https://doi.org/10.33271/nvngu/2023-1/032

D. T. Ivadilinova[*1],
orcid.org/0000-0002-9731-0587,
T. K. Issabek[1],
orcid.org/0000-0001-7718-933X,
D. K. Takhanov[2],
orcid.org/0000-0002-2360-9156,
G. B. Yeskenova[1],
orcid.org/0000-0001-8184-4085

1 – Non-profit joint-stock company "Abylkas Saginov Karaganda Technical University", Karaganda, the Republic of Kazakhstan
2 – Scientific Research Center ISM Group LLP, Karaganda, the Republic of Kazakhstan
* Corresponding author e-mail: d.ivadilinova@gmail.com

PREDICTING UNDERGROUND MINING IMPACT ON THE EARTH'S SURFACE

Purpose. Development of a digital model of the stress-strain state of a rock mass during the extraction of coal by an underground method to predict the displacement of the earth's surface.

Methodology. The proposed technique is based on modeling the stress-strain state of a rock mass using the finite element method. Computer simulation of the stress-strain state of the rock massif was carried out in the area of lavas worked out in previous years in layers with the index K of the Karaganda suite of the mine named after Kostenko of the Karaganda coal basin, where instrumental surveying measurements were previously made to monitor the vectors and numerical values of the displacements of the earth's surface undermined by mining.

Findings. The reliability of the obtained finite element model of a rock mass for predicting the process of displacement of rocks and the earth's surface is confirmed by the results of full-scale instrumental mine surveying measurements on the earth's surface.

Originality. For the first time, a method has been proposed for predicting the shifts of points on the earth's surface, taking into account the physical and mechanical properties of rocks, based on a finite element model of a rock mass. A new approach was applied to assess the reliability of the model of the stress-strain state of a rock mass based on a comparison of the results obtained with the data of instrumental mine surveying.

Practical value. A technique for computer simulation of the stress-strain state of a rock mass during the extraction of hard coal at the mine named after Kostenko, owned by one of the world's leading steel producers, JSC ArcelorMittal. For modeling, a site was chosen in the area of lava mining along the coal seams of the Karaganda Formation of seams, starting from the K18 seam to the K10 seam, that is, a rock mass with a depth of more than 700 m. Previously, within this area a series of instrumental surveying observations was carried out of the displacement of the earth's surface during the working out of these lavas using the method of roof management – complete collapse. The obtained values of vertical displacements of a point on the earth's surface according to the results of computer simulation of the stress-strain state of a rock mass correspond to the data of field mine surveying observations of displacements of the same point, which confirms the reliability of the constructed model.

Keywords: *modeling, stress-strain state of the massif, rocks, coal, displacement, earth's surface*

Introduction. At present, the technological aspects of coal mining in urban areas do not sufficiently ensure the safety of objects on the earth's surface, and do not always make it possible to carry out mining operations in the most rational way in terms of the least loss of reserves left in the subsoil. In connection with the rapid development of the capabilities of computer programs that successfully apply the methods of mathematical modeling of various processes and the processing of a large amount of digital and graphic information, mining engineers have learned the ability to design and to adjust the elements of technological flow charts used in the development of minerals, including those in forecasting processes arising from the mining of coal in the thickness of rocks [1] and on the daylight surface.

Modeling in geomechanics aims at evaluating the qualitative and quantitative characteristics of the process under study. Geomechanical modeling using the capabilities of information systems allows displaying and analyzing planar and spatial data and the distribution of physical and mechanical properties of rocks [2, 3].

© Ivadilinova D. T., Issabek T. K., Takhanov D. K., Yeskenova G. B., 2023

The complex of physical and mechanical properties of rocks is one of the determining factors of any technological process of a mining enterprise. Knowing the physical and mechanical properties of rocks and modeling physical processes that occur in them [4] are necessary to select the optimal variant of technological flow charts for mining and related equipment, its efficient operation, improving labor productivity, reducing costs and financial costs [5].

In different years studying the issues related to the geomechanical processes based on modeling the stress-strain state of the rock massif was carried out by such scientists as I. D. Nassonov, S. F. Alekseyenko, Yu. A. Petrenko, Yu. A. Borovkov, A. V. Dementiev, A. A. Kasparyan, R. O. Davis, A. P. S. Selvadurai, John C. Small, C. J. Turner. D. Healy, R. R. Hillis, M. J. Welch, and others.

At the same time, over the years, such scientists as S. G. Avershin, K. N. Paffengolts, E. G. Root, Z. M. Smagulov, K. K. Elimanov, P. E. Kleshchev, G. G. Poklad, S. D. Semenyuk, V. F. Demin, Sh. A. Altay, M. P. Vasilyev and others were working in the field of studying safety and security of objects on the earth's surface that were undermined by operations for mining coal.

