On Wave and Rheidity Properties of the Earth’s Crust

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Abstract—The properties of the Earth’s solid crust have been studied on the assumption that this crust has a block structure. According to the rotation model, the motion of such a medium (geomedium) follows the angular momentum conservation law and can be described in the scope of the classical elasticity theory with a symmetric stress tensor. A geomedium motion is characterized by two types of rotation waves with short- and long-range actions. The first type includes slow solitons with velocities of $0 \leq V_{sol} \leq V_{0, max} = 1–10$ cm s$^{-1}$; the second type, fast excitons with $V_{0} \leq V_{ex} < V_{S} - V_{P}$. The exciton minimal velocity ($V_{0} = 0$) depends on the energy of the collective excitation of all seismically active belt blocks proportional to the Earth’s pole vibration frequency (the Chandler vibration frequency). The exciton maximal velocity depends on the velocities of $S$ ($V_{S} \approx 4$ km s$^{-1}$) and/or $P$ ($V_{P} = 8$ km s$^{-1}$) seismic (acoustic) waves. According to the rotation model, a geomedium is characterized by the property physically close to the corpuscular–wave interaction between blocks that compose this medium. The possible collective wave motion of geomedium blocks can be responsible for the geomedium rheidity property, i.e., a superplastic volume flow. A superplastic motion of a quantum fluid can be the physical analog of the geomedium rheid motion.

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1. INTRODUCTION

Actual solids include numerous defects, which can be represented as large tolerant formations with many ordered and regularly located mesodefects [1]. When a body is deformed, its mesostructures turn in block, and turning angles reach $10^\circ$ and more [2]. Even short-term loads caused by shocks can result in that monoblocks turn by ~$3^\circ$ in the plastic flow and elastic regions [3]. A translation–rotation vortex rather than a shear is a plastic deformation elementary act. These formations can be micro-, meso-, and macro-vortices [4].

Attempts to describe and understand the properties of actual solids according to classical concepts are extremely invalid if the density of dislocations is high and their collective soliton properties are taken into account [5]. When solids with internal degrees of freedom were considered, the Cosserat, Mindlin–Eringen, Leroux, and similar models were constructed [6, 7], and, as a consequence, the elasticity moment theory was developed. Such a research trend has been successfully developed (see, e.g., [8]). In particular, advanced construction materials with micro- and nanostructures, in which the grain size is among the main material quality parameters directly affecting the material strength and viscoelastic properties, are developed [9].

According to [6], “...the theories of the Cosserat medium and other bodies hypothetically fall in between the classical elasticity theory and solid state physics, according to which structural levels exist. A single mass point in a microstructured medium has “a reasonable” degree of complexity, which makes it possible to describe the material structure (this cannot be described by the elasticity theory) and deformation waves (this cannot be described in the scope of material engineering) ...Heavy lies “the crown” for researchers that take this path since they deal with the spheres of material engineering and elasticity theory and can be criticized from both sides.”

We should note that the elasticity moment theory is essentially a mathematical theory [10, 11] and runs into physical difficulties, which were observed almost
immediately when the theory appeared in 1910 ([12], p. 26). At the same time, the angular momentum conservation law is invalid in the scope of the moment elasticity theory. The existence of moment moduli of elasticity would inevitably affect solid body thermal properties: a body heat capacity should have been one—two orders of magnitude as high as the observed heat capacity [13].

Generally speaking, the problem of stress tensor symmetry has been solved in a physical theory of elasticity. Nevertheless, the followers of the classical course “The Elasticity Theory” in the first (1987) and the next editions (see, e.g., [14, pp. 17–18]) consider this problem again and present new evidence that the stress tensor is symmetric, which was constructed in the scope of the general microscopic theory.

The following question arises: can the stressed state of a medium with a symmetric tensor and internal degrees of freedom be described by wave models? According to the terminology presented in [6], the same question as follows: can “the crown” be kept in the scope of the classical physical elasticity theory [14]?

In the present publication, which continues the geophysical works [15, 16], we formulate the Earth’s crust stressed state problem as such a rotation problem with intrinsic degrees of freedom of the crust elementary volumes, using the rotating Earth elastic shell (i.e., the Earth’s solid crust) as an example. In the scope of this problem, we can obtain wave solutions with a symmetric stress tensor [17–19]. It is assumed that the Earth’s crust has a thickness of 30–40 km and is composed of blocks [20, 21]. For such a medium, “the crown” can be kept in the case when we reject the Cauchy stress principle [14], which is traditional for the elasticity theory, and replace the solid body point concept [11] by a solid body elementary volume with intrinsic moment. A difference of our approach [17, 22] from the traditional one [11, 14] is as follows. First, a rotating solid elementary part—the Earth’s crust block—is a rigid non-deformable volume; second, the block moves under the action of intrinsic moment; third, such a motion results in a change in the stressed state in the Earth’s crust around the block.

