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MODEL REPRESENTATION OF ANTHROPOGENICALLY MODIFIED SUBSOIL AS A NEW OBJECT IN LITHOSPHERE*

Geoecology of subsoil use is concerned with fundamental geomechanical study into the anthropogenic impact on processes running in the dynamic structure of the lithosphere. It is required to solve a two-side problem including, on the one hand, disclosure of the behavior of natural lithosphere objects under anthropogenic attack aimed at production of mineral resources and, on the other hand, determination of the conditions for the continuous recovery of stable dynamic structures such that no natural disasters initiate or are initiated in the lithosphere.

Model representation of the anthropogenic modification of the lithosphere in the course of commercial production of mineral resources needs geophysical image-building of the lithosphere as an element of the global geosystem. Anthropogenically modified subsoil can be presented as an object surrounded by the virgin lithosphere. Inside this object, there is a zone of anthropogenic damage and a zone of the damage-induced change of stress state. The zone of total destruction in the lithosphere (after mineral mining) can be imaged using the known model of movement of density discontinuities in the solid environment in the earth's gravitational field. In this case, extraction of some part from the lithosphere is presented as the process of growth and movement of discontinuities with zero density. The notion of anthropogenically modified subsoil also includes lithosphere areas (objects) which are altered without change in density. Accordingly, it is critical to delineate the zone of these collateral changes, i.e. the boundary of a new man-made object in the lithosphere.

A solid is represented by an ideal continuum where strains due to external forces are only totally reversible if internal stresses are below limiting values of strength of this solid. Inside the solid, different-scale discontinuities are uniformly spread at the spacing much larger than the size of these discontinuities. The discontinuities are responsible for irreversible strains: stresses concentrate and relax with time at these discontinuities.

This article presents a general problem, its solution procedure and equations for each specific combination of the lithosphere properties and the nature of anthropogenic modification. The results provide insight into the mechanism of change in the behavior and properties of rock mass in the zone of geophysical ecotone (transient behavior zone) which appears in the natural geophysical environment under anthropogenic disruption of general dynamic balance in the course of mineral mining.

Keywords: *Anthropogenically modified subsoil, natural-and-technical systems, different-scale discontinuities, solid, lithosphere, ecotone, strains, stresses, relaxation, elastic and inelastic strains, mineral deposit.*
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General provisions

Anthropogenic modification of subsurface is limited by the capacity of geophysical structures to localize the area of human impact and to involve it eventually into the ongoing evolution of surrounding rock mass. In this way, geoecology of mineral mining is connected with fundamental geomechanical study into effect of man-caused loads on processes in the dynamic lithosphere structures and calls for solving a two-side problem. This problem includes disclosure of regular variation in properties of natural lithosphere objects under anthropogenic invasion aimed to produce mineral resources, on the one side [1–12], and, on the other side, determination of conditions for persistent recovery of stable dynamic structures such that no natural disasters initiate or are initiated in the lithosphere.

In its turn, the first part of this basic problem is composed of two different-nature elements mutually deterministic through the shared final objective. Attaining this objective needs:

- A model representation of subsoil altered by man as an object that originates in the lithosphere under anthropogenic invasion with intent to obtain mineral resources;
- A generalized model of the invasion process as a cause of the local alteration of undisturbed lithosphere properties, which allows outlining the areas with altered properties as new-type lithosphere objects.

Visualization of anthropogenic modifications in the lithosphere in the course of commercial-scale mineral mining requires geophysical imaging of the lithosphere as an element of the global geosystem. Having translated the notions of the living matter and stagnation matter by the Academician Vernadsky into geophysics, we represent the currently technology-accessible portion of the lithosphere as a coating made of the geodynamical *stagnation* matter above the geodynamically *living* body of our planet [13]. Naturally, dynamic events of various scale and strength occur in the

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lithosphere, but, in the framework of our assumption, these events are not initiated by the matter of the lithosphere but are reflective (expressive) of the dynamic processes running in the much deeper interior of the planet. Such assumption is moreover required to skim excessive complexity off the problem on interaction of two dynamic systems (man-altered subsurface and primary lithosphere) in terms of technology-governed accuracy of the final result.

