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SIMULATION OF ROOF CAVING IN WHILE CONDUCTING EXCAVATION MINING WORK

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Peculiarities of geo-environment evolution as a nonlinear dynamic system with the self-organized limiting feature are discussed. Calculations of the initial and subsequent roof cavings for different advancing rates were fulfilled. Special attention was given to the study of unsteady nonequilibrium deformation process in the roof at high face advancing rate. It is shown that other features of such systems are the existence of calm zones in the area of looming crisis and peculiarities of slow dynamics of deformed systems can be sure portents of the fact that the process of destruction epicenter formation is moving to become a superfast catastrophic evolution stage.

Keywords: simulation, roof caving, rate, destruction, distribution.

Traditional criteria approach of phenomenological macroscopic mechanics is not capable in principle to solve the problem of destruction prognosis, as it is based on macroscopic scale of averaged description, while all solid objects and types of geo-medium are multi-scale systems. The Evolution concept of destruction foundation [1] is an idea of hierarchical and multi-scale nature of deformation process – basic ideas of Physical Mesomechanics and Nonlinear Dynamics [1-4]. Nonlinear Dynamics sheds a new light onto a problem of prognosis too, even when it "deprived us of an illusion of a global predictability: we cannot forecast, starting from some horizon of prognosis, the behavior of simple enough systems" [3]. Thus not so simple a question arises: what is the horizon of prognosis for the process of destruction of a medium with a given rheology? Or in other words: starting from which stage or scale can we answer the question, where and when will the slow quasi-stationary phase of the heart of destruction formation come up to escalation at the studied macroscopic scale?

We see a significant progress in the area of catastrophic events prediction, which includes the problem of destruction. This progress is connected to a new concept of self-organized criticality of nonlinear dynamic systems [5, 6], which contradicts seriously with traditional thinking, based on which rare catastrophic phenomena were deemed accidental independent events, where the future is not practically impacted by the past. Such approach leads to Gaussian statistics - normal Gaussian distribution of probability for an independent accidental event.

The statistics of natural disasters – earthquakes, hurricanes, floods, technogenic catastrophes: the destruction of different constructions, industrial explosions, as well as many other disasters - crash at the stock-markets, information leaks, etc., as a rule, is subject to power law probability distribution [3, 7].

Power law distribution is a fundamental property of evolution of the majority of multi-scale hierarchical nonlinear systems, and in the event of loaded media it reflects their following most important qualities: 1) formation of long space and time correlations in the evolving system, that scope all hierarchy of scale; 2) self-similarity of destruction processes, stipulated by self-similar character of accumulating the defects and damages in all hierarchy of scale; 3) migration of deforming activity in a formed area of space and time correlation.

The other most important side of such nonlinear systems is the existence of slow dynamics within, that is a dynamic correlated process, significantly slower than fast information exchange in a dynamic system. In deforming solid objects and media the processes of locating deformation and damage, forming of the deformation fronts of different scale, epicenters and different waves of damage constitute the slow dynamics of nonlinear system in the process of deformation. And information in these systems is transmitted via tension (voltage) waves distributed with the speed of sound that exceeds the typical speed of slow dynamic processes by a lot [8].

Systems with such properties are called the systems with self-organized criticality [5, 6]. In such systems any event, because long cause and effect relations appear, – will inevitably call the next event, etc., provoking the avalanche of events, touching upon all hierarchy of scale, i.e. all system as a whole. In other words, the fundamental property of the systems with self-organized criticality is the fact that they evolve (speed) to critical condition by themselves [3]. Consequently, the main danger of "power" catastrophes is not only in the fact that its probability is much higher, than in Gaussian system, and it cannot be disregarded, but in the fact that the catastrophe in the system with self-organized criticality is inevitable. Indeed, if the process of destruction is correlated statistically in all hierarchy of scale up to the macroscopic scale of a sample, then it will inevitably reach that macroscopic scale. This process is governed by nonlinear character of properties of a dynamic system as a whole, which follows from nonlinear character of evolution of tense and deforming condition (nonlinear equation of deformed solid objects' mechanics), nonlinear character of rheology (nonlinear state of definitive equations, including kinetic equations of aggregating non-elastic deformations and damages in a different scale and a nonlinear state of media durability properties' degradation), nonlinear quality of positive and negative feedback. Consequently, in critically self-organized systems one cannot single out statistically independent mesoscopic scales.

At this moment it is considered proven that deformed solid objects are truly dynamic nonlinear systems showing properties of self-organized criticality. For geo-media, the widely known Gutenberg-Richter and Omori laws reflect the relevant statistics of seismic events. Analysis of destruction processes of laboratory samples [9], as well as of constructions [10] by the acoustic emission method leads to the same universal dependence - Gutenberg-Richter and Omori laws.

