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OPTIMIZATION OF THE CALCULATION OF THE PERIODICITY PARAMETERS OF THE ROCK MASS ZONAL DESTRUCTION MODEL

An overview of new and most significant mining research using the non-Euclidean continuum model to describe the stress field distribution around a circular cross-section roadway. The accuracy of the calculation of created model parameters has been studied and compared with real experimental data. Specific periodicity parameters of the rock mass zonal destruction model around a deep circular roadway have been studied individually. The selection of this parameter is based on its prognostic significance for solving problems in mining deposit research. A comparative analysis has been made of the analytical and numerical determination of this parameter with physical data from two independent fields. The technique for combined use of the analytical and numerical approach, depending on the active task at surveyed field, has been described and justified.

Keywords: highly compressed mass; zonal destruction; parameters; non-Euclidean model; mass; field data

INTRODUCTION

Research into geological materials to resolve issues related to the mining industry is currently a priority field in many countries and involves experts from around the world. Recent efforts by A.M. Guzev and A.A. Paroshin helped them obtain significant results in developing new methods and approaches in this field. They were the first to propose the non-Euclidean continuum medium model to describe stress field distribution around a circular cross section roadway [1]. Instead of Saint-Venant's strain compatibility condition, the authors introduced the rock mass defectiveness function for plane deformation; this function complies with the biharmonic equation with preset limit conditions. The obtained result served as a basis for new surveys and provided new understanding of rock mass zone disintegration around deep underground mines [2–8].

In particular, the authors of the work [2] found a solution to end the problem of stress field distributed around a mine in the event of deformation and under non-hydrostatic loads. The task is presented as two integral components, while the solution refers to the expansion of the elastic stress field into the sum of the fields; the first is due to incompatible deformations of disturbed zones; the second is due to joint deformations of non-disturbed zones. In the first case, the elastic stresses can be determined with the non-Euclidean model; for the second one — using the standard elastic-mechanical model. As a result, using the Mohr-Coulomb stress criteria, the authors determined the number of disturbed areas, their location, that depend on physical and mechanical properties of the rock material as well as on non-Euclidean parameters.

In their work [3] the authors determined the quantity and size of disturbed and non-disturbed zones using the proposed non-Euclidean model of zone disintegration of geological material around a circular cross-section roadway. Zone quantity and size characteristics are shown with reference to natural, tangential and radial stresses, intermediate main stress coefficient as well as RMR (Rock Mass Rating) classification coefficient.

The work [4] presents the dynamic model for survey zone disintegration in enclosing mine rock mass around deep circular tunnels under hydrostatic stress condition. The non-Euclidean dynamic equation is obtained based on non-equilibrium thermodynamics; the solution of the equation is determined by direct and inverse Laplace transformations. It has been shown that the number of disturbed areas increases depending on the step-up of rock disturbance factor, relief rate, as well as subject to a decrease in monoaxial compression strength, GSI geological index, strength m_i, and Poisson coefficient ν.

The work [5] presents a new non-Euclidean model to survey impacts of deep penny-type mining cavities and natural axial stress on zone disintegration. The deformation energy density coefficient was used to determine the stress intensity coefficient for penny-type cavity peaks. The numerical calculation shows that both size and location of the rupture zone are sensitive to micro- and macromechanical parameters as well as non-disturbed mass stress.

The work [6] described a non-Euclidean model which was used to analyze the relation between zone disintegration and rock bumps. The formation mechanism for secondary micro cracks and the mechanism for their transfer to a non-stable state, expansion and secondary micro crack build-up and macro crack formation (resulting in rock bumps) were studied.

Despite the uniqueness of the research, the authors of the works [2–6] made the following conclusions:

- under high depth conditions, rock mass zone disintegration around underground mines is normal;
- zone disintegration structure features repeated the roadway contour and sequence of disturbed and relatively non-disturbed geological material;
- non-Euclidean mathematical models are the most suitable models for describing zonal disintegration effects.

However, there are some serious issues with the works presented here: there is no comparison with real experimental data, the algorithm used to determine the created mathematical models parameters is incomplete. In view of the above, the reliability of the built model parameters, as well as calculation accuracy and its influence on surveyed physical effects and rock phenomenon, remain uncertain.

Stress field distribution around a circular cross-section roadway

Let's consider field stress distribution around a circular cross-section roadway. This shall be analyzed as plane and stationary, non-compressible, with hydrostatic load for infinite distance [1]. This task shall be solved based on the obtained equilibrium equation

$$\frac{\partial \sigma_{rr}}{\partial r}+\frac{1}{r}(\sigma_{rr}-\sigma_{\phi\phi})=0, \qquad (1)$$

biharmonic equation for defect function

$$\Delta^2 R-\gamma^2 R=0, \qquad (2)$$

and limiting conditions

$$R\big|_{r=r_0}=0,\ \left.\frac{\partial R}{\partial r}\right|_{r=r_0}=0, \qquad (3)$$

where σ_{rr} is normal radial stress; $\sigma_{\phi\phi}$ – normal tangential stress; $\sigma_{r\phi}$ – shearing stress; Δ – Laplace operator; γ – model periodicity parameter. In polar coordinates for biharmonic equation

$$\left(\frac{\partial^2}{\partial r^2}+\frac{1}{r}\frac{\partial}{\partial r}\right)^2 R=\gamma^2 R \qquad (4)$$

the solution under the condition $r\to\infty$ for the distance between the roadway center to a mass point is presented as equality:

$$R(r)=aJ_0(\sqrt{\gamma}r)+bN_0(\sqrt{\gamma}r)+cK_0(\sqrt{\gamma}r), \qquad (5)$$

where J_0, N_0, K_0 is the Bessel, Neumann, and Macdonald zero-order function.