It should be noted that today, in the Republic of Kazakhstan there are sectoral regulatory documents regulating the issues, the interactions between mining enterprises and owners of undermined facilities on the earth's surface, including business facilities, private land users, social security facilities (water pipelines, roads and railways, power lines, etc.). The KazNIMI developed rules for the protection of surface structures and objects of the Karaganda coal basin.

The body. Countries that have reserves and have been mining coal for many years since the beginning of the last century have similar problems in extracting reserves with the appropriate qualitative and quantitative characteristics needed for mining, as well as convenient for extraction in the context of developing updated technological equipment and mining transport equipment. These problems are associated with the location of these reserves in such boundaries where there are residential and industrial buildings on the earth's surface.

The Karaganda coal basin, one of the largest in the Eurasian continent, has faced and is facing similar problems today, especially when it comes to mining the Karaganda formation of seams, which has fairly large balance reserves of coking coal needed for metallurgical production, in the cities of Karaganda and Saran, as well as in Aktas and Dubovka settlements, where many civil facilities and industrial zones are located.

As of 2022, the Coal Department of the ArcelorMittal Temirtau JSC, the largest coal mining enterprise in the Karaganda coal basin that mines hard coal by underground mining, includes eight mines, four of them are located in the Tentek coal-bearing region (Tentekskaya, Kazakhstanskaya, Shakhtinskaya, and Lenin mines), one in the territory of the Cherubai-Nura coal-bearing region (Abayskaya mine), and three mines in the territory of the Saransk and Karaganda sites (Saranskaya, Karagandinskaya and Tusup Kuzembayev mines).

Describing the technological aspects of the mines of the ArcelorMittal Temirtau Coal Department, it should be noted that the length of the mine workings varies depending on the specific mine.

The greatest length of mine workings is noted at Kostenko mine, one of the oldest mines in the basin, and the smallest ones are at the mines that were built later, namely at the Abayskaya and Shakhtinskaya mines.

Speaking of the current state of the mining operations development in the Karaganda coal basin, it should be noted that the land and mining allotments of the mines of the ArcelorMittal Temirtau JSC Coal Department approved by the Subsoil Use Contract, are located on the lands of the cities of Karaganda, Saran, Abay, Shakhtinsk, Bukharzhyrau and Abay districts of the Karaganda region and occupy the total area of more than 11,000 hectares.

The largest mine in the Karaganda coal basin is Kostenko mine located directly in the city of Karaganda, on the Industrial site. Kostenko mine was formed as a result of the merger and reconstruction of Kostenko, Stakhanovskaya and Karagandinskaya mines.

Based on analyzing and studying the surface plan of Kostenko mine (Fig. 1, the green outline shows the boundary of the land allotment), as well as the data from the Automated System of the State Land Cadastre of the Republic of Kazakhstan, the information was obtained on the presence of more than 200 outside land users within the mining and land allotments of the mine (Table 1).

According to the information from the cadastral map of the Automated Information System of the State Land Cadastre of the Republic of Kazakhstan for the city of Karaganda, it can be seen that one of the land allotments of Kostenko mine with cadastral number 09-142-111-094 and the area of 1,111,191 sq. m (Fig. 2), contains within its boundaries a number of objects that do not belong to the mine, that is, they belong to outside land users.

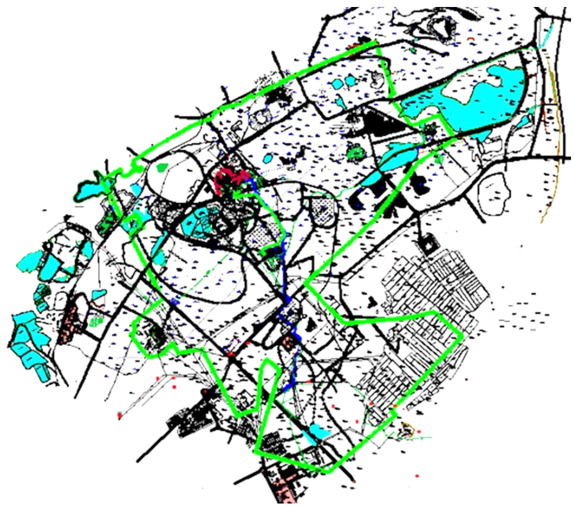

Fig. 1. Chart extract from the surface plan of Kostenko mine with presenting the land allotment boundaries

