Права колонка є графічним зображенням імовірності розподілу гірських порід за характером насичення (нагадуємо, на початковому етапі підготовки даних було проведено осереднення геофізичних параметрів з кроком 0,4 м глибини). Як бачимо в інтервалах глибин, розкритих перфорацією, характеристика порід розрізу за даними дискримінантного аналізу відповідає результатам випробувань. Розподіл імовірності віднесення порід до відповідних груп за характером насичення виконаний формально, тому в деяких інтервалах з'явились досить високі значення. Імовірність наявності газонасичених порід на рівні 0,98 – 0,99 свідчить про те, що ознаки таких порід досить близькі до статистичних характеристик центру відповідної еталонної групи. Слід підкреслити, що розраховані і представлені на рис.4 є власно імовірнісними характеристиками подібності до центів певних класів багатомірних розподілів за обраним комплексом геофізичних ознак. Ці імовірнісні характеристики певною мірою є відображенням характеру насичення порід, але їх не можна порівнювати або ототожнювати з коефіцієнтом нафтогазонасичення. У певних інтервалах за переважаючими ймовірностями однієї групи з'являються ознаки іншої. Це можна розглядати як прояв декількох чинників, у тому числі обмеженої вхідної геофізичної інформації, спрощеної лінійної моделі дискримінантної функції, дуже складної структури реальної фізико-геологічної моделі розрізу і т.д. У такому випадку слід враховувати лише основну складову імовірності характеру насичення порід.

У межах інтервалів перфорації навіть за однозначних результатів випробувань знаходяться різні групи порід з різними колекторськими властивостями. Тому вибірки в еталонних групах не можна вважати однорідними. Це призводить до певного зменшення ефективності класифікації під час дискримінантного аналізу.

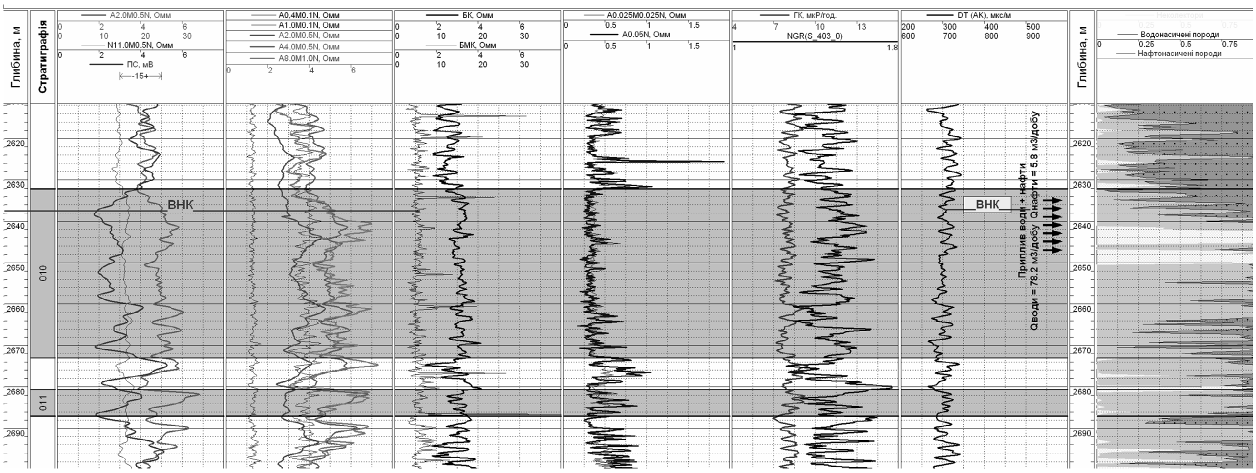

Рис. 5. Фрагмент розрізу свердловини родовища Субботіна

Висновок. Можна вважати, що за невеликої кількості методів промислово-геофізичних досліджень, у разі відсутності необхідної інформації для проведення якісної інтерпретації даних ГДС, використання альтернативного способу дискримінантного аналізу, як методу виявлення продуктивних порід-колекторів, є доцільним. Метод може бути ефективно застосовано на відкритих родовищах вуглеводнів у процесі пошуків раніше невиявлених продуктивних пластів у складних типах розрізів, наприклад, відкладах майкопу. Для його використання потрібна наявність двох обов'язкових умов: каротажних даних, записаних у цифровій формі, та достатня кількість інтервалів випробувань з отриманими припливами різних флюїдів (нафта або газ і пластова вода) та з відсутністю дебітів останніх для створення еталонних груп.