Methodological approaches

The key geoecological feature of subsoil use aimed to obtain resources for development of the modern civilization is the massive and volume attack on the environment. All geospheres suffer from this disturbance: lithosphere, hydrosphere, atmosphere, biosphere and anthroposphere (sphere of man's interests) [14]. The lithosphere experiences the highest scale transformations, both qualitatively and quantitatively. A part of the lithosphere is extracted to ground surface and involved in the circulation of the matter and energy outside the self-balancing system of the lithosphere. The model representation of man-altered subsurface may use terms and notions from theoretical ecology but converted for specific geoecological conditions of subsoil use.

The problems of biological ecology are usually plane (two-dimensional), while geoecology problems within lithosphere are always three-dimensional. By analogy with structure of man-caused damage in biota, the geoecological change zone (anthropogenically modified subsoil) includes areas of complete violation of virgin state, up to voiding. This is the volume of anthropogenic damage in the lithosphere. Within an envelope surrounding this volume, the lithosphere matter preserves physical state but changes mechanical properties (density, stresses, strains, etc.). The size and shape of this envelope are governed by the natural properties of the lithosphere material and by the nature of anthropogenic transformation in the complete damage zone in the lithosphere. Having extended the classical ecology triad, namely, pollution—transit medium—deposit medium—to the described conditions [15], we arrive at the formulation that: destruction of a certain volume in the primarily equilibrium lithosphere results in distortion of geophysical fields (pollution); through the transit medium—gravity field of the Earth—*pollution* is transferred to the virgin areas in the lithosphere and sets them in a new stress state (by depositing there). Such interaction circuit, by analogy with theoretical ecology, means that the pollution zone has its external boundary occupied by the elements of the primary system. In this manner, the man-altered subsurface can be presented as a volume surrounded by the virgin lithosphere whereas inside this volume there is the zone of anthropogenic damage and the zone of the damage-caused change of stress state. Visualization of the zone of total damage in the lithosphere (volume void after extraction of mineral) can use the known model of movement of density discontinuities in the gravity field of the solid earth. Extraction of some part from the lithosphere can be presented as movement of discontinuities with zero density. Inasmuch as the notion of *anthropogenically modified subsoil* also includes areas (volumes) though disturbed but with unaltered density, it is critical to identify the external boundary of the state change, i.e. the boundary of a new man-caused object in the lithosphere.

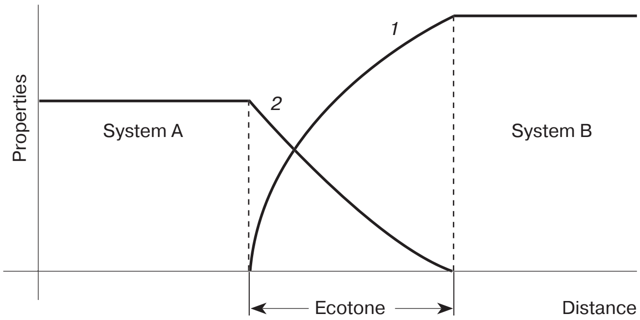

Fig. 1. Transient behavior zone (ecotone) at the contact of two different systems:
1 — law of degeneracy of properties B; *2* — law of degeneracy of properties A

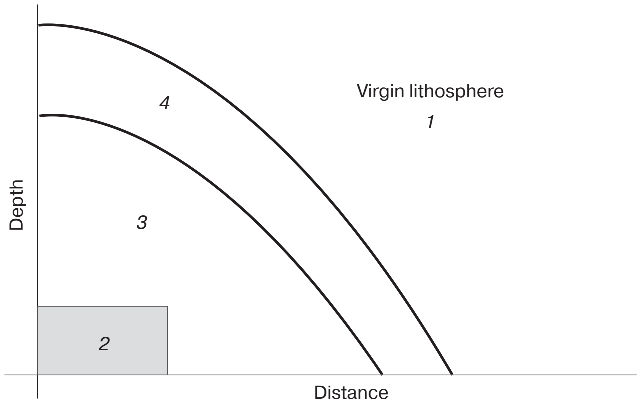

Fig. 2. Anthropogenically modified subsoil:
1 — virgin lithosphere; *2* — total destruction; *3* — distorted geophysical properties; *4* — geophysical ecotone (intercross degeneracy of properties of contact systems)

The problem on transitions between two systems with different properties is the classical problem in theoretical ecology. It has the notion of *ecotone*—a transitional community between different biological communities: influences of these communities intercross in this transition zone (**Fig. 1**) [16].