The following data obtained as a result of the geological and geophysical studies indicate that such a rotation approach [17, 22] to the problems of geodynamics is possible. The Earth’s crust is a block—structure (piecewise [21]) medium, the state of which depends on the inner motion potential [20] and intrinsic energy [23]. According to the mechanical concept, a motion with such properties [20, 21, 23] can be implemented only under the action of block motion intrinsic angular momentums (in essence, their spins [24]), the interaction between which can be responsible for the entire Earth’s crust motion and the crust volume flow in the cold state [25] and/or rheidity properties [26].

2. STRESSES WITH FORCE MOMENT

As is known, spin rate Ω, at which the coordinate system rigidly related to a body (the Earth) rotates at a given instant, is independent of this system, and each Earth’s crust element and/or block can be characterized by the same angular momentum (M) directed in parallel with the Earth’s rotational axis: $\mathbf{M} = I\dot{\Omega}$. Here I is the block spin moment of inertia. The Earth’s crust motion along the Earth’s surface results in a change in the angular momentum orientation $\mathbf{M}_1 \rightarrow \mathbf{M}_2$ (Fig. 1a), which leads to the appearance of force moment $\mathbf{P}_1$ applied to a block from the environment (the Earth’s crust) according to the angular momentum conservation law (Fig. 1b).

We use the following imaginary experiment in order to determine the force moment (K) value and orientation. First, we stop a block (which is considered to be a homogeneous spherical volume) in position B, applying elastic stresses with force moment $-\mathbf{P}_2$ to this block. Then, we spin the block to the initial state in position A with momentum $\mathbf{M}_1$, applying elastic stresses with force moment $\mathbf{P}_1$ to this block. Assuming that the block rotation kinetic energy is always transformed into elastic stresses and vice versa without loss of energy ($|\mathbf{P}_1| = |\mathbf{P}_2| = P$), we find that

$$|\mathbf{K}| = 2P \sin \beta / 2$$

for force moment K according to the cosine theorem.

It is important that elastic stresses with force moment K are applied from the ambient medium (the Earth’s crust) to a block through its surface according to such a rotation piecewise problem statement. Precisely stresses with force moment (1) applied to the Earth’s crust block are responsible for the nature of

![Fig. 1](image-url)
seismic moment of an earthquake with a source in this block.

Thus, we come to the model where the description of the motion of a geomedium block rotating at spin rate \( \Omega \) is mechanically equivalent to the block motion (turn by angle \( \beta \)) in a nonrotating (inertial) coordinate system under the action of intrinsic angular momentum \( \mathbf{M} \), which corresponds to force moment that generates an elastic field \( \mathbf{K} \) in the Earth’s crust around a block. The elastic stress field with force moment in the Earth’s crust, generated during such a rotational block motion, follows the angular momentum conservation law \([15–17]\).

Internal or intrinsic momentum \( \mathbf{M} \) has a specific geodynamic property: it cannot disappear owing to the physical conservation law and due to the Earth’s crust plastic deformation. Therefore, rotation stresses with force moment \( (1) \) will accumulate in the Earth’s crust as a result of the block progressive motion (since the block turn angle \( (\beta) \) increases and angle \( \alpha \) is constant, Fig. 1), which can explain such a known geomedium phenomenon of seismic emission, proper to the Earth at different depths and under various geological and tectonic conditions \([27]\), can also be related to the geomedium energy saturation property.

3. ELASTIC FIELD AROUND A ROTATING BLOCK

We assume that the Earth’s crust block (supposedly nonrotating inertial), rotating under the action of intrinsic momentum, generates elastic stresses with force moment \( (1) \) in an enclosing rock mass. We formulate the following problem for a solid body in the \( r > R_0 \) region in order to determine elastic stresses and their energy \( (W) \) and force moment (seismic moment) \( \mathbf{K} \) generated by a spherical block with radius \( R_0 \), rotating under the action of intrinsic momentum \( \mathbf{K} \). We solved the equation of elastic equilibrium

\[
\text{grad} \mathbf{U} - a \text{curl} \text{curl} \mathbf{U} = 0
\]

with zero displacements at infinity

\[
|\mathbf{U}| \rightarrow 0
\]

at

\[ r = (x_1^2 + x_2^2 + x_3^2)^{1/2} \rightarrow \infty, \]

zero force applied to a block with volume \( V \)

\[
F_i = \int \sigma_{ij} n_j dS = 0
\]

and nonzero force moment independent of a block size

\[
K_i = \int x_i e_{ikl} \sigma_{jl} dS_j \neq f(R_0).
\]

Here, \( a = (1 - 2\nu)/(1 - \nu) \), \( \nu \) is the Poisson’s ratio, \( e_{kl} \) is the Levi–Civita tensor, and \( n_j \) is the normal to the block surface element \( (dS) \) along which the integration is performed in the last two expressions. Subscript \( i \) in the expressions for force \( (F_i) \) and force moment \( (K_i) \) in the orthogonal coordinate system \( (x_i) \) is \( i = 1, 2, 3 \). According to the general rule, the summation is performed over recurrent indices, and \( f(x) \) is an arbitrary function.