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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

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

The questions on definition of fundamental elastic parameters on the basis of non-classic base model including the development of the software for preparation of 2D thin layered models of real environment and also the calculation of the sections of elastic parameters of the environment are considered.

Розглянуто питання по визначенню фундаментальних пружних параметрів на основі некласичної базової моделі, що включає розробку програмного забезпечення для підготовки двохвимірних тонкошарових моделей реального середовища, а також розрахунки розрізів пружних параметрів середовища.

Introduction. The modern state of techniques, technologies of the field and well geophysical investigations allow to record data regarding the medium with high accuracy. More productive computers and effective softwares provide the operative and enhanced processing and interpretation of the derived information. All these allow solving more complex and earlier inaccessible tasks on the geological medium study. One of these tasks is the study the changes of physical-mechanical properties of the medium occurring in process of oil and gas fields operation. With this purpose approximately every 5-7 years the monitoring of fields is performed with application of 4D seismic method of investigations. Studying the changes of amplitudes, velocities of propagation of compressional, shear waves in medium layers according to results of seismic inversions, the change of medium properties occurring in monitoring period is defined at every measure. In offshore fields the monitoring is also performed in the section upper part with purpose to identify the safety evaluation of the drilling platform position.

At the seismic inversion with set models, performed with utilization of seismic survey and geophysical well logging (GWL) data, there define 2D or 3D thin-layer models of medium on the velocities of compressional (V_p), shear (V_s) waves and rocks density (ρ). Using the above-mentioned, there calculate different parameters of medium, including elasticity coefficients [15]. Interpreting these data, within the studied area they forecast the physical-mechanical, lithological, properties, oil-and-gas saturation of rocks, abnormally high formation pressures (AHFP) and other properties of medium.

It is known that physical-mechanical properties of rocks vary at medium pressure and temperature change. Usually in practice in seismic survey the different empirical dependences of velocities upon the pressure $V = f(P)$ and temperature $V = f(T)$ are applied to take into account the pressure influence upon the seismic waves' propagation velocity, and upon the medium elastic parameters accordingly. These empirical dependences are determined by results of summarization of GWL data on various studied areas as well as on data of cores laboratory tests. But these dependences, under the complex media, don't often provide the necessary precision of velocities definition on the specific object of study. Even within one area, when the dependence is determined on one well, the application of $V = f(P)$ in areas, remote from well, can bring to significant errors in velocities due to change of geological structure and geodynamic state of the medium. But the data on laboratory tests are corresponded to real geophysical data in different ways, because the technique of measurement and rocks samples are not quite identical to thermodynamic conditions in real medium. All these bring to great error of forecast by values of elasticity parameters of the medium lithological characteristics and its oil-and-gas saturation, especially for complex media and zones with AHFP.

When investigating the complex media, on the assumption of insignificant change of lithological composition of the layers rocks in lateral, the values V_P, V_S and their ratios can differ greatly in various areas of field due to difference in geodynamic conditions. Thus the values of elasticity coefficients, calculated using the dynamic method, including the Poisson coefficient, will be different in area on one and the same layers. The similar will be also observed in case when lithologically very similar layers are in different geodynamic conditions in geological section. Thus, it is necessary to take into account the pressure effect for correct definition of the rocks lithological composition by elastic parameters' values before their calculation. For this purpose, the values of elastic parameters of medium, determined by results of seismic inversion or by GWL data should be normalized proceeding from conditions as the pressure has a constant value along the whole geologic section. Only in this case the difference of elastic parameters will be specified with difference of layers lithology. This allows to interpret unambiguously the results of inversion on definition the medium properties. Proceeding from non-classic linearized theory in [11] there had been developed an approach to define the Poisson coefficient for stressed non-linear media.

Theoretical preconditions for the elastic parameters determination. It is known that stressed state of the geological medium is determined by weight of overlying rocks, influence of tectonic processes, formation pressure, mechanical and structural properties of the sedimentary rocks and other factors. In complex media the ratio of ground pressure in vertical and horizontal directions can reach different values depending on geological structure, geodynamic conditions of the studied region of works. At definite thermobaric conditions the sedimentary rocks are characterized by higher porosity and poor compactness that the root rocks. In this connection, even the insignificant change of the medium geodynamic state can influence noticeably upon the physical-mechanical properties of these rocks.

It is known that we deal with deformed medium when performing GWL and seismic survey. It is mean that due to objective natural circumstances the studied media are prestressed before excitation of seismic waves in them. Study of dynamic, kinematic and polarization parameters of the compressional, shear and converted waves shows that the medium intensity and deformation nonlinearity play a significant role when forming the seismic wave field.

