Multifactorial Estimation of Geoecological Risks for Environment

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***Abstract*—The prediction problem of the geoecological destructive impact to environment from natural and technogenic explosions is multifactorial problem. There are factors that reduce ecological impact from the explosions in near ground atmosphere: snow cover, forest, surrounding area relief. The explosions generate seismic waves in the Earth and infrasound acoustic waves in the atmosphere. The paper presents a mathematical simulation of the elastic waves propagation from infralowfrequency source taking into account snow cover. The programs for calculation of the acoustic levels through mathematical model based on the conservation laws and differential equations for porous snow medium are implemented. The results of the processing and analysis of the experimental data taking into account the snow cover is executed.**

***Keywords*—Snow cover, porous medium, elastic waves, transverse and longitudinal waves**

I. Introduction

The paper represents the multifactorial problem of estimation of the geoecological risks to environment and social infrastructure from mass technogenic and natural explosions. As shown previously the impact of meteo factors complex to the infrasound propagation at specific conditions may leads to multiple increasing the geoecological risks [1]. At the same time, there are factors such as snow cover, forest and surrounding area relief that lead to attenuation of the ecological risks.

The author suggest a mathematical simulation of the elastic waves propagation from lowfrequency source taking into account a snow cover based on the theory of dynamic poroelasticity. The snow cover is approximated as porous medium saturated with liquid or air, where the three elastic parameters are expressed via three elastic wave velocities via the Biot theory using elastic parameters of the snow. Note that the obtained solutions allow to study the peculiarities of the elastic wave's propagation in the liquid or air, which saturating snow cover. In this case, the obtained formulas allow to simulate the displacement velocity of the porous frame and the saturating fluid in it, as well as the pore pressure and the stress tensor components with given elastic parameters of the medium and the velocities of propagation of transverse and longitudinal waves in the porous medium.

II. Statement of Problem

In poroelasticity theory [2] the stress-strain relations for a porous aggregate including the effects of fluid's pressure and dilatation are considered. As well as in [3, 4] we study the dynamics of a material and the coupling between a fluid and a solid provided that the material is statistically homogeneous and isotropic in the region of interest, behaves in a linearly elastic manner and that thermoelastic effects are negligible. The macroscopic stress-strain relation for the medium was derived by assuming the isotropic medium. The coupling effect between the elastic skeleton and the compressible fluid was taken into account by introducing a kinetic coefficient into the dissipation function of the system [2]. Dissipation of energy by the viscous fluid was expressed in terms of a relative velocity between the fluid and the solid.

The constitutive relations describing the porous material by the tree parameters are the following [5]:

$$\sigma_{ij} = 2\mu\varepsilon_{ij} + \tilde{\lambda}\varepsilon_{kk}\delta_{ij} - \left(1 - \frac{K}{\alpha\rho^2}\right)p\delta_{ij}$$

$$p = (K - \alpha\rho\rho_s)\varepsilon_{kk} - \alpha\rho\rho_l e_{kk}$$

$$\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right), \quad e_{ij} = \frac{1}{2}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)$$

where σ_{ij} is the stress in the solid framework; p is the fluid pore pressure; ε_{kk} and e_{kk} are the dilatations of the solid and the fluid; ε_{ij} is the strain in the solid, and δ_{ij} is the Kronecker delta, $u = (u_1, u_2, u_3)$ and $U = (U_1, U_2, U_3)$ are the displacement vectors of the elastic matrix and the saturating fluid; ρ_s and ρ_l are partial densities: $\rho = \rho_s + \rho_l$, $\tilde{\lambda} = \lambda - (\alpha\rho^2)^{-1}K^2$, $K = \lambda + \frac{2}{3}\mu$, $\lambda, \mu, \alpha\rho^2$ are elastic parameters of the porous medium [2].