We analytically solved the problem in the \( r > R_0 \) region in the spherical coordinate system \( (r, \theta, \phi) \) with origin \( r = 0 \) at the block center and with plane \( \theta = 0 \) orthogonal to intrinsic momentum for force moment \( K \)

\[
K = -8\pi^{3/2} \Omega R_0^4 \frac{\rho G}{5} \sin \beta/2. \tag{2}
\]

The minus sign means that force moment is applied to a geoblock from an enclosing body, i.e., the Earth’s crust. In this case energy \( W \) is defined by the equality

\[
W = \frac{16}{15} \pi \rho \Omega^2 R_0^5 \sin^2 \beta/2, \tag{3}
\]

and the symmetric stress tensor is defined by the expression

\[
\sigma_{\phi\theta} = \sigma_{\phi\phi} = 4\Omega R_0^4 r^{-3} \frac{\rho G}{5\pi} \sin \theta \sin \beta/2. \tag{4}
\]

The remaining stress tensor components are zero.

In this case \( \rho \approx 3 \text{ g cm}^{-3} \), and \( G \approx 10^{12} \text{ dyn cm}^{-2} \) are the geomedium density and shear modulus, respectively; \( \Omega = 7.3 \times 10^{-5} \text{ rad s}^{-1} \) is the Earth’s spin rate. Directly substituting obtained solutions \( (2)–(4) \) in the initial equations, we can be convinced that these solutions are accurate.

For earthquakes with \( M \approx 8 \) \((7.5–8.5)\), which are characterized by sources with \( R_0 \approx 100 \text{ km} \), the values of the geomedium density and shear modulus indicated above, and the Earth’s spin rate, the theoretical values \( (K \approx 10^{27} \text{ dyn cm} \text{ and } \sigma \approx 10^{9}–10^{10} \text{ bar}) \) obtained based on model relationships \( (2) \) and \( (4) \) almost coincide with the experimentally determined values of seismic moment and stresses released at a seismic source \([28]\). Relationship \( (2) \) indicates that the seismic moment value is directly proportional to the product of the centrifugal velocity \( (V_\phi = \Omega R_0) \) by the source volume \( (\sim R_0^3) \). In this case the block (earthquake source) turn angles are \( \beta_0 = 10^{-4}–10^{-2} \text{ rad} \), which corresponds to a spin rate of \( 10^{-7}–10^{-4} \text{ rad yr}^{-1} \) (determined based on the instrumental geodetic \([29]\) and geophysical \([30]\) measurements) in the case when such earthquakes recur once per \( 100–1000 \) years at one site. It is clear that the range of the geoblock spin rates corresponding to the rotation model meets the range of the instrumentally determined geodynamic spin rates, which can indicate that the constructed block rotation model \([31]\) and its consequences \([13, 17, 32, 33]\) are correct.
4. INTERACTION BETWEEN BLOCKS: LONG- AND SHORT-RANGE ACTIONS

In the model of two blocks \( (R_{01} \text{ and } R_{02}) \) located at distance \( l \) from each other, it became possible to analytically calculate the interaction energy between these blocks \( (W_{\text{int}}) [31] \). For this purpose, we calculated the third term, equal to a double product of the first and second stress tensor invariants for the elastic energy in the expression for the energy related to the interaction between two blocks \( (W = G \int (a_1 + a_2)dV = G \int a_1^2dV + G \int a_2^2dV + 2G \int a_1a_2dV = W_1 + W_2 + W_{\text{int}}, \) where \( a_{1,2} \) are the elastic deformation tensors generated by either rotating block separately). As a result, we obtained the following expression for the energy of such an interaction

\[
W_{\text{int}} = \frac{2}{2} \pi \rho \Omega^2 R_{01}^4 R_{02}^4 l^{-3} \cos \phi,
\]

where \( \phi \) is the angle between block moments. Either block tends to turn another block due to this energy. We determine force moment related to the interaction between blocks by differentiating (5) with respect to angle \( \phi \):

\[
K_{\text{int}} = -\frac{3}{2} \pi \rho \Omega^2 R_{01}^4 R_{02}^4 l^{-3} \sin \phi.
\]  

Force moment (6) is applied from the elastic field to the surface of either block and is directed so that the energy of interaction between these blocks would be decreased. This moment has the same absolute value for both blocks but is directed oppositely.