There are numerous investigations to define the elastic parameters; they are partially reflected in [1, 2, 4 – 7, 9, 13 – 18]. Basically the theoretical results had been derived on the base of linear theories of elasticity and propagation of elastic waves in undeformed elastic media.

Theory of wave dynamics accounting the medium preliminary intensity within the mechanics of continuous medium had been created in [9]. The same paper includes an extensive list of scientific publications of various experts in the present field. In papers [2, 11, 10, 13, 17], proceeding from theoretical results [9] there had been developed the practical approaches to study the different geologic-geodynamic tasks. In [8, 10 – 12] these approaches when research the issues related with seismic survey, are classified as non-classic theoretical base model.

Results of theoretical investigations, non-classic theoretical base model show that when defining the fundamental parameters of the stressed media elasticity it is possible to take into account the changes of its stressed state. In other words, to define the values of the physical-mechanical properties of rocks composing the geological section. The design formulae had been proposed to determine the basic physical-mechanical parameters of the geological medium – Poisson coefficient (ν) and Young modulus of elasticity (E):

$$\nu = \frac{V_{pzp}^2 - 2V_{sxp}^2 - F(\rho, V_{pz0}, V_{sx0}, P)}{2[V_{pzp}^2 - V_{sxp}^2 - F_1(\rho, V_{pz0}, V_{sx0}, P)]};$$

$$E = 2(1+\nu)[\rho V_{sxp}^2 - F_S^R(\rho, V_{pz0}, V_{sx0}, P)],$$

where: V_{pzp}, V_{sxp} – current values of the compressional and shear waves' velocities; V_{pz0}, V_{sx0} – values of these parameters in stress-free state; ρ – rocks densities; P – pressure; F, F_1 and F_S^R – known algebraic expressions characterizing the nonlinear actions of medium, the look of which is concretized with setting of look of the elastic potentials.

For different stressed states of medium (before excitation of seismic waves in it) and the variants of modeling of elastic oscillations shapes, the formulae of F, F_1 and F_S^R calculation differ [8]. In the classic approach $F \equiv F_1 = F_S^R = 0$. In the present work the calculations were performed by theories of the greater and second variant of small initial deformations [16] using the true velocities. Results show that at known values F, F_1 and F_S^R one can calculate accurately the values of Poisson coefficient and Young modulus for the set parameter of pressure [11]. Application of these formulae allows to describe analytically the dependence of values of elastic parameters upon the pressure for one and the same rocks. In its turn it allows to calculate the true values of the medium elastic parameters for fixed values of pressure. Thus, there is a possibility to recalculate the elastic parameters of the studied medium for conditions in which the stressed state is constant in lateral and vertical.

Software. In the present work, proceeding from the above-mentioned theoretical developments, the algorithm of seismic information processing had been created within the non-classic linearized base model. This algorithm allows calculating the true values of the fundamental parameters of the medium elasticity on the base of real seismic and well data.

The programs had been developed on the created algorithms and different calculations had been performed on the base of geophysical program package (CWP) of Denver University (Colorado School of mines). It operates in Linux and can be used at the personal computers and the work stations as well. The package has good technological capabilities to compile the graph of seismic data processing, extensive set of standard procedures as well as accessible software tools to supplement the package with new programs.

Using the program package CWP we had compile the software (GEOPRESS) to model the physical parameters of the medium. The following possibilities to set and use the data on the medium models are provided in GEOPRESS:

- models of the medium physical parameters are set with regular or irregular step on vertical and lateral;
- the models' discreteness, on which the medium parameters are determined, is equal to sample interval of the seismic records in vertical, and in lateral – to the observation step at seismic works;
- models of the medium physical parameters or any other data can be in depth or in time measurements, and there is a possibility for their recalculation from one unit to another;
- possibility to generate or correct the models on various analytical and graphic dependences;
- possibility of easy exchange of data and results of other geophysical softwares.

The software operates the data of seismic survey, GWL and results of laboratory measures on rocks' samples. These data are used in preparation of 2D models of medium as the time or depth sections, on which different procedures of modeling are performed. Some standard procedures, realized by new programs, differ from standard ones that they allow creating and operating with data on medium parameters with minimal discreteness, equal to sample interval of the seismic data. The developed programs also allow performing different transformations with data on the media models. The basic part of the programs provides the extrapolation of model of he medium physical parameters, determined by GWL data, in borehole environment taking into account the medium geological structure, to correct the model due to geodynamic and thermodynamic state of medium, to calculate the different elastic parameters of medium within the classic and non-classic theory of deformations, recalculate the elastic parameters for various stressed states of medium, to calculate the attributes of seismic records as well as the synthetic records. The application of CWP package together with GEOPRESS allows the processing of real 2D seismic data, to determine the models of physical-mechanical properties of medium, to perform the modeling of seismic records.