Table 1

Information on the outside land users on the land allotment of Kostenko mine

	Power line	Water supply	Infrastructure sites	Forestry	Automobile road	Railway	Communication line
Name of the object	HVL-6 kV F-14, p/st Sortirovka, Transformer substation, HVL-6 kV F-628, p/st Kostenko mine, HVL-35 kV Novy gorod-Kostenko 1.2; HVL-110 kV Novy gorod-Santekhnicheskay, HVL-110 kV Karaganda-Novy gorod 1.2, etc.	Batyr LLP, car camping, water supply without a name, etc.	LLP "Triada Limited" (cemetery), boiler room, warehouse, gas station, car service, storage depot, residential building, pig farm, Pond farm, Parkhomenko Karaganda Machine-Building Plant LLP, Cottages of the PCS "Ryabinushka" and others	CA "Karaganda farm for the protection of forests and wildlife"	Roadway, unnamed road, st. Volgodonskaya, st. Obyezdnzya	To Kostenko mine, to the machine-building plant, to the trade and warehouse base	cable duct MMC 56-24, wells, Kazakhtelecom JSC (FOCL)
Area, ha	2.044	1.1456	291.2721	136.0564	38.207	0.3296	0.2655
Number of outside land users	77	8	92	4	9	1	12

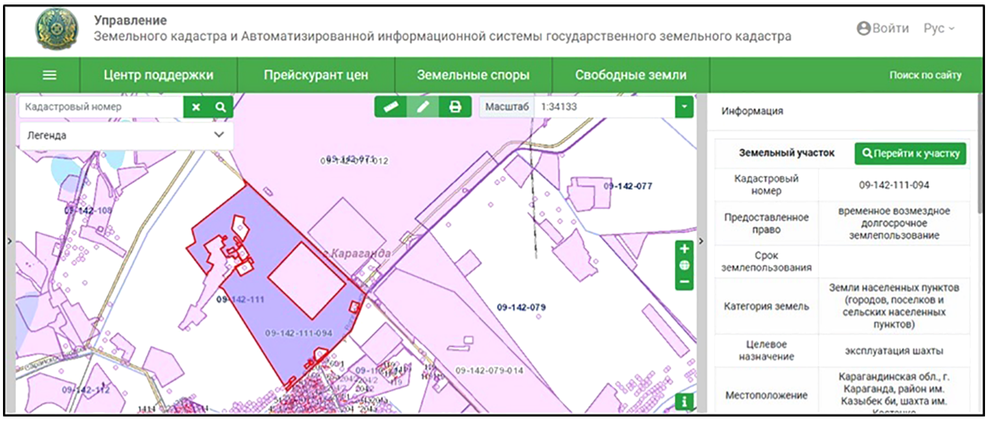

Fig. 2. Information on the land allotment with the cadaster number 09-142-111-094 located at Kostenko mine

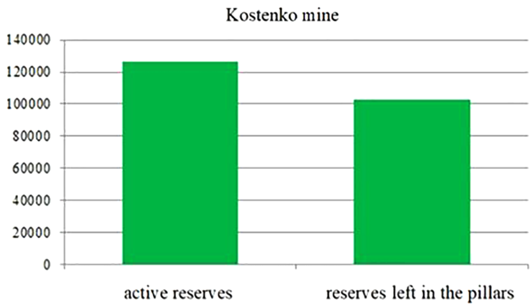

Fig. 3. Information on Kostenko mine reserves

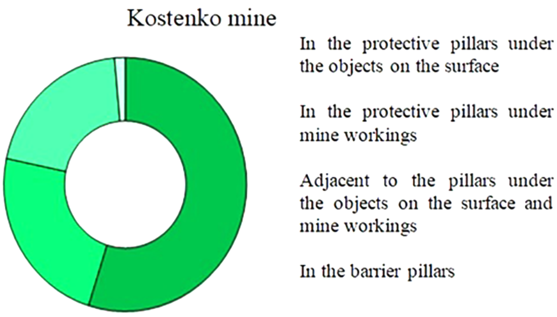

Fig. 4. Reserves left in the pillars at Kostenko mine

The amount of calculated and recorded balance reserves of Kostenko mine according to the Coal Seam Mining Project makes more than 230 million tons (Fig. 3).

The information on the reserves left in the pillars can be divided into the following categories (Fig. 4).

For the development of a model of the stress-strain state of the rock massif, a mining site was selected in the territory of Kostenko mine of CD ArcelorMittal Temirtau JSC in the area of longwall face 48 K12-1-v. At this, the average development depth was 310 m, the extracted reservoir thickness was 5.4 m.

Since 1997, in the Karaganda coal basin, the Rules for protection of structures and natural objects against harmful effects of underground mining have been approved and are currently in force. Traditionally, to calculate the expected values of the earth surface displacements for the conditions of each of the operating mines, a computer program "Deformations" has been developed. The choice of the method of protection of surface objects, the calculation of allowable and limiting deformations for each of the objects under consideration is made manually based on the formulas given in the Rules [6].

