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Fractal Characteristics of Seismic Process in Rock Mass Surrounding the Excavation at Mining. Mathematical Modelling and Analysis

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Abstract. It is shown in the paper that the system of equations of solid mechanics, which has a mixed type, demonstrate the most common features of evolution of nonlinear dynamic systems. Previous investigations of seismic process were carried out on the base of simplified (sand-pile, land-slide) models which gave a graph of recurrence of seismic events and information about the state of self-organized criticality (SOC). However, these simplified models do not contain the information about the stress-strain state of the loaded geomedia and its proximity to the critical state. In the proposed paper the model of rock mass with excavation is constructed and general step of roof caving is modelled. On the base of these modelling the formation of critical state in loaded geomedia is studied. The fluctuations of stress-strain state at different points of geomedia are studied as the reflection of fracture process occurring in the main elements of rock mass: roof and floor, when the coal face is advanced. It is shown that the PDF dependencies, amplitude-frequency characteristics reflect the state of the rock mass and might be considered as the fractal characteristics of fracture process within. The evolution of these dependencies shows the dramatic change when the critical state is formed in the rock mass surrounding the underground opening.

INTRODUCTION

The solution of forecasting problem and risk assessment is actual for the majority of human activities. The problem of forecasting the dangerous manifestations of rock pressure, including the rock bursts, is one of the significant in this range. More widely this is the problem of forecasting the catastrophic fracture of Earth crust elements, earthquakes and also the fracture of any solids and construction's elements. From the theoretical point of view these problems might be solved with the deep understanding of common laws of evolution of nonlinear dynamic systems since all solids and geomedia are related to such systems. The main goal of studying the evolution of stress-strain state (SSS) in loaded media, as a dynamic system, is the forecast of critical states. The forecasting of both place and time of possible large earthquakes and rock bursts is made empirically on the base of analysis of chosen sequence of earthquakes [1, 2], and data of monitoring or precursors.

The "sand pile" model is usually used as one of the basic models of geomedia. In the same manner the large experience of mining and data of geophysical monitoring underlie the forecasting of dangerous dynamic phenomena. The amount of papers dedicated to development of common physical theory of seismic process is increasing continuously. The majority of these theories have the simple equations of nonlinear dynamics as the basis. However, many details of fracture foci formation, as well as seismic process, are not quietly studied. The widely accepted physical model of fracture process doesn't exist. That is why the imitation models became wide spread. They demonstrate several features of real dynamic systems, for example, blow-up regimes, power-law distributions and some other important features of dynamic systems evolution.

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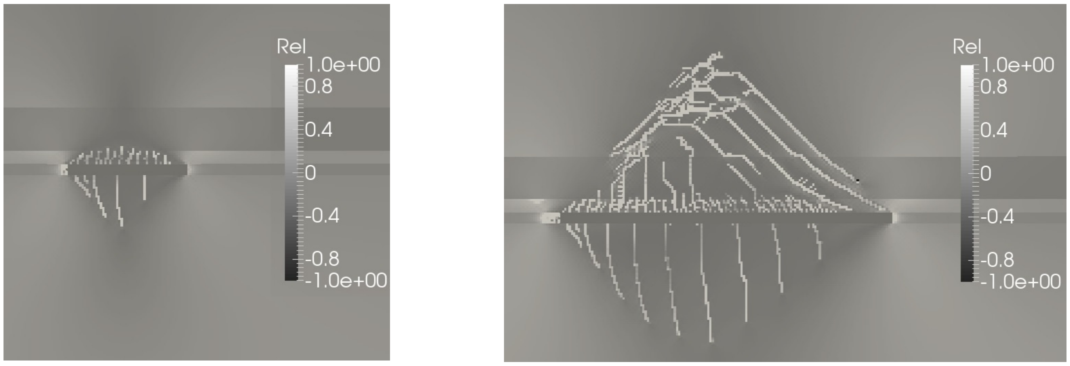

(a) (b)

FIGURE 1. The distribution of relative Coulomb stresses in the elements of rock mass: when the coal advanced for 55 m (a), when the coal advanced for 150 m (b)

The mathematical theory of evolution of loaded solids and media [3] underlies the methodology for analysis of SSS in rock mass surrounding the excavation. The system of solid mechanics equations composes the core of this theory. The rich history of mechanics demonstrates that these equations model the deformation processes, including the fracture. The numerical solutions of solid mechanics equations demonstrate all known characteristic features of nonlinear dynamic system evolution, if the positive and negative feedbacks and equations of state, characterizing the rate of non-elastic strain and damage accumulation, are included in the system.