Processing flow had been prepared, where the following programs are indicated: "suwind" program to download 2D models of medium on different physical-mechanical parameters, "suweight" program to multiply the model by the set coefficient, "time_depth_time" program to recalculate the section from time into depth scale, "elastic_stress" the basic program to calculate the elastic parameters by non-classic theory, "compare_model" program of the quantitative comparison of models' sections and "suximage" program to visualize the models' sections and the elastic parameters.

Geologic structure of the studied medium. To evaluate the effectiveness of GEOPRESS application there had been used the geophysical data on one of the structures of the South Caspian Depression (SCD). It is known that SCD has a complex geological structure and is rich with oil and gas fields. There are numerous extinct and acting mud volcanoes. The structural buildings mainly have the diapiric form that is characterized by steep angles of dip, numerous amplitude dislocations [3]. Difference of depths of the arch and synclinal parts of folds can reach to 2 km approximately. Here the terrigenous section is basically consists of alternation of the thin-layer strata of clays, siltstones, sands and rare sandstone. Here the abnormally high formation pressure is a usual phenomenon. Pressure on individual layers is some tens percentages higher than in the surrounding ones. At depths 5-6 km the pressure and temperature reach approximately to 0.09-0.12 GPa (900-1200 atm.) and 100^0-130^0C accordingly. Effectiveness of study of the geological structure and physical-mechanical properties of such a complex medium using the geophysical methods along with other factors, also depends significantly upon the accounting of influence of the medium geodynamic state.

Modeling to define the elastic parameters of the medium. The acoustic and geodynamic models of the studied medium in the South Caspian depression had been prepared by data of geophysical investigations. Using the data of acoustic logging on the compressional and shear waves and density logging data on deep wells, located in the arch part of the structure, the thin-layer 1D models of media had been created on the velocities of the compressional and shear waves, rocks densities and hydrostatic pressure (Fig.1). Then 2D models were calculated by extrapolation of 1D models along the seismic horizons for the rest common depth points (CDP) of 2D profile, running near the deep well which locates approximately on point CDP=701 of the profile. Taking into account the configuration of seismic horizons and distribution of rocks density in depths and profiles, there had been also calculated the 2D model of geostatic pressure. 2D model of hydrostatic pressure was corrected taking into account the change of geostatic pressure in depth and along the seismic profile. 2D models were calculated as time and depth sections, like the usual sections of the seismic profiles. On models shown in figure 2 it is seen that in sections of formation velocities of the compressional and shear waves the values of V_p and V_s increase for one and the same layers as far as they get deeper, that is caused by pressure increase with depth. Model of hydrostatic pressure had been prepared (Fig. 3a). Section of pressure difference along the strata between the points, where the deep well locates, and the current points of profile is in figure 3b. It is seen that the difference in pressure along the layers of the same name increases as far as moving off the well.

The depth sections of Poisson coefficient had been calculated by 2D models using classic (Fig. 4a) and non-classic theories: – by the first theory of small initial deformations (Fig. 4b). In addition it was supposed that the stress in medium is distributed evenly in the vertical and horizontal directions. When comparing the results it is seen that unlike the figure 4a, on figure 4b the values of elastic parameter on one and the same layer doesn't change along the profile. It means that the pressure difference between the well and current point of profile had been taken into account correctly. Thus, in the given example the elastic parameters are recalculated for conditions when in each layer the well-pressure is constant along the whole profile. The comparison of ν values had showed that by non-classic formula its value turns out lesser than by the classic one. Difference of two sections of Poisson coefficient is in figure 5a. From this it follows that on one and the same layers the difference reaches its maximal value between the arch and synclinal parts of the structure, where the difference of hydrostatic pressure also reaches the maximal value (Fig. 3b). In individual layers the difference reaches to 8 %. The section of Poisson coefficient difference, calculated by the second variant of theory of small initial deformations, is given in figure 5b. Here the difference in greater than by the theory of great initial deformations. By the second variant of small initial deformations the maximal value of difference reaches to 12 %, but the number of layers with great values of difference are more than by the theory of great initial deformations. The depth section of Young module had been also calculated by these models. Here, its values by classic theory 2-4 % lesser than by non-classic one.