The solution [7] of biharmonic equation (2), unlike [1], provides the following for limiting conditions:

$$\left.\frac{\partial R}{\partial r}\right|_{r=r_0}=0,\ \left.\frac{\partial R}{\partial r}\right|_{r=r^*}=0, \qquad (6)$$

corresponding to the following zonal rock disintegration, subject to the following approach: first limiting condition for the function R shall be considered as its extremity at the roadway boundary; while the second limiting condition shall be considered as the extremity in the middle of the first disturbed zone, etc.

However, here the reliability and quality of the analyzed model parameters remain uncertain. An important problem is the reliability of the determination of the periodicity parameter and its influence on the reliability of predictions, number, locations, and length of rock mass disintegration zones. While studying this problem, we developed two separate approaches to determine the parameter γ.

Method for determining the rock mass zone disintegration periodicity model parameter

Analytical approach. For the surveyed fields, the analytical dependence between the parameter γ and the distance from roadway boundary to the middle of the first disturbance zone (in roadway radius units) was obtained based on real experimental data

$$\gamma(r^*/r_0) = -10(r^*/r_0) + 23, \quad (7)$$

where r^* is the middle of 1st disintegration zone starting from the roadway boundary; r_0 is the roadway radius, m [7].

Numerical approach. This approach is based on the numerical selection of the parameter γ, with which the parameters *a* and *b* of the defect function take on maximum negative values at the roadway boundary, i.e. they will reach defect function at the roadway boundary extreme value and, therefore, the presence of a disintegration zone [8].

Each of the proposed approaches has its specific advantages and disadvantages; in particular, the analytical approach determines the parameter with an accuracy up to an γ integral number; however, it has not been fully tested on unknown fields, but it is very simple for calculations. The numerical approach is a common method to determine the parameter γ. This method helps calculate the target parameter with preset accuracy level. However, this is a time-consuming calculation method.

Using these two approaches for calculating the periodicity parameter of surveyed fields shows a variance in accuracy of up to 11.21 % in some cases (Table 1).

The calculations of relative accuracy for the surveyed fields (Tables 2, 3) show that an increase in the number of characters after the comma produces a positive impact on the calculation of the disintegration boundary in general.

For Norilsk mine (see Table 2) it can be concluded that the relative error of disintegration zone I boundary calculation is less, when $\gamma = 3$, e.g. the parameter, takes on an integral value. Analysis of the Dingji coal mine (China) data (Table 3) shows that an increase in digits after the dot in the parameter γ reduces the accuracy error for the calculation of all disintegration zone boundaries. With a more detailed analysis, it can be concluded that the increase in the number of digits for Zone I defines more exactly the accuracy error, since such an error reduces by more than 1 %, while the relative accuracy error for other disintegration zones reduces much more − by 2–4 %.

CONCLUSION

With reference to the above, we still cannot say that one periodicity calculation approach is better than the other. Therefore, both numerical and analytical approaches shall be used, depending on the specific task. In particular: for initial analysis of the roadway at a new field, the analytical approach is recommended to decide on further development of the mine. However, if a more detailed analysis is required to determine the number of zones, their radial length, zone occurrence depth, exact location of the last disintegration zone and the boundary of a single mine area, the numerical method shall be used to obtain more reliable data.

The combined use of numerical and analytical methods to determine the periodicity model of rock mass zone disintegration will result in a higher reproducibility of theoretical and field survey data. Such combined usage helps reduce the relative error during calculation of the surveyed model parameters, which would increase the accuracy and reliability of the results obtained with this model.

Table 1

Parameter γ for various fields

Geological rock location	r^* / r_0	γ	γ^*	Relative accuracy, %
Norilsk fields	2.0	3	3.336526	11.21
Donbass fields	1.0	13	13.050143	0.38
Primorsky Krai, Artyom Mine (settlement Shkotovo)	0.6	17	17.637309	3.75

Table 2

Norilsk field

Parameter value γ	Relative accuracy calculation of close and remote disintegration zone boundaries, %			
	Zone I		Zone II	
$\gamma = 3$	0.71	4.86	19.06	6.8
$\gamma = 3.2$	2.14	5.36	17.18	5.29
$\gamma = 3.29$	3.57	5.67	16.25	4.53

Table 3

Dingji coal mine (China)

Parameter value γ	Relative accuracy calculation of close and remote disintegration zone boundaries, %							
	Zone I		Zone II		Zone III		Zone IV	
$\gamma = 9$	0	2.69	10.60	10.80	11.60	3.00	9.51	7.04
$\gamma = 9.9$	0	1.81	8.09	8.17	8.00	0.13	5.45	3.44
$\gamma = 9.93$	0	1.61	8.00	8.07	7.88	0.22	5.33	3.33

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Abstract:	An overview of the new, the most significant results in the field of mining research based on the use of non-Euclidean continuum model to describe the distribution of the stress field around the development of circular cross-section. The question of the accuracy of calculation of the parameters of the models constructed and compared with field experiments. Considered separately taken model parameter frequency zonal fracture rock mass around deep development of circular cross section. Selecting this option justified its prognostic significance for solving problems in the study of mining deposits. A comparative analysis of analytical and numerical determination of this parameter with the field data of two independent fields. The technique is described and sharing analytical and numerical approach, depending on the task on the test field.
Keywords:	highly compressed array; zonal destruction; options; non-Euclidean model; array; Full-scale data
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