Research findings

As seen in Fig. 1, ecotone is a band within which properties of the contact systems degenerate to zero. In each specific case, the law of degeneracy of properties is governed by the properties of the systems and by the nature of their interaction. The structure and contents of this model adequately describes interaction between the anthropogenically modified subsoil and the virgin lithosphere but the problem becomes three-dimensional. The anthropogenically modified subsoil can be represented as a closed three-dimensional lithosphere object between two conditional surfaces of *zero* influence of the contact systems. No influence of the virgin lithosphere shows itself on the inner surface of this object, while no effect of the anthropogenically modified subsoil manifests on its external surface (**Fig. 2**).

Given such formulation of the problem, for determining basic parameters of the lithosphere object—anthropogenically modified subsoil, it is necessary to provide insight into the major object of geomechanics—rock mass—in its three states:

- In the virgin lithosphere;
- In the direct man-caused damage zone;
- In the zone of distorted geophysical fields (transient behavior zone—ecotone).

Given the existing vision of a physical model of solid and the physical postulates of mechanical models, we put forward our idea of a mechanical model of the virgin lithosphere as a structured solid.

A solid is an ideal continuum; its strains due to external forces are only totally reversible if internal stresses are not to exceed limiting values of strength of this body. At the same time, the solid contains various-scale discontinuities uniformly spread in its volume, and the spacing of the discontinuities is much more than their sizes. These discontinuities are responsible for irreversible strains: they concentrate stresses and relax with time. We assume this as the only mechanism of dissipation of mechanical energy in solid.

At any preset rate of strain, deformation energy is dissipated by discontinuities of the same size (more properly, of the same narrow range of sizes) as smaller discontinuities relax fast from stresses while larger discontinuities have no time to relax.

The volume occupied by discontinuities of the same size makes a small fraction of the volume of the solid. Denote the size of the discontinuities by l and their number in unit volume by n; then the volume of discontinuities in the interval d ($1n$) is given by:

$$\frac{l^3 dl}{d\ln l} = \frac{2}{\pi Q}, \tag{1}$$

where Q is the Q-factor determined by attenuation of elastic vibrations in solid [17].

The formula above involves no characteristic sizes so that volumes of different size solids are similar in terms of the number of discontinuities they contain. In the meanwhile, in terms of mechanical properties, these volumes are only similar when the sizes of energy-absorbing discontinuities are proportional to the size of the body.

All discontinuities are equal: the volume of discontinuities of each size in the interval proportional to the size of the discontinuity ($d\ln l = dl/l$) is the same.

Inasmuch as the discontinuities of each size occupy a small fraction of the volume, deformation of the solid can only be characterized by values averaged over space. Regarding stresses, their nonuniform distribution inside is the qualitative feature of the proposed model. Thus, we consider them in more detail.

The inner stress state of a solid is comprised of two components: elastic stresses caused by volume changes or reversible form deviation of a uniform medium, and local stress at discontinuities responsible for irreversible strains. Using some law of distribution of discontinuities in a solid, it is possible to convert local stresses to average values in any cross-section. These average stresses connected with stress concentrations at discontinuities are called inelastic stresses by us. The elastic stresses in a uniform material are connected with reversible strains by the linear relation (Hooke's law) although more general nonlinear relations are applicable too. Excess stresses (or their equivalent—inelastic stresses) only arise at discontinuities at finite velocity of deformation, and spontaneous relax with time.

