Research Journal of Applied Sciences 11 (6): 281-286, 2016
ISSN: 1815-932X

Development of Numerical Models for Rock Mass Stress-Strain Behavior Forecasting During Ore Deposit Open-Pit Mining

Kaerbek Rafkatovich Argimbaev and Henry Alexandrovich Kholodjakov
National Mineral Resource University "University of Mines",
21 Line V.O 2, 199106 St. Petersburg, Russia

Abstract: Results of numerical models for rock mass stress-strain behavior presented in the paper allow to reduce the risk of technogenic accidents during mineral deposits open-pit mining with taking into account the construction sequence, the pit depth and the degree of water cut. The methods in which the continuous medium is approximated by a discrete model at the stage of the numerical model development are referred to the computational methods of rock mass stress-strain behavior forecasting. In this case where further idealization when formulating and solving equations is not applied, integration is replaced by finite summation and partial differential equations are replaced by systems of linear algebraic or ordinary differential equations. In addition, the continuous medium is replaced by a discrete model having a finite number of degrees of freedom.

Key words: Numerical simulation, stress-strain behavior, continuous medium, deformation, finite element method, stability factor, pit dept

INTRODUCTION

A significant advantage of numerical methods is a possibility to obtain quantitative results when solving problems that take into account real-time conditions of facilities operation in relation to external influences, geometrical dimensions, nonhomogeneous clots and mechanical properties of rock mass (Argimbaev and Kholodjakov, 2015). Each group of problems has an optimal solution method. It can be chosen provided that there is a clear understanding of the nature of facility operation and the interaction of its individual components in real-time conditions. Researches carried out by methods of continuum mechanics are based on a joint solution of three systems of equations:

- Equilibrium equations that are the basic condition for any mechanics problem
- Equations of constraints between deformations and displacements and resulting equations of strain compatibility relating to geometrical conditions
- Equations of states characterizing dependence of deformations on strain, time and temperature

Mathematical formulation of the problem (Argimbaev *et al*., 2015) consists of the abovementioned equations formulation as well as compliance with the boundary conditions (specified values of strain, displacement of body points or the combination of the first and the latter) and initial conditions (values of displacement, strain or their speed at certain moments of time).

MATERIALS AND METHODS

The Finite Element Method (FEM) is an approximate numerical method designed to solve geomechanics problems. This method is based on the solution of differential equations of equilibrium and compatibility of deformations with fulfillment of the conditions for material equilibrium and continuity at each point of a deformable body. The infinite domain under consideration while applying the FEM is replaced by a finite one and is divided into a finite number of elements. Thus, the conditions of equilibrium and compatibility of deformations are kept only in common joint element knots (Eshiett and Udosen, 2009).

To determine unknown forces in knots and knot displacement considering pre-set forces or movements on the border of the domain, equations of equilibrium and strain compatibility are formulated and their number shall correspond to the number of knots of the computational model. FEM provides an opportunity to take into account strength and deformation characteristics of rock for the calculations while only strength properties were used in earlier methods of soil mechanics.

The basic procedure of FEM provides for a solution of linear problems: steady laminar filtration and stress-strain behavior of the environment with

Corresponding Author: Kaerbek Rafkatovich Argimbaev, National Mineral Resource University "University of Mines", 21 Line V.O., 2, 199106 St. Petersburg, Russia

linear-elastic coupling of stress and strain. Various non-linear solutions can be formulated by means of multiple repetitions of linear solutions (Argimbaev *et al*., 2015).

Numerical techniques become more and more popular for solving geomechanics problems. Limited dimensionality of the task to be solved is the main restriction of the approach (limited size of RAM, CPU speed) (Argimbaev and Yakubovskiy, 2014).

The finite element method is a product and at the same time, a powerful promoter of the modern scientific and technological progress. The wide capabilities of FEM have been most pronounced in mechanics of soils and rocks with their wide variety of materials mechanical properties and loading conditions (Behim *et al*., 2007; Argimbaev and Yakubovskiy, 2014).