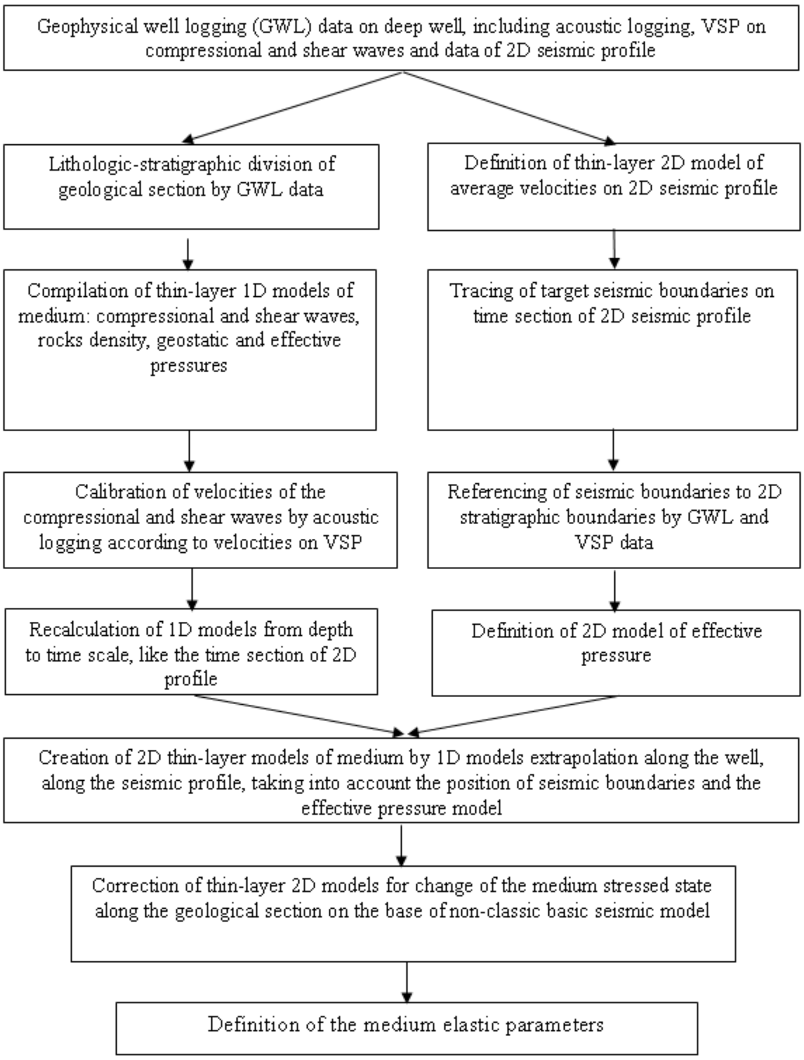

Fig. 1. Block diagram of 2D model of medium by fundamental parameters of elasticity

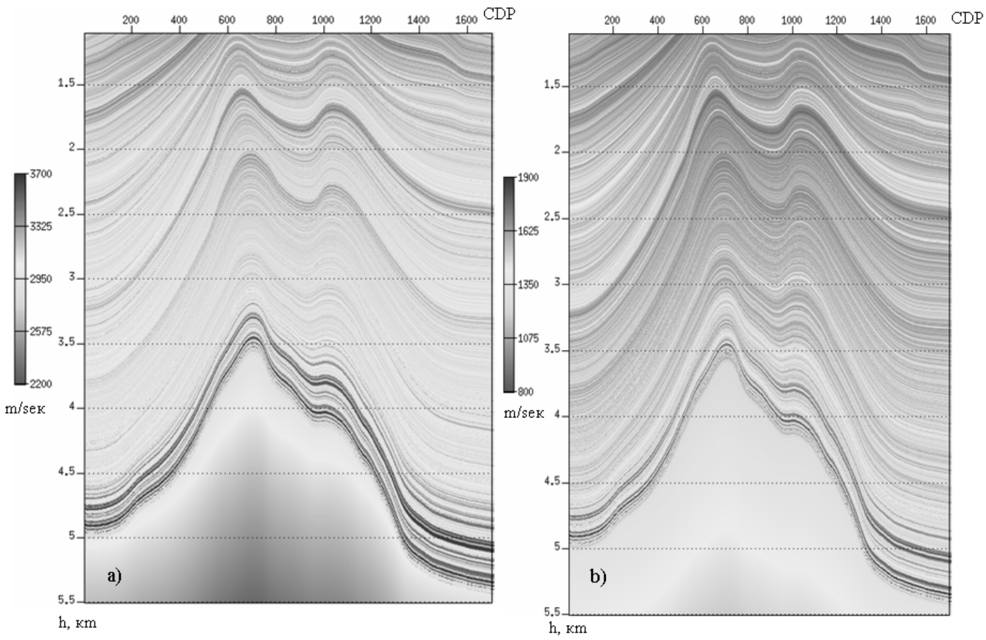

Fig. 2. Depth sections by formation velocities of the compressional (a) and shear (b) waves