However, this method for calculating the expected values of displacements and deformations of the earth's surface does not allow taking into account and using various mining methods for protecting surface structures and the earth's surface [7].

Therefore, there is proposed a method for predicting displacements and deformations of the earth's surface based on modeling the stress-strain state of the rock massif and the earth's surface.

It should be noted that in the current conditions, numerical methods undoubtedly and with high accuracy make it possible, under various boundary conditions, to make calculations, including those in mining, that is, using a wide range of physical and mechanical properties of soils.

The finite element method makes it possible to take into account various and complex properties of soils, thereby stimulating the development of methods for testing soils and rocks and new theories of their strength and deformability [8].

In order to obtain a reliable model of the stress-strain state of the rock massif required for the study, a computer program was used that works in a plane and allows solving a number of problems, including:

- flat deformed state or axial symmetry;
- elastic or plastic materials;
- phased work (up to 50 stages);
- a lot of materials;
- support (bolts/sprayed concrete);
- constant or gravitational stress;
- rock fracturing;
- groundwater (including pore pressure for the analysis).

At the first stage, for geomechanical modeling of the rock massif, the plans for mine workings were studied in the K18, K14, K13, K12, K10 seams in the area of the 48-K12-1-v longwall face.

As a result, according to the geological section of geological exploration well No. 2188 located next to the considered longwall, as well as according to the existing marks of the conveyor and ventilation drift, a section was built along the longwall across and along the strike of the reservoir.

At the next stage, by importing the file of the exchange format, the sections were entered into the program for modeling the stress-strain state of the rock massif [9] (Fig. 5).

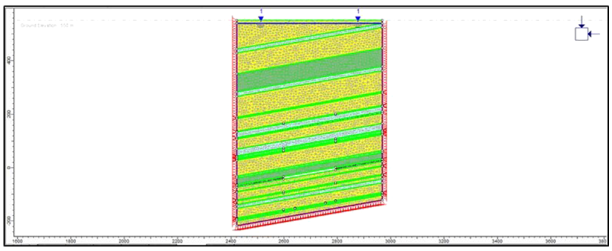

Fig. 5. Graphic presentation of the boundary conditions of the rock thickness under study

Table 2

Physical and mechanical properties of the rocks at Kostenko mine

Indicator	Unit	Sand	Siltstone	Mudstone	Coal
Modulus of elasticity (Young modulus)	MPa	30500	27000	12000	3500
Poisson's ratio		0.22	0.2	0.21	0.26
Compression resistance	MPa	51–78	35–45	20–28	10–20
Tensile strength	MPa	5.1–7.4	3.7–4.7	2–2.9	1.5–2
Volume weight	MN/m^3	2.61	2.5	2.48	1.64
Cohesion	MPa	14.2	10.2	8.7	1.2–3.6
Angle of internal friction	degree	35	35	35	35

Then, for each coal seam and rock [10] in the sections, as well as for sediments, there were set physical and mechanical properties that are characteristic of the mining and geological conditions of Kostenko mine (Table 2).

In the period from 1950 to the present, in this area hard coal was mined in coal seams K18, K14, K13 that were located closer to the earth's surface than seam K12 [11].

In the plane of the longwall under consideration, the areas where mining operations were carried out [12] for excavating coal along the K18, K14, K13, K12 seams were identified separately and were gradually set in the program as a worked-out space.

At the next stage, the stress-strain state of the rock massif [13] was calculated across and along the strike of the seam. It was divided into 6 stages, according to the coal seams and the years of their mining, starting from the earliest mining period (Fig. 6), which made it possible to interpret the entered data and to obtain the information for each stage of the process under study (vertical, horizontal, absolute deformations, compression sigma, and others).

A wide range of natural conditions of minerals occurrence [14], methods of mechanization and organization of mining [15] requires that the mining system used in each case meet all these requirements, which explains the existence of a large number of very diverse mining systems.

Therefore, before dwelling on the use of a particular development system [16], the factors that speak for and against its use are usually analyzed, since each system has its own specific features.

The task is complicated by the fact that the factors influencing selection of the development system can be different not only for different deposits but also for individual mine fields [17] and even their parts, for example, changing the thickness of the reservoir or its dip angle along the strike or to the dip within the mine field.

Without denying the presence of specific conditions [18] in the development of certain minerals, it is believed that the main factors that determine the used system of development should remain common, regardless of the type of mineral [19], since the types of the development systems should be determined by the preparatory work that serves to reproducing the moving workplace: the stope, and the accepted methods for conducting the stope operations causing certain phenomena in the surrounding rocks [20].