For equal blocks \( R_{01} = R_{02} = R_0 \), the ratio of the block interaction moment (6) to block intrinsic momentum (2) is found from the relationship

\[
\frac{K_{\text{int}}}{K} = \frac{3}{16\sqrt{5\pi}} \frac{\Omega R_0}{V_S} \left( \frac{R_0}{l} \right)^3 \sin \phi / \sin \beta/2 = \chi,
\]

which indicates that the moment interaction becomes more substantial with increasing centrifugal velocity \( V_R = \Omega R_0 \) (i.e., with increasing body spin rate \( \Omega \) and block size \( R_0 \); \( V_S = \sqrt{G/\rho} \) is the wave velocity). The maximal (\( \sin \phi = 1 \)) moment span \( (l = l_{0K}) \) at which the elastic field moment \( K_{\text{int}} \) will be equal \( (\chi = 1) \) to block intrinsic momentum \( K \) will be written in the following form at the model parameters accepted above

\[
l_{0K} = \left( \frac{3}{8\sqrt{5\pi}} \right)^{1/3} \left( \frac{V_R}{V_S} \right)^{1/3} R_0 = R_0.
\]

Thus, the limit moment interaction between geoblocks is observed at small distances (not more than a block size) and (as well as forces of the molecular interaction between medium particles in the classical elasticity theory) can essentially be a short-range action.

Similarly, calculating the ratio of the block interaction energy (5) to the block intrinsic energy (3) for span \( l = l_{0W} \) (characterizing the limit energy interaction), we obtain the expression

\[
l_{0W} = \sqrt[3]{6\pi GS} \sqrt{\frac{2}{3}} \simeq 1.7 R_0.
\]

This expression indicates that the rotation elastic field responsible for the energy interaction propagates over substantially larger distances (larger than block dimensions by two orders of magnitude) and can thereby be a long-range field.

Thus, in the scope of the presented rotation model, a geomedium is characterized by a specific corpuscular–wave interaction between blocks. First, by a short-range action owing to the moment exchange between adjacent blocks \( K_{\text{int}} \) (6) rather than due to (as in the moment elasticity theory) friction along the boundary between these blocks that hinders the interaction between blocks according to the rotation model. The examples of such an interaction are known in seismology. First of all, they include the strongest earthquakes-duplets (and multiple quakes) with closely located sources [13, pp. 119–123]. In addition to the strongest quakes, intense free oscillations of the planet are always excited in wide areas on the Earth’s surface in this case. Second, by a long-range action owing to the energy interaction \( W_{\text{int}} \) (5) between blocks at large (much larger than a block size) distances. The examples of such an interaction are also widely known in seismology: the migration of earthquake sources along seismic belts over many ten thousand kilometers [33], distant foreshocks and aftershocks, and pairs of earthquakes with sources located at distances much larger than source dimensions occurring on short time intervals [13, pp. 119–123].

Short- and long-range actions are often related to corpuscular (through particle boundaries) and wave (through a medium where particles are located) interactions. According to the block-structure geomedium concept described in the work, the structural elements composing a geomedium can be considered as elementary particles. Consequently, according to the rotation model, the geodynamic interaction between blocks can be a physical analog of the general principle, i.e., a corpuscular–wave dualism: both corpuscular and wave properties are observed in the motion of geophysical blocks, tectonic plates, and other geological structures. We illustrate such a concept using the interaction between geomedium blocks in the scope of the rotation model we developed [13, 31].

5. BLOCK CHAIN MOTION EQUATION

For a block generating an intrinsic elastic field with force moment (2) and interacting with intrinsic elastic fields of other equal chain blocks according to (5) and (6), we obtained the motion law in the form of the
sine–Gordon (SG) equation in the dimensionless form [13, 15]
\[ \frac{\partial^2 \theta}{\partial \xi^2} - \frac{\partial^2 \theta}{\partial \eta^2} = \sin \theta. \]
Here, \( \theta = \beta/2, \xi = k_0 z, \) and \( \eta = v_c k_0 t \) are dimensionless coordinates; \( z \) is the distance along the mass (block) chain; and \( t \) is time. Assuming that the wavelength is close to the block size \( (\lambda = R_0) \) (a tectonic approximation [10]) and the wave number is \( k_0 = 2\pi/R_0 \), we obtain the following expression for the characteristic process development rate \( (v_0) \)
\[ v_0 = \sqrt{\frac{15}{8\pi^2} \Omega R_0 \sqrt{G/\rho}} \]
\[ = \sqrt{\frac{15}{8\pi}} V_r V_R = 0.2 \sqrt{V_r V_S}. \] (9)

The block chain motion law is predetermined by the expression for elastic field force moment in form (2). Therefore, the SG equation obtained in [31] directly results from the angular momentum conservation law. This makes it theoretically possible to ignore the interaction between geodimensions blocks due to friction, as is assumed in the momentum elasticity theory (see, e.g., [10]), in the geodynamic rotation problem of the chain of interrelated geodimensions blocks. As a result, such an approach makes it possible to physically transparently interpret the characteristic rate of the geodynamic process that is described by the SG equation, if solutions (2) and (3) of the rotation problem were obtained according to the classical elasticity theory [14] with a symmetric stress tensor (4).