Advantages ensuring FEM popularity are as follows: possibility to get certain solutions using the available finished program; possibility to condense the grid of elements at expected areas with high gradient of the parameter under consideration; possibility to set any boundary conditions; principal possibility to implement arbitrary mechanical properties of material, any sequence of loading, etc., in the programs (Eyo and Abasiekwere, 2009).

The basic concept of FEM lies in the fact that the required continuous variable whether it is the pressure of the filtration flow or displacement of the deformed body points, is approximated by a piecewise set of elementary functions defined over limited finite subdomains (elements) (Argimbaev and Yakubovskiy, 2014). This procedure allows reducing the integration of differential equations to solving a system of linear equations. Quantitative values of the unknown variable are found in a limited number of points (knots) of the domain while the values and derivatives of the function within the elements are determined by approximating functions and its derivatives.

Modern software systems designed for the evaluation of stress-strain behavior using the finite element method allow obtaining numerical solutions when carrying out structural calculations for a wide range of materials with different mechanical characteristics and behavior (Kholodjakov and Argimbaev, 2014).

Besides FEM there is the Boundary Element Method (BEM). Unlike FEM that presupposes discretization of the entire computational domain, only the boundary is discretized in BEM. Transition from the initial boundary value problem for partial differential equations to relations linking unknown functions on the boundary of the domain is carried out by means of boundary integral equations or some functionals. In the first instance BEM is reduced to the methods of boundary integral equations, in the second one to variational techniques (Argimbaev and Kholodjakov, 2013; Balaji *et al*., 2013; June and Khalaf, 2009).

Combined methods (FEM-BEM, the initial parameters method, the method of bar system mechanics) also became widespread techniques for solving mining geomechanics problems.

A number of factors influence the stress-strain behavior of the near edge zone: geological and hydro-geological structure of the deposit, pit wall parameters-depth and pit wall angle. In this regard, it is required to consider all of these factors in the course of numerical simulation to obtain a complete and accurate picture of the near edge zone deformation.

RESULTS AND DISCUSSION

The objective of the mathematical modeling was to study parameters of the stress-strain behavior of homogeneous near edge mass and carry out a detailed study of horizontal deformations distribution as well as their changes with deepening of the pit. Such problems do not have precise analytical solutions, so the most effective methods of studying the stress-strain behavior of mass under such conditions are physical or mathematical modeling. In our case we used mathematical modeling based on the finite element method that despite some idealization of real-time conditions has significant advantages for research opportunities. A homogeneous slope with gradual model development was designated as the subject of inquiry. The computational model is shown in Fig. 1. Solution of such a problem will allow determining

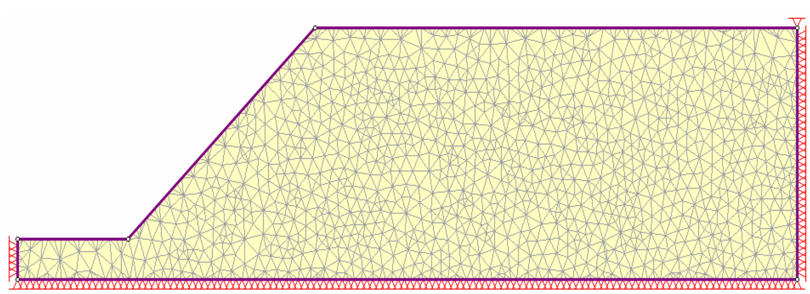

Fig. 1: The computational model of a homogeneous near-edge mass split by elements

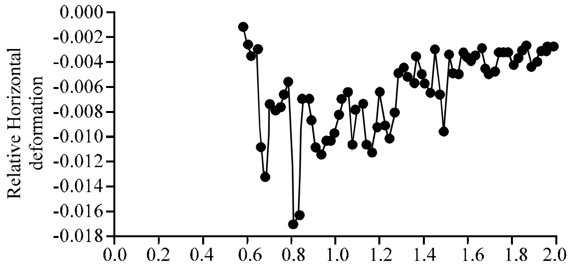

Fig. 2: Distribution of relative horizontal deformations across the surface after the first stage of pit mining simulation