The equation of excess (relative to elasticity level) stresses at discontinuities can be, for instance:

$$\frac{d\Delta\sigma_1}{dt} = \rho c^2 \varepsilon - v\frac{\Delta\sigma_1}{l}, \tag{2}$$

where $\Delta\sigma_1$ is the excess stress at discontinuity with size l; c is the S-wave (elastic) velocity; ρ is the solid density; ε is the shear strain rate; v is a constant to characterize stress relaxation rate.

The major inference of this equation is that stress relaxation rate at a discontinuity is proportional to stress and inversely proportion to discontinuity size.

While not refining definition of excess stress, we analyze the time change of the excess stresses in deformation.

The integral of Eq. (2) at the constant deformation velocity starting from the moment $t = 0$ is given by the formula:

$$\Delta\sigma_l = \rho c^2 \varepsilon \cdot \frac{l}{v}\left(1 - e^{-vt/l}\right). \tag{3}$$

At the initial time ($t \ll l/v$) stresses increase at discontinuities with time by the linear law:

$$\Delta\sigma_l = \rho c^2 \varepsilon \cdot \frac{l}{v}\left(1 - 1 + \frac{vt}{l}\right) = \rho c^2 \varepsilon t. \tag{4}$$

Later on, the buildup of stresses decelerates, and at each size discontinuity its own stress is stabilized:

$$\Delta\sigma_l = \rho c^2 \varepsilon \frac{1}{v}. \tag{5}$$

The larger discontinuities experience higher stresses at the preset velocity of deformation. In an infinitely large body, at any deformation velocity, there are always discontinuities of sufficient size to concentrate excess stresses which result in failure of the body. We denote the limiting excess stress sufficient to induce failure as σ′ and find the minimum size l_0 of a discontinuity that concentrates stress equal to the limiting value:

$$l_0 = \frac{\sigma'}{\rho c^2} \cdot \frac{v}{\varepsilon}. \tag{6}$$

Thus, at the constant deformation velocity, the solid body parameters are added with a parameter with dimension of length, and the solid is no more neutral to scale.

In bodies with sizes commensurable with l_0 or smaller, the constant velocity deformation takes place without failure as all stresses cannot rise up to a limiting value because of relaxation. Or, put it otherwise, for any body, it is possible to select such low velocity of deformation that the body is not to fail.

The situation is different during slow deformation of large bodies: all discontinuities within a finite-size body have time to relax from stresses. The total volume of the discontinuities becomes commensurable with the volume of the body, and the parted domains of elastic stresses no more play the defining role.

In this case, the solid acquires properties similar to the properties of viscous fluid. Transition to quasi-liquid state involves no change of state at a molecular scale and is, thus, less energy-consuming. At the same time, resistance to displacement of masses drops by an order of magnitude.

Under increased velocity deformation, some discontinuities in a quasi-liquid solid have no time to relax from stresses, and, after initiation of cracking, the medium loses its continuity, and the solid disintegrates. This limiting state appears when a portion of the body displaces relative to the other portion at the velocity of ~10 cm/year (this is the estimate for rocks in the crust).

Displacement at the limiting velocity results in the formation of faults and blocks.

The blocky structure of the earth crust makes it movable and reduces inelastic stresses inside the blocks. Deformation of the crust owing to mutual displacement of the blocks creates conditions for local high-stress areas. These renewable areas are the response to the displacement of the blocks. The intrablock space is as a rule in the static equilibrium and mechanical properties are stable there.

Behavior of rocks in the zone of the direct anthropogenic attack depends on the mineral extraction processes, which is a set of necessary actions. Severality being digressed, the target of mineral mining—involvement of the lithosphere resources into the circulation of the matter and energy in the techno-sphere—requires that mineral is accessed from ground surface, made movable and lifted to the surface. In this fashion, the generalized functional model of anthropogenic modification of subsoil in mineral mining includes there obligatory stages:

• Access from ground surface to the place of occurrence of mineral in the lithosphere;

• Making the mineral movable in the lithosphere;

• Lifting the movable mineral to ground surface.

In underground construction, when a void (underground tunnel) is a useful component, the pattern is, in principle, the same. At the second stage, not a mineral but the lithosphere matter filling a future useful void is to be made movable. Then, this material is lifted to ground surface at the second stage.

