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Control of rock massifs state for sustainability of natural and man-caused slopes and underground structures under influence of contemporary seismic and tectonic processes

A D Melikulov[1,2*], K D Salyamova[3], N Yu Gasanova[4], and A S Ismailov[5]

[1]Special Administration Co. Ltd. 53 Billur str., Tashkent, 100158, Uzbekistan
[2]Department of Mining. Almalik Branch of Tashkent State Technical University. 5 Mirzo Ulugbek str., Almalik, 110100, Uzbekistan
[3]Department of Dynamics of Spatial Systems and Hydraulic Structures. The Institute of Mechanics and Seismic Stability of Constructions of the Science Academy of the Republic of Uzbekistan, 31 Durmon Yuli str., Tashkent, 100125 Uzbekistan
[4]Department of Mathematics. Tashkent State Technical University. 2 University str., Tashkent, 100095, Uzbekistan
[5]Department of Geotechnology of Coal Deposits. Tashkent State Technical University. 2 University str., Tashkent, 100095, Uzbekistan

E-mail: Konchilik@Mail.Ru

Abstract. The article deals with issues related to the peculiarities of the formation and change in time of the stress-strain state of rock massifs as objects of active man-caused impact of engineering facilities, both surface and subsurface, hydrotechnical and road construction, mining operations, including development of mineral deposits by open-cut and underground methods. Arrays of rock formations have a wide range of properties that manifest themselves as hazardous natural geological events, and also under any technological influences to them, including the method of blasting destruction. The peculiarities of the behavior of such arrays consist in the combination of the characteristics of solid as elastic and plastic bodies, including brittle, and viscous-flowing bodies, and creep.
Technological impact on the rock mass can lead to undesirable dangerous consequences both from the point of view of the object's stability and safety, and the need for additional material costs to maintain the equilibrium in the new conditions. The identification of the potential area of permissible deformations and the conditions for the destruction of such an array of rocks, taking into account the time factor, is of practical interest for selecting effective parameters of mining technology that allow the prevention of dangerous undesirable consequences of destruction.

1. Introduction

More than 10^{12} t of various ores, solid fuels and building materials are moved around the world annually by various engineering methods in the field of construction and mining. In the world practice of mining there is a steady tendency of a natural increase in the depth of mining of mineral deposits. Along with the desire to increase the volume of mining, strict requirements are put forward to improve the working conditions of miners, to ensure the safety of work, the use of new more efficient technologies [4, 7, 8, 16].

The countries of Central Asia are rich in minerals, they traditionally develop the extraction of gold, uranium, oil, gas, copper, coal and a number of other types of mineral raw materials. More than 3,000 deposits of about 100 kinds of minerals have been identified in Uzbekistan, more than 1,400 deposits containing more than 70 types of mineral raw materials, including more than 50 noble deposits, more than 40 deposits of non-ferrous, rare and radioactive metals, etc., have been discovered [1, 3, 5].

With the development of deposits with favorable geological conditions, as well as lying at shallow depths, the depth of field mining development increases, mining and geological conditions become more complicated, rock pressure and water cut of the massif increase, which requires additional costs for maintaining underground workings during the required long-time of their operation [6, 8].

Particular attention from the point of view of underground mining technologies attracts stress fields that are formed under the influence of tectonic forces as a result of uneven movements and deformations of the earth's crust. Such stresses in an array of rocks caused by tectonic processes, according to experts in various mining regions of the world, can exceed 10 to 20 times the tension from the total weight of the rock column. Under the action of these forces acting in the subhorizontal plane, qualitatively new conditions arise both in studying the natural stress field and in calculating the steady state of the rocks around the workings [2, 20].

2. Materials and methods

2.1. Statement of seismotectonic processes and fields of stresses

One of the characteristic features of mineral deposits in the countries of Central Asia is their location in the highlands or even in high mountains. For example, the polymetallic deposit Khandiza (Uzbekistan) is located in the spurs of the Tien Shan at the level of 1300 – 1800 m above sea level; coal deposit Shargun – at a mark over 1550 m; mercurial deposit of Khaidarkan (Kyrgyzstan) - at the level of 1500 – 2350 m. The well-known railway tunnel Angren-Pap, which is the longest in Central Asia, was built in the mountains at 1320-1420 meters, the elevation points on the surface of this mountain pass reach a mark of 2,845-3,476 meters above sea level [8, 13, 19].

It is noted that the tectonic forces on the scales of long geological time vary in both magnitude and direction [3, 20].

In areas covered by active new tectonic movements, the change in tectonic forces over time is of interest for the problems of rock mechanics.

