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STUDY OF STRESS-STRAIN STATE AND WAVE FIELDS CONCERNING THE WATERFLOW OBJECTS SHORES STRUCTURE

Keywords: stress-strain state, wave field, waterflow objects

Abstract

In the study concerning waterflow objects it is taken into account the state and behavior of the state of the upper crust structures of the Earth in the vicinity of the banks of the rivers, lakes, other near water objects. The state of those objects is investigated in the connection with waterflow situations connected with strengthening of the rivers banks with concrete confirmation and also with the state of the bottom base of waterflow objects and obtaining geophysical parameters of the vicinity upper crust.

INTRODUCTION

In various studies concerning waterflow objects it is necessary to take into account the state and behavior of the state of the upper crust structures of the Earth in the vicinity of the banks of the rivers, lakes, other near water objects. The state of those objects it is also absolutely necessary to know in the connection with waterflow situations connected with strengthening of the rivers banks with concrete confirmation and also with the state of the bottom of waterflow objects

In this relationship one of important problems in the design and construction of bridges, viaducts, tunnels for various purposes is forecasting ecological and geophysical character of the mechanical conditions of the adjacent massif in order to determine the stability and durability of waterflow type becomes clear. Stress-strain state of soils and bridge structures is determined by geometrical properties with different deformation characteristics, distribution and characteristics of peak values of stress and strain in investigated structures.

On the basis of stress-strain state of these type structures affect the strength of soil, depth of layering of the foundations of structures, processes of soil freezing and melting, the supplies of the groundwater level and more is studied.

PROBLEM OF STUDY SHORES WATER OBJECTS

At present time the situation of waterflow structures state prediction based on numerical experiments utilizing the finite element method (FEM) is used [1,2]. In this paper the methodology of mathematical modeling, designed to solve the problem is elaborated. It should match the character of the stressed state of the soil surrounding the object array, the specific of construction and its displacement and vibration behavior.

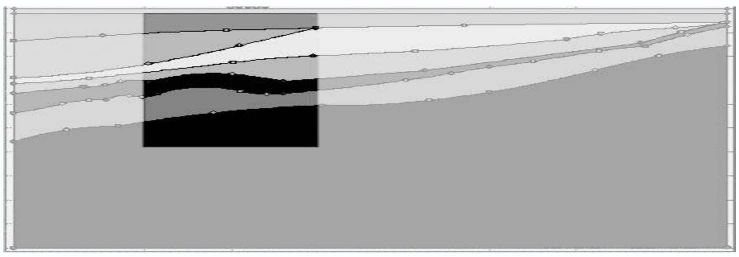

Fig.1. Model of the inhomogeneous half-space horizontal cross-section, where on the surface bridges type structure is placed

Formulation of the problem. Used in this paper method (FEM) is based on the variational approach and determining of the potential energy (П) minimum for the studied medium

$$\delta\Pi = \delta\Lambda - \delta \mathrm{W} = 0\,.$$

Where $\Lambda = \dfrac{1}{2}\int\limits_V \boldsymbol{\varepsilon}^{\mathrm{T}}\boldsymbol{\sigma}\, d\mathrm{v}$ – deformational energy of the system;

$\boldsymbol{\varepsilon}^{\mathrm{T}}, \boldsymbol{\sigma}$ – consequently transposed column strain vector and column stress vector.

$W=W_C+W_P+W_B$ – external energy forces, consists consequently of energies W_B – body forces (F), W_P – surface forces, W_C – energy of concentrated nodal forces. For the energies determining following expressions have place:

$$W_B = \int\limits_{V^{(e)}} \mathbf{U}^T\mathbf{N}^{(e)T}\mathbf{F}\, dv,\ W_P = \int\limits_{S^{(e)}} \mathbf{U}^T\mathbf{N}^{(e)T}\mathbf{P_2}\, ds,\ W_C = \mathbf{U}^T\mathbf{P_1}.$$