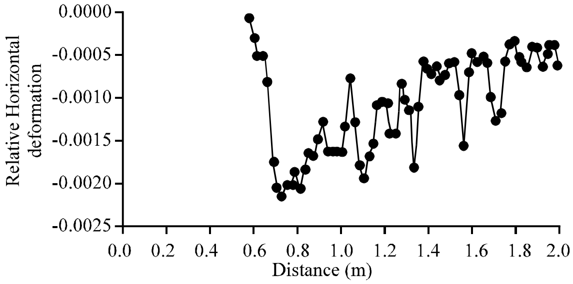

Fig. 3: Distribution of relative horizontal deformations across the surface after the third stage of pit mining simulation

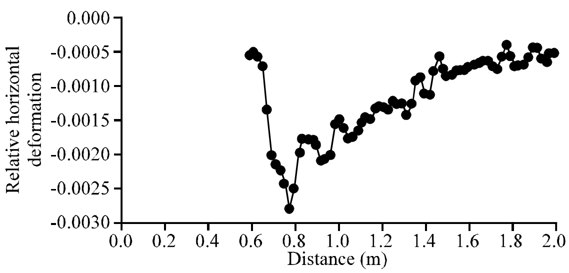

Fig. 4: Distribution of relative horizontal deformations across the surface after the fifth stage of pit mining simulation

deformations development in a homogeneous slope by means of a numerical method and will provide an opportunity to compare the findings with the results of the equivalent material simulation study conducted by the Mining University.

Particular attention was paid to studying the process of horizontal deformations distribution in the pit wall depending on the pit mining phasing. Diagrams of distribution of relative horizontal deformations across the slope daylight area at different stages of model development are shown in Fig. 2-5. The slope foot at the end of pit mining was accepted as the reference point.

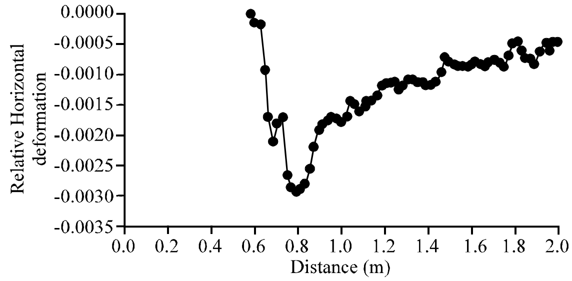

Fig. 5: Distribution of relative horizontal deformations across the surface after the seventh stage of pit mining simulation

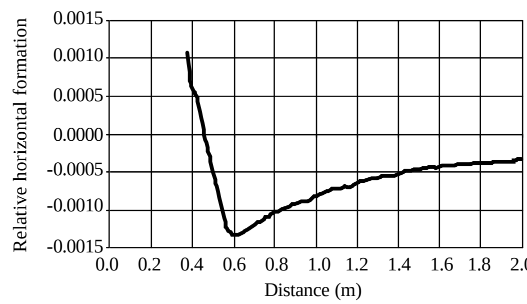

Fig. 6: Distribution of relative horizontal deformations at a depth of 0.4H from the pit surface after the first stage of pit mining simulation

The modeling outcomes showed that the parameters of the stress-strain behavior of mass under consideration in the vicinity to the surface are almost of the same shape and as for the quantity they depend on the phasing of the pit mining model as far as the pit depth increases, values of horizontal deformations increase.

At the beginning of pit mining simulated by the model we can see abrupt distribution of horizontal deformations across the surface line with the maximum value at a distance of 0.35H where H is the pit depth (Fig. 5).

This dependence gives evidence of fishstake formation. Further development of the model depth results in changes in the nature of horizontal deformations distribution.

The amplitude of jumps decreases at the fifth stage of mining (Fig. 4 and 5) and the concentration of deformations at a distance of 0.4H from the slope top increases. The result of this distribution of horizontal deformations is formation of a vertical break line of the assumed sliding wedge.

Let us monitor the process of formation of the stress-strain behavior of the near-edge area mass at a depth of 0.4H from the pit surface. The slope foot at the end of pit mining was accepted as the reference point. The results are shown in Fig. 6-9.