When parameters \( G, \rho, \) and \( R_0 \) are fixed, rate \( v_0 \) (9) depends only on spin rate \( \Omega \); i.e., such a deformation type is caused by the Earth rotation [19]. Therefore, the model was called a rotation model [13, 31]. At the Earth’s crust parameters accepted above, the characteristic rate value is \( v_{0, \text{max}} = 10^{-2} \text{m/s}. \)

6. ROTATION WAVES

We analyzed the case of a chain with nonuniformly rotating blocks, which more corresponds to an actual geodynamic process. These blocks are characterized by force moment deviations from equilibrium positions \( \gamma \) with regard to friction forces \( \alpha \) along the block boundaries. Here, friction is considered again as a dissipative factor, which hinders the block rotation interaction caused by friction forces, rather than as a mechanism by which blocks interact owing to their mutual engagement according to the elasticity momentum theory. As a result, the law of block motion in a chain was obtained in the form of a modified SG equation
\[ \frac{\partial^2 \theta}{\partial \xi^2} - \frac{\partial^2 \theta}{\partial \eta^2} = \sin \theta + \alpha_f \frac{\partial \theta}{\partial \eta} + \mu \delta(\xi) \sin \theta, \]
which was solved numerically using the McLaughlin–Scott method. Here \( \delta(\xi) \) is the Dirac function. The initial conditions corresponded to the average strain rate in seismically active regions. In the model calculations, coefficients \( \alpha_f \) and \( \mu \) corresponded to actual faults. An analysis indicated that the interaction between blocks (earthquake sources) was mainly accompanied by slow motion (creep) during a long seismic cycle period, when the rotation deformation transmission rate was \( c_{0, \text{max}} \approx 1-10 \text{ cm/s} \) [19].

Thus, taking into account the fact that the functional dependence of rate \( c_0 \) is the same as such a dependence for \( v_0 \) (9) \( c_0 = v_0 = \sqrt{\rho V_r V_S} \) and the rate maximal values are \( c_{0, \text{max}}/v_{0, \text{max}} = \gamma' = 10^{-3}, \) we can represent the characteristic transmission rates of rotation deformations (stresses with force moment) in the block geomedium model as [15]
\[ c_0 = \gamma' v_0 = \gamma \sqrt{\rho V_r V_S}, \]
\[ c_{0, \text{max}} = 1-10 \text{ cm/s}, \] (10)
where \( \gamma = 10^{-4} \). Equality \( \gamma = K^{-1}, \) where \( K \approx 10^4 (10^3-10^5) \) is the geomedium nonlinearity coefficient equal to the ratio of the third-order elasticity moduli to the second-order elasticity moduli (linear elasticity moduli) [34], seems to be nonrandom and makes it possible to interpret parameter \( \gamma \) as a nonlinear parameter characterizing an actual block chain (equal and nonuniformly rotating owing to friction), i.e., the set of earthquake sources filling a seismic belt.

The SG equation has many solutions. Modeling the motion in long molecular chains, Davydov [35] indicated that wave motions in such chains are described by the nonlinear modified SG equation with two types of excitations as solutions: solitons and excitons (solutions I and 2 in Fig. 2, respectively). Such solutions are characterized by limit velocities \( V_{1, \text{max}} \) and \( V_{2, \text{max}} \) corresponding to maximal excitation energies \( (E_{\text{max}}) \).

All migration rates of the Pacific earthquake sources, which were published and obtained in [18, 32], are presented in Fig. 3. The global (along the entire seismic belt, I) and local (within strong earthquake sources, II) migration dependences \( M_{1,2}(\log V_{1,2}) \), the limit velocities \( (V_{1,2}) \), and the corresponding maximal magnitudes \( (M_{1,2, \text{max}}) \) are:
\[ M_1 \approx 2 \log V_1, \quad V_{1, \text{max}} = 1-10 \text{ cm/s}, \]
\[ M_{1, \text{max}} = 8.5-9, \] (11)
\[ M_2 \approx \log V_2, \quad V_{2, \text{max}} = V_S - V_P = 4-8 \text{ km/s}, \]
\[ M_{2, \text{max}} = 8.5. \] (12)
Here, \( V_P = 8 \text{ km/s} \) and \( V_S = 4 \text{ km/s} \) are the values of \( P \) and \( S \) seismic velocities for the Earth’s crust.