In the proposed paper we suppose that the change in fractal characteristics of fracture process might be used as the precursors of critical state formation in rock mass surrounding the underground opening when the coal face is advanced.

MATHEMATICS

The mathematical model include the fundamental conservation laws of continuum mechanics. The equation of state (EOS) is taken in the form of isotropic Hooke's law. The non-elastic deformation of rock mass elements is descripted within the Drucker–Prager yield function with non-associated flow rule. The components of inelastic strain rates tensor are defined according to the Nikolaevskii plastic potential. The fracture of the rock mass elements is considered within the theory of damages accumulation. In more details, an applied model is considered in [4].

RESULTS OF MODELLING AND ANALYSIS

The proposed model of the rock mass has following characteristics, there are 5 bedding planes: (1) the upper-lying strata (siltstone formation), (2) main roof plane (sandstone formation), (3) immediate roof (mudstone formation), (4) coal seam, (5) floor (siltstone formation). The initial condition is the gravitation stress field. The step of calculation grid is 0.5 m. The mining work is made on the depth of 250 m. Other physical-mechanical parameters are in paper [5].

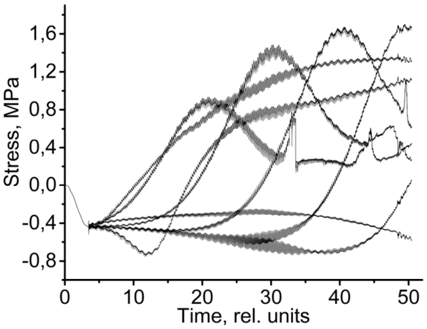

FIGURE 2. The registration of stress fluctuations in rock mass at several gauges when the coal face is advanced

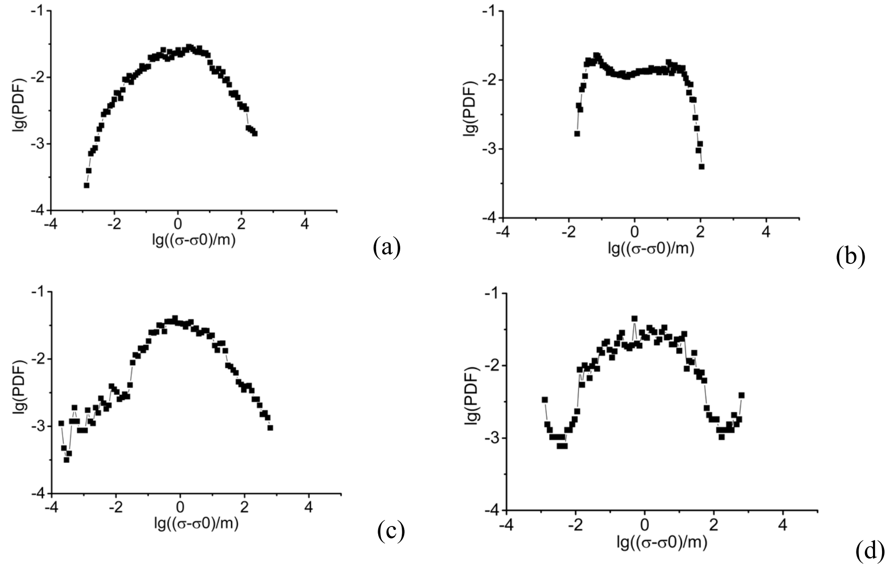

FIGURE 3. The evolution of PDF-dependency

Since the Drucker–Prager model is applied in the paper, it is useful to analyze the stress-strain state in terms of relative Coulomb stresses (1) which show the actual state of the media in particular point (Fig. 1):

$$\sigma_c = \tau/(C + \alpha P), \tag{1}$$

where τ—intensity of stresses, *C*—current value of cohesion, *P*—hydrostatic pressure.

If σ_c is equal to 1, then the stress-strain state is on the yield surface and non-elastic deformation occurs. The local loss of elastic stability and transition to inelastic state is accompanied with the relaxation of stresses. Such local acts of inelastic deformation might be considered as a small scale catastrophes (or avalanches, in terms of self-organized criticality theory). Each catastrophe produces the stress wave.

