ARTICLE

THE STUDY OF THE SEISMOELECTRIC METHOD FOR THE LOCALIZATION OF GEODEFORMATIONAL CHANGES IN THE CONTROL OF THE SUBGRADE OF THE RAILWAY

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ABSTRACT

The article substantiates and studies an integrated approach to solving the problems of monitoring the subgrade of railway tracks in order to identify the initial stage of its destruction based on the combination of the phase-metric geoelectric and seismic methods of monitoring of the geological environment. The methodology of laboratory modeling of the natural-technical system "railway track" is reviewed with the aim of assessing the prospects of using the seismoelectric effect in the tasks of monitoring the subgrade of the railway. The results of laboratory studies are presented, confirming the adequacy of the models and methods used in solving the problems of monitoring the subgrade of railway tracks.

KEY WORDS
subgrade, geodynamic processes, phase-metric method, monitoring of the geological environment, seismoelectric method, correlation function, amplitude-frequency characteristic

INTRODUCTION

Currently, due to the ever-increasing intensity of railway operation, requirements for railway reliability are increasing. At the same time, special requirements for the construction and operation of railways are imposed in karst-hazardous areas. This is due to the possible activation of near-surface geodynamic processes (such as karst and suffusion processes) under the intensive cyclic effect of passing trains [1, 2]. The intensity of transport vibration is equivalent to an earthquake of 3-6 points on the Richter scale [3]. It should be noted that the activation of near-surface geodynamics occurs during the operation of railway tracks and is not fixed at the stage of engineering surveys and construction works. Activation of karst processes in the area of passage of railway tracks can lead to the destruction of the subgrade of railway tracks [Fig. 1] [4, 5]. In addition, the reasons for the deformation of the subgrade can be: a mismatch between the strength of the upper structure of the railway track and the intense dynamic loads of the transport; adverse effects of climatic and engineering-geological factors (karst processes, landslides, mudflows, floods, fluctuations in groundwater levels, etc.).

Fig. 1: The sudden destruction of the subgrade of the railway as a result of natural factors

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Thus, uneven precipitation and deformation of the subgrade lead to the transition of the "railway track - soil base" system to an unstable state, which is currently not predicted. To detect the occurrence and prediction of deformation processes of the soil base and subgrade of railway tracks at an early stage, it is necessary to have predictive information about the condition of the subgrade and possible catastrophic changes.

Monitoring the geological environment in the area of railways by direct geophysical control methods (drilling engineering-geological wells) is technically and economically impractical. In this case, to obtain continuous information about the main elements of the geological environment, as well as its physical and mechanical properties, it is necessary to apply monitoring methods of shallow geophysics engineering. Currently, the following methods are used to obtain information about the structure of the upper layers of the earth bed: GPR sounding [6], electro dynamic sounding method [7], vibro seismic methods [8], electrometric control methods [5, 9].

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In the tasks of conducting automated control of geodynamic objects, the use of geo electric methods of sensing media is the most promising. These methods provide effective organization of observations of geological objects, assessment of the state of objects and prediction of their changes. This is a consequence of the high manufacturability of geo electric methods [10]. However, as practice shows, the use of the considered methods separately in geodynamic monitoring is ineffective. In addition, the various elements of the geological section and their condition with varying degrees are manifested in the results obtained using various geophysical methods. For each specific task, it is necessary to choose the most preferred research method [11]. The combined use of geo electric and seismic methods will reduce the ambiguity of the assessment of geophysical data. Such an application of the seismo electric control method [12, 13] will increase the efficiency of studies of the geological environment.

The aim of the work is the justification and study of an integrated approach to solving the problems of monitoring the subgrade of railway tracks and identifying the initial stage of its destruction based on the combination of the geo electric and seismic method of monitoring the geological environment in the zone of railway tracks.

Application of seismic-electric method of control of railway track bed

The seismo electric method belongs to the class of mechano electric control methods based on secondary seismic effects: piezoelectric and seism electric. This method is based on recording variations in current strength in rocks during the propagation of elastic vibrations with a fixed potential difference in the studied area of the geological environment (seismo electric effect of the first kind) [14]. This effect determines the nature of the effect of vibrational seism acoustic noise caused by the movement of the train on the results of electrical measurements.

