). From the depth of 2 m to 12 m visible frequency is increased by 65 % P wave and 35 % S wave. For a 2–28 m interval, a relationship between the frequency (f, Hz) and the velocity (V, km/sec) is determined jointly by both waves. The dependence is approximated by a linear function, with a correlation coefficient of 0,925.

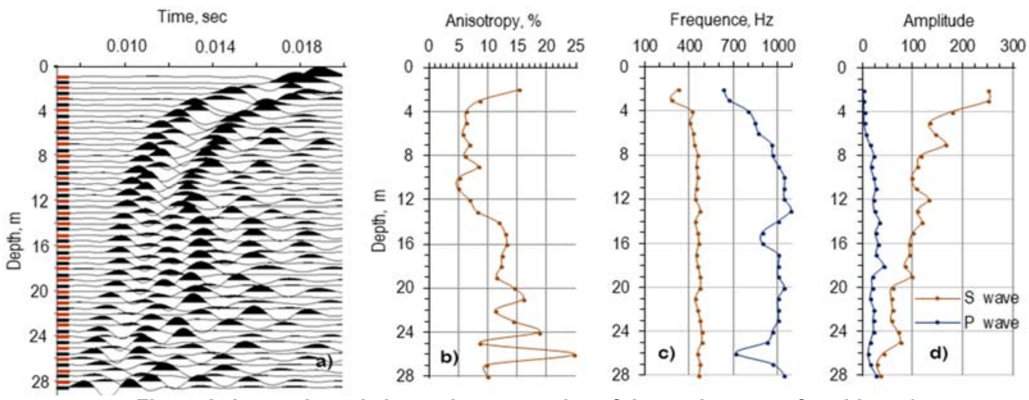

Fig. 4. Anisotropic and absorption properties of the environment for object_1:
a – (—) and (—) type shear wave seismic records; b – anisotropy coefficient; c – visible

The amplitude of the phase of the wave signal is substantially higher than y (fig. 4, d). At depths of 2–28 m, the amplitude gradient is +0,6/m in P wave and –6.2/m in SH wave. Despite the increase in the frequency P of the wave with depth, its amplitude also increases, which indicates a weak absorption of it in the rocks of the medium. The large and negative gradient of the amplitude of the SH wave is probably due not to an increase in its absorption with depth, but to a decrease in its intensity upon its excitation. It is assumed that the impact force to the well wall was a source of wave excitation and was stable at all depths. Therefore, the change in the SH wave amplitude characterizes the variability of the medium rocks in depth. Thus, the absorbing property of the medium rocks is not a determining factor of influence on the values of the wave amplitudes. The determining factor is the conditions for the excitation of waves in the rocks of the medium.

The properties of the rocks' seismic velocities for Object_2. During 2 years the studies by NSCW method was performed twice within the present object. According to the results of both studies, as the depth increases, V_s gradually increase with varieties (fig. 5, a). This is explained by the fact that as the geostatic pressure increases, the porosity of the rock decreases, which leads to an increase and improvement of the contacts between its grains. Variation of velocity V_s at different depths is related to lithological variability. According to the first NSCW study, after a depth of 8m (full water saturation), the V_p does not increase substantially. For this object, the velocities are low, which is explained by high clayiness, porosity and water saturation of the rocks of its environment. For this reason, there is no correlation between the values of the V_p and V_s (fig. 3). In this depth interval, the maximum anisotropy value is about 2 %. Such a low value of anisotropy is explained with high clay content of rocks.

After the first NSCW study the abnormal pressure of layers was reduced significantly at the object site. It was related with construction of great number of the deep concrete piles. Therefore, in rocks the porosity and water saturation are reduced, the density is increased. Then the NSCW work was conducted for the second time with a view to monitoring. A comparison of the results of the two studies is given in (fig. 5). After monitoring V_p and V_s aregenerally increased.In the depth interval 1–7 m V_p did not change, but after 7 m it gradually increased (fig. 5, a). The difference in the values of V_s is gradually increasing after 25 m. After monitoring, the gradient of the V_p increase with a depth greater than V_s. This is due to the decrease in layer pressure and, accordingly, porosity, water saturation of rocks. At a depth of 40 m, the increase in the values of V_p and V_s is 35 % and 24 %, respectively.