A comparison of the data presented in Figs. 2 and 3, where the earthquake magnitude \( (M) \) and the elastic energy \( (E) \) released during earthquakes are connected by the known relationship \( M = \log E, [E] = J \), indicates
that the theoretical (model for molecular chains, Fig. 2) and experimental (migration for earthquake source chains, Fig. 3) dependences qualitatively coincide with each other. This makes it possible to interpret experimental migration dependences (11) and (12) as soliton and exciton solutions for the SG equation with characteristic limit velocities $V_{01} = V_{1,\text{max}}$ and $V_{02} = V_{2,\text{max}}$. In this case the limit velocity of the soliton ($I$ in Fig. 2) solution ($V_{01} = 1-10 \text{ cm s}^{-1}$) coincides with the maximal value of characteristics velocity $c_{0,\text{max}}$ (10) determined according to the rotation block nonlinear geomedium model. This makes it possible to interpret a geomedium as a velocity of the SG equation soliton solution: $c_{0} = V_{01}$.

Thus, the mathematical closeness of the wave equation solutions for the chains composed of blocks (I and II in Fig. 3, relationships (11) and (12)) and molecules ($I$ and $2$ in Fig. 2), which are one-dimensional and long, made it possible to assume that the interactions between the solution elementary components are physically identical. It is known that the soliton solutions to the SG equation are characterized by several important properties corresponding to the properties of actual elementary particles [35]. At the same time, excitons are such disturbances that degenerate into ordinary waves in a linear approximation [35], i.e., into $P(V_P)$ and $S(V_S)$ seismic waves in our case. Therefore, the soliton and exciton solutions with limit velocities $V_{01} = c_{0,\text{max}}$ and $V_{02} = V_S - V_P$ revealed in the scope of the rotation model can essentially be a new type of elastics waves in solids, i.e., rotation waves [17, 19], which can be responsible for corpuscular–wave interactions between blocks in rotating block-structure mediums (a geomedium). Essentially the same fast (exciton) and slow (soliton) deformation [37] and pendulum [38] waves were instrumentally registered in mines and modeled under laboratory conditions [39]. The geophysical interrelations between rotation, pendulum, and deformation waves were considered in more detail in [15, 16].

The conclusion that a new type of solitary waves, the velocity of which is not higher than certain limit

![Fig. 2. Wave solutions $E(V)$ to the SG equation [35]. Solitons ($1$) and excitors ($2$). $V_{01}$ and $V_{02}$ are the characteristic process velocities corresponding to limit energies $E = E_{\text{max}}$ of the soliton ($0 \leq V < V_{01}$) and exciton ($0 \leq E \leq E_{\text{max}}$, $V_{01} < V < V_{02}$) solutions, respectively. $E_{\text{max}}$ is the maximal energy value corresponding to small earthquake magnitudes, and $E_0$ is the energy value corresponding to a collective excitation of the entire set of molecules in a chain [35] (earthquake sources in a seismic belt as a whole) when the chain remains immovable ($V_0 = 0$); zero frequency of such a seismic belt oscillation predetermines the planet’s pole nutation, i.e., the Chandler vibration.](image)

![Fig. 3. Velocities of the global ($I$, along the entire Pacific margin) and local ($2$, within individual sources of strong Pacific earthquakes) earthquake migrations depending on their magnitudes $M$ [18, 32]. $I$ and $2$ are the global and local dependences $M(\log V)$ determined using the least squares method, and $V_S$ is the velocity of $S$ waves.](image)
values, was formulated for nonlocally elastic solids [40]. The existence of a slow mode, the propagation velocity of which is much lower than the velocity of sound in a fluid, solid granule material, and gas, was theoretically and experimentally justified in [41]. A slow dynamics and its influence on material elastic properties were established in [42]. The rotation model conclusion that the entire seismic belt has zero oscillation frequency (Fig. 2) is also confirmed in [43]. Thus, when an intermetallic film extension increases, oscillation frequency (Fig. 2) is also confirmed in [43].

Thus, when an intermetallic film extension increases, oscillation frequency (Fig. 2) is also confirmed in [43].

The situation dramatically changes if we pass to the rotation mode \( c_0 \) (10), i.e., global geodynamic motions with limit velocity \( c_{0, \text{max}} \) (1 in Fig. 3) depend on collective motions of the sets of geophysical blocks, tectonic plates, and geological structures. Expression (10) indicates that a limit value \( c_{0, \text{max}} \) typical of such a mode is five orders of magnitude as small as \( S \) and \( P \) seismic velocities, and the Debye temperature for this mode is not higher than a negligible quantity

\[
\theta_D \approx 10^{-2} \text{K},
\]

which can indicate that a geodynamic rheid motion [26] and/or its superplastic flow is possible when this medium is in a solid state [25].