Where $\mathbf{U}^T = (\mathrm{u}_{3i-2},\ \mathrm{u}_{3i-1},\ \mathrm{u}_{3i},\ \ldots\ \mathrm{u}_{3j-2},\ \mathrm{u}_{3j-1},\ \mathrm{u}_{3j},\ \ldots\ \mathrm{u}_{3k-2},\ \mathrm{u}_{3k-1},\ \mathrm{u}_{3k})$ – transposed column vector of displacements in the apexes i, j, k=1,N_e of discretized into N_e pyramids solid (triangulated in the two-dimensional case). **F** – vector of volum forces, $\mathbf{P_2}$ – vector of surface forces and $\mathbf{P_1}$ – vector centered at the nodes forces. $\mathbf{N}^{(\mathbf{e})} = \begin{bmatrix} N_i & 0 & 0 & \ldots & N_j & 0 & 0 & \ldots & N_k & 0 & 0 \\ 0 & N_i & 0 & \ldots & 0 & N_j & 0 & \ldots & 0 & N_k & 0 \end{bmatrix}$ – function form matrix, which establishes a relationship between displacements in the tops of the element and the body in the form

$$\mathbf{u} = \mathbf{N}^{(\mathbf{e})}\mathbf{U}\,,$$

where $\mathbf{u} = (\mathrm{u}^i, \mathrm{u}^j, \mathrm{u}^k)^T$ – displacement vector in the medium, i, j, k = 1, …,Ne; Ne – number of finite elements mesh partitioning model. Using this approach for the triangle on the Fig.2 the displacement in each point of the medium can be written in the form

$$u=N_i u_i+N_j u_j+N_k u_k,$$

where nodal values of scalar quantities u_α ($\alpha = i, j, k$) denote u_i, u_j, u_k, and the coordinates of a pair of three units – through (X_i, Y_i), (X_j, Y_j), (X_k, Y_k). And

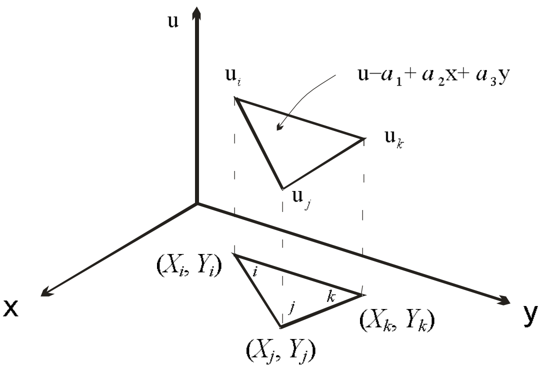

Fig.2. Two-dimensional element of the medium

$$N_i = \frac{1}{2A}\left[a_i + b_i x + c_i y\right],$$

$$\begin{cases} a_i = X_j Y_k - X_k Y_j, \\ b_i = Y_j - Y_k, \\ c_i = X_k - X_j; \end{cases}$$

$$N_j = \frac{1}{2A}\left[a_j + b_j x + c_j y\right]\ ,\quad \begin{cases} a_j = X_k Y_i - X_k Y_i, \\ b_j = Y_k - Y_i, \\ c_j = X_i - X_k; \end{cases}$$

$$N_k = \frac{1}{2A}\left[a_k + b_k x + c_k y\right]\ ,\quad \begin{cases} a_k = X_i Y_j - X_j Y_i, \\ b_k = Y_i - Y_j, \\ c_k = X_j - X_i. \end{cases}$$

The relationship between strains and displacements written in matrix form is

$$\boldsymbol{\varepsilon} = \mathbf{B}^{(e)}\mathbf{U}\,,$$

where $\mathbf{B}^{(e)}$ is the differential operator.

Similarly equation of state (Hook's law) concerning considered cross-section has the form

$$\boldsymbol{\sigma} = \mathbf{D}^{(e)}\boldsymbol{\varepsilon}\,,$$

where $\mathbf{D}^{(e)}$ – matrix of elastic properties of the element (e).

Substituting the expressions for strain and stress into the expression for the deformational energy and into the work of external forces expression, utilizing the expression for minimum of potential energy summarizing for N_e elements, we obtain the matrix presentation of FEM equation of medium state as a system of linear algebraic equations

$$\mathbf{K}\ \mathbf{U} = \mathbf{f}\ ,$$

where $\mathbf{K}$ – is called the stiffness matrix,
f – vector-column outside applied, surface and point forces.