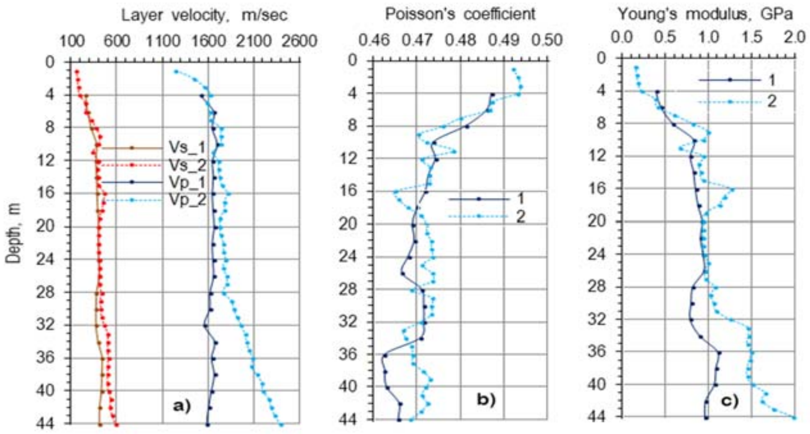

Fig. 5. Properties of the environment rocks at object_2 after the first (1) and second (2) NSCW studies:
a – layer velocity of the pressure and shear waves; b – by ; c – by

Elastic properties of the rocks for Object_2. The value of modulus of the rocks elasticity of the present object shows the presence of less elasticity in comparison with other objects. After a second NSCW study, the values of the ν and the E were increased by 2% and 41 % (fig. 5, b, c). A small and reverse change in the value of the Poisson's ratio is associated with a higher increase in the value of V_p than V_s (fig. 5, a). This shows that the use of ν to determine the elastic properties of highly porous water-saturated rocks is not sufficiently effective.

Velocity and elastic properties of the rocks for Object_3. With increase of depth the velocity of P and S waves gradually increase with variations. For S wave the strongest gradient of the velocities' increase is observed in the depth interval 1–4 m that is caused the clayey rocks compaction. At the depth interval of 5–17 m there is a small gradient of velocities increase on the pebble rocks. The significant increase of velocities and intensity of P waves is observed at the depths of 17–20 m that is caused by the beginning of gravels' saturation with groundwater. This is not observed by the S wave. It is known that under the equal conditions the better contact between the rocks particles the quicker propagation of wave *(Puzyrev et al., 1985; Garotta, 2000; Boganik and Gurvich, 2006)*. The values of V_p and V_s in pebbles are noticeably higher than in clays, sands and even in the limestones. Due to this, the values of V_s are increased, but V_p are decreased as compared to other objects with clayey sediments. Thus, the real object was obtained consisting of local coarse gravel, ν value of the rocks calculated by the classic theory, not water-saturated at the depth of 1–3 m and negative at the depth of 6 m, not real at the other depths and well water-saturated at the depths of 18–20 m (table 1).Thus, because of higher precise of definition of wave S velocity and its independence from the water saturation, it characterizes the velocity and elastic properties of the rocks more precisely.

Conclusions. As a result of the research by the method of NSCV of the upper part of geological media, the properties of rocks by seismic velocity and elasticity were determined. In addition to these, the following was identified:

- the amplitude of the shear wave better than its frequency reflects the variability of the properties of the rocks of the medium;
- the anisotropy of the seismic velocity of the differently polarized shear waves is due to the direction of packing of the rock particles;
- moduli of elasticity of 3nd are more sensitive to the variability of the elastic properties of rocks than 2nd modules, and it is possible to test porosity of rocks on them;
- the application of the nonclassical theory of deformation made it possible to more reliably determine the elastic properties of the rocks in the medium.