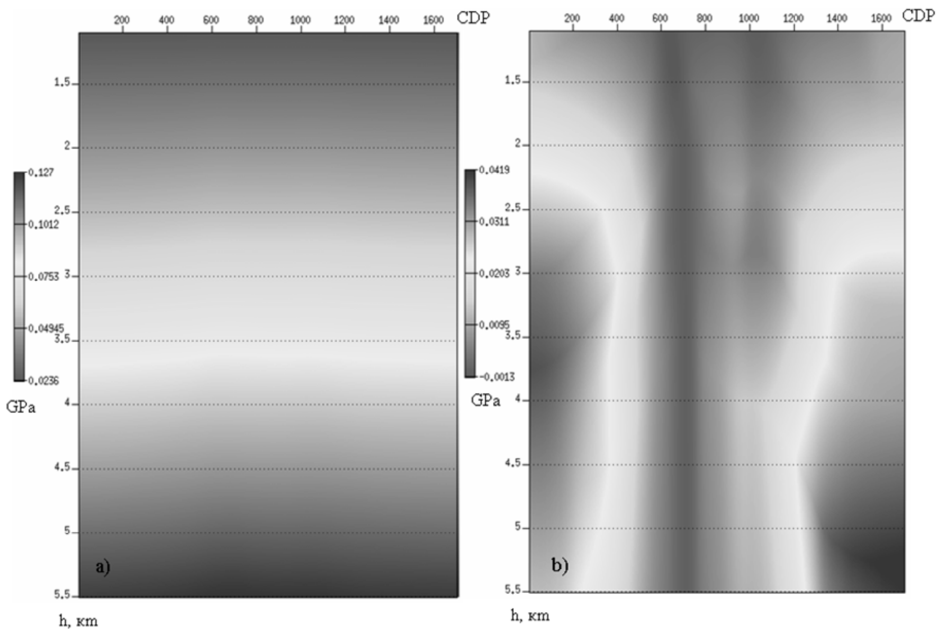

Fig. 3. Depth sections of the hydrostatic pressure (a) and difference of pressure along the layers between points where the well is, and the profile current point (b)

Results, derived with application of theory of great initial deformations, theoretically are the most accurate, so they should be accepted as basic ones. It is seen that results of improvement by this theory are nearly 2 times differ from the results of theory of small initial deformation, though the last theory also reflects correctly (qualitatively) the nature of pressure effect upon the numerical values of fundamental elastic parameters of the medium.

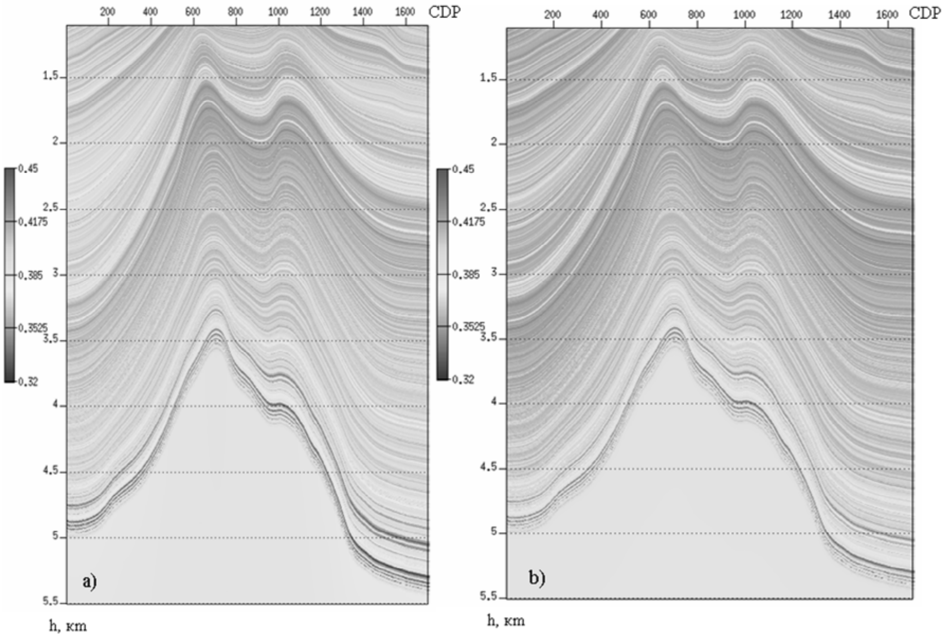

Fig. 4. Depth section of Poisson coefficient calculated by classic (a) and non-classic theories (b)