Regarding mineral mining, there are no qualitative differences between the opencast and underground methods in the functional model. The only difference is the value of the ratio between the cross-sections of the access (S_a) and the lithosphere area under mining (S_m):

• $S_a^3 S_m$ — opencast mining;

• $S_a < S_m$ — underground mining (including surface–borehole fluid production).

The new property for the lithosphere matter — movability — is ensured in the framework of an applied geotechnology, either by disintegration of the matter in a preset volume (majority of solid minerals), or by changing its state (e.g. burning-out of sulfur), or by creating conditions for migration of a valuable component: physical (oil, gas, water, heat) or chemical (in-situ leaching of metals).

In the first case (disintegration), the diversity of engineering solutions and process designs used in solid mineral mining can be grouped with respect to their effect on the change of properties of lithosphere objects, geomechanical parameters as well as dynamics and scale of the anthropogenic attack consequences in the lithosphere.

Each group features its own techniques of modifying properties of the lithosphere areas enclosing mineral and its own consequences during recovering of equilibrium in the man-modified subsoil after completion of mineral mining. These features, reflective of the dynamics of change in parameters and properties of anthropogenically modified subsoil, can be effectively applied in generalized modeling of human invasion in the lithosphere as well as in predicting consequences of such invasion and dynamics or mechanism of recovery of stable dynamic structure in the environment after invasion is terminated.

The first group embraces engineering solutions and process designs connected with formation of various shape cavities in subsurface capable to sustain disturbance of in-situ stress state due to formation of such cavities. Stresses and strains arising at the boundary of underground tunnels relax with time without any noticeable effect on surrounding rock mass. The lifetime of such tunnels last for centuries without any observable changes caused to surrounding natural objects in the lithosphere.

Such underground excavations include various-purpose tunnels in underground construction, or in production of dimension stone, rock salt, ferrous and nonferrous metal ore, especially in mining under bottoms of seas and other water bodies, when stress redistribution covers inconsiderable area in adjacent rock mass. This method features low (round 30–40%) extraction ratio, and major mineral reserves remain in pillars.

Perturbation of the lithosphere under such anthropogenic impact is limited to surface changes at the boundaries of underground excavations and pillars, while stress redistribution takes place in a small area of adjacent rock mass. Drivage of such excavations is well described by classical elastic problems. In opencast mining, mineral is extracted only after removal of overburden subject to variation of geophysical properties. For this reason, in the above generalized model of anthropogenically modified subsoil, the zone of total destruction and extraction of the lithosphere material fully swallows the zone of change in physical properties, and the anthropogenically modified subsoil structure only includes the open pit and the adjacent zone of transient behavior.

The second group encompasses technologies of mineral mining with caving of overlying strata, which is the most popular in coal industry, ferrous and nonferrous metallurgy and in chemical industry. Modifications of this method are applied in extraction of gently dipping, inclined and steeply dipping bodies of any shape, staring from shallow depths down to thousands meters and more below surface. The feature of such technologies is obligatory caving of overlying rocks after mineral extraction. Mineral mining proceeds top downward in steeply dipping or inclined ore bodies or seams, or from center sideways, or from one side toward the other in mining gently dipping strata.

As mining advances, the mined-out voids are filled with caved dirt rocks, the zones of inelastic displacements develop behind the zone of loosening, and a subsidence trough appears on ground surface. These processes develop synchronously with mining. Then, irreversible strains die gradually in enclosing rock mass, and caved rocks compact inside the subsidence trough. In mining very strong and hard rocks ($E = 1 \cdot 10^5 \div 1 \cdot 10^6$; $m < 0.2$), caving can be late. As a result, monolith hanging wall rocks overhang. The overhang can later on move instantly toward the mined-out void concurrently with generation of high-energy seismic vibrations commensurable with natural earthquakes (e.g. Apatity, Tashtagol).

In development of stratified deposits, the subsidence trough form similarly. This process is well studied in specific mining regions (Donbass, Kuzbass, Pechora Coal Field).