We assume that a quantum fluid superfluidity, corresponding to the states of the entire fluid [47], can be physically similar to a geodynamic rheid flow responsible for a collective motion of blocks that compose this medium. This is possible because the concept of the states of individual atoms has no sense in a quantum mechanical system with strongly interacting particles, such as a quantum fluid [48]. This similarity of a block-structure geomedium and a quantum fluid is considered in more detail below.

The Debye temperature is responsible for the maximal energy quantum that can excite oscillations of the entire grid [49]. We indicated [13, pp. 244–258; 43] that the Chandler frequency of the planet pole vibration is the characteristic frequency for the entire seismic belt of the Earth. Precisely the motion of the entire belt with \( V_0 = 0 \) can depend on zero oscillation energy \( E_0 \) (Fig. 2).

8. DISCUSSION OF THE RESULTS

The rotation model for a geomedium was constructed on the assumption that a geomedium elementary block is a nondeformable volume with intrinsic moment. Such a model makes it possible to explain the nature of earthquake moment, which is an intrinsic moment of the Earth’s crust block where this earthquake source is located. The conclusions that a new type of rotation geodynamic waves exists was formulated and is confirmed by the theoretical and experimental data of physical acoustics [40–42], solid state physics [1–3, 44], instrumental observations in mines [37, 50], and laboratory studies of massive block chains [38, 51]. It became possible to explain several geodynamic (seismic, geophysical, volcanological, and tectonic) regularities using the concept of a symmetric stress tensor [13, 15–17, 32, 33]. In other words, “the crown” [6] can be kept for a geomedium...
according to the rotation model. We assume that the elements of the rotation geodynamic model described in the work can also be used in continuum mechanics and solid state physics.

1. The geological environment is saturated [23] with an intrinsic energy [20] and is characterized by a constant seismic emission [27]. Intrinsic moment of such a geomedium block is essentially spin [24]. Precisely such an interpretation of geomedium block intrinsic moment, which is considerable (up to $K = 10^{27}$ dyne cm and more) when block dimensions reach several hundred kilometers at a high Earth spin rate, makes it possible to most generally render the results achieved based on this interpretation.

First, by definition, spin is among the specific concepts of quantum mechanics reflecting the essence of this mechanics [52]. At the same time, spin is the same primary property of a particle as quite classical particle parameters (mass, charge) [53]. At such a spin definition, the spin origination problem becomes unessential; therefore, intrinsic moment can be attributed to a particle independently of whether this particle is elementary or complex [52] with micro- or macrodimensions.

Second, numerous experimental data indicate that the elementary particle spin properties are prominent in the region of micromanifestations and in the behavior of macroscopic systems [54]. Such spin properties predetermined the introduction of quasi-particle formalism [48] on the one hand and made it possible to assume that macroscopic body parts have intrinsic moment on the other hand [24].

Third, the number of blocks that compose the Earth’s crust is extremely large. The general character of the regularities in the systems that include so many particles is largely independent of mechanics that describes the individual particle motion: classical or quantum mechanics. The so-called statistical regularities related to the presence of many particles that compose a body cannot be reduced to purely mechanical regularities. The specificity of these regularities consists in that they lose any subject-matter in going to mechanical systems with few degrees of freedom [55].

On the one hand, the intrinsic moment—spin geoblock concept [24] is quite physically reasonably used in geodynamic problems. On the other hand, the usage of the intrinsic moment—spin concept as a basic one made it possible to explain such a collective property of the geological environment as a medium rheid flow [26], which (as well as quantum fluid superfluidity [47, 48]) cannot apparently be understood in a standard way [15, 56].

Rotation waves and a rheid state are closely related to the so-called vortex motions of the geological environment, i.e., vortex geological structures with dimensions varying from several meters to 1000 km and more, which were in situ formed in the solid state and due to the upper mantle substance as arc-shaped structures rather than mechanically twisted from initially rectilinear structures [15, 32]. The phenomenon essence was briefly described in [32, 56] and was described in detail in monograph [57]. In the present work, vortex motions of a geomedium were not considered.

2. The block turn angle time derivative, i.e., the rotation deformation rate depending on the Earth’s spin rate ($\beta$) and the propagation velocity of a rotation wave, which is a solitary $S$ wave polarized perpendicularly to the propagation direction [19], rather than the block turn angle ($\Omega$) contains more physical information used to describe the deformation process in the scope of the rotation model. An analysis of the dispersion properties in such complex block-structure systems indicates [11] that waves of micro- and macrorotations, which are similar to spin waves in their properties and characterize internal rotations of mediums [58], appear in these systems.