The detailed results of studies by NSCW method can be used in the studies in the construction sites with complex surface of the seismic properties as well as in the studies of low-velocity zones of the multiwave seismic surveys.

Acknowledgment. The present work was performed within the grant project № 6284 of the Science and Technology Center in Ukraine.

Список використаних джерел

Александров, К.С., Продайвода, Г.Т., Маслов, Б.П. (2001). Метод определения нелинейных упругих свойств горных пород. *Докл. РАН,* 380(1), 109-112.

Александров, К.С., Продайвода, Т.Г. (2000). Анизотропия упругих свойств минералов и горных пород. Новосибирск: Издательство СО РАН.

Антипов, В.В., Офрихтер, В.Г. (2016). Современные неразрушающие методы изучения инженерно-геологического разреза ©*Вестник ПНИПУ. Строительство и архитектура,* 7, 2. DOI: 10.15593/2224-9826/2016.2.04

Безродна, І., Безродний, Д., Голяка, Р. (2016). Математичне моделювання впливу мінерального складу та пористості на параметри пружної анізотропії складно побудованих теригенних порід Волино-Поділля. *Вісник Київського національного університету. Геологія,* 73, 27-32.
Боганик, Г.Н., Гурвич, И.И. (Ред.) (2006). Сейсморазведка. Учебник для вузов. Тверь: Издательство АИС.
Выжва, С.А., Маслов, Б.П., Продайвода, Г.Т. (2005). Эффективные упругие свойства нелинейных многокомпонентных геологических сред. *Геофизический журнал,* 27(6), 1012-1022.
Гаротта, Р. (2000). Поперечные волны: от регистрации до интерпретации. Краткий курс лекций для высших учебных заведений.
Дейнеко, С., Вижва, С., Нестеренко, Г., Берневек, А., Іващенко, С. (2017). Сейсмоакустичний моніторинг стану ґрунтів Дністровського схилу (у зоні розміщення напірно-стаціонарного вузла). *Вісник Київського національного університету. Геологія,* 78, 30-35.
Дугаров, Г.А., Оболенцева, И.Р., Чичинина, Т.И. (2011). Анализ анизотропии скоростей и поглощения сейсмических волн в среде с одной системой параллельных границ. *Технологии сейсморазведки,* 3, 29-41.
Карпов, И.А., Горшкалёв, С.Б., Вишневский, Д.М. (2014). Два механизма образования взаимно ортогонально поляризованных поперечных волн по данным ВСП. *Материалы Всероссийской конференции, посвященной 100-летию со дня рождения академика Н.Н. Пузырёва, 8–13 декабря, Новосибирск*, 49-54.
Кулиев, Г.Г. (2000). Определение коэффициента Пуассона в напряженных средах. *Доклады РАН,* 370(4), 534-537.
Маслов, Б.П., Продайвода, Г.Т., Выжва, С.А. (2000). Матиматичне моделирования впливу тиску і у тріщинуватих гірских породах. *Геофизический журнал*, 22, 113-118.
Ошкин, А.Н., Ермаков, Р.Ю., Рагозин, Н.А., Игнатьев, В.И. (2016). Межскважинное сейсмическое просвечивание - опыт, методология, аппаратура. *Приборы и системы разведочной геофизики,* 3, 37-47.
Пузырев, Н.Н., Тригубов, А.В., Бродов, Л.Ю. и др. (1985). Сейсмическая разведка методом поперечных и обменных волн. М.: Недра.
Ясницкий, А.А., Колодий, А.А., Шабарин, В.Н. (2012). Сравнение эффективности применения метода MASW с традиционными методами сейсморазведки *для* целей инженерных изысканий. *8-я международная конференция и выставка – Инженерная геофизика, 23-27 апреля, Геленджик, Россия,* 1-5.
Aghayev, KH.B., Amrahov, A.T., Mehralyev, F.E. (2012). Engineering-geophysical reserches by translucence of cross-hole phase method. *Geophysics news in Azerbaijan,* 1-2,17-21.