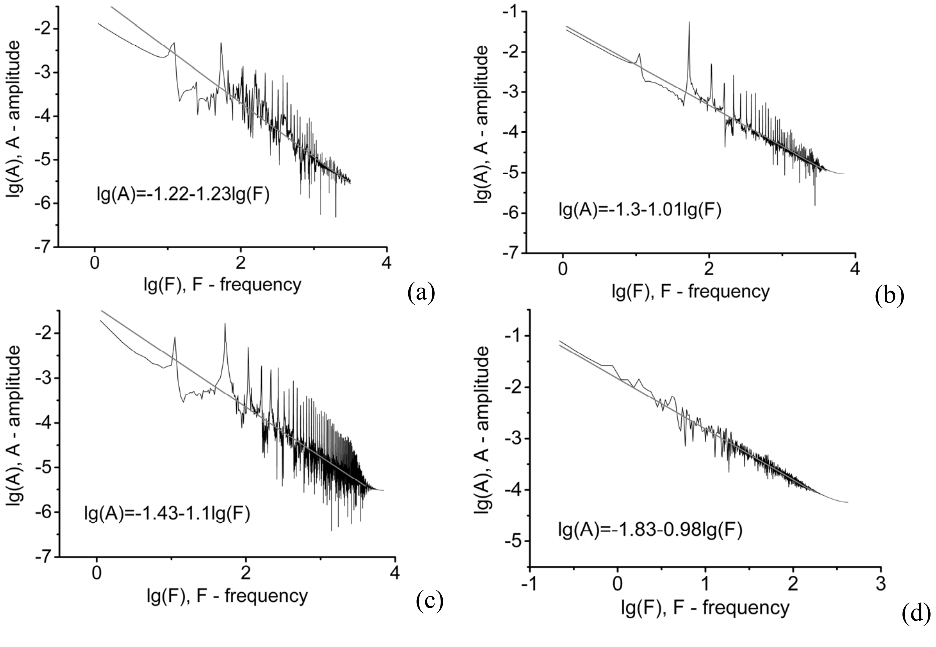

FIGURE 4. The evolution of AFC

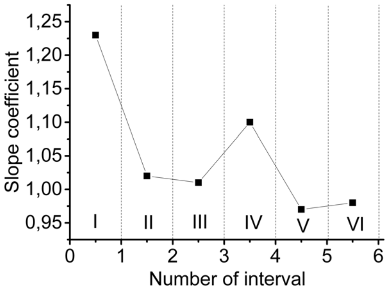

FIGURE 5. The evolution of AFC slope

If we look through the registration of stress fluctuations in several points of rock mass (seismic gauges), than we shall see that the fluctuations reflect the superposition of fracturing of many scales (from micro to macro, Fig. 2). These stress waves give information about the current state of the rock mass as the whole dynamic system.

The PDF-dependency show the dynamic chaos state in the beginning of coal advance, the small scale fractures occur almost independently from each other (Fig. 3a). The following changes indicate the transition to self-organized criticality state because of appearance of leading frequency in distribution (Fig. 3b) and loss of spatio-temporal symmetry of fluctuations (Fig. 3c), after the general caving of roof, the distribution rehabilitates the symmetry but doesn't correspond to the initial state (Fig. 3d).

The evolution of the AFC shows the dramatic change of the slope when the critical state is formed in the rock mass (Figs. 4 and 5). It occurs when the coal face advance is close to the step of general caving.

CONCLUSION

The fluctuations of stress-strain state at different points of geomedia are studied as the reflection of fracture process occurring in the main elements of rock mass: roof and floor, when the coal face is advanced. It is shown that the PDF dependencies, amplitude-frequency characteristics reflect the state of the rock mass and might be considered as the fractal characteristics of fracture process within. The evolution of these dependencies shows the dramatic change when the critical state is formed in the rock mass surrounding the underground opening. Particularly, the slope of amplitude-frequency characteristic drops dramatically when the length of mined space gets close to the step of general caving.

The results of numerical modelling show that the developed model, applied for simulation of stress-strain state evolution over the mined space demonstrate all known characteristic features of nonlinear dynamic system evolution.

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REFERENCES

1. P. Shebalin, V. I. Keilis-Borok, A. Gabrielov, L. Zaliapin, and D. Turcotte, Tectonophysics **413**, 63–75 (2006).
2. A. B. Shapoval and M. G. Sniirman, Inform. Technol. Calcul. Syst. 58–65 (2011).
3. P.V. Makarov, Phys. Mesomech. **11**(5–6), 213–227 (2008).
4. P. V. Makarov and M. O. Eremin, Phys. Mesomech. **16**(3), 207–226 (2013).
5. M. O. Eremin, P. V. Makarov, A. Yu. Peryshkin, E. P. Evtushenko, and S. A. Orlov, AIP Conf. Proc. **1683**, 020048-1-4 (2015).