We indicated above that fast and slow waves, which are close to rotation waves (excitons and solitons, respectively) in their velocity characteristics, were experimentally registered in mines as deformation waves [37, 38] and were modeled under laboratory conditions as pendulum waves [39]. Such a disturbance wave character of the seismic energy release regime was an important diagnostic parameter for the stress-strain state level of rock mass controlled zones [59, 60]. Moreover, when the pendulum wave origination was analyzed, it was indicated that friction between interacting blocks disappear [38]. These data can confirm the rotation model conclusion that geomedium wave motions are related to rheological properties of this medium, i.e., to the possibility of a rheid (frictionless) volume [25, 26] flow.

It is theoretically possible to combine such superfluously contradictory data on geomedium properties in the scope of the known matter plastic flow models in particular. Indeed, it was indicated that the plastic flow localization in metals and alloys has a clearly defined wave character, and the localization patterns observed at different sliding stages represent different types of wave processes [61, 62].

The interaction between rotation geodynamic phenomena (including instrumentally registered float oscillations of the Earth as a whole, perpendicular to the plane of the Earth rotation around the Sun) and gravity, which was discussed in detail in [63, 64], was not considered in the present work.

3. Generally speaking, quasiparticles including solitons and excitons are defined differently by different authors [35, 36, 48, 49, 55, 65]. In the present work, we interpret solitons and excitons as was performed in [35].

The Earth’s crust is a solid body mainly (at depths larger than several kilometers) composed of crystallized rocks. Therefore, it seems physically reasonable to apply the Debye theory to geodynamic problems.
To prove that it is possible to pass to the rotation mode $c_0$ (9), (10) in the Debye theory, it is necessary to go from elastic phonons, which are quanta of the interaction between point (with zero dimensions and without intrinsic momentums) atoms in the crystal lattice, to tectonic solitons (9), (10), which are mediating particles for the geodynamic interaction between blocks of a (rotating) geomedium and, as a result, possess intrinsic angular momentums (1), (2) (Fig. 1).

4. As was indicated in the work, the global rotation elastic field of the Earth is composed of specific quanta, i.e., local fields independently generated by each block (plate, geological structure) moving progressively along the rotating Earth surface (Fig. 1, relationships (2)–(4), and interactions between these geological objects (relationships (5) and (6)). Force moment (relationships (2) and (6)) is the same inherent characteristic parameter of each rotation local field as, e.g., spin of photon, i.e., electromagnetic field quantum, and/or electron, i.e., an elementary particle. According to the rotation concept we developed, the genetic interrelation between the “elastic field stress” and “force moment” concepts is maintained by the angular momentum conservation law, which can explain the nature of the geodynamic field dualism (the wave and particle properties typical of this field) at the macroscopic planetary level.

9. CONCLUSIONS

We indicated that it is possible to avoid the main continual theory difficulties (the determination of the moment stress physical sense and the relation between medium material constants and structural parameters [8]). Indeed, the rotation model with a symmetric stress tensor makes it possible to combine the geomedium block structure with its wave and rheological properties. The justification and importance of the main two statements of the geodynamic rotation model described in the work (the geomedium block structure and the possibility of taking block rotations into account) also result from the data obtained in different scientific fields: solid state [1, 2, 9] and fracture [60, 66] physics, physical mesomechanics [4, 8], and engineering geology [37, 51, 59]. The possibility of describing the geomedium block wave motion is confirmed by the studies in the fields of mesomechanics [11], solid state physics [35, 65], physical acoustics [40], plastic flow macrolocalization [61, 62], and tectonophysics and practical geology [38, 50]. In other words, we managed to physically reasonably combine still incompatible theories [6]: the classical physical elasticity theory and the continuum structure concepts. The results achieved in the scope of the rotation geodynamic model are confirmed by numerous field geological and instrumental geophysical observational data on the rock mass stressed state and by experimental physical data obtained under laboratory conditions.

The grain size of a “laboratory” solid body is many orders of magnitude as small as the geomedium block size. Therefore, rotation interactions between grains can be insignificant against a background of other interactions in usual bodies. Nevertheless, the effect of material fatigue (irreversible strain accumulation), which is essentially close to the rock energy saturation, makes it possible to assume that moment stresses (with force moment) can operate in “laboratory” solids.

We assume that a contradictory situation was at first sight formed in continuum mechanics, which is related to the problems of symmetry [14, 15], i.e., asymmetry [7, 10] of the stress tensor and “the crown” [6]. On the one hand, the Cosserat and similar models are mathematically [10, 11] and physically [12, 13] contradictory. On the other hand, this scientific field is nevertheless actively developed theoretically [8], and the achieved results are applied in practice [9]. We try to understand how this contradiction is explained based on the statements of two Nobel prize winners. Thus, R. Feynman stated: “I feel that it is safe to say that nobody understands quantum mechanics” [67]. Nevertheless, Gell-Mann assumed that researchers perfectly embraced this mechanics [68].

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