INTRODUCTION

The present study is central to acoustic investigations of natural media properties that have found reflection in many papers (e.g., [1–6]). Interest in different manifestations of structural inhomogeneity of natural materials has increased lately [1–9]. One of these structural inhomogeneity manifestations is so-called “slow dynamics” [10–13], which lies in the logarithmic ($\propto \ln t$, where $t$ is the time) relaxation of deformations in structurally inhomogeneous materials after intensive actions. To explain this damping law a phenomenological model of the cascade relaxation of states with different energy levels was proposed in [12]. It was noted in [13, 2] that the logarithmic law took place both in the process of microcontact excitation in a single crack and during relaxation of perturbations. A mechanism of thermal microdeformations was proposed to explain the observed behavior.

The analysis of paper materials points to a general character of slow perturbation relaxation of different origin that is characteristic for the majority of materials with an inner structure at a microscopic level. E.g., in [14, 15] an analogy between (micro) plastic deformations in a solid state and magnetization is used to describe the irreversible processes in ferromagnetics where a logarithmic law of spontaneous magnetization decrease holds.

Unconsolidated natural materials including near-surface sedimentary are multiphase systems with complex internal bonds [16]. Thus it seems interesting to analyze the reactions of such media to strong actions, which are capable of distorting phase equilibrium inside a natural composite. The problem considered has an applied aspect. A process with a logarithmic time dependence of the parameter, e.g., shear modulus, points to the nonequilibrium multiphase system and its metastable state. These processes revealed at the initial stages of engineering construction will help lower the risk of construction damage after the construction is over.

THE MECHANISM RESPONSIBLE FOR “SLOW” DYNAMICS

Let us cite the known literary data on logarithmic (over time) processes of perturbation relaxation of different origin. The velocity of deformation variations, associated with dislocations and defects can be represented as the Arrhenius equation (a relation between the Arrhenius law and processes at a microscopic level is analyzed in [17]):

$$\dot{\varepsilon} = \dot{\varepsilon}_0 \exp \left( -\frac{\Delta G(\sigma)}{kT} \right),$$  (1)

where $\Delta G(\sigma)$ is equal to the Gibbs free activation energy; $\sigma$ is the strain acting on dislocations; $T$ is the absolute temperature and $k$ is the Boltzman constant. The preexponential factor $\dot{\varepsilon}_0$ assumed to be independent (or weakly dependent) of strain and temperature [17]. In general, the energy $\Delta G(\sigma)$ can be considered as a phenomenologically averaged magnitude dependent on internal (hidden) variables.

Macroscopic plastic deformations at different loads can be described with mechanical state equations. In many cases (e.g., for ordinary deformations and lesser curvature deformations) there is a unique functional-free relation between deformation velocity,
owing to the presence of \( \dot{\epsilon} \), in (2) appears as the result of the \( \dot{t} \) motion and deformation velocity \( \dot{\sigma} \), where \( M = (\partial \sigma / \partial \dot{\epsilon}) \), is the rigidity modulus; is \( \Lambda = (\partial \sigma / \partial \ln \dot{\epsilon}) \), the strain’s sensitivity to deformation velocity in case of a constant plastic deformation. The Gibbs thermodynamic potential does not explicitly depend on displacement and is defined as follows \([20]\): 
\[
\frac{dG}{d\sigma} = -S dT - V^* d\sigma, 
\]
where \( S \) is the entropy and \( V^* \) is the volume associated with macroscopic processes which determine relaxation character (1). The term \( \propto d(\ln \dot{\epsilon}) \) in (2) appears as the result of the inequality \( \Delta G/kT > 1 \). After taking a logarithm from (1) and differentiating over the \( \sigma \) value of \( \Lambda \) in (2) can be brought into conformity with \( kT/V^* \), which allows for the determination of the activation volume \( V^* \) from the experiment.

Differentiating Eq. (2) over time and assuming outside forces to be constant \( (d\sigma = 0) \), we get the following equation:
\[
M \dot{\sigma} + \Lambda \frac{d\dot{\sigma}}{dt} = 0, 
\]
where \( \dot{\sigma} = \dot{\ln} \dot{\epsilon} \). Thus, the time derivative of the deformation velocity \( \dot{\sigma} \) is proportional to the squared deformation velocity. Solving differential equation (3) we get the following equation for the relaxation velocity: \( \dot{v}(t) = \Lambda \dot{\epsilon}^{-1}/M \). It is not difficult to see that the character of relaxation owing to the presence of the term \( \propto d(\ln \dot{\epsilon}) \) in (2) qualitatively changes (integration constants being omitted):
\[
\dot{\epsilon}(t) = \frac{\Lambda}{M} \ln(t). 
\]

A peculiarity of Eq. (2) lies in the fact that the second term depends not on the deformation velocity (as with relaxation in a medium with Newtonian viscosity), but on the formation velocity. From a mathematical point of view the logarithmic time dependence appears due to relation (1) at \( \Delta G/kT \gg 1 \) and the locality of interaction between strain, deformation and deformation velocity (2). From the point of view of physics the logarithmic dependence appears due to the fact that the relaxation velocity is proportional not to the difference of the current and equilibrium state energies, but to the exponential function of the great argument. If the activation energy were low \( \Delta G \ll kT \), then due to thermal fluctuations, any two states would not be isolated and the relaxation law would be the same as that in a viscous liquid. Thus, the logarithmic dependence \( \propto \ln r \) is related to at least two localized thermodynamic equilibrium states. At that, for these states to exist, it is of principle importance for the condition \( \Delta G \gg kT \) to be met. Otherwise thermal perturbations will result in the braking of localized states and significant deformation of the equilibrium function of the (quasi)particle energy distribution \([17]\).

The existence of energy barriers necessitates the presence of several stable states. In case of multiphase structures, the potential energy of component interaction can be determined by different space scales (e.g. \([21–23]\)), which makes the existence of metastable states possible.

The experiment on the observation of perturbation relaxations in an unconsolidated soil, which will be considered below, is aimed at revealing the “slow dynamics” of these processes. We assumed the bonds between grains in an unconsolidated medium weak enough to be broken in the process of impact action on the soil. E.g., a liquid fraction which partially fills an intergranular space can yield two states with possible energy barriers (Fig. 1) \([21]\). Each energy state is characterized by a specific spatial distribution of material grains. Thus, in the process of relaxation of internal strains (deformations), the material is repacked and the grain configuration becomes denser than that in the case of a state with partially broken bonds.

**DESCRIPTION OF THE TECHNIQUE OF EXPERIMENTAL DATA PROCESSING AND PRESENTATION**

An array of sensors used in the experiment is shown in Fig. 2. The figures stand for the number of geophones (2–8) and accelerometers which monitor the magnitude of the force \( F_c \). A large down-directed vertical arrow schematically shows the region of short-time action on the soil. This force action was the result of a fall of a 35 kg mass from 1 meter onto a rigid surface of the specified area. Thus it was possible to evaluate the action (force, pulse, energy) applied to the soil.

The technique of experimental data presentation is worthy of detailed consideration. We assumed that the fall of the load would result in both consolidation and