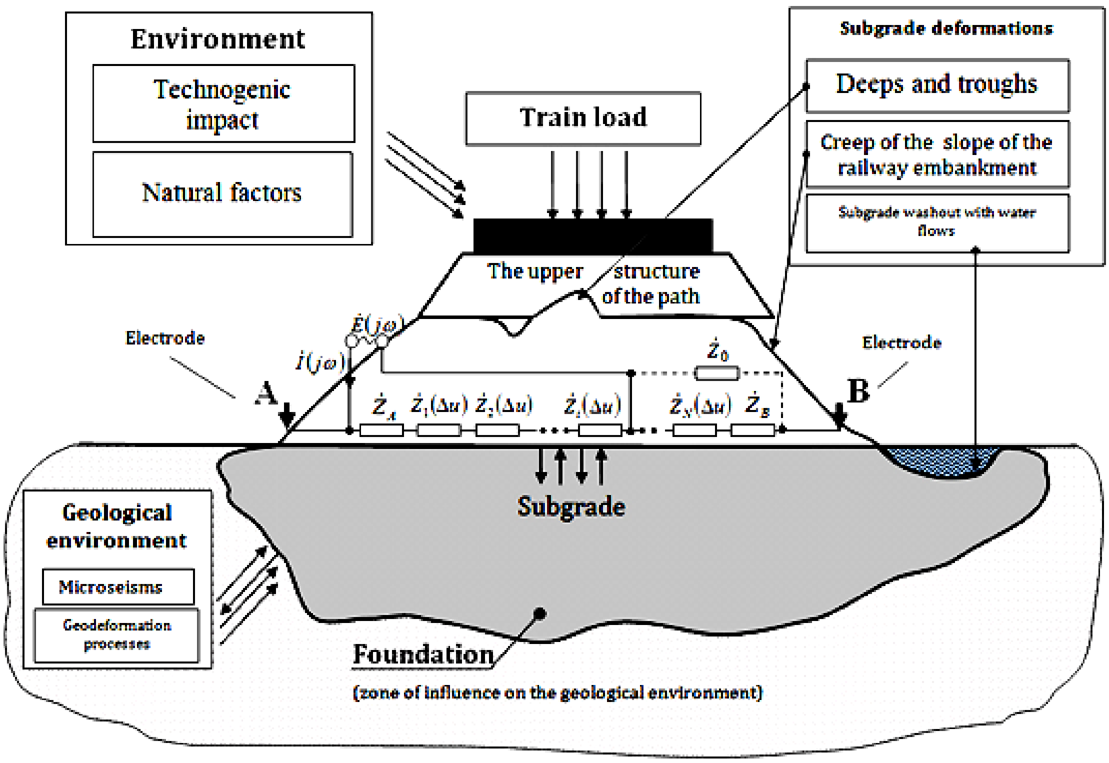

Fig. 2: The principle of application of seismo electric control of the subgrade of railway tracks

In this case, as an informative parameter, a parametric transfer function is used in the form of the complex resistance of the studied section of the geological environment [15]:

$$\dot{H}(j\omega,\Delta u)=\frac{\dot{E}(j\omega)}{\dot{I}(j\omega)}=\dot{Z}_A(j\omega)+\dot{Z}_B(j\omega)+\sum_{i=1}^{n}Z_i(j\omega,\Delta u)\,, \qquad (1)$$

where $\dot{Z}_A(j\omega),\dot{Z}_B(j\omega)$ - the grounding resistance; $E(j\omega),I(j\omega)$ - the source parameters of the electric field; ω - the frequency of the probing signal; $\dot{Z}_i(j\omega,\Delta u)$ - resistance of the i - th element of the studied area of the geological environment under seismic and acoustic influence Δu .

Representation of the transfer function (1) of the studied section of the geological medium in the form of a geo electric model of series-connected complex resistances allows the use of the model of an N-layer imperfect dielectric. The presented model contains N elements with a layer thickness d and electrical parameters of the i-th element - dielectric constant εi and electrical resistivity ρi. In this case, the transfer function of the studied section of the geological environment can be represented in the form of series-connected RC - chains with the following parameters [16]:

$$C_i = \varepsilon_i \, S(j\omega, \Delta u_i)/d\,(\Delta u_i)\ ,\ R_i = \rho_i \, d(\Delta u_i)/S\,(j\omega, \Delta u_i)\ , \tag{2}$$

where $S(j\omega)$ - effective area of the medium element, determined taking into account the skin-effect.