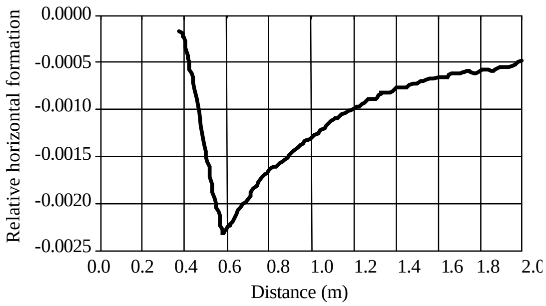

Fig. 7: Distribution of relative horizontal deformations at a depth of 0.4H from the pit surface after the third stage of pit mining simulation

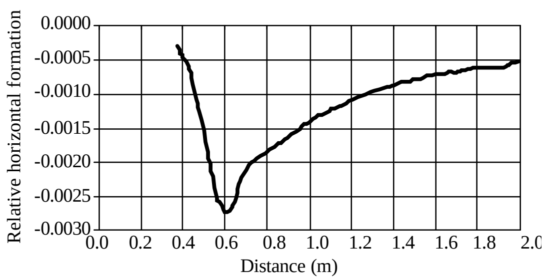

Fig. 8: Distribution of relative horizontal deformations at a depth of 0.4H from the pit surface after the fifth stage of pit mining simulation

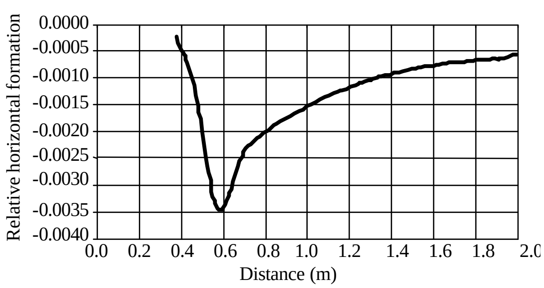

Fig. 9: Distribution of relative horizontal deformations at a depth of 0.4H from the pit surface after the seventh stage of pit mining simulation

So, the nature of horizontal deformations distribution across the near-edge area mass at a depth of 0.4H from the pit surface is constant, it is changed only in terms of quantity as far as the depth increases the values of deformations increase. The maximum values of horizontal deformations at all stages of mining are located at a distance of 0.35H and vary from 0.0013-0.0035.

A fuller picture of formation of stress-strain behavior of homogeneous near-edge mass of the model in the case of phase-by-phase mining can be seen in Fig. 10-14.

Figure 10-14, it is clear that the core of maximum horizontal deformations is located deep in near-edge mass at a distance of 0.4H from the pit surface. It indicates that the maximum tension subsequently resulting in rupture is located in the active pressure prism. The slip plane in the pit wall consisting of homogeneous mass is circular cylindrical and it crops out at a distance of 0.2H from the pit bottom but not to the slope foot.

These simulation results revealed a number of laws of deformations development across a homogenous slope. In the process of phase-by-phase model mining spasmodic distribution of horizontal deformations is observed on the slope surface and the maximum value is registered at the distance of 0.2 m from the slope top. This phenomenon could be explained by cracks forming on the surface in the process of pit mining. The maximum tension deformations which values increase with increasing the model depth, show the real point where part of the mass is splitting off and caving. The maximum horizontal deformations zone is located deep in the mass and is associated with the center of the slope. Values of the maximum horizontal deformations increase with increasing the depth of model mining. The result of such a stress-strain behavior of mass is bulging rock across the slope line (Fig. 14).

CONCLUSION

Numerical modeling based on the finite element method, in general, allows monitoring the slope deformation process up to the limiting state. Taking into

