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Improvement of the transitional technology from open pit to underground mining of magnetite quartzite

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Abstract. The paper analyzes the disadvantages of the technology of iron ore open pit mining and current environmental problems of open pit mining. The paper also addresses problems of possible displacement and strains of rocks in the classical open pit mining method with extraction of minerals exclusively by open pit mining, studies current transitional technologies from open pit to integrated open pit-underground and subsequent underground mining, and presents an improved methodology for studying the stress-strain state of the massif during transition from open pit mining to integrated open pit-underground and subsequent underground mining. There are studied, developed and proposed options of environmentally friendly technologies of integrated open pit-underground mining with mining waste disposal in the worked-out space of underground mines and open pits, highly efficient calculation schemes for studying the stress-strain state of a rock massif during transition from open pit to underground mining with formation of protective barrier pillars, an option with the development of the lower room of stage II under protection of an ore pillar left within the contours of the upper room of stage I, and an option with the development of the lower room of stage II under protection of an artificial pillar made of the consolidating backfill in the upper room of stage I. The stress-strain state of the massif and possibilities of forming internal waste rock dumps when applying integrated open pit-underground mining technologies are studied and substantiated. Transition technologies from open pit to underground mining of iron ore raw materials under the bottom of an operating open pit are developed and proposed on the example of Kryvyi Rih iron ore basin.

1 Introduction

Kryvyi Rih iron ore basin is one of the oldest in Ukraine. Relatively modern mining of rich iron ores began about 150 years ago. Long-term iron ore mining, especially open pit mining, has resulted in disturbances of considerable areas by open pit mining operations.

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Significant areas of arable land are occupied by open pits and their dumps and tailings storage facilities, [1, 2].

Hundreds of thousands of hectares of fertile Ukrainian land are already unsuitable for agricultural use, and sometimes even for human habitation. Every year, thousands of tonnes of dust from open pits caused by massive ore extraction, dust from dumps and tailings storage facilities deteriorate the environmental situation and pollute the air in Kryvyi Rih and other mining regions.

Large scale blasting in open pits during rock breaking is the most powerful factor in air pollution which results in emitting significant amounts of harmful dust and carcinogenic substances into the atmosphere. The environmental situation in open pit mining areas is often close to critical. In addition, the seismic effect of large-scale blasting creates a seismic wave and, in some cases, destroys civilian buildings and industrial facilities, [3, 4].

Several hundred-meter-high dumps change the surface topography, turning the steppe region of Ukraine into a foothill-like one. At the same time, open pits-canyons, which are not covered with vegetation, are significantly heated in summer, and contribute to the flow-up of large amounts of dust into the surrounding air. Such man-made technological transformations change the wind rose in the basin, contribute to formation of new wind flows with a lot of dust in the air. This, in turn, affects the nature of cloud formation, changes the direction and strength of rain flows, significantly altering the microclimate of the basin, [5 – 7].

Thinking about the future of Ukraine's mining regions; one should clearly understand the responsibility for the environmentally sustainable development of the country. Gradual transition from open pit mining to integrated open pit-underground and subsequent underground mining technologies is one of the main ways to preserve natural resources. This way is a forced step and at the same time it is a single option of development of mining areas, in particular Kryvyi Rih iron ore basin [8, 9]. From a technological point of view, one of the main problems of such transition is geomechanical stabilization of the rock massif during construction of underground mines in areas of possible impacts of open pit fields.

Nowadays, in Kryvyi Rih basin, there are no basic studies on the problems of managing the stress-strain state of the rock massif during transition from the open pit to integrated mining technology, [10 – 12].

In Ukraine, there are no strategic studies of the problem of implementing technologies for integrated mining with formation of a transition belt with backfilling the worked-out space with combined backfill mixtures. There are no necessary studies to substantiate the possibility of forming internal waste rock dumps when applying integrated open pit-underground mining technologies, [13].

Therefore, the presented results of studies of the stress-strain state of the massif during transition from open-pit to integrated mining technology, the research results and proposed technological solutions that facilitate transition to integrated open pit-underground and subsequent underground mining are topical and of great scientific and practical importance.

2 The choice of object to study

Thus, the progress in mining technologies and strict environmental requirements for the mining industry in the context of mining operations deepening and deterioration of mining and geological characteristics of deposits have led to the search for new ways of extracting iron ore, in Kryvyi Rih iron ore basin [14 – 16].