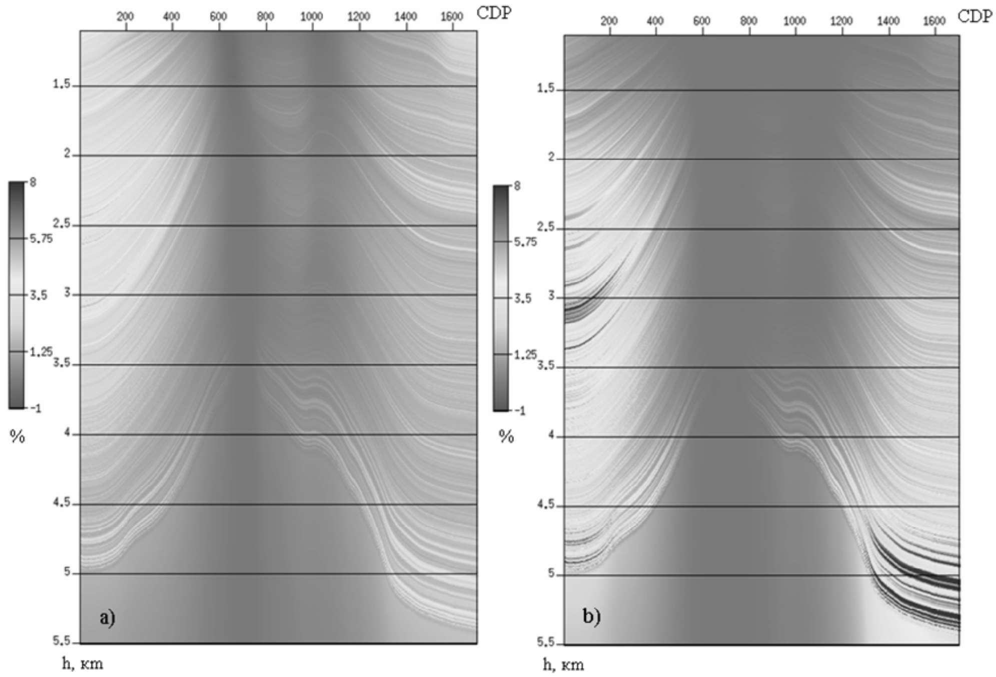

Fig. 5. Difference of sections of the Poisson coefficient calculated by classic and non-classic theories: by theory of great initial deformations (a) and the second variant of theory of small initial deformations (b)

As an example there had been derived results on calculation of elastic parameters for thick layer mainly consisting of siltstone rocks. The data are as follows:

$$P = 0.0 \text{ GPa}, \quad V_{pz0} = 2.529 \text{ km/s}, \quad V_{sx0} = 0.909 \text{ km/s}, \quad V_{sy0} = 0.982 \text{ km/s}, \quad \rho = 2.34 \text{ g/cm}^3,$$

$$P = 0.05 \text{ GPa}, \quad V_{pzp} = 2.847 \text{ km/s}, \quad V_{sxp} = 1.099 \text{ km/s}, \quad V_{syp} = 1.187 \text{ km/s}, \quad \rho = 2.34 \text{ g/cm}^3,$$

Outputs are as follows:

$$\nu_{кл} = 0.41245,\ \nu_{некл} = 0.42582,\ E_{кл} = 7.3 \text{ GPa},\ E_{некл} = 4.8 \text{ GPa},$$

$$a = 253 \text{ GPa},\ b = -4065 \text{ GPa},\ c = 11432 \text{ GPa},$$

where: $\nu_{кл}$, $\nu_{некл}$, $E_{кл}$ and $E_{некл}$ – Poisson coefficient and Young modulus calculated by classic and non-classic methods; a, b and c – moduluses of elasticity of the 3rd order.