Burger, H. R., Sheehan, A. F., Jones, C. H. (2006). Introduction to Applied Geophysics: Exploring the shallow subsurface W.W. Norton & Co., New York.
Burger, H.R. (1992). Exploration geophysics of the shallow subsurface. United States. Prentice Hall.
Crice, D. (2011). Near-surface, downhole shear-wave surveys: A primer. *The Leading Edge,* 30(2), 164-171.
Gheslagni, F., Santamarina, J.C. (1998). Data pre-processing in cross-hole geotomography: *Journal of Environmental and Engineering Geophysics,* 3, 41–47.
Guliyev, H.H., Aghayev, Kh.B., Hasanova, G.H. (2016). Determining the Elastic Moduli of the Third Order for Sedimentary Rocks Based on Well-Logging Data. *Izvestiya, Physics of the Solid Earth,* 52(6), 836-843.
Guliyev, H.H., Aghayev, Kh.B., Shirinov, N.M. (2010). The research of the influence of the pressure to the values of elastic parameters of geological medium on the basis of seismic and well data. *Visnyk of Taras Shevchenko National University of Kyiv. Geology,* 50, 10-16.
Li G., Stewart, R. R. (1996). Data processing methods for crosswell seismic imaging. *Seismic Exploration,* 5, 213-228.
Manufacturer of seismic borehole equipment for tomography, crosshole and downhole applications (n. d.). Retrieved from www.crosswellinstruments.de
Moret, G.J.M., Knoll, M.D., Barrash, W. Clement W. P. (2006). Investigating the Stratigraphy of an Alluvial Aquifer Using Crosswell Seismic Traveltime Tomography. *Geophysıcs,* 71, 3. B63-B73. 14 FIGS. 10.1190/1.2195487
Park, C. B., Miller, R.D. Xia, J., Ivanov, J. (2007). Multichannel analysis of surface waves (MASW) – active and passive methods. *Kansas Geological Survey, Lawrence, USA, THE LEADING EDGE JANUARY*, 60-64.
Park, C.S., Lim, J.Y., Choi, C.L., Kong, B.C., Mok, Y.J. (2008). Recent development of borehole seismic tests. *World Conference on Earthquake Engineering, October 12-17, Beijing, China.*
Pratt, R.G., Sirgue L., Hornby B., Wolfe J. (2008). Crosswell waveform tomography in fine-layered sediments. *Meeting the challenges of anisotropy 70th EAGE Conference & Exhibition, 9 - 12 June, Rome, Italy,* 1-5.
Suroso, T., Laksono, H., Triyoso, W., Priyono, A. (2017). Estimating an isotropy parameter by shear wave splitting of crosswell seismic data: a case study on inter-bedded sand-shale layers. *IOP Conf. Series: Earth and Environmental Science. Sci.* 62/ 012019, 1-7. DOI: 10.1088/1755-1315/62/1/012019.
Taeseo, K., Paul, W. (2013). Evaluating the In Situ Lateral_Stress Coefficient (K_o) of Soils via Paired Shear Wave Velocity Modes. *Journal of geotechnical and geoenvironmental engineering,* 775-787. DOI: 10.1061/(ASCE)GT. 1943-5606.0000756.
Thomsen, L. (2002). Understanding Seismic Anisotropy in Exploration and Exploitation. *Distingwished İnstructor Short Course. Distingwished İnstructor Series*, 5, 238.
Tokeshi, K., Harutoonian, P., Leo, C. J., Liyanapathirana S. (2013). Use of surface waves for geotechnical engineering applications in Western Sydney Adv. *Geosci.,* 35, 37–44. DOI: 10.5194/adgeo-35-37-2013
Wadhwa, R.S., Ghosh, N., Chaudhari, M.S., Ch.Subba Rao and Raja Mukhopadhyay (2005). Pre and post-excavation cross-hole seismic and geotomographic studies for a Nuclear Power Project. *J. Ind. Geophys. Union,* 9(2), 137-146.