On the whole, the model of such anthropogenic invasion can be considered as a certain volume exposed to modification with irreversible processes in the near range and with further compaction of this zone due to inelastic expansion (failure) of rocks into the depth of rock mass. Boundaries of anthropogenic modification in this case are conditioned by equilibrium between the lateral earth pressure of the intact rock mass and the thrust of caved and compacted rocks in the caving zone.

The third group of mineral mining technologies is connected with backfill of mined-out voids with artificial material with certain strength and deformation characteristic. Sometimes, to decrease strains in the overlying rock mass and to reduce cost of artificial backfill with certain strength and deformation characteristics, regular vertical pillars of post-limit strength are left in mined-out areas. Inside backfill, such pillars act as reinforcement and improve deformation characteristics of material the backfill is made of.

Similarly, enclosing rock mass deforms in oil and gas field development: resistance to pressure of overlying rocks lowers, and the overlying strata gradually subside by the value commensurable with the recovered volume of oil or gas.

In this manner, in the third model of anthropogenic attack on the lithosphere, the removed volume of the lithosphere material is replaced by man-made material with known (preset) strength and deformation characteristics which govern the size of the transient behavior zone, which, together with removed volume, represents the anthropogenically modified subsoil as a new lithosphere object. Judged from the nature of relaxation processes, this model is in-between the two above-described cases.

Rock mass in the transient behavior zone (geophysical ecotone) between the virgin lithosphere and the zone of direct anthropogenic damage can be represented by a statistical model of deformation of structured solid when a cavity is created in it by means of continuous extraction of material. Let in a solid medium infinitely loaded by pressure P a spherical cavity be made by continuous extraction of material as in roadheading. For simplicity, it is assumed that the pressure P_1 at the boundary of the future cavity with radius $r = r_0$ reduces by the linear law:

$$P_1 = P(1 - t/T), \tag{7}$$

where T is the pressure reduction time (typical time of roadheading).

From the general qualitative analysis of behavior of a solid with discontinuities above, this problem should split into two subproblems within different time intervals.

At the first stage, as pressure lowers in the surrounding medium of the cavity, the elastic stresses are added with inelastic stresses resulting from stress concentration at discontinuities. The inelastic stresses reach maximum values when deformation of the medium due to pressure reduction ceases.

At the second stage, after pressure reduction in the cavity down to zero, redistribution of stresses and strains in the medium is set by relaxation of the excess inelastic stresses accumulated at discontinuities. In the course of the excess stress relaxation, the total stresses should tend to values which ensue from the same problem solution for the ideal elastic medium.

The total system of equations used to solve the formulated problem in spherical symmetry is given by:

$$\sigma_{rr} = \sigma^{\gamma}_{rr} + \sigma'_{rr}, \tag{8}$$

$$\sigma_{\varphi\varphi} = \sigma^{\gamma}_{\varphi\varphi} + \sigma'_{\varphi\varphi}, \tag{9}$$

$$\sigma^{\gamma}_{\varphi\varphi} = \frac{2\rho c^2}{1-2v}\left[(1-v)\frac{\partial u}{\partial r} + 2v\frac{u}{r}\right], \tag{10}$$

$$\sigma^{\gamma}_{\varphi\varphi} = \frac{2\rho c^2}{1-2v}\left[v\frac{\partial u}{\partial r} + \frac{u}{r}\right], \tag{11}$$

$$\frac{d\Delta\sigma_{rr}}{dt} = \rho c^2 e_{rr} - v\frac{\Delta\sigma_{rr}}{e}, \tag{12}$$

$$\Delta\sigma_{rr} + 2\Delta\sigma_{\varphi\varphi} = 0 \text{ or } \sigma'_{rr} + 2\Delta\sigma'_{\varphi\varphi} = 0, \tag{13}$$

$$\frac{l^3 dl}{d\ln l} = \frac{2}{\pi Q_\mu}, \tag{14}$$

$$\frac{\partial\sigma_{rr}}{\partial r} + \frac{2(\sigma_{rr} - \sigma_{\varphi\varphi})}{r} = 0, \tag{15}$$