The dynamic poroelasticity theory for the porous media is derived using the method of conservation laws, which have the forms [6]

$$\frac{\partial u_i}{\partial t}+\frac{1}{\rho_s}\frac{\partial \sigma_{ik}}{\partial x_k}+\frac{\rho_l}{\rho_s\rho}\frac{\partial p}{\partial x_i}+\frac{\rho_l}{\rho_s}\chi\rho_l(u_i-v_i)=F_i,$$

$$\frac{\partial v_i}{\partial t}+\frac{1}{\rho}\frac{\partial p}{\partial x_i}-\chi\rho_l(u_i-v_i)=F_i,$$

$$\frac{\partial \sigma_{ik}}{\partial t}+\mu\left(\frac{\partial u_k}{\partial x_i}+\frac{\partial u_i}{\partial x_k}\right)+\left(\frac{\rho_s}{\rho}K-\frac{2}{3}\mu\right)\delta_{ik}\operatorname{div}\vec{u}-\frac{\rho_s}{\rho}K\delta_{ik}\operatorname{div}\vec{v}=0,$$

$$\frac{\partial p}{\partial t}-(K-\alpha\rho\rho_s)\operatorname{div}\vec{u}+\alpha\rho\rho_l\operatorname{div}\vec{v}=0,$$

where χ is the friction coefficient.

The porous material is determined by the three elastic parameters K,μ and α . These parameters are expressed in terms of the velocity of propagation of the shear wave c_s and of the velocities of the longitudinal waves c_{p_1} , c_{p_2} .

$$\mu=\rho_s c_s^2,\ K=\lambda+\frac{2}{3}\mu$$

$$K=\frac{\rho}{2}\frac{\rho_s}{\rho_l}\left(c_{p_1}^2+c_{p_2}^2-\frac{8}{3}\frac{\rho_l}{\rho}c_s^2-\sqrt{\left(c_{p_1}^2-c_{p_2}^2\right)^2-\frac{64}{9}\frac{\rho_l\rho_s}{\rho^2}c_s^4}\right)$$

$$\alpha_3=\frac{1}{2\rho^2}\left(c_{p_1}^2+c_{p_2}^2-\frac{8}{3}\frac{\rho_s}{\rho}c_s^2+\sqrt{\left(c_{p_1}^2-c_{p_2}^2\right)^2-\frac{64}{9}\frac{\rho_l\rho_s}{\rho^2}c_s^4}\right).$$

The velocities c_s and c_{p_1} , c_{p_2} are determined by the Biot parameters A, N, R, and Q. These parameters are calculated from the four measurable coefficients for the snow. The friction coefficient is expressed by the dissipation coefficient from [3, 4].

III. Results of Numerical Simulations

Numerical simulation of the wave fields from lowfrequency source taking into account snow cover is implemented. Snow layer is considered in the model of the porous fluid-saturated medium with ice frame and pores are filled with air (fresh snow) or air and water (melted snow).

We have been used the algorithm of numerical solving of the 2D dynamic problem of seismic wave propagation in the porous medium with allowance for the energy dissipation. To solve numerically this problem, we used the method for combining the Laguerre integral transform with respect to time with a finite-difference approximation along the spatial coordinates. The proposed method of the solution can be considered as analog to the known spectral-difference method based on Fourier transform only instead of frequency we have a parameter m i.e. the degree of the Laguerre polynomials. However, unlike Fourier transform, application of the Laguerre integral transform with respect to time allows us to reduce the initial problem to solving a system of equations in which the parameter of division is present only in the right side of the equations and has a recurrent dependence. The algorithm used for the solution makes it possible to perform efficient calculations when simulating a complicated porous medium and studying wave effects emerging in such media.

The example of calculation wave's field results for different models is represented on the figures 1 and 2. There was given the medium model, consisting of snow layer and elastic semispace.