A predictive model, - capable of describing the mechanism of forming the epicenter of the future destruction, and, importantly, of predicting when and under what conditions the slow quasi-stationary phase of evolution will turn into the superfast catastrophic regime, - can be only the model that accounts for all most important properties of the loaded nonlinear media's evolution process, including the characteristic properties of self-organized criticality. In ISPMS SB RAS the evolutionary approach to modeling of solid objects and media's destruction is being developed [1, 2]. This approach describes the processes of self-organizing in the loaded geo-medium, locating non-elastic deformations and damages in it, forming of block hierarchy; allows to model the slow stages of evolution at any time, including geological, as well as the superfast catastrophic regimes of evolution, - so-called acute regimes.

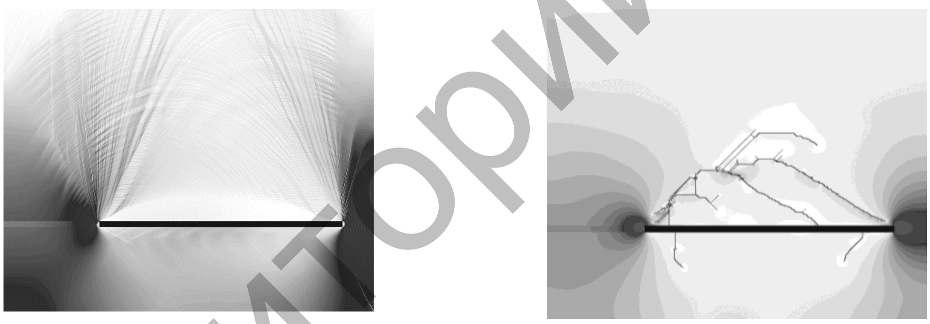
The proposed evolutionary concept of describing the deformation feedback to the loading of solid objects is based on the ideas of nonlinear dynamics and dynamic equations of solid objects' deforming mechanics. Such approach describes the destruction of solid objects and media (elastic and brittle) as common mutual growth process of non-elastic (plastic) deformation, related damage, degradation of medium durability, and, finally, macroscopic destruction, which happen upon a catastrophic decline of local durability to zero. Therefore, numerical solutions demonstrate the fundamental property of all evolutionary processes - the existence of two stages: 1) quasi-stationary stage of relatively slow accumulation of changes in a nonlinear system; 2) catastrophic superfast stage of evolution, when the events develop in an acute regime.

Based on the discussed model [1, 2] the calculations of a loaded and deformed condition of a massif evolution over the mine in the field of gravity forces were carried out. The model takes into account the internal friction, dilatancy, and accumulation of damages and degradation of geo-medium's durability characteristics. The developed method of calculations allows solving practical problems of mining stability under the timing factor more accurately and correctly. The developed models of a damaged massif allow modeling the processes of damage accumulating and developing of cracks of different sizes, as well as catastrophic collapse of rock.

Attention of this work is focused on the research of the three following important problems: specifics and mechanism of forming the destruction centers in brittle and quasi-brittle media, study of the destruction transition process from a slow quasi-stationary phase to a superfast catastrophic regime, evaluation of risks, and a prospect of prognosis of possible catastrophic destruction of massif elements with mining. Numerical solution is carried out in two-dimensional dynamic stage for the condition of plain strain.

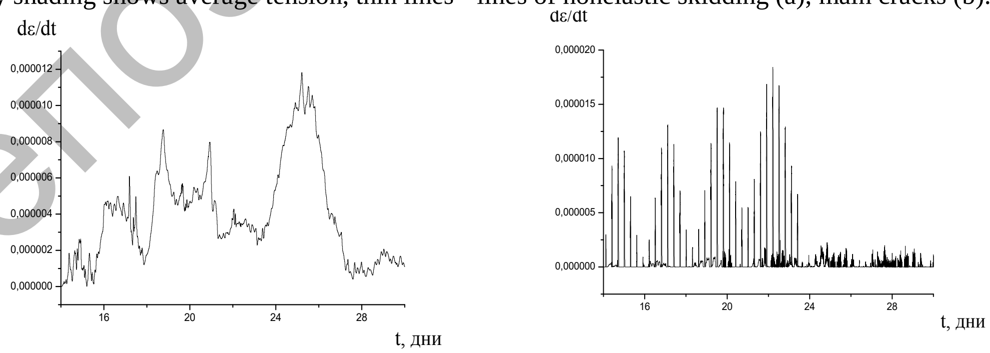
Equations system, solution method and detailed formulation of the problem were published earlier [11]. The proposed approach allows describing the stages of slow preparatory phase of stress strain state evolution, forming of destruction stages and superfast acute regime. Relevant times and scale of these evolution stages are determined by nonlinear qualities of geo-medium on the relevant scale. Thus in high speed of mining we have lengthy sections of hanging roof, so a nonequilibrium destruction regime takes place. It is also shown that depending on the competition of negative feedback, stabilizing the deformation process and evening out of inhomogeneous pieces in parameter distribution, and positive feedback, caused by the degradation of loaded medium, the scenario of medium evolution can change from a typical viscoplastic course to a brittle behavior.