where u is the displacement in pure radial strain; σ_{rr}, $\sigma_{\varphi\varphi}$ are the total stresses in the medium; σ^{γ}_{rr}, $\sigma^{\gamma}_{\varphi\varphi}$ are the elastic stresses; σ'_{rr}, $\sigma'_{\varphi\varphi}$ are the inelastic stresses; $\Delta\sigma_{rr}$, $\Delta\sigma_{\varphi\varphi}$ are the local excess stresses at discontinuities; c, D are, respectively, the P-wave velocity and Poisson's ratio; $e_{rr} = \frac{\partial u}{\partial r} - \frac{1}{3}\left(\frac{\partial u}{\partial r} + 2\frac{u}{r}\right)$ is the radial strain in the tensor–deviator.

In the above system, Eqs. (10) and (11) express Hooke's law for elastic stresses, Eq. (15) is the condition of equilibrium, while Eqs. (12)–(14) define behavior of inelastic stresses. The inelastic stresses are calculated by a regular procedure, by averaging excess stresses at discontinuities. For instance, the radial inelastic stress is found as:

$$\sigma'_{rr} = \frac{2}{\pi Q_\mu} \cdot \int_l \Delta\sigma_{rr} \cdot d\ln l, \tag{16}$$

and summation under the integral is carried out with respect to sizes of all discontinuities in a body (or an object if the body is boundless).

It is impossible to obtain a general solution of this system but an approximate solution of any accuracy is obtainable sufficiently simply. In the discussed problem, it is assumed that concentration of excess stresses is below critical (destructive) values; otherwise, new discontinuities would appear in the material and, thus, redistribution of (14) would take place. For this reason, the local excess stresses Δσ are treated as being lower than the elastic stress σ^y, and for the inelastic stress we obtain:

$$\sigma' = \frac{2}{\pi \cdot Q_\mu} \cdot \int_l \Delta\sigma \cdot d\ln l \approx \frac{2}{\pi \cdot Q_\mu} \cdot \int_l \sigma^y \cdot d\ln l = \frac{2}{\pi \cdot Q_\mu} \cdot \ln\frac{l_{max}}{l_{min}}. \quad (17)$$

If the size range l_{min}—l_{max} of discontinuities in a body is narrow and $\ln {l_{max}}/{l_{min}} \approx 1$, we have $\sigma' = 2\sigma^y/(\pi Q_\mu)$. The total stress σ in the medium equals the sum of the elastic stress σ^y and the inelastic stress σ´, i.e.:

$$\sigma = \sigma^y + \sigma' \cong [1 + 2/(\pi Q_\mu)]\, \sigma^y. \quad (18)$$

The Q-factor of rocks is about 10 [18]. Then, the estimate of σ shows that stress concentration at discontinuities weakly distorts fields of stresses and, consequently, strains in a loaded body.

Regarding the formulated general problem, solution of these equations at each specific combination of the lithosphere properties and anthropogenic attack nature provides insight into mechanisms of change in the behavior and properties of rock mass in the zone of geophysical ecotone (transient behavior zone) that appears in the natural geophysical environment under man-induced disequilibrium during mineral mining.

Conclusion

Based on the adopted model of anthropogenically modified subsoil, the goal of the related research into this new ecological object is formulated as follows: the width of the geophysical ecotone during large-scale expansion of total destruction zone in the lithosphere should be zero.

Meeting this goal objective is absolutely impossible. Nevertheless, it is clearly understood that the science and geotechnology should pursue minimization of all characteristics of anthropogenically modified subsoil by targeted adjustment of mining technologies.

When developing this hypothesis on anthropogenic modification of subsoil, it is possible to rest on the dialectical method of acquiring knowledge. In particular, a pathway to a new point of knowledge goes through discovery and surmounting of opposites at their common foundation being sustained. In our case, in analyzing ecological aspects of anthropogenic modification of subsoil, this foundation is the internal functional and notional structure of the concept definition.

Exploration of influences exerted on the structure of *geophysical ecotone* during underground mineral mining designates tendencies in advancement of geotechnology towards creation and application of mining systems such that to minimize (or eliminate) extensional deformation in undermined rock mass as well as differently directed deformation of ground surface.

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