2.2. Monitoring of the conditions of mine works

Observations have shown that the magnitude of tectonic stresses can change noticeably when passing from the mine to the mine. Even within the same mine and on the same horizon (for example, in the 600 m of the Rasvumchorrsky mine, Russia) tectonic stresses change more than twice in magnitude. Thus, against the background of the general pattern of excess of horizontal tectonic stresses over gravitational verticals, a statistically significant change in the tectonic stresses at different sites is observed [9, 14, 18].

Such factors are the reason that some of the coal mines (Shurab in Tajikistan, Sulukta and Kizilkiya in Kyrgyzstan, et al.), signs of rockbursts have a depth of about 200 m development. The case was observed in the construction of an inclined mine for the transportation of coal by a conveyor on Angrensky coal mine (Uzbekistan), when the deformation of the array curved the axis of production and made it impossible to equip it with a conveyor.

In connection with the technological peculiarities of the repair conditions for the damaged support or the working site in underground cramped and dangerous conditions of the threat of continuing collapses, the cost of repairing each meter of the emergency site of underground mining may even exceed the cost of constructing one meter of new gallery.

2.3. Analysis of the information basis on the seismic events

In order to quantify the impact of seismotectonic processes, extensive studies are carried out at geodynamic polygons. Experts based on long-term observations compiled a map of young and modern geological movements of the territory of Uzbekistan. At the Central Kyzylkum geodynamic range, the vertical displacement rate is from (-4) to (+2) mm per year, and in the zone of tectonic faults the displacement module reaches up to 18-22 mm per year. In the narrower part of this region in the zone of Marjanbulak earthquake on May 26, 2013 (Uzbekistan, there are several gold mines here), the displacement speed in the flat zone is up to 10 mm per year, in the foothills - up to 20-30 mm per year, in the mountains - up to 50 mm per year; as a result of this earthquake, the magnitude of stress relief is estimated at 12 MPa [1, 2, 15, 17].

In modern geomechanics methods for assessing the influence of acting factors through the probabilities of events [3, 16]. Especially relevant is the probabilistic approach to the evaluation of random events scattered in space and time, such as earthquakes. In addition, earthquakes vary greatly in intensity, depth of manifestation, distance from the epicenter to the object, engineering-geological conditions of the environment, etc. [19].

For the probabilistic estimation of the effect of seismic phenomena, statistical studies of the field of events were carried out, which took the region of Central Asia and Kazakhstan, located within the parallels of 35-45 degrees North latitude and meridians 63-82 degrees East longitude. For ease of use, information on earthquakes registered in this region with a magnitude $M \geq 2.8$ based on the annual earthquake bulletins is registered as an electronic database [3, 10, 14].

The collected database covers on average more than 2800 events (earthquakes) occurring annually within this region, each of which is represented by 7 main features: date, time, geographic coordinates, depth of focus, accuracy class of the epicenter coordinates, energy class [2, 3].

2.4. Computational experiment: modeling of sustainability of underground mine workings

Modern mathematical methods and technical computing means allow obtaining qualitatively new and multivariate solutions of problems with subsequent evaluation of the degree of their identity to real processes. The authors developed computer application programs for the quantitative evaluation of the strength of underground workings, taking into account the features of their design, piecewise inhomogeneous physical and mechanical characteristics of the surrounding rock mass for the accepted calculation schemes and numerical models [4, 8, 11, 12].

2.5. A flat task in the study of the stress-strain state of a rock mass around mine workings

For the numerical solution of the problem, the infinite region surrounding the underground mine is replaced by a finite region of volume V_1, at the boundaries of which the corresponding boundary conditions are put or loads are applied.

The mathematical formulation of the task includes the variational equation:

$$\delta A = -\int_V \sigma_{ij}\delta\varepsilon_{ij} dV + \int_V \vec{f}\delta\vec{U} dV + \int_{\sum P} \vec{P}\delta\vec{U} d\sum = 0, \quad (1a)$$

$$(V = V_1 + V_2), \quad (1b)$$

where $\vec{U}$, σ_{ij}, γ_{ij}, - are components of the displacement vector, stress and deformations tensors; $\delta\vec{U}$, $\delta\varepsilon_{ij}$ - variations of displacements and deformations; $\vec{f}$ – vector of mass forces; $\vec{P}$ – vector of external forces applied to the surrounding area.