The authors chose the boundary conditions and the values of model parameters taking into account physical medium's features. The medium's features were specified as

1. Snow layer with parameters $\rho_0=0.4$ g/cm^3 is density, $\rho^f_{0.1}=0.01$ g/cm^3 is density, $c_{p_1}=1.1$ km/sec, $c_{p_2}=0.25$ km/sec, $c_s=0.7$ km/sec, d=0.5 is porosity coefficient, χ=100 cm^3/(g sec) is absorption
2. Lower elastic semispace with parameters $\rho=1.5$ g/sm^3, $c_p=1.2$ km/sec, $c_s=0.8$ km/sec.

Thickness of the upper snow layer is equal 20 meters. Wave field is modeled from point source like expansion center with coordinates $x_0=200$ meters, $z_0=4$ meters, situated in upper layer. The figure 1 demonstrates snapshot of wave's field for vertical velocity component of displacement u_z in the fixed moment of time T=0.15 sec. Time signal in the source was given as Puzyrev's pulse with main frequency equaled 100 Hz:

$$f(t)=\exp\left(-\frac{2\pi\, f_o(t-t_0)^2}{\gamma^2}\right)\sin(2\pi\, f_0(t-t_0))$$

The figure is shown that in snow's layer the multiply reflected waves arise. They generates different longitudinal and transverse waves in elastic semispace.

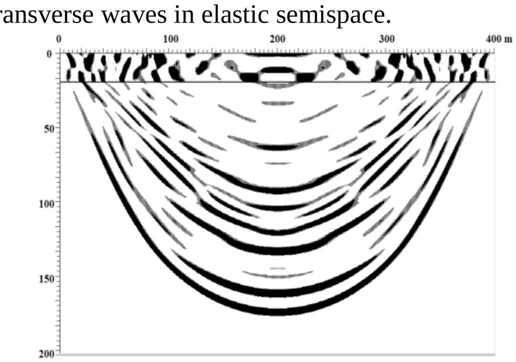

Fig. 1. Snapshot of the wave's field for vertical displacement velocity component $u_z(x,z)$ in the time moment t=0.15 sec. The main frequency of signal in the source is equal 100 Hz

The figure 2 represents the snapshot of wave's field for vertical velocity of displacement u_z when thickness of the snow layer is 3 meters. The right snapshot shows the wave field with absorption in the snow's layer and the left snapshot presents wave field without absorption.

From analysis of figures 1 and 2 It is shown that if thickness of the snow layer less spatial length transverse and quick longitudinal wave, then presence of absorption in medium significantly influences to wave field. Since the presence of absorption firstly significantly influences to attenuation of the slow longitudinal waves and decreases the number of reflections in thin layers.

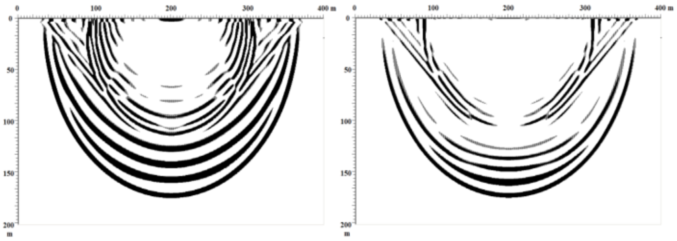

Fig. 2. Snapshots of the wave field for vertical component of displacements velocity $u_z(x,z)$ in the moment time t=0.15 sec. On the left side without absorption, on the right side with absorption. The main frequency of signal in the source is equaled 100 Hz.

IV. Results of Experiments

The experimental works are associated with processing and analysis of the data accumulated during 2013-2014. The data were obtained as result of vibrational sounding of the media “Earth-atmosphere” through seismic and acoustic oscillations from infralowfrequency vibrational source. There were experiments to estimate the quantitative characteristics of the snow impact to acoustic field level. As source of the seismic and acoustic oscillations, the seismic vibrator CV-40 (40 ton) has been used in the frequencies range of 6.25—11.23 Hz. Power of the acoustic oscillations is equal 5% from seismic power. The acoustic oscillations we may record on the distance of the hundreds km due to smaller acoustic oscillations attenuation. In accordance with experiments, the track “Source-receiver” is equal 50 km and it covered radiation point vibroseismic test ground Bystrovka and receiver point of the acoustic oscillations in the settlement Kluchi. Corresponding azimuth is equal 50.7 degrees. Recording of the seismic and acoustic oscillations was implemented together with the seismic sensor CK1-P and the acoustic sensors PDS-7. As example of the processing on fig.3 there are represented acoustograms from the acoustic sensors PDS-7 and seismograms from the sensor CK1-P, obtained in winter (3.12.2014, upper part) and in summer (29.08.2013, lower part). Seismic waves arrive on 8-th second and acoustic waves are on the 140-th second. Difference of the winter and summer acoustograms and seismograms is consist of acoustic waves level in summer strongly above that in winter.