Inertial and dissipative forces distributed by volume, so they can be considered as part of the body forces. Taking into account the inertial forces in the elementary volume $\rho\ddot{\mathbf{U}}$ (ρ - density of the body) and the dissipative force $c\dot{\mathbf{U}}$ (c – attenuation per unit volume obtained experimentally) for the discretized model for N_e elements we have

$$\mathbf{f_i} = \mathbf{M}\ddot{\mathbf{U}}\ , \quad \mathbf{M} = \sum_{e=1}^{E} \int_{V^{(e)}} \rho_e \mathbf{N}^{(e)T}\mathbf{N}^{(e)}\, dv\ ,$$

$$\mathbf{f_D} = \mathbf{C}\dot{\mathbf{U}}\ , \quad \mathbf{C} = \sum_{e=1}^{E} \int_{V^{(e)}} c_e N^{(e)T} N^{(e)} dv\ .$$

Taking into account that inertial $\mathbf{f}_i$ and dissipative forces $\mathbf{f}_D$ are directed against motion (vectors must have "minus") and substituting the last two equations into FEM equation of state we obtain the equation of motion in matrix form:

$$\mathbf{M}\ddot{\mathbf{U}} + \mathbf{C}\dot{\mathbf{U}} + \mathbf{K}\mathbf{U} = \mathbf{f}\ .$$

As previously **f** is vector-column of external forces. In stationery loading **M**=**C**=**Z. Z** is zero matrix.

Modeling results. This case was considered as in the solution of the practical problem of modeling of the state of loaded bottom of the cross-section of the river flow. It was considered modeling the stress-strain state riverbed. Investigated two options - without fortification Fig.3a and reinforced concrete right bank of Fig.3b. Chosen model size was 40 m by OX and depth of 20 m along the axis OZ. The depth of the river in model was 10 m.

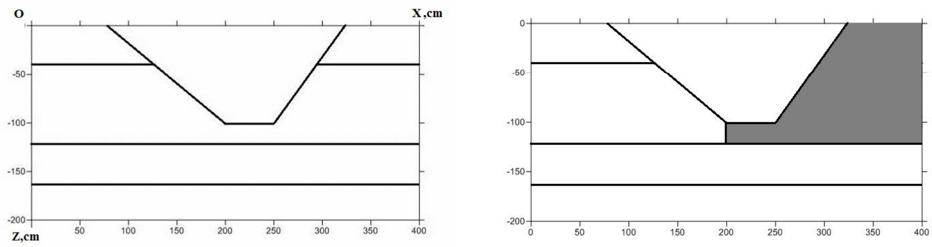

Fig.3. Model riverbed in layered media

Concerning this model layers features are shown in Tabl.1. From left to right are shown number of modeled layer, depth of the layer (№), depth of the layer (H), density (Ro), velocity of longitude waves (Vp), velocity of shear waves (Vs).

Tabl.1

№	H (м)	Ro (кg/м^3)	Vp (м/s)	Vs (м/s)
1	4	1,50*10^3	300	120
2	12	1,75*10^3	500	320
3	16	2,00*10^3	760	480
4	20	2,20*10^3	1400	850

For concrete strengthening the right river bank of the river cross-section parameters characterizing the stress-strain state of the model were taken – Young's modulus E = 2.2 10^{10} N/m^2, Poisson's ratio ν =0.18, density ρ =2.5 10^3 кg/м^3. The relationship between E, ν, ρ and Vp, Vs are the following [3]:

$$Vp = \sqrt{\frac{E(1-\nu)}{\rho(1-2\nu)(1+\nu)}}\ , \quad Vs = \sqrt{\frac{E}{2\rho(1+\nu)}}\ .$$

Figure 4 presents the distribution of strain and stress on the cross-section of the modeled waterflow object. Left graph shows the unfortified coast, right picture present the strengthened concrete riverbed. Charts are presented in the form of "shaded relief map" in order to better understand and detect differences in the two simulated stress-strain cases.