Fig. 1 shows the results of the calculation of roof rock deformation at the moment when the excavation reached 50 meters in length (calculation and excavation can continue). Different values of damage accumulation parameters were chosen, which allowed the possibility to describe the behavior of the geo-medium either as viscid (Fig. 1.a), or as brittle (Fig. 1.b), depending on the medium property, as well as the specifics of loading.



a) b)

Fig. 1. The character of damage development in a massif over excavation (black horizontal line). Grey shading shows average tension, thin lines - lines of nonelastic skidding (a), main cracks (b).



a) b)

Fig.2. The graph of nonelastic deformation speed in the roof monitoring.

The built graphs of monitoring the speed of nonelastic deformation (damage) in the chosen points of the roof are shown in Fig. 2. One can see that in a case of a viscid feedback of a medium (Fig. 2.a) nonelastic course in the roof is developing in waves, at the rate as excavation continues, and creates even bigger tension and deformation in the caving roof. Roof caving in brittle geo-medium (Fig. 2.b) is developing as a sequence of periodic catastrophes (extension of a main crack), at the rate of continuing excavation; the period here is related to the character of excavation movement and geo-medium properties, in part to the speed of accumulating damages in it. Therefore, the obligatory stage of a geo-medium evolution is reflected in the model: the catastrophe at the relevant scale. Physically, this regime means the burst of destruction from a minor scale to a larger one, the increase of the destruction scale is always developing in the acute regime.

Fig. 3 shows the nature of growth of damage function D ($0\leq D\leq 1$) for a main crack in the roof over an excavated space (medium viscid-brittle). One can see that on Day 28 the slow quasi-stationary phase of damage evolution D is replaced by a catastrophic regime (Fig. 3a). Consequently, the yield strength degradation speed is also transformed into an acute regime (yield strength $Y=Y_0(1–D)$, where $D\rightarrow 1, Y\rightarrow 0$) and, as a result, the roof collapse happens.

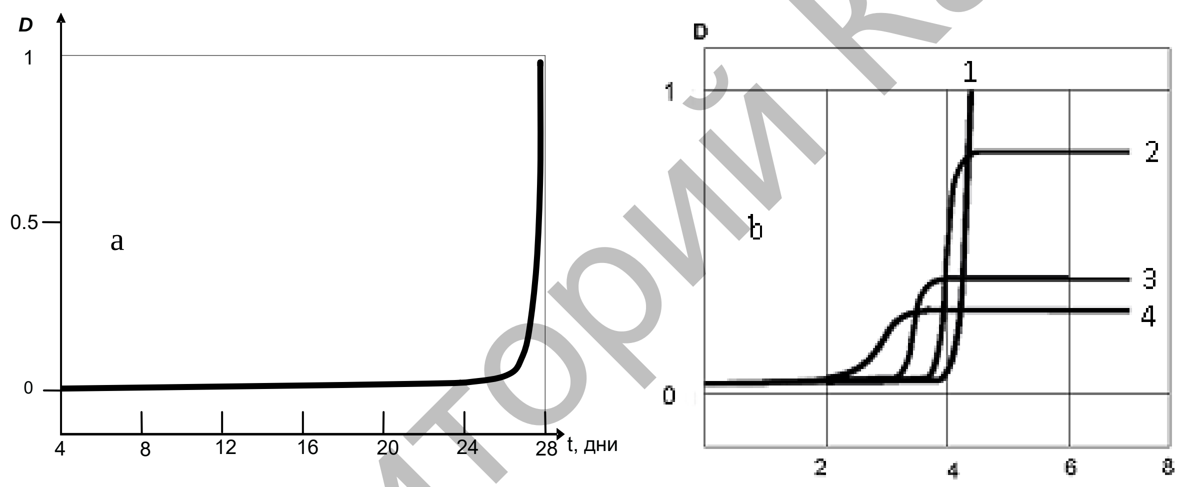


Fig. 3. The character of damage function growth in the roof.

The fundamental property of evolution is the existence of calm zones before a catastrophe. This phenomenon is demonstrated in Fig. 3b. In numeric calculation of a problem of roof collapsing, the damage accumulation speed monitoring in the nearest zone of a future catastrophic event was executed. The processes of damage accumulation for accompanying cracks forming in this area stopped still (curves 2, 3, 4 on Fig. 3b), and the accumulation of damage in the future main break has peaked sharply (curve 1 on Fig. 3b).