The development of coal seams in the Karaganda coal basin is mostly carried out in the direction from the overlying seams to the underlying seams with the development system in the full thickness of the deposit [21].

The data of the project, namely the quantitative characteristics of the elements [22] of the built model from stage to stage, are shown in Fig. 7.

Interpretation of the results of modeling the stress-strain state of the rock massif showed the boundaries of influence [23] on the rock massif after the longwall mining [24] for each of the coal seams K18, K14, K13, K12, K10 successively.

The modeling and interpreting data of the obtained model (Fig. 8) in terms of vertical deformations of the points on the earth's surface [25] along the line of the central part of longwall 48-K12-1-v from stage 1 (1955–1956) to stage 5 (2007). showed that the vertical displacement was approximately 0.07 m.

According to the graph of vertical deformations of the point depending on time [26], it is possible to determine $H_{beg.act.st.}$ for the point located in the middle of the longwall along the K12 layer: it is 0.075 m

$$H_{beg.act.st.} = 0.0125 \cdot t_{beg.act.st.} = 0.075.$$

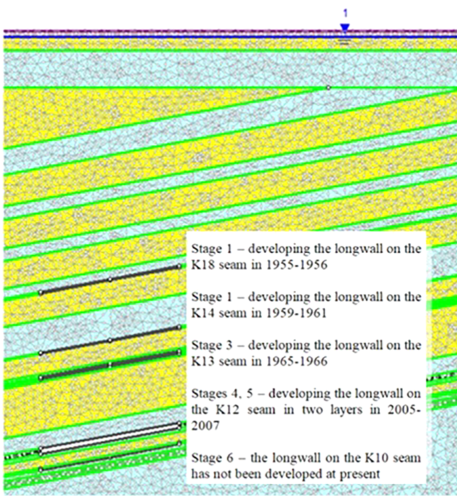

Fig. 6. Stages of calculating and their graphic presentation

Field Stress

Field stress: gravity
Ground surface elevation: 550 m
Unit weight of overburden: 0.027 MN/m3
Total stress ratio (horizontal/vertical in-plane): 1
Total stress ratio (horizontal/vertical out-of-plane): 1
Locked-in horizontal stress (in-plane): 0
Locked-in horizontal stress (out-of-plane): 0

Mesh

Mesh type: uniform
Element type: 6 noded triangles
Number of elements on Stage 1: 9501
Number of nodes on Stage 1: 19197
Number of elements on Stage 2: 9471
Number of nodes on Stage 2: 19160
Number of elements on Stage 3: 9433
Number of nodes on Stage 3: 19107
Number of elements on Stage 4: 9377
Number of nodes on Stage 4: 19018
Number of elements on Stage 5: 9347
Number of nodes on Stage 5: 18981
Number of elements on Stage 6: 9325
Number of nodes on Stage 6: 18960

Fig. 7. Information on the model built

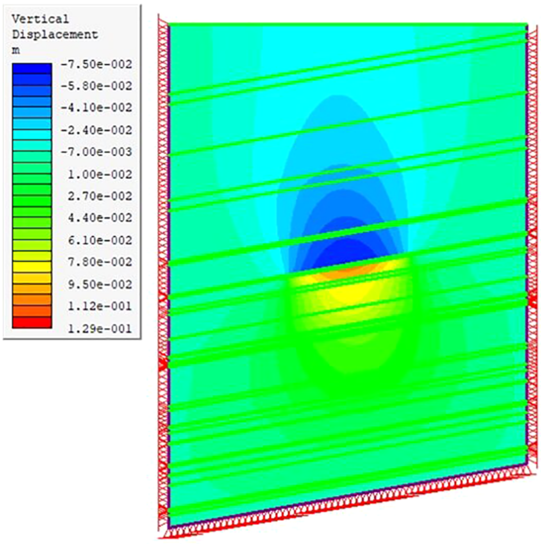

Fig. 8. Interpreting the model for the vertical deformation indicator

According to the graph of changes in vertical deformations of the same point, it is also approximately 0.07 m (Fig. 7), which confirms reliability of the model of the stress-strain state of the rock massif.

Manifestation of the processes that occur in rocks when their balance is disturbed can quite naturally proceed differently depending on the form and conditions of the mineral occurrence, its strength, enclosing rocks strength and the methods of extraction used, that is, the whole complex of works in the stoping space [27].

The rock massif is characterized by relatively low tensile strength, and sometimes its complete absence. The occurrence of discontinuous microfracture means that in the future this volume of the massif will not be able to perceive tensile stresses, although resistance to compression and shear is preserved to one degree or another [28]. In the tensile region, the deformation process can be considered linear until the moment of macrofracture.