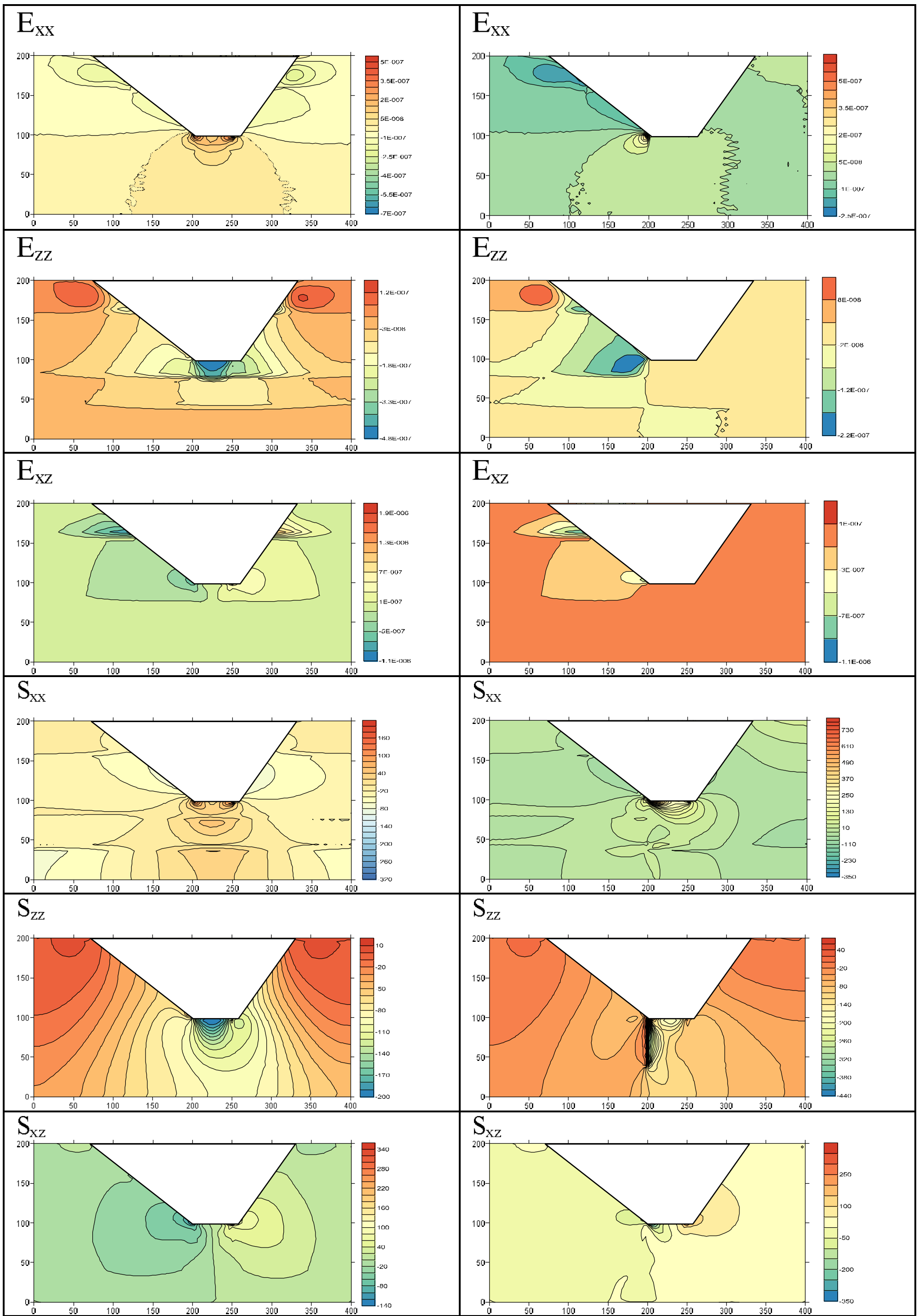

Fig.4. Distribution of strain (E_{xx}, E_{zz}, E_{xz}) and stress (S_{xx}, S_{zz}, S_{xz}) in a "contour map", derived numerical values on the edge of the water-shore shown as a column on the right of each graph. The influence of hydrostatic pressure is taken in to account

Decomposition of frequency-time vibrations. The situation with the study of stress-strain state of the model is closely connected with the knowledge of the physical parameters of the medium, necessity of knowledge which was sown in previous example. Therefore it was shown in the paper the approach how to obtain the parameters of the medium. It was based on the spectral methodology closely connected with the investigation of the frequencies of the vibrations in separate points of the river banks, where the prospecting boreholes are to be organized.