Border conditions:

a) under the influence of gravity forces

$$\sum\nolimits_1^1 \ u \ \sum\nolimits_1^3 \ : U=0, \quad (2)$$

$$\sum\nolimits_1^4 \ : V=0$$

b) under the influence of external (tectonic) forces

$$\begin{aligned}
&\textstyle\sum_1^4 \;:\; V=0, X=0,\\
&Y=0, U=0,\\
&\textstyle\sum_1^1 = \sum_p \;:\; \sigma_{11} = q_r,\\
&\textstyle\sum_1^3 = \sum_p \;:\; \sigma_{11} = -q_r,\\
&\textstyle\sum_1^2 = \sum_p \;:\; \sigma_{22} = -q_b.
\end{aligned} \tag{3}$$

c) under the natural stress state, i.e. when combined action of gravitational and tectonic forces - the same as in b).

Physical properties of body material ($n = 1$) and lining ($n = 2$) are described by Hooke's law

$$\sigma_{ij} = \lambda_{ij}\varepsilon_{kk}\delta_{ij} + 2\mu_{ij}\delta_{ij},\; i, j = 1{,}2, \tag{4}$$

where λ_{ij}, μ_{ij} - the Lamé constants; δ_{ij} – the Kronecker symbol.

The relationship between deformations and displacements in a plane formulation is determined by the Cauchy relations. Using the developed algorithm of the Finite Element Method, the variational task (1) reduces to solving a system of algebraic equations with respect to displacements of the form

$$[K]\,\{X\}=\{f\}, \tag{5}$$

where [K] - stiffness matrix, {f} – vector of required nodal displacements.
The system of equations (4) is solved by the Gauss method.

3. Results and discussion

COSMOS/Works is a finite element analysis system integrated into 3D SolidWorks. The combination of design systems and finite element analysis has made it possible to obtain a tool for calculating and optimizing designs consisting of a large number of elements. In the rock massif with the accepted average physical-mechanical properties (modulus of elasticity, Poisson's ratio, volume weight, angle of internal friction, coefficient of adhesion), a mining with design parameters is constructed at a given depth. Based on the results of calculations of the state of the array, the acting stresses are set [2,8,10].

Figures 1 and 2 show horizontal and vertical displacements of points as a result of successive explosions of the central cut hole (single charge), then in a group of cut holes that are disposed around a 1.5 m diameter circle. The duration of the explosion of the first charge in the central hole is $1{,}0\text{x}10^{-3}$ s, the duration of its action on the array continues for $1{,}0\text{x}10^{-2}$ s, after which its influence on the rocks dies out. Then, at a time of $12\text{x}10^{-3}$ s, detonation occurs in two symmetrically located boreholes of the next series, the duration of explosion of which is also $1{,}0\text{x}10^{-3}$ s, the duration of this explosion action on the array also continues for $1{,}0\text{x}10^{-2}$ s, i.e. up to the moment $23\text{x}10^{-3}$ s.

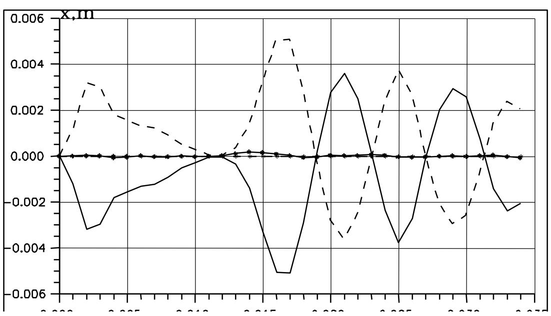

Figure 1. Horizontal displacements of points on the face of shaft at consecutive blasting of cuttings.

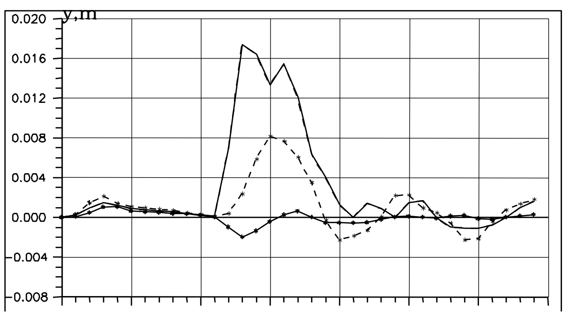

Figure 2. Vertical displacement of points on the face of shaft at consecutive blasting of cuttings.

Figures 3 – 4 show the schemes of the stress-strain state of the bottomhole massif of rocks during the explosion of the first and second group of cut holes in the period of $1{,}0x10^{-3} – 23x10^{-3}$s.