The finite element method in terms of application in mining within the framework of the study was applied on the basis of solving a number of problems using a computer program for modeling:

- determining the nature of the stress distribution, taking into account the difference in the modules of rocks for compression and tension;
- establishing the boundaries of zones, in which the stresses reach the elastic limit, that is, zones in which the dependence of transverse strains on stresses becomes non-linear;
- determining the moment of beginning the development of macrocracks and determining the stress-strain state of the massif, taking into account the nonlinear nature of the dependence of longitudinal and transverse deformations on stresses.

The proposed method for predicting the values of deformations of the earth's surface using modern methods for modeling the stress-strain state of the rock massif should be applied in determining the further trend of developing underground coal mining in the Karaganda coal basin in urban areas.

Conclusions. As a result of the research work carried out, the following conclusions can be drawn:

1. The built discrete finite element mathematical model of the process of rock displacement during the sequential development of the coal seams formation in the conditions of Kostenko mine of the CD ArcelorMittal Temirtau JSC allows determining the magnitude and direction of displacement of the earth's surface.

2. The computer finite element modeling of the stress-strain state of the rock massif in the untouched state following the repeated undermining of the earth's surface after the completion of the stoping operations for each of the removed coal seams K18, K14, K13, K12, K10 with the complete collapse of the roof based on the actual physical and mechanical properties of rocks [29] made it possible to calculate the expected values of vertical, horizontal and total deformations of the earth's surface.

3. The values of displacements of the earth's surface obtained as a result of finite element modeling are confirmed by the data of full-scale surveying and geodetic measurements of the area under consideration.

4. The proposed method for predicting the expected values of deformations and displacements of points on the earth's surface is innovative and can be used to predict the extent of the underground mining impact [30] on the extraction of coal onto the earth's surface at various coal mining enterprises.

References.

1. Baykenzhin, M., Asanova, Z., Rashid, Z., Kasimov, A., Ivadilinova, D., & Zhunis, G. (2022). Modeling the influence of rolled profile strengtheners on the arch support load-bearing capacity. *Mining of Mineral Deposits*, *16*(1), 84-91. https://doi.org/10.33271/mining16.01.084.

2. Ivadilinova, D.T., Zhunis, G.M., & Issabek, T.K. (2018). Geomechanical modeling of a rock massif in underground coal mining. *Bulletin of Pavlodar State University named after S. Toraigyrov, Energy series*, (2), 136-142.

3. Ignatiev, S.A., Sudarikov, A.E., & Imashev, A.Zh. (2019). Modern Mathematical Forecast Methods of Maintenance and Support Conditions for Mining Tunnel. *Journal of Mining Institute, Saint-Petersburg Mining University*, *238*, 371-375. https://doi.org/10.31897/pmi.2019.4.371.

4. Ivadilinova, D.T., & Amrenov, K.K. (2014). Geodetic observations of technogenic processes. *IX International Conference of Students and Young Scientists "Science and Education". Eurasian National University n.a. L.N. Gumilyov*, 4548-4552. Retrieved from https://dspace.enu.kz/handle/data/12174.

5. Adoko, A.C., Saadaari, F., Mireku-Gyimah, D., & Imashev, A.A. (2022). Feasibility Study on The Implementation of Neural Network Classifiers for Open Stope Design. *Geotechnical and Geological Engineering: Springer*, *40*(2), 677-696. https://doi.org/10.1007/s10706-021-01915-8.

6. *Rules for the protection of structures and natural objects from the harmful effects of underground mining in the Karaganda basin* (current) (1997). Karaganda: KazNIMI. Retrieved from https://my-files.ru/tmx1da/ rules for the protection of structures from the harmful effects of underground mining in the Karaganda coal basin.pdf.

7. Kozhogulov, K.Ch., Takhanov, D.K., Kozhas, A.K., Imashev, A.Zh., & Balpanova, M.Zh. (2020). Methods of Forward Calculation of Ground Subsidence above Mines. *Journal of Mining Science*, *56*(2), 184-195.

8. Kurlenya, M.V., Serdyukov, A.S., Chernyshov, G.S., Yablokov, A.V., Dergach, P.A., & Duchkov, A.A. (2016). Methods and results of studying the physical and mechanical properties of cohesive soils by the seismic method. *Physical and technical problems of mineral development*, (3), 3-10.

9. Karasev, M.A., & Sotnikov, R.O. (2021). Forecast of the stress state of sprayed concrete lining under multiple seismic impact. *Notes of the Mining Institute*, *251*, 626-638. https://doi.org/10.31897/PMI.2021.5.2.

10. Wu, Zh., Xia, T., Nie, J., & Cui, F. (2020). The shallow strata structure and soil water content in a coal mining subsidence area detected by GPR and borehole data. *Environmental Earth Sciences*, *79*, 500. https://doi.org/10.1007/s12665-020-09178-x.