The transfer function of a geo electric section without taking into account the grounding parameters can be expressed in terms of the electrical parameters of a layered imperfect dielectric (2):

$$\dot{H}(j\omega, \Delta u) = \sum_{i=1}^{N} \frac{R_i}{1+x_i^2} - j\sum_{i=1}^{N} \frac{R_i x_i}{1+x_i^2}, \tag{3}$$

where $x_i = \omega R_i C_i = \omega \varepsilon_i \rho_i$.

When using the phase-metric method of recording geodynamic variations of the controlled area of the medium, the transfer function (3) has the following form:

$$\dot{H}(j\omega, \Delta u) \approx \frac{\dot{Z}_A + \sum\limits_{i=1}^{N_A} Z_i(j\omega, \Delta u)}{\dot{Z}_B + \sum\limits_{i=N_A+1}^{N} Z_i(j\omega, \Delta u)}\ . \tag{4}$$

During propagation of a seismic-acoustic wave in the medium, each i-th element is under mechanical influence, which is determined by the deformation tensor $\Delta u = \{\Delta u_x, \Delta u_y, \Delta u_z\}$.

For the spatially-stationary model, we introduce the parameter $a_i(j\omega)$, which characterizes the geometric dimensions of the i-th layer of the layered half-space taking into account the skin effect. In this case, equation (4) will take the final form:

$$\dot{H}(j\omega, \Delta u) = \frac{\sum\limits_{i=1}^{N_A} \frac{\rho_i/a_i(j\omega)}{1+x_i^2}\frac{1+u_x^i}{1+u_y^i+u_z^i} - \sum\limits_{i=N_A}^{N} \frac{\rho_i/a_i(j\omega)}{1+x_i^2}\frac{1+u_x^i}{1+u_y^i+u_z^i} - j\sum\limits_{i=1}^{N} \frac{\rho_i\, x_i/a_i(j\omega)}{1+x_i^2}\frac{1+u_x^i}{1+u_y^i+u_z^i}}{\sum\limits_{i=1}^{N} \frac{\rho_i/a_i(j\omega)}{1+x_i^2}\frac{1+u_x^i}{1+u_y^i+u_z^i} - j\sum\limits_{i=1}^{N} \frac{\rho_i\, x_i/a_i(j\omega)}{1+x_i^2}\frac{1+u_x^i}{1+u_y^i+u_z^i}} \tag{5}$$

Equation (5) shows that the method under consideration makes it possible to isolate in homogeneities in the medium due to the registration of a phase signal with localization of the inhomogeneity region due to seismic effects.

We denote the studied geological environment in the presence and absence of elastic impact by the impulse response as he(t) and hes(t), respectively. In this case, it is possible to evaluate the presence of heterogeneities and deformation processes in the geological environment by the cross-correlation function of these characteristics.

$$B_{es}(\tau) = \int_{-\infty}^{\infty} h_e(t) h_{es}(t-\tau)\,dt\ . \tag{6}$$

The most informative is not the time but the frequency domain. Therefore it is possible to go from the cross correlation function to mutual energy spectrum data characteristics Wes(ω), associated with the cross-correlation function of the Fourier transform

$$W_{es}(\tau) = \int_{-\infty}^{\infty} B_{es}(\tau) e^{-j\omega\tau} d\tau\ . \tag{7}$$

Based on formulas (6) and (7), we obtain a generalized expression for the mutual energy spectrum of the impulse characteristics of the geological environment in the presence and absence of elastic impact

$$W_{es}(\tau) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} h_e(t) h_{es}(t-\tau) e^{-j\omega\tau} dt\, d\tau\ . \tag{8}$$

The source of the seismic signal can be trains that pass through the study area. The advantages of this approach are that an intense and continuous seismic signal is generated by rail. The parameters of this signal in time vary slightly with respect to the passing composition. No additional sources of seismic signal are required.

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The noise level generated by rolling stock consists of three components [17, 18]. Noise from the drive and aerodynamic noise can be considered stationary, background. The noise from the rolling of the wheels occurs due to the contact of the wheel with the rail and is associated with a high pressure rolling steel on steel, characteristic of the system "wheel - rail" [19]. This type of noise is most significant in seismic studies of the subgrade of the railway. This noise can be considered impulsive. The rolling noise power increases in proportion to the third power degree. [20, 21].

Constant in magnitude loads that move along the soil surface are a source of low-frequency oscillations. The propagation velocity of these oscillations coincides with the speed of the train. Four main frequency ranges with the largest amplitudes can be distinguished in the spectrum of a seismic signal: 3-5 Hz, 7-13 Hz, 35-45 Hz, 60-80 Hz.