The geomechanical state of a rock massif is an important factor that impacts development of mining technologies and the mineral mining method. Knowledge of the nature of the stress-strain state and values of active stresses in the rock massif enables a general picture of the current and future situations.

The study and forecasting of impacting factors of the chosen technology, the possibility of modeling the geomechanical state of the massif under conditions of multifactorial dependencies when choosing a method of mineral mining and stoping make it possible to justify the choice of the optimal technology for deposit mining from technological, economic, and environmental points of view [17 – 20].

Determination of the geomechanical state of the massif during transition from open pit to integrated mining technology is an important element of the research to determine recommendations for changing mining technologies.

Therefore, when transiting from open pit mining of magnetite quartzite to integrated open pit-underground and subsequent underground_mining of iron ore raw materials, it is necessary to perform a set of studies that will allow proposing the state-of-the-art environmentally friendly technologies for development of mining basins, [21 – 23].

One of the most important issues is the monitoring of rock displacements in the areas of open pit fields disturbed by underground mining. Expedient solutions to such problems include analytical methods of studying the geomechanical state of the rock massif, [24, 25]. Undoubtedly, the existing technologies of open pit mining of magnetite quartzite when transiting to integrated open pit-underground and subsequent underground mining of iron ore raw materials can be potential sources of man-made disasters. Transitions of this kind are especially dangerous in areas of mutual influence of open pits and underground mines in the case of applying integrated open pit-underground methods, [26 – 28].

The results of studying natural and artificial elements of the combined environment, the results of studying possible disturbances of these environments are extremely necessary at both the design stage and in the process of transition from open pit mining to integrated open pit-underground and subsequent underground mining technologies [29 – 32].

Thus, the object of the study is the processes of transition from open pit mining technologies to integrated open pit-underground and subsequent underground mining technologies for iron ore raw materials, a comprehensive assessment of values of active stresses in the massif, forecasting of the nature and causes of their change during integrated open pit-underground and subsequent underground mining, [33 – 35].

The data obtained will make it possible to reasonably assess the basic current mining, geological and technical conditions of the deposits and provide input data to improve the current and develop new combined flowcharts of integrated open pit-underground mining, to select optimal parameters of stoping operations and determine their rational sequence.

3 Research methods

To study the stress-strain state of a rock massif using analytical methods when applying transitional technologies, there are several analytical techniques that can be used to calculate stress distribution around open pit and underground workings and model the rock massif behavior in the process of technological mining.

In the present study, Ansys 22 software package is used to calculate stresses and strains [21 – 23]. The calculations are performed for Kryvyi Rih iron ore basin, where magnetite quartzite is mined in open pits of five mining and beneficiation plants (GZKs), [36 – 38].

Today, the depth of the open pits reaches 400 m. Such depths significantly increase the cost of production which equals and sometimes even exceeds that of underground mining. Considering the critical state of the environment caused by open pit mining, the optimal solution is to transit to open pit-underground and subsequent underground mining of magnetite quartzite.

Table 1 shows the input physical and mechanical properties of the rock massif and the backfill when calculating stresses and strains using Ansys 22 software package.

To calculate the stress-strain state of the combined massif, options of the classical flowsheet of open pit mining of magnetite quartzite are adopted for the average statistical conditions of transition from open pit to underground mining.

Table 1. Physical and mechanical properties of rocks and backfill.

Parameters	Magnetite quartzite, waste rock	Backfill
Young's modulus, MPa	15000 – 60000	500
Volume weight, kg/m^3	3400	2000
Tensile strength, MPa	6 – 18	0.5 – 1.0
Compressive strength, MPa	60 – 180	5 – 10
Poisson's ratio	0.25	0.15

The current average pit depth of 350 m is taken as the final pit depth (or the boundary for the transition from open pit to underground mining). The general input scheme of integrated open pit-underground mining for calculating stresses and strains in the combined massif by the proposed options is presented in Fig. 1.