Decomposition of frequency-time wave field impulses concerning the shores structure of waterflow objects is a fundamental component spectral analysis of wave fields and is used in almost all stages of data processing. This is because the frequency variations of the wave field are closely related, to the structure of the geological medium and to its physical parameters. At present there are many methods to determine various frequency components of the wave field, but each has its limitations, requiring generalization. The paper presents an analysis and calculation of different frequencies for interconnected by power relations oscillators.

In seismic survey there is a close relationship between the frequency components of day vibrations of the Earth's surface with the deep structure and physical parameters of geological structures observed during the identification and interpretation of the frequency characteristics for the wave field of geophysical research wells. This is because the spectral analysis is one of the main stages of processing and interpretation of seismic data. Utilized spectral analysis is based on Fourier transform method, which helped to introduce seismic trace as a infinite sum of trigonometric functions and identify among them dominant. The main limitation of the Fourier transform is impossibility to establish exactly the time, when the signal has a defined phase frequency. In other words, the Fourier transform does not allow the time-frequency analysis, but a number of methods, such as serial Prony method [3] and generalized functions package [4-6], implementing the specified analysis in the selected time window, using Fourier trigonometric functions. Other more general methods: Hilbert transform [7], wavelet Haar [8], have departed from the basic functions of Fourier series and use other basic functions - cuh waves. Wavelet analysis [9] extended the informative features of wave fields by frequency localization signal parameters over time. Front of modern studies of the physical properties of inhomogeneous continuum is associated with impulsive Dirac delta function from the point of scientists [8,9], but provide spectral representation of signals in time without regard to the physical nature of the process of origin and environment, that does not eliminate the main limitations of existing methods. Namely, comprehensive physical meaningfulness of the information they provide. Further expansion properties informative methods of spectral analysis of wave processes in the specified direction is recommended to start with the use of communication frequency parameters of the energy parameters of the signal that are directly related to the physical parameters of the processes of energy transfer and the parameters of the most technical and physical systems and physical space in general. In particular, the transfer of a acoustic waves given energy into geological environment during seismic experiments.

Model wave field, which forms the acoustic wave in the geological environment has quasiharmonic representation of receiver stochastic signal

$$s(t) = A(t)\cos\left(w(t)t + \varphi(t)\right), \qquad (1)$$

where $A(t)$ - instantaneous amplitude;

$w(t)$ - Instantaneous frequency;

$\varphi(t)$ - Instantaneous phase.

The task is to carry out a complete spectral decomposition of the signal $s(t)$. The signal is seen with instant spectral parameters, each of which is characterized by its dimensionless amplitude $\tilde{s}(t) = s(t)/A(t)$, phase and frequency. Each of the parameters will characterize specific physical properties of the wave field and the environment, despite the fact that it has a fixed value (energy state) in time - $\tilde{s}(t_i)$, phase - $\varphi(t_i)$ and changing in time - $\frac{d\tilde{s}(t)}{dt}$ (in the space provided) with the dimension of frequency, ie, main metrological parameters are: : rad, s, $\frac{1}{s}$ або $\frac{rad}{s}$. Despite such metrological limitations of this method of pulse-frequency decomposition of the wave field, especially the physical meaningfulness of the model parameters (1) will be expanded. Different features of instantaneous integral (periodic) values of frequency parameters determined.

Known method of calculating the instantaneous component seismic signal based on the analytical representation of these same signals is using Hilbert transformation [2]. Hilbert transform method combine real (specified) characteristic of signal with its imaginary integral characteristic that allows to calculate instantaneous spectral parameters of the signal, namely amplitude, frequency, phase, but without the transparency of physical information that is difficult to define.

Thus, today registered acoustic (seismic) signal determined by following frequencies:

- Cyclic frequency harmonic signal (the Fourier frequency), defined for periodic time window;

- Frequency Prony defined in the periodic time window;
- Instant discordant frequency signal (the Gilbert frequency), measured at a point.

As already mentioned, the common between the frequencies is only dimension. Transparency of information about the physical meaning of these frequencies is a separate research question.