Reference

Aghayev, KH.B., Amrahov, A.T., Mehralyev, F.E. (2012). Engineering-geophysical reserches by translucence of cross-hole phase method.*Geophysics news in Azerbaijan,* 1–2,17–21.
Aleksandrov, K.S., Prodajvoda, G.T., Maslov, B.P. (2001). Metod opredeleniya nelinejnyh uprugih svojstv gornyh porod. *Dokl. RAN,* 380(1), 109–112.[in Russian]
Aleksandrov, K.S., Prodajvoda, T.G. (2000). Anizotropiya uprugih svojstv mineralov i gornyh porod. Novosibirsk*:* Izdatelstvo SO RAN. [in Russian]
Antipov, V.V., Ofrikhter, V.G. (2016). Modern nondestructive method of researching of geological-engineering section.*PNRPU Bulletin Construction and architecture*, 7, 2, 37–49. DOI: 10.15593/2224-9826/2016.2.04. [in Russian]
Bezrodna, I., Bezrodnyi, D., Holiaka, R. (2016). Mathematical modelling of influence of the mineral composition and porosity on elastic anisotropic parameters of complex sedimentary rocks of Volyn-Podolia area.*Visnyk of Taras Shevchenko National University of Kyiv. Geology,* 73, 27–32.[in Ukrainian]
Boganik, G.N., Gurvich, I.I. (Eds.) (2006). Sejsmorazvedka. Uchebnik dlya vuzov. Tver: Izdatelstvo AIS. [in Russian]
Burger, H. R., Sheehan, A. F., Jones, C. H. (2006). Introduction to Applied Geophysics: Exploring the shallow subsurface W.W. Norton & Co., New York.
Burger, H.R. (1992). Exploration geophysics of the shallow subsurface. United States. Prentice Hall.
Crice, D. (2011). Near-surface, downhole shear-wave surveys: A primer. *The Leading Edge,* 30(2), 164–171.
Dejneko, S., Vizhva, S., Nesterenko, G., Bernevek, A., Ivashenko, S. (2017). Sejsmoakustichnij monitoring stanu gruntiv Dnistrovskogo shilu (u zoni rozmishennya napirno-stacionarnogo vuzla). *Visnyk of Taras Shevchenko National University of Kyiv. Geology,* 78, 30–35. [in Ukrainian]
Dugarov, G.A., Obolenceva, I.R., Chichinina, T.I. (2011). Analiz anizotropii skorostej i poglosheniya sejsmicheskih voln v srede s odnoj sistemoj parallelnyh granic. *Tehnologii sejsmorazvedki,* 3, 29–41. [in Russian]
Garotta, R. (2000). Poperechnye volny: ot registracii do interpretacii. Kratkij kurs lekcij dlya vysshih uchebnyh zavedenij. [in Russian]
Gheslagni, F., Santamarina, J.C. (1998). Data pre-processing in cross-hole geotomography: *Journal of Environmental and Engineering Geophysics,* 3, 41–47.
Guliyev, H.H., Aghayev, Kh.B., Hasanova, G.H. (2016). Determining the Elastic Moduli of the Third Order for Sedimentary Rocks Based on Well-Logging Data. *Izvestiya, Physics of the Solid Earth,* 52(6), 836–843.
Guliyev, H.H., Aghayev, Kh.B., Shirinov, N.M. (2010). The research of the influence of the pressure to the values of elastic parameters of geological medium on the basis of seismic and well data. *Visnyk of Taras Shevchenko National University of Kyiv. Geology,* 50, 10–16.
Karpov, I.A., S.B. Gorshkalyov, S.B., Vishnevskij, D.M. (2014). Dva mehanizma obrazovaniya vzaimno ortogonalno polyarizovannyh poperechnyh voln po dannym VSP. *Materialy Vserossijskoj konferencii, posvyashennoj 100-letiyu so dnya rozhdeniya akademika N.N. Puzyryova, 8–13 dekabrya, Novosibirsk,* 49–54. [in Russian]
Kuliev, G.G. (2000). Opredelenie koefficienta Puassona v napryazhennyh sredah. *Dokl. RAN,* 370(4), 534–537. [in Russian]
Li G., Stewart, R. R. (1996). Data processing methods for crosswell seismic imaging.*Seismic Exploration,* 5, 213–228.
Manufacturer of seismic borehole equipmentfor tomography, crosshole and downhole applications (n. d.). Retrieved from www.crosswellinstruments.de
Maslov, B.P., Prodajvoda, G.T., Vyzhva, S.A. (2000). Matimatichne modelirovaniya vplivu tisku i u trishinuvatih girskih porodah. *Geophys. journal*, 22, 113–118. [in Ukrainian]
Moret, G.J.M., Knoll, M.D., Barrash, W. Clement W. P. (2006). Investigating the Stratigraphy of an Alluvial Aquifer Using Crosswell Seismic Traveltime Tomography. *Geophysıcs,* 71, 3, B63-B73. 14 FIGS.10.1190/1.2195487
Oshkin, A.N. Ermakov, R.Yu. Ragozin, N.A. Ignatev, V.I. (2016). Mezhskvazhinnoe sejsmicheskoe prosvechivanie – opyt, metodologiya, apparatura. *Pribory i sistemy razvedochnoj geofiziki*, 3, 37–47. [in Russian]
Park, C. B., Miller, R.D. Xia, J., Ivanov, J. (2007). Multichannel analysis of surface waves (MASW) – active and passive methods. *Kansas Geological Survey, Lawrence, USA, THELEADINGEDGEJANUARY*, 60-64.
Park, C.S., Lim, J.Y., Choi, C.L., Kong, B.C., Mok, Y.J. (2008). Recent development of borehole seismic tests.*World Conference on Earthquake Engineering, October 12–17, Beijing, China.*
Pratt, R.G., Sirgue L., Hornby B., Wolfe J. (2008). Crosswell waveform tomography in fine-layered sediments.*Meeting the challenges of anisotropy 70th EAGE Conference & Exhibition, 9–12 June, Rome, Italy,*1–5.
Puzyrev, N.N., Trigubov, A.V., Brodov L.Yu. et al. (1985). Sejsmicheskaya razvedka metodom poperechnyh i obmennyh voln. M.: Nedra. [in Russian]
Suroso, T., Laksono, H., Triyoso, W., Priyono, A. (2017). Estimating anisotropy parameter by shear wave splitting of crosswell seismic data: a case study on inter-bedded sand-shale layers. *IOP Conf. Series: Earth and Environmental Science. Sci. 62/ 012019, 1–7.*DOI: 10.1088/1755-1315/62/1/012019.
Taeseo, K., Paul, W. (2013). Evaluating the In Situ Lateral_Stress Coefficient (K_o) of Soils via Paired Shear Wave Velocity Modes. *Journal of*