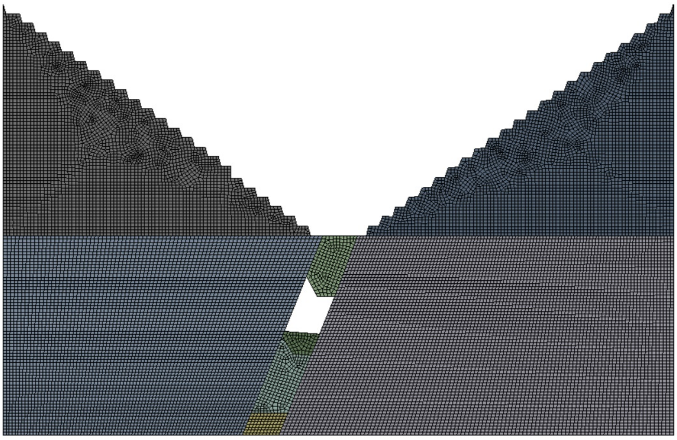

Fig. 1. Finite element grid with the size of the input calculation model adequate to that of the area of the integrated open pit-underground mining technology application.

The idea behind the presented calculation scheme for integrated open pit-underground mining consists in breaking the massif into a finite element grid. The size of the input calculation model is assumed to be adequate to that of the area where the integrated technology under study is applied. To build stress diagrams using the finite element method, the 3D model is divided into quadrilaterals with a side size of 5 m (Fig. 1).

4 Research results

The study of the stress-strain state of the rock massif enables obtaining a general picture of distribution of stresses and strains and their numerical values.

Fig. 2 visualizes distribution of principal stress isolines in the massif when applying integrated open pit-underground mining of the magnetite quartzite deposit with room ore extraction and formation of a barrier pillar made of the consolidating backfill.

The results of calculating stress fields in the rock massif when applying stoping operations under the pit bottom and backfilling the worked-out rooms with the consolidating backfill are also presented.

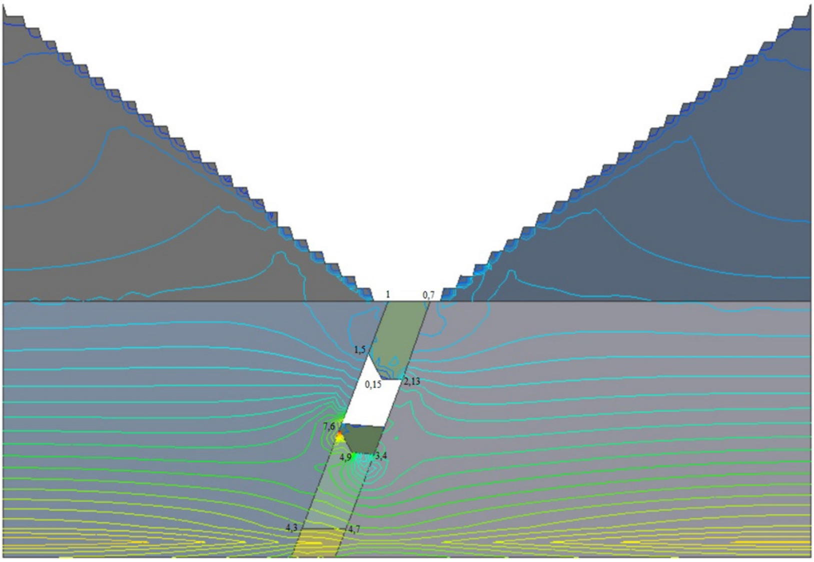

Fig. 2. Distribution of principal stress isolines in the massif during integrated open pit and underground mining of the magnetite quartzite deposit with room ore extraction and creation of a barrier pillar made of the consolidating backfill.

Distribution of principal stress isolines in the contours of the open pit around the underground rooms with an open stoping space partially backfilled with broken ore is presented. Distribution of principal stress isolines around the upper room backfilled with the consolidating material is also shown in Fig. 2. The consolidating backfill serves as an artificial barrier that separates open pit mining operations from the working room of the underground level.

The analysis of the obtained calculations enables establishing the general picture of the stress field distribution in the combined massif. The highest absolute stresses occur near the corners of the room. There is a slight concentration of stresses in the corners at the bottom of the room. Significant maximum stresses σ_1 in the corners of the room occur because of compressive stresses. Deepwards into the ore massif, the stresses σ_1 decrease, and their distribution becomes more uniform.

Concentration of maximum stresses σ_1 is observed in the lower part of the backfilled rooms. Their maximum value is 2.13 MPa, which is significantly lower than the strength of the artificial massif made of the consolidating backfill at the upper level.