METHODS

The methodology of experimental studies on the model

To assess the prospects of using the seismo electric effect in the tasks of monitoring the subgrade of the railway, laboratory modeling of the natural-technical system “railway track” was carried out. For this, a laboratory setup was created [Fig. 3], which allows simulating the seismic effect of a passing train and natural processes (changes in soil moisture, suffusion). The laboratory setup includes: a model of a geodynamic object, sources of sounding signals, devices for measuring and recording signals in the environment, a device for processing geodynamic data. The model of the geodynamic object is a reservoir with sand, in which it is possible to carry out full and partial collapse of the soil.

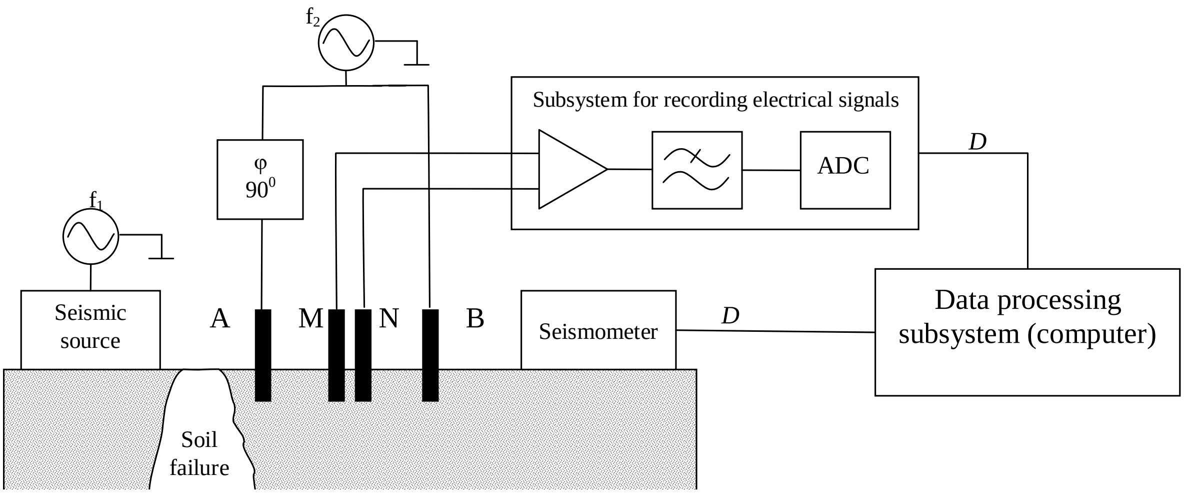

Fig. 3: Modeling of the control method in the laboratory

Previously, the noise of a moving train was recorded using a microphone placed in the ground. In the simulation, the seismic effect was simulated by reproducing the recorded noise using the source of the seismic signal - the vibration speaker.

During the research, modeling of soil collapse was carried out with registration of changes in the characteristics of seismic and electrical signals. These data provide information on the initial stage of soil collapse. As a result, it becomes possible to detect and isolate the initial phase, the irreversible destruction processes roadbed and to prevent the occurrence of industrial accidents and disasters in natural technical system "railway track".

RESULTS

[Fig. 4] shows the spectra of the output signals of the studied medium in the presence and absence of elastic action with a frequency of 70 Hz. The frequency of the electrical signal corresponded to a value of 40 Hz. Thus, it is possible to obtain data on the manifestation of a seismo electric effect of the second kind, that is, on the excitation of an electromagnetic field under the influence of elastic vibrations.

[Fig. 4] shows the results of recording a phase signal during studies to simulate a soil failure. The results of the experiment [Fig. 4 and 5] show a change in the amplitude of the electric signal and the appearance of combination frequencies at the moment of cavity formation (180 second) and its arch collapse (two partial collapses for 363-400 sec and 512-699 sec, and the subsequent formation of a dip 623 -799 sec).