We calculated the acoustic waves levels recorded on the sensor CK1-P in summer and in winter when snow of different thickness (from 0 to 67 cm). On fig. 4 there is a plot of correlations of average levels of the acoustic waves recorded on the seismic sensor CK1-P and on the acoustic sensors PDS-7 on different seasons. The distance “source-receiver” is equal 50 km. Comparative analysis showed when snow is present that maximum level of the acoustic waves may reduce in dependence of the snow cover thickness more than 10 times.

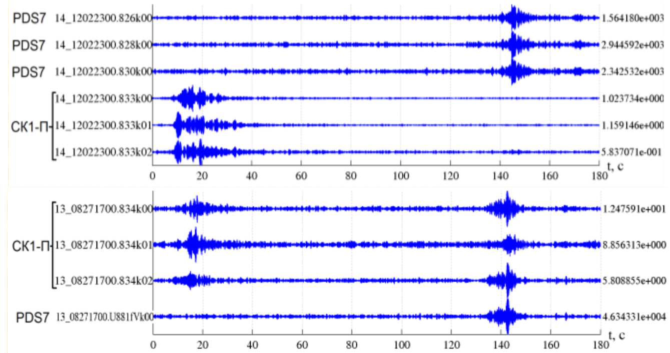

Fig.3 Example of acoustograms and seismograms, s. Kluchi, 50 km from source.

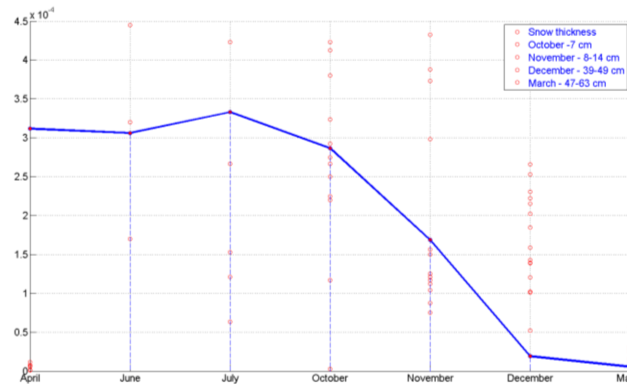

Fig.4. Correlations of average levels of the acoustic waves recorded on the seismic sensor CK1-P and on the acoustic sensors PDS-7 on different seasons.

V. Summary

1. The numerical results of mathematical simulation for wave seismoacoustic fields from low-frequency source taking into account model: snow medium on elastic semispace (modified model Biot) are presented. From analysis of these results and presented plots follows that if thickness of snow layer less than spatial length of transverse and quick longitudinal waves hence presence of absorptions in snow medium significantly influence on attenuation of the slow longitudinal waves. Therefore, the amplitude of elastic waves running through snow layer are decreased. These results confirm influence of the snow cover to the elastic waves propagation.
2. The experiments were carried out to estimate quantitatively of the seismoacoustic fields levels taking into account snow. The seismic vibrator CV-40 was considered as source of the seismic and acoustic waves in the frequency range of 6.25—11.23 Hz. The levels of acoustic waves, recorded on the seismic sensors SK1-P in winter (snow layer is present) and in summer (snow layer absents), were calculated. Comparative analysis showed that when snow is present the maximum level of the acoustic waves may decreases more than 10 times depending on snow thickness.

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