Fig. 3 presents stress diagrams in the form of a gradient color diagram of the rock massif, which visualizes stress values in its different parts.

For visual determination of the stress value, all isolines have a specific value in P_a and correspond to a specific color on the color scale. The technological idea behind the considered option consists in the following. Magnetite quartzite is extracted by the underground method applying a room mining system. After the complete drawing of the broken ore from the upper room, the worked-out space is backfilled with a consolidating material thus forming an artificial barrier pillar that separates the open pit from the lower room of the next underground level.

Subsequent underground mining of minerals, magnetite quartzite in this case, is carried out by room mining systems under protection of an artificial pillar made of the consolidating backfill.

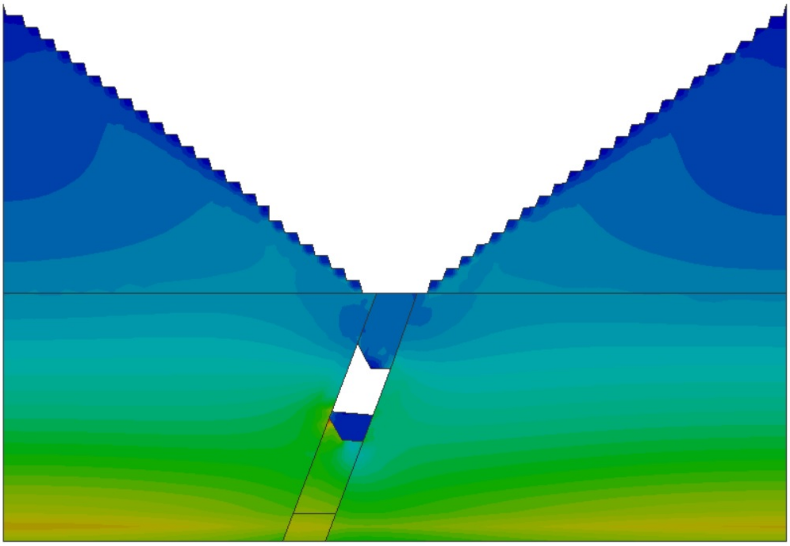

Fig. 3. Stress diagrams in the form of a gradient color diagram of a combined rock massif, an artificial barrier pillar made of the consolidating backfill and a working room.

When transiting from an open pit to the integrated open pit-underground or underground mining method of magnetite quartzite extraction in Kryvyi Rih iron ore basin, we believe it expedient to maintain the following basic principles of transitional technologies. It is advisable to locate vertical shafts in the footwall of the deposit.

The most rational level height for underground mining of magnetite quartzite is 80 m to 90 m. Under such basic conditions, at a depth of transition from open pit to integrated open pit-underground mining of magnetite quartzite from a depth of 350 meters, the first main crosscut is driven from the shaft to the ore deposit on the level – 440 m.

Subsequently, the classical circular ort scheme of development is used to prepare the underground level, according to which haulage drifts are driven along the strike of the deposit, in the footwall and the hanging wall.

Drifts of the footwall and the hanging wall are joined by ring access orts and block raises along the conditional boundaries of the future stoping block. These preparatory workings divide the working level into stoping blocks. Then, workings in the block are driven according to the classical schemes that were used at Kommunar and Hihant-Hlyboka underground mines of the former Mine Group named after Dzerzhynskyi and are used today at the underground mine named after Kolachevskyi of the PrJSC "Central GZK".

The underground mine named after Kolachevskyi of the PrJSC "Central GZK" is currently the only one in Kryvyi Rih basin that produces poor magnetite quartzite, which is sent to the PrJSC "Central GZK" for beneficiation.

Due to high strength of magnetite quartzite, a level-room mining system is employed for stoping. Drilling and blasting operations in the block are carried out based on the accumulated experience.

Ore is drawn and extracted in accordance with the accepted mining systems and accumulated experience. The next lower level is driven at – 530 m. Several other promising highly efficient technologies for transition from open pit to integrated open pit-underground and subsequent underground mining are proposed for further research.

During the research, all the proposed technological schemes are reduced to a single modeling scale, which enables high accuracy of the results obtained when studying the stress-strain state of the combined massif. The obtained dependencies have a high correlation coefficient and confirm the known results of research conducted by other scientists dealing with similar problems.