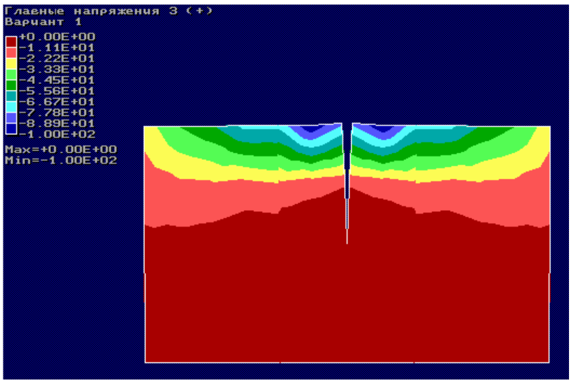

Figure 3. Scheme of distribution of horizontal stresses at the explosion of the first group cut holes on the face of shaft.

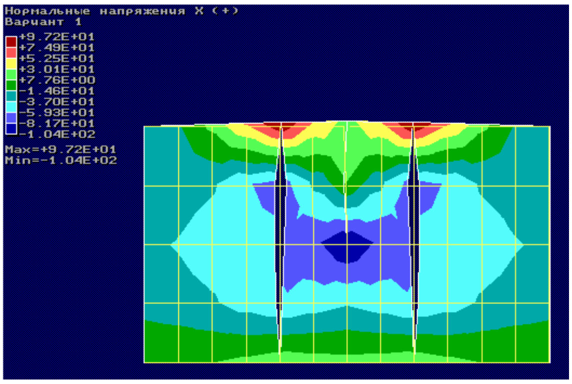

Figure 4. Scheme of distribution of horizontal stresses at the explosion of the second group cut holes on the face of shaft.

The results of solving this problem make it possible, on the basis of the wave interaction of simultaneously exploded charges in each group of the exploded series, to select the optimal range of the following parameters for blasting operations: the mass and number of charges in each series of deceleration, the sequence and the delay of the explosion of charge explosions both within each series, and between series of explosive charges. The control of the action of explosive charge during the construction of the mine makes it possible to achieve a qualitative and uniform fragmentation of the blasted rock mass in the shaft. At the same time, the maximum integrity of the rock massif behind the design outline of mine workings is ensured, which is one of the measures to preserve the stability of the rock massif and the constructing underground gallery. This quality of blasting operations will also prevent negative impact on the surrounding massif without causing unnecessary cracking and deformation, including the avoidance of dynamic (induced) manifestations of rock pressure in the tectonically tense zone of the rock massif.

It should be noted that such broad opportunities to manage the process and the result of blasting when constructing underground mine workings arise using modern means of non-electric initiation of charges of explosives.

4. Summary

In addition, with the depletion of reserves of deposits with favorable geological conditions, mining works continue to develop for more complex natural conditions.

The Central Asian region and many areas of modern orogenic processes are characterized by the manifestation of seismotectonic processes, the results of which, on the one hand, complicate engineering conditions of work, and on the other become a powerful engine for the further development of mining technologies. As a result of anthropogenic activity, in the solution of global regional problems, there are cases of creating additional sources of danger leading to the stimulation of technogenic-tectonic or induced seismicity.

The human need to solve the problems that have arisen, has led on the basis of study of Earth's physics and engineering mathematics to the intensive development of modern methods of geomechanics, tectonics, geophysics, and geodynamics.

Numerical methods of modeling mining-geological objects and processes of any complexity with the use of modern technical and software tools offer new opportunities in solving technological problems, especially in areas where physical experiments in the traditional view are difficult - in underground mining facilities, processes of destruction and mining of minerals using blasting technologies.

Modern investigations in the discussed field of science and mining production give an instrument for preliminary substantiated evaluation of technical solutions, the forecast of possible adverse consequences, the threat of catastrophic events, the safety of objects and people, and material and economic losses. The original development of the methodology for calculations with the use of models allows us to solve the modern tasks in a new way using computer programs developed, as well as to offer technological measures for managing the state of the array in the production of blasting operations in underground workings, taking into account the safety and prevention of the dynamic manifestations of the rock pressure.

5. References

[1] Artikov T U, Ibragimov R S, Ibragimova T L and Mirzaev M A 2020 Models of the macroseismic field earthquakes and their influence on seismic hazard assessment values for Central Asia *Geodynamics & Tectonophysics* **11 (3)** 606–623 DOI:10.5800/GT-2020-11-3-0494

[2] Buriev A T, Salyamova K D, Turdikulov Kh Kh and Takhirov Sh M 2020 Numerical analysis of earth dam stress-strain state under seismic impact considering the wave dynamics *Construction Materials and Products* **3 (3)** 5–20 DOI: 10.34031/2618-7183-2020-3-3-5-20

[3] Gasanova N Yu 2017 Formation of the earthquake database for evaluation of their influence on the slope stability of deep quarries *European science* **6(28)** 24-26