11. Konovalova, Y.P., & Ruchkin, V.I. (2020). Assessment of influence of short-period geodynamic movements on stress-strain behavior of rock mass. *Mining Informational and Analytical Bulletin*, (3-1), 90-104. https://doi.org/10.25018/0236-1493-2020-31-0-90-104.

12. Khanal, M., Guo, H., & Adhikary, D. (2019). 3D Numerical Study of Underground Coal Mining Induced Strata Deformation and Subsequent Permeability Change. *Geotechnical and Geological Engineering*, *37*, 235-249. https://doi.org/10.1007/s10706-018-0605-9.

13. Krutskikh, N.V. (2019). Assessment of the transformation of the natural environment in the zone of influence of mining enterprises using data from remote sensing of the earth. *Mining magazine*, (3), 88-93. https://doi.org/10.17580/gzh.2019.03.17.

14. Rybak, Ya., Khairutdinov, M.M., Kuziev, D.A., Kongar-Syuryun, Ch.B., & Babyr, N.V. (2022). Prediction of the geomechanical state of the massif during the development of salt deposits with back-

filling. *Notes of the Mining Institute*, *253*, 61-70. https://doi.org/10.31897/PMI.2022.2H.
15. Dzhonek-Koval'ska, I., Ponomarenko, T.V., & Marinina, O.A. (2018). Problems of interaction with stakeholders during implementation of long-term mining projects. *Journal of Mining Institute*, *232*, 428. https://doi.org/10.31897/pmi.2018.4.428.
16. Jovanovic, S., Gligoric, Z., Cedomir Beljic, C., Gluscevic, C.B., & Cvijovic, C. (2014). Fuzzy Model for Selection of Underground Mine Development System in a Bauxite Deposit. *Arabian Journal for Science and Engineering*, *39*, 4529-4539. https://doi.org/10.1007/s13369-014-1173-9.
17. Zhang, M., Li, J., Zuo, Qu., Yao, L., Chen, H., & Liang, W. (2016). The Research of 3D Geological Modeling in the Main Mining Area and East Mining Area of Bayan Obo Deposit. *GRMSE. Communications in Computer and Information Science*, *699*, 353-362. Springer, Singapore. https://doi.org/10.1007/978-981-10-3969-0_39.
18. Klishin, V.I., Anferov, B.A., & Kuznetsova, L.V. (2017). Directions for improving the development of thick seams with the release of coal of the subroofing thickness. *Innovations in the fuel and energy complex and mechanical engineering: Sat. tr. International scientific-practical conference*. Kemerovo, KuzSTU, 57-63. Retrieved from https://www.elibrary.ru/item.asp?id=28921001.
19. Kovalevska, I., Barabash, M., & Snihur, V. (2018). Development of a Research Methodology and Analysis of the Stress State of a Parting under the Joint and Downward Mining of Coal Seams. *Mining of Mineral Deposits*, *16*(1), 76-84. https://doi.org/10.15407/mining12.01.076.
20. Vdovkina, D.I., Koshliakov, O.Y., Ponomareva, M.V., & Ponomareva, E.V. (2022). Estimation of clay swelling properties in karaganda territory using machine learning methods. *Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering*, *333*(2), 204-210. https://doi.org/10.18799/24131830/2022/2/3358.
21. Portnov, V.S., Filimonov, E.N., Mausymbaeva, A.D., Akhmatnurov, D.R., & Musin, R.A. (2016). Evaluation of the gas content of the K10 reservoir under the conditions of the Sherubaynura area based on the actual gas release data. *Integrated use of mineral raw materials*, (2), 3-10.
22. Joao Marcelo Leal Gomes Leite, Edilson F. Arruda, Laura Bahiense, & Lino G.Marujo (2020). Modeling the integrated mine-to-client supply chain: a survey. *International Journal of Mining, Reclamation and Environment*, *34*(4), 247-293. https://doi.org/10.1080/17480930.2019.1579693.
23. Rajdeep, D., & Patrick, J. (2017). Finite volume-based modeling of flow-induced shear failure along fracture manifolds. *International Journal for Numerical and Analytical Methods in Geomechanics*, *41*(18), 1922-1942. https://doi.org/10.1002/nag.2707.
24. Vikram, Sh., Jiraj, K., & Subrahmanyam, D.S. (2019). Influence of underground workings on the stress state of the rock mass. *Physico-technical problems of mineral development,* (2), 43-48.
25. Wang, H., Deng, D., Shi, R., Yang, G., Xu, Sh., & Jiang, Ya. (2020). Investigation of Fault Displacement Evolution During Extraction in Longwall Panel in an Underground Coal Mine. *Rock Mechanics and Rock Engineering*, 1809-1826. https://doi.org/10.1007/s00603-019-02015-z.
26. Issabek, T.K., Dyomin, V.F., & Ivadilinova, D.T. (2019). Methods for monitoring earthsurface displacement at points of small geodetic network under the underground method of coal development. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu***,** (2), 13-21. https://doi.org/10.29202/nvngu/2019-2/2.
27. Ignatiev, S.A., Sudarikov, A.E., & Imashev, A.Zh. (2021). Determination of the stress-strain state of rock mass and zone of inelastic deformation around underground mine excavation using modern methods of numerical modeling. *Journal of Sustainable Mining: Central Mining Institute*, *20*(3), 220-227. https://doi.org/10.46873/2300-3960.1324.
28. Belyaev, V.V., & Agafonov, V.V. (2020). Substantiation of parameters of technological systems of coal mines taking into account risks. *Coal,* (2), 24-31. https://doi.org/10.18796/0041-5790-2020-12-24-305.
29. Kozyrev, A.A., Panin, V.I., Semenova, I.E., & Rybin, V.V. (2019). Geomechanical support of mining operations at the mining enterprises of the Murmansk region. *Mining magazine*, (6), 45-50. https://doi.org/10.17580/gzh.2019.06.05.
30. Xiaojun, Zh., Guangli, G., Liu Hui, L., & Xiaoyu Ya. (2019). Surface subsidence prediction method of backfill-strip mining in coal mining. *Bulletin of Engineering Geology and Environment, 78*, 6235-6248. https://doi.org/10.1007/s10064-019-01485-3.