Discussion. The derived results on application of new theoretical developments on continuous media mechanics and the appropriate software open quite new possibilities when seismic investigations, in particular:

- definition of true (free of pressure influence) values of the medium elastic parameters;
- compilation of more reliable pattern of change of the physical-mechanical properties of rocks on geological

section, where the influence of pressure differences is excluded;

- forecast of the medium stressed state on values of elastic parameters calculated according to geophysical data.

Conclusions. Thus, new theoretical investigations and software had allowed to create new possibilities to interpret the seismic information taking into account the geodynamic conditions of medium, and to get new results on synthetic 2D models of medium. For further assessment of effectiveness of the software the acoustic model of medium is preparing according to results of inversion of the real seismic records.

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ВИЗНАЧЕННЯ РІВНЯ СЕЙСМІЧНОЇ НЕБЕЗПЕКИ БУДІВЕЛЬНОГО МАЙДАНЧИКА НСК "ОЛІМПІЙСЬКИЙ" В М. КИЄВІ

(Рекомендовано членом редакційної колегії д-ром геол. наук, проф. С.А. Вижвою)

Інститутом геофізики ім. С.І. Субботіна НАН України проведені вишукувальні роботи з встановлення рівня сейсмічної небезпеки (уточненого значення сейсмічної бальності, з урахуванням впливу ґрунтових умов) майданчика НСК "Олімпійський" у м. Києві. На території майданчика виділено три відносно однорідні (в сейсмічному відношенні) таксонометричні одиниці. Для кожної з них було встановлено рівень сейсмічної небезпеки в балах шкали сейсмічної інтенсивності MSK-64.

The research work by establishment of seismic hazard level (the improved value of seismic intensity taking into account the influencing of soil conditions) for National Sports Complex "Olimpiyskiy" site in Kyiv is conducted by S.I. Subbotin Institute of geophysics of the National Academy of Sciences of Ukraine. Three relatively homogeneous (in the seismic relation) taxonomic units on the territory of site are selected. The level of seismic safety in the balls of MSK-64 seismic intensity scale was set for each of this taxonomic units.

Інститутом геофізики ім. С.І. Субботіна НАН України проводилися роботи з встановлення рівня сейсмічної небезпеки (уточненого значення сейсмічної бальності, з урахуванням впливу ґрунтових умов) будівельного майданчика НСК "Олімпійський" в м.Києві.

Мета робіт – кількісна оцінка розрахункової інтенсивності сейсмічних струшувань в балах шкали MSK-64 на основі комплексного аналізу уточнених даних загального сейсмічного районування (ЗСР) і робіт з сейсмічного мікрорайонування (СМР) будівельного майданчика методами: інженерно-геологічних аналогій, сейсмічних жорсткостей і реєстрації мікросейсм.

Майданчик НСК "Олімпійський" розташований на території Печерського району м. Києва, біля підніжжя Черепанової гори, в місці зчленування Хрещатого яру з долиною річки Либідь. З результатів аналізу фондових і опублікованих матеріалів [1, 2] відомо, що на території м. Києва неодноразово спостерігалися сейсмічні струшування від потужних підкорових землетрусів зони Вранча (Румунія) і можуть проявитися локальні сейсмічні ефекти від потенційно можливих землетрусів з місцевих сейсмоактивних зон [3 – 9], які пов'язані з сейсмоактивними розломами Східноєвропейської платформи (СЄП). Вогнища потужних підкорових землетрусів зони Вранча розташовані на відстані 600 км від Києва [10 – 12].

При руйнівних землетрусах в зоні Вранча, магнітуда (*M*) яких знаходилася в межах значень 6,8–7,4, інтенсивність сейсмічних струшувань в балах шкали MSK-64 в м. Києві складала 5-6 балів (26.10.1802, *M*=7,4), 5 балів (17.11.1821, *M*=6,7; 6.11.1908, *M*=6,8; 10.11.1940, *M*=7,3) та 4-5 балів (22.01.1838, *M*=6,9; 22.10.1940, *M*=6,2) [13-15]. Під час землетрусів, які спостерігалися в Києві наприкінці 20 століття інтенсивність струшувань дорівнювала 4-5 балам (4.03.1977, *M*=7,2) та 4 балам (30.08.1986, *M*=6,8) [11, 15, 16].

Лише за останні 200 років зафіксована на території м. Києва інтенсивність землетрусів зони Вранча досягала 5 балів у 1802 році і 5 балів у 1940 році [12, 13, 17]. На рис. 1 представлені ізосейсти цих землетрусів. Слід зазначити, що енергія всіх зазначених вище землетрусів була значно меншою від максимально можливої для зони Вранча (з імовірністю 1 раз в 5000 років) [18 – 20].