[4] Ismailov A S, Melikulov A D, Sadinov Sh M, Sultanov K S, Salyamova K D and Gasanova N Yu 2016 Features of rock massifs lengthy deformation process and monitoring by them at deep quarries *Problemy Nedropolzovaniya* **3** 18-23 DOI: 10.18454/2313-1586.2016.03.018

[5] Karablin M M and Prostov S M 2020 Angren coal pit Centralny landslide slope stability analysis based on a three-dimensional geological-geophysical model *Izvestiya vysshikh uchebnykh zavedenii.Gornyi zhurnal (News of the Higher Institutions. Mining Journal)* **3** 39–49 DOI: 10.21440/0536-1028-2020-3-39-49

[6] Kocharyan G G, Kishkina S B, Budkov A M and Ivanchenko G N 2019 On the genesis of the 2013 Bachat earthquake *Geodynamics & Tectonophysics* **10 (3)** 741–759 DOI:10.5800/GT-2019-10-3-0439

[7] Kulikova E Yu 2021 Methods of forming an integral risk assessment in mine and underground construction *Mining Inf Anal Bull* **2-1** 124-133 DOI: 10.25018/0236-1493-2021-21-0-124-133

[8] Melikulov A D, Aripov A T, Salyamova K D and Rumi D F 2018 *Investigation and maintenance of underground mining developments in seismic-tectonic active areas of the Central Asia* (Proceedings of the 25–Word Mining Congress Astana Kazakhstan) 1506–1515 https://wmc2018.org/ru/kongress/

[9] Pankov I L 2019 Theoretical estimation of in-situ stressed state of rock massifes under conditions of tectonic influence *News of the Tula State University. Earth Sciences* **4** 292-304

[10] Rebetsky Yu L 2020 Pattern of global crustal stresses of the Earth *Geotectonics* **6** 3-24 DOI: 10.31857/S0016853X20060119

[11] Rybin A K, Leonov M G, Przhiyalgovskii E S, Batalev V Yu, Bataleva E A, Matyukov V E, Lavrushina E V, Zabinyakova O B and Schelochkov G G 2018 Upper crust structural and morphological ensembles of the Pamir-Tien Shan segment of Central Asia and their reflection in geophysical fields *Vestnik of Saint Petersburg University. Earth Sciences* **63 (4)** 478–501 https://doi.org/10.21638/spbu07.2018.405

[12] Shapoval V, Shashenko O, Hapieiev S, Khalymendyk O and Andrieiev V 2020 Stability assessment of the slopes and side-hills with account of the excess pressure in the pore liquid *Mining of Mineral Deposits* **14 (1)** 91–99 https://doi.org/10.33271/mining14.01.091

[13] Sultanov K S, Salyamova K D, Khusanov B E and Melikulov A D 2003 Analysis of the stress-strain state of engineering structures under dynamic loads *Bulletin of Tashkent State Technical University* **2** 107–111

[14] Sidorov D V, Potapchuk M I, Sidlyar A V and Kursakin G A 2019 Assessment of rockburst hazard in deep layer mining at Nikolayevskoye field *Journal of Mining Institute* **238** 392-398 DOI: 10.31897/PMI.2019.4.392

[15] Sycheva N A and Mansurov A N 2020 Seismotectonic deformation of the lithosphere in the Pamir and adjacent territories *Geodynamics & Tectonophysics* **11 (4)** 785–805 DOI:10.5800/GT-2020-11-4-0507

[16] Tyupin V N 2019 Estimation of critical depth of deposits by rockburst hazard condition *Journal of Mining Institute* **236** 167-171 DOI: 10.31897/PMI.2019.2.167

[17] Vogler D, Walsh SDC and Saar MO 2020 A numerical investigation into key factors controlling hard rock excavation via electropulse stimulation *Journal Rock Mechanics and Rock Engineering* **12** 793–801 https://doi.org/10.1016/j.jrmge.2020.02.002

[18] Wesseloo J 2020 Addressing misconceptions regarding seismic hazard assessment in mines: *b*-value, M_{max}, and space-time normalization *The Journal of the Southern African Institute of Mining and Metallurgy* **120 (1)** 67–80 http://dx.doi.org/10.17159/2411- 9717/855/2020

[19] Zhai S, Su G, Yin S, Zhao B and Yan L 2020 Rockburst characteristics of several hard brittle rocks: A true triaxial experimental study *Journal of Rock Mechanics and Geotechnical Engineering* **12** 279-296

[20] Zhu H, Chen M, Zhao Y and Niu F 2017 *Stability assessment for underground excavations and key construction techniques* (Singapore: Springer Nature Singapore Pte, Ltd) 157 DOI: 10.1007/978-981-10-3011-6

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