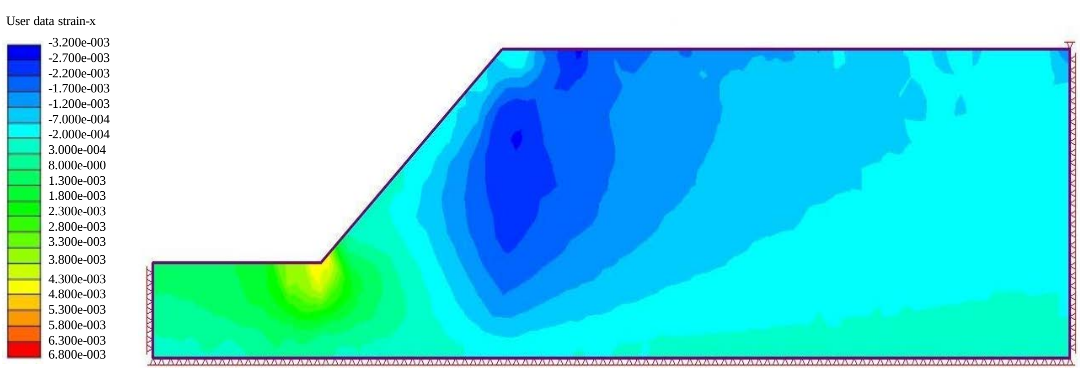

Fig. 10: Distribution of relative horizontal deformations of the model slope after the first stage of pit mining simulation

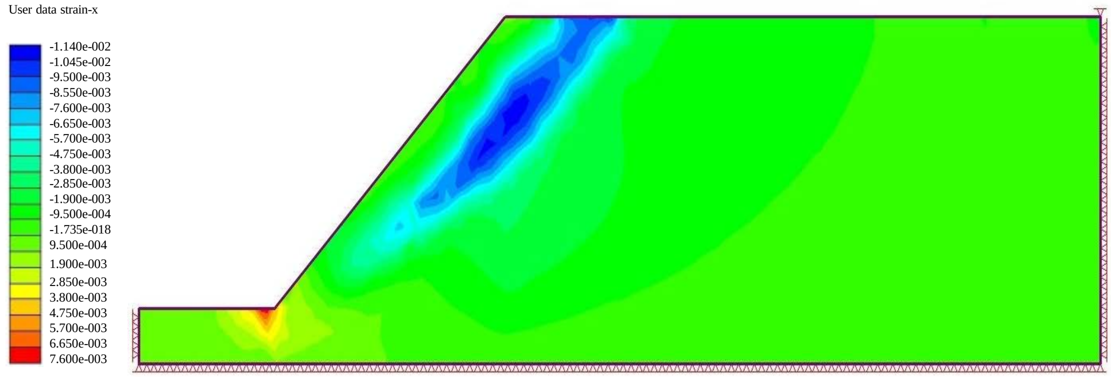

Fig. 11: Distribution of relative horizontal deformations of the model slope after the third stage of pit mining simulation

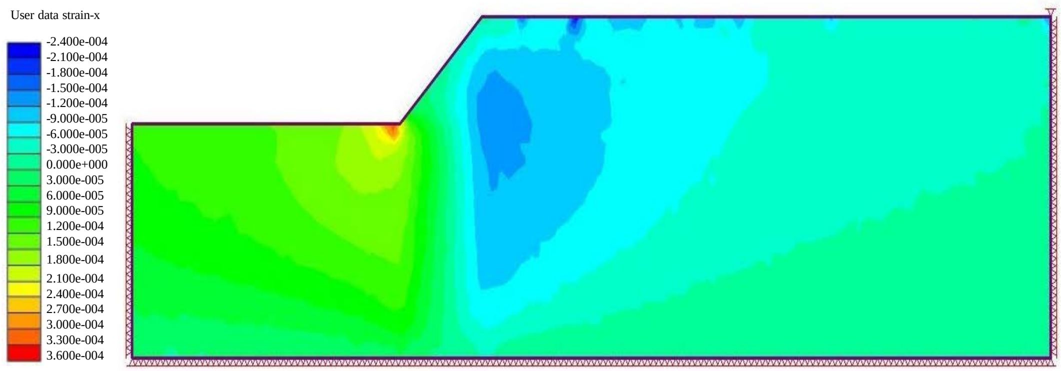

Fig. 12: Distribution of relative horizontal deformations of the model slope after the fifth stage of pit mining simulation