geotechnical and geoenvironmental engineering, 775-787.DOI: 10.1061/(ASCE)GT. 1943-5606.0000756.
Thomsen, L. (2002). Understanding Seismic Anisotropy in Exploration and Exploitation. *Distingwished İnstructor Short Course. Distingwished İnstructor Series*, 5,238.
Tokeshi, K., Harutoonian, P., Leo, C.J., Liyanapathirana S. (2013). Use of surface waves for geotechnical engineering applications in Western Sydney Adv. *Geosci.,* 35, 37–44. DOI: 10.5194/adgeo-35-37-2013
Vyzhva, S.A., Maslov, B.P., Prodajvoda, G.T. (2005). Effektivnye uprugie svojstva nelinejnyh mnogokomponentnyh geologicheskih sred. *Geophys. Journal,* 27(6), 1012–1022. [in Russian]
Wadhwa, R.S., Ghosh, N., Chaudhari, M.S., Ch.Subba Rao and Raja Mukhopadhyay (2005). Pre and post-excavation cross-hole seismic and geotomographic studies for a Nuclear Power Project. *J. Ind. Geophys. Union,* 9(2), 137–146.
Yasnickij, A.A., Kolodij, A.A., Shabarin, V.N. (2012). Sravnenie effektivnosti primeneniya metoda MASW c tradicionnymi metodami sejsmorazvedki dlya celej inzhenernyh izyskanij. *8-ya mezhdunarodnaya konferenciya i vystavka – Inzhenernaya geofizika, 23–27 aprelya, Gelendzhik, Rossiya,* 1–5. [in Russian]