Fig. 1 and Fig. 2 show a fragment of the real seismic signal (pulse forming line in physical space), which runs along the wellbore with informative frequencies, which carry a specific physical meaning, information is investigated in basic studies [12,13,15, 16, 17].

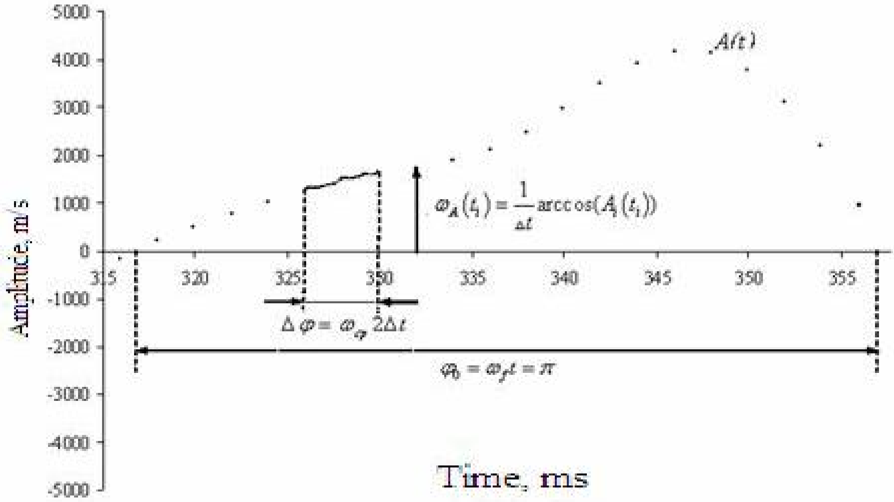

Fig.5 Fragment of the seismogram (dependent from time) and meaning of frequencies instantaneous, transfer, averaged

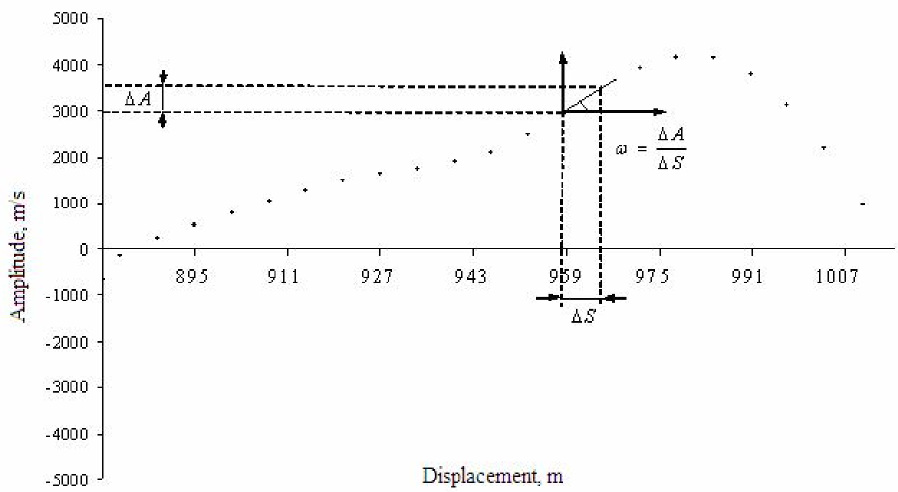

Fig.6. Seismogram fragment in a space with explanation of transfer frequency and its physical sense – phase velocity of P-waves

Analysis of frequencies carried out gives the possibility to obtain synthesized simulated seismogram, which is dissolved in parameters dependent from the physical parameters of the upper crust modeled. Those petro-physical parameters are calculated solving the inverse dynamic seismology problem going out of upper presented point of view.

According to the results of the developed theoretical basis of the method of impulse time-frequency decomposition of the seismic prospecting acoustic wave field following results are obtained.