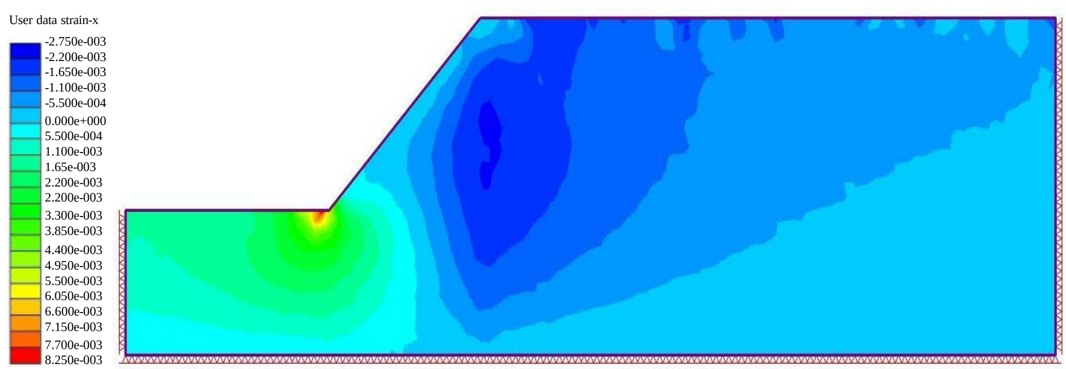

Fig. 13: Distribution of relative horizontal deformations of the model slope after the seventh stage of pit mining simulation

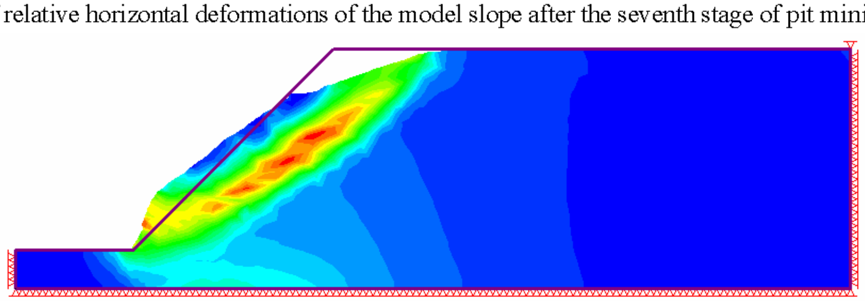

Fig. 14: Fall of the homogenous slope model

the consideration the revealed laws will be helpful to avoid formation of landslides in pits by means of preventing the mass edge destruction.

REFERENCES

Argimbaev, K.R. and H.A. Kholodjakov, 2013. Determining the safe working height of an power shovel for the development of iron-bearing tailing dumps. World Appl. Sci. J., 27: 1087-1090.

Argimbaev, K.R. and H.A. Kholodjakov, 2015. Erection methods and constructions of primary tailing dike. Intl. J. Ecol. Develop., 30: 47-54.

Argimbaev, K.R. and M.M. Yakubovskiy, 2014. Economic substantiation of a quarry usage and an overburden dumps, considering the disposal of industrial waste in them. World Appl. Sci. J., 29: 1621-1625.

Argimbaev, K.R., M.M. Yakubovskiy and M.A. Ivanova, 2015. Design justification of drainage and anti filter facilities of the tailings at various methods of their constructions. Intl. J. Ecol. Develop., 30: 76-85.

Balaji, G., S. Vengataasalam and S. Sekar, 2013. Numerical investigation of second order singular system using single-term Haar wavelet series method. Res. J. Appl. Sci., 8: 9-13.

Behim, K.M., M. Bounouala and M.L. Boukelloul, 2007. Stability study of the mining methods by rooms and pillars of the Chaabet EL Hamra Mine Ain Azel (Algeria). Res. J. Applied Sci., 2: 1130-1134.

Eshiett, A.A. and C. Udosen, 2009. Hydrogeologic characteristics of surface-mine spoil in Okaba Coalfield of Kogi State. Res. J. Applied Sci., 4: 142-147.

Eyo, A.E. and U.A. Abasiekwere, 2009. Numerical scheme for wave propagation problem. Res. J. Applied Sci., 4: 148-151.

June, L.W. and W.S. Khalaf, 2009. A linear programming approach for the project controlling. Res. J. Applied Sci., 4: 202-212.

Kholodjakov, H.A. and K.R. Argimbaev, 2014. Waste storage feasibility of concentrating mill in overburden dumps. World Appl. Sci. J., 30: 738-740.