Надійшла до редколегії 17.12.18

Г. Кулієв[1], д-р фіз.-мат. наук, проф., акад. НАНА
Керівник відділу "Тектонофізика і геомеханіка"
E-mail: hatamguliyev@gmail.com, тел.: +994 12 5105617;
Х. Агаєв[1], канд. геол.-мінералог. наук
Пров. наук. співроб. відділу "Тектонофізика і геомеханіка"
E-mail: khagayev@yahoo.com, тел.: +994 12 5105617;
Ф. Мехралієв[2], директор GeoGlobe Ltd
E-mail: fuadmehrali@yahoo.com, тел.: +994 12 4977421;
Е. Ахмедова[1], мол. наук. співроб. відділу "Тектонофізіка і геомеханіка"
E-mail: ella_ezizova@mail.ru, тел.: +994 12 5105617
[1]Інститут геології і геофізики НАНА,
пр. Г. Джавіда, 119, Баку, AZ1143, Азербайджан
[2]GeoGlobe Ltd, вул. М. Мухтарова, 9, Баку, AZ1001, Азербайджан

ДО ПРОБЛЕМИ ВИЗНАЧЕННЯ ФІЗИЧНИХ ВЛАСТИВОСТЕЙ СКЛАДНО ПОБУДОВАНИХ СЕРЕДОВИЩ З ВИКОРИСТАННЯМ МЕТОДУ NEAER-SURFASE CROSWELL

***Мета.** Вивчення акустичних, пружних і анізотропних властивостей верхньої частини розрізу складнопобудованих геологічних середовищ.*
***Методика.** На ділянках будівельних об'єктів, розташованих у різних сейсмогеологічних умовах, проведено сейсмічні спостереження в неглибоких свердловинах методом NSCW – near-surface cross well testing. Опрацьовано польові сейсмічні записи. Визначено кінематичні та динамічні параметри поздовжньої й різнополяризованих поперечних хвиль. Побудовано та проінтерпретовано тонкошаруваті одновимірні моделі фізичних властивостей середовища на основі нелінійної теорії еластодинаміки.*
***Результати.** Визначено, що навколишнє середовище з високопористими, водонасиченими породами і аномально високим пластовим тиском має аномально низьке значення швидкостей і градієнта збільшення їх з глибиною. При повторному вивченні цього середовища, після побудови там глибоких паль отримано завищені значення сейсмічних швидкостей, що пояснюється зменшенням у розрізі аномально високого пластового тиску і, відповідно, пористості порід після монтажу паль. При збільшенні пустотності в ненасичених галькових породах, при розрахунках за стандартною методикою отримано від'ємне значення коефіцієнта Пуассона. При вивченні швидкостей поперечних хвиль виявлена сейсмічна анізотропія, що пов'язана з напрямком упаковки зерен порід. Зміна властивостей порід з глибиною має більш тісний зв'язок із частотами хвиль, ніж з їхніми амплітудами.*
***Наукова новизна.** Визначено модулі пружності 3-го порядку, які більш чутливі до мінливості нелінійних пружних властивостей порід середовища, ніж модулі 2-го порядку. Значення коефіцієнта Пуассона для одних і тих самих порід, що перебувають у різних умовах гірського тиску, перераховані для умов заданого тиску на основі некласичної теорії деформацій.*
***Практична значимість.** Отримані результати можуть застосовуватися для дослідження середовищ, що характеризуються складними сейсмогеологічними гідродинамічними умовами і представлені глинисто-піщаними породами високої пористості та водонасичення.*
***Ключові слова:** приповерхнева свердловина, тиск, поперечна хвиля, сейсмічна швидкість, модуль пружності, анізотропія, насичення, поглинання.*