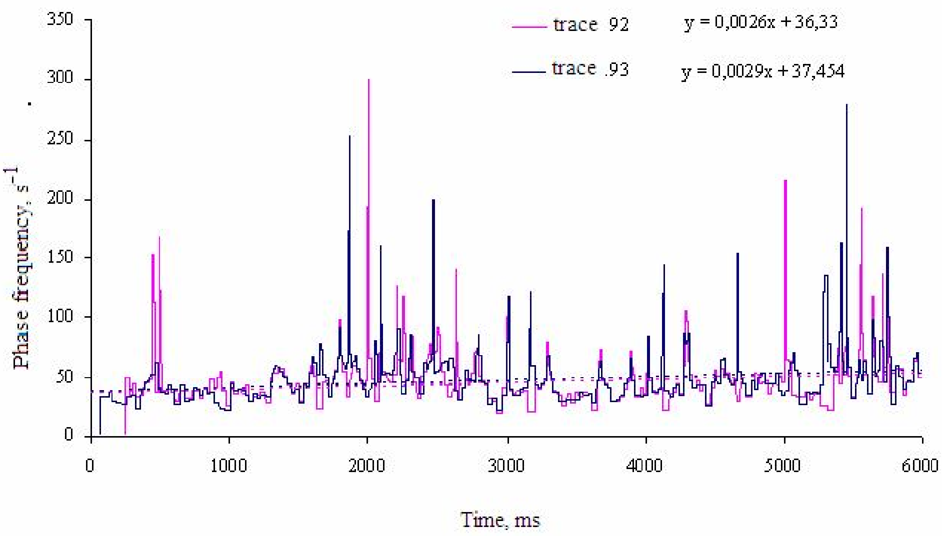

Fig.7. Characteristic of phase-phase distribution of experimental (blue) and simulated seismogram (red) along the direction of borehole analyzed

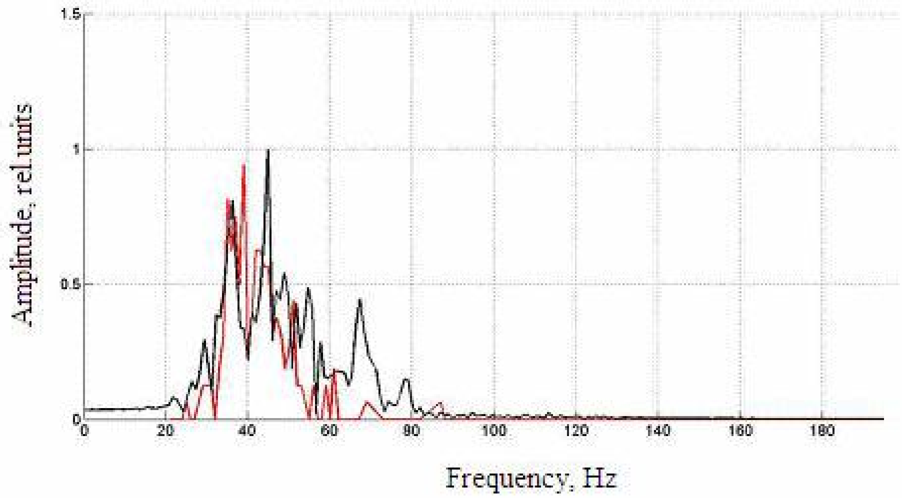

Fig.8. Characteristic of amplitude-phase distribution of experimental (blue) and simulated seismogram (red) along the direction of borehole analyzed.

CLOSING REMARKS

1. Algorithms and applications in MATLAB environment on defining frequency and physical parameters of acoustic wave fields are elaborated;
2. Studies of parametric interpretation seismological cuts in the above parameters with comparing the results with the results of geophysical surveys and drilling wells uncovered productive horizons.
3. Positive research results allowed to develop theoretical foundations and algorithms to determine geophysical parameters of geological medium layers: Young's modulus, Poisson's ratio, density, dynamic viscosity and differential pressure saturating fluid reservoir and geological characteristics determine species, namely, collector ,,dry", collector, ,,fluyidsaturated", weak, poorly compacted clay rocks and rugged, heavily compacted, cemented rocks and others.

The proposed method provides physical data transparency regarding acoustic wave field geophysical structure of the geological environment and is informative technology to interpret seismic data with a resolution of 1 ms in time and in space 25m up to 4m.

Theoretical confirmation of the proposed solution of the inverse seismology problem based on the seismic data in the investigated points of the geological medium will be given in the following paper.

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