Прогнозування ступеня впливу підземних гірничих робіт на земну поверхню

*Д. Т. Іваділінова**[1], *Т. К. Ісабек*[1], *Д. К. Таханов*[2], *Г. Б. Єскенова*[1]

1 – Некомерційне акціонерне товариство «Карагандинський технічний університет імені Абилкаса Сагінова», м. Караганда, Республіка Казахстан
2 – ТОВ «Науково-дослідний центр ISM Group», м. Караганда, Республіка Казахстан
* Автор-кореспондент e-mail: d.ivadilinova@gmail.com

Мета. Розробка цифрової моделі напружено-деформованого стану масиву гірських порід під час видобутку кам'яного вугілля підземним способом для прогнозу зрушень земної поверхні.

Методика. Запропонована методика заснована на моделюванні напружено-деформованого стану масиву гірських порід з використанням методу кінцевих елементів. Комп'ютерне моделювання напружено-деформованого стану масиву гірських порід проводилося на ділянці відпрацьованих у минулі роки лав по пластах з індексом *К* карагандинської світи шахти ім. Костенко Карагандинського вугільного басейну, де раніше проводилися інструментальні маркшейдерські виміри для моніторингу векторів і чисельних значень зрушень підробленої гірничими роботами земної поверхні.

Результати. Достовірність отриманої кінцево-елементної моделі масиву гірських порід для прогнозування процесу зсуву гірських порід і земної поверхні підтверджується результатами натурних інструментальних маркшейдерських вимірів на земній поверхні.

Наукова новизна. Уперше була запропонована методика прогнозування зрушень точок на земній поверхні з урахуванням фізико-механічних властивостей гірських порід на основі кінцево-елементної моделі масиву гірських порід. Було застосовано новий підхід до оцінки достовірності моделі напружено-деформованого стану масиву гірських порід на основі порівняння отриманих результатів із даними інструментальної маркшейдерської зйомки.

Практична значимість. Наведена методика комп'ютерного моделювання напружено-деформованого стану масиву гірських порід при видобуванні кам'яного вугілля на шахті ім. Костенко, що належить одному зі світових лідерів із виробництва сталі, компанії АТ «ArcelorMittal». Для моделювання була обрана ділянка в районі відпрацювання лав по вугільних пластах карагандинської світи пластів, починаючи від пласта K18 до пласта K10, тобто товща гірських порід глибиною більше 700 м. Раніше в межах даної ділянки була виконана серія інструментальних маркшейдерських спостережень за зсувом земної поверхні при відпрацювання цих лав за методом управління покрівлею – повне обвалення. Отримані значення вертикальних переміщень точки на земній поверхні за результатами комп'ютерного моделювання напружено-деформованого стану масиву гірських порід відповідають даним натурних маркшейдерських спостережень зсувів цієї точки, що підтверджує достовірність побудованої моделі.

Ключові слова: *моделювання, напружено-деформований стан масиву, гірські породи, кам'яне вугілля, зсув, земна поверхня*

The manuscript was submitted 07.02.22.