Г. Кулиев[1], д-р физ.-мат. наук, проф., акад. НАНА
Рук. отдела "Тектонофизика и геомеханика"
E-mail: hatamguliyev@gmail.com, тел.: +994 12 5105617;
Х. Агаев[1], канд. геол.-минералог. наук
Ведущ. науч. сотр. отдела "Тектонофизика и геомеханика"
E-mail: khagayev@yahoo.com, тел.: +994 12 5105617;
Ф. Мехралиев[2], директор GeoGlobeLtd
E-mail: fuadmehrali@yahoo.com, тел.: +994 12 4977421;
Э. Ахмедова[1], мл. науч. сотр. отдела "Тектонофизика и геомеханика",
E-mail: ella_ezizova@mail.ru, тел.: +994 12 5105617
[1]Институт геологии и геофизики НАНА,
пр. Г. Джавида, 119, Баку, AZ1143, Азербайджан
[2]GeoGlobeLtd, ул. М. Мухтарова, 9, Баку, AZ1001, Азербайджан

К ПРОБЛЕМЕ ОПРЕДЕЛЕНИЯ ФИЗИЧЕСКИХ СВОЙСТВ СЛОЖНОПОСТРОЕННЫХ СРЕД С ПРИМЕНЕНИЕМ МЕТОДА NEAER-SURFASE CROSWELL

***Цель.** Изучение акустических, упругих и анизотропных свойств верхней части разреза сложнопостроенных геологических сред.*
***Методика.** На участках строительных объектов, расположенных в различных сейсмогеологических условиях, проведены сейсмические наблюдения в неглубоких скважинах методом NSCW – near-surface cross well testing. Обработаны полевые сейсмические записи. Определены кинематические и динамические параметры продольной и разнополяризованных поперечных волн. Построены и проинтерпретированы тонкослоистые одномерные модели физических свойств среды на основе нелинейной теории эластодинамики.*
***Результаты.** Определено, что среда с высокопористыми, водонасыщенными породами и аномально высоким пластовым давлением имеет аномально низкое значение скоростей и градиента увеличения их с глубиной. При повторном изучении этой среды, после построения там глубоких свай получены завышенные значения сейсмических скоростей, что объясняется уменьшением в разрезе аномально высокого пластового давления и, соответственно, пористости пород после монтажа свай. При увеличении пустотности в ненасыщенных галечных породах, при расчётах по стандартной методике получено отрицательное значение коэффициента Пуассона. При изучении скоростей поперечных волн выявлена сейсмическая анизотропия, связанная с направлением упаковки зёрен пород. Изменение свойств пород с глубиной имеет более тесную связь с частотами волн, чем с их амплитудами.*
***Научная новизна.** Определены модули упругости 3-го порядка, которые более чувствительны к изменчивости нелинейных упругих свойств пород среды, чем модули 2-го порядка. Значения коэффициента Пуассона для одних и тех же пород, находящихся в разных условиях горного давления, пересчитаны для условий заданного давления на основе неклассической теории деформации.*
***Практическая значимость.** Полученные результаты могут применятся для исследования сред, характеризующихся сложными сейсмогеологическими гидродинамическими условиями и представленными глинисто-песчаными породами высокой пористости и водонасыщения.*
***Ключевые слова:** приповерхностная скважина, давление, поперечная волна, сейсмическая скорость, модуль упругости, анизотропия, насыщение, поглощение.*