Therefore, any macroscopic destruction is an obligatory catastrophic stage of a geo-medium evolution - an acute regime at the relevant scale. Physically this regime means the plunge of destruction from a minor scale to a larger one. Consequently, the increase of destruction scale is always developing as a catastrophe in the acute regime, and all the processes of damage accumulation and medium degradation in the area of preparation to a multi-scale event are stopping still.

The developed method of calculations allows describing the first and subsequent roof cavings for modern conditions of increasing pace of excavation movement and a non-equilibrium condition of the rock in the bared roof.

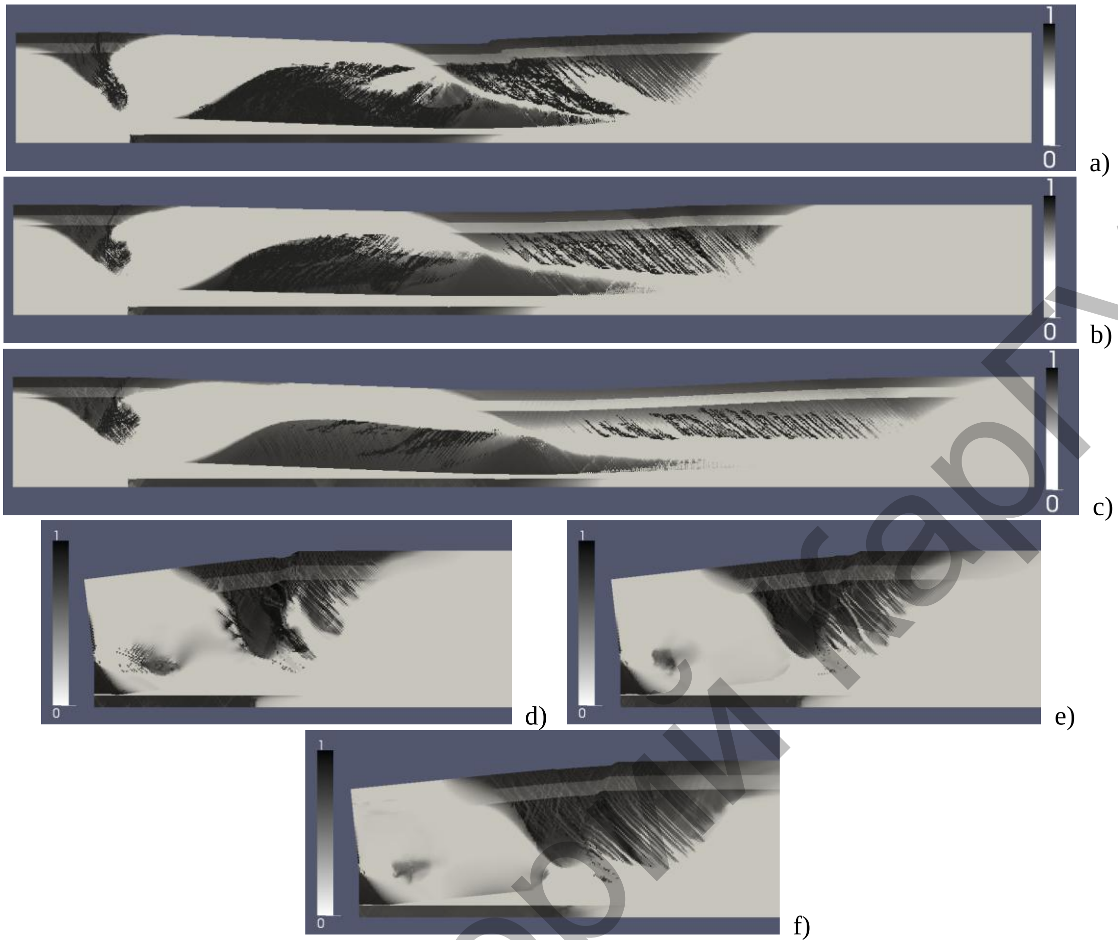


Fig. 4. The modeling of a first (a,b,c) and secondary (d,e,f) roof collapses for different speeds of excavation pace: 2m/24hrs (a,d), 4m/24hrs (b,e), 8m/24hrs (c,f). The accumulated damage of a geo-medium in conditional values from 0 to 1 is reflected.

Fig.4 shows the results of roof caving modeling for different speeds of extending the excavation shaft. For primary caving in the border conditions the model approximation for the roof was used in the form of a beam created in the process of excavation, for the secondary one - consoles (cantilevers). For slow speed of excavation, a larger damage accumulation in the roof geo-medium is typical, and therefore, more viscid (lengthier in time) character of roof caving. This work was supported by grant RFBR № 12-05-00503-a.

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