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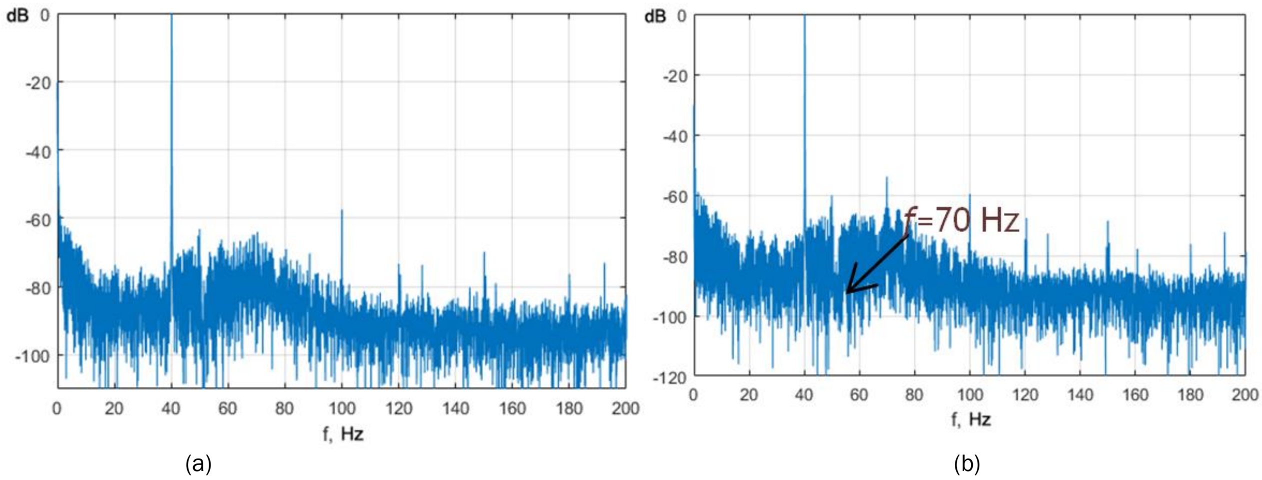

Fig. 4: Spectra of the output signals of the studied medium in the presence and absence of elastic impact

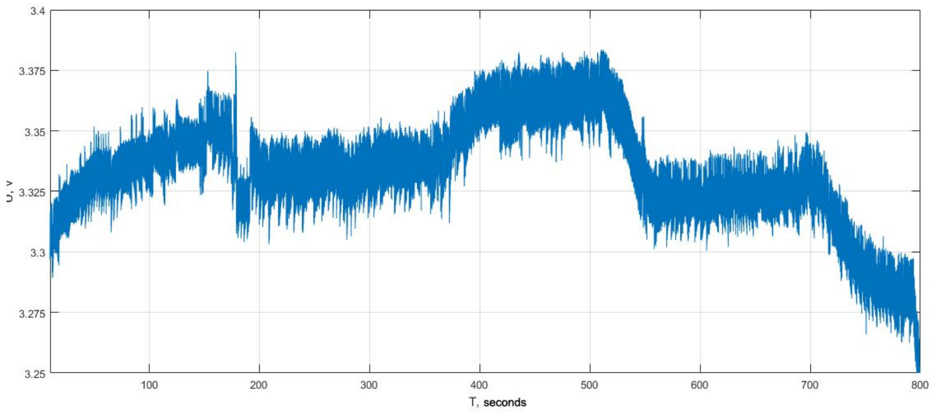

Fig. 5: The process of changing the electrical signal of a signal during a crash simulation

From the presented implementations, it can be seen that the phase-metric method is highly sensitive to the initial phase of the destruction processes in a controlled area of the soil. Moreover, as can be seen from the results obtained, the combined processing of geo electric and seismic signals in accordance with the proposed algorithm allows us to determine the presence of heterogeneity in the medium, its depth and its geodynamic changes.

CONCLUSION

An integrated approach to solving the problems of monitoring the subgrade of the railway is substantiated based on the combination of two geophysical methods for monitoring the natural environment: geo electric and seismic acoustic methods. It is shown that when conducting work for the diagnosis of subgrade, it is necessary to take into account a number of features that are not found in engineering geology. To increase the efficiency of applying geo electric methods for monitoring the subgrade of the railway, the properties of vibrational seism acoustic noise caused by the movement of the train and the nature of the effect of this noise on the results of electrical measurements are analyzed. The use of the correlation function and amplitude-frequency characteristics, which are the most informative and sensitive to heterogeneities of the medium, in the algorithm for processing geo electric and seismic acoustic signals is substantiated. The relevance of using specialized algorithms based on the use of the phase-measuring method for processing seismic-electric railroad track data necessary for recording a weak useful electric signal caused by seismic-acoustic effects against a background of external industrial and natural disturbances of a high level is noted.

CONFLICT OF INTEREST

There is no conflict of interest.

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FINANCIAL DISCLOSURE

None.

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