Therefore, the proposed methodology for studying the stress-strain state of the massif during transition from open pit mining technologies to integrated open pit-underground and subsequent underground mining technologies for iron ore raw materials is adopted for further studies of combined massifs using analytical methods and visualization of problems and tasks to be solved to achieve the goals set in this work.

To reduce the negative environmental impact and to provide rational use of the daylight surface, it is proposed to form an internal waste rock dump at the pit bottom. The internal waste rock dump will free up significant areas of fertile agricultural land which are now intended for construction of new dumps. In addition, waste rock disposal in the pit shell and subsequent reclamation of the earth surface will partially enable restoring safe environmental conditions of the mining basin.

Technologically, the internal dump is formed after creating an artificial pillar of the consolidating backfill and it’s gaining the standards-complient strength. Fig. 4 shows distribution of principal stress isolines in the massif when a magnetite quartzite deposit is mined by the integrated open pit underground mining system with room ore extraction under protection of an artificial barrier pillar made of the consolidating backfill, and the subsequent stage I of creating an internal waste rock dump at the pit bottom.

The height of the stage I internal waste rock dump is 30 m. The maximum value of principal stresses in the artificial massif of the barrier pillar made of the consolidating backfill is σ_1 = 6.5142 MPa. The strength of the consolidating backfill is to ensure stability of the artificial pillar and exceed the maximum value of the principal stresses in the massif of the barrier pillar made of the consolidating backfill.

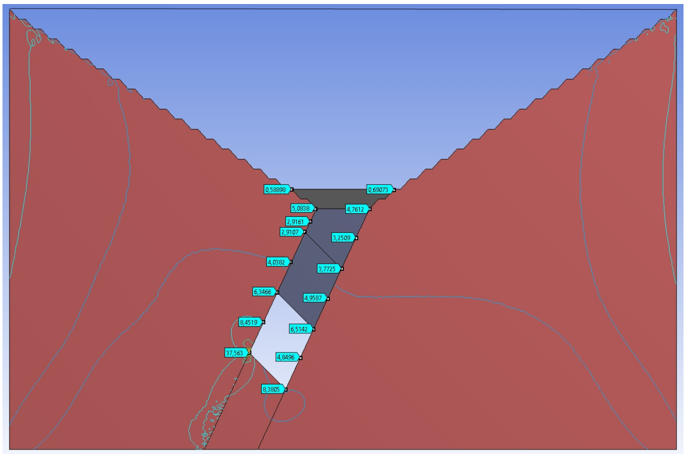

Fig. 4. Distribution of principal stress isolines in the massif when applying the integrated open pit-underground mining system with room ore extraction under protection of an artificial barrier pillar made of the consolidating backfill, and stage I of creating an internal waste rock dump at the pit bottom.

Fig. 5 shows distribution of principal stress isolines in the massif when a magnetite quartzite deposit is mined by the integrated open pit-underground mining system with room ore extraction under protection of an artificial barrier pillar made of the consolidating backfill, and stage II of creating an internal waste rock dump in the pit shell.

The height of the stage II internal waste rock dump is 105 m.

In this case, the maximum value of principal stresses in the artificial massif of the barrier pillar made of the consolidating backfill will be equal to $\sigma_1 = 7.705$ MPa.

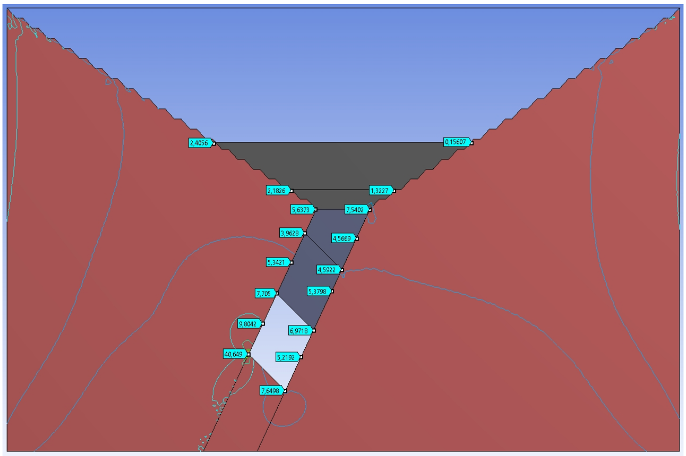

Fig. 5. Distribution of principal stress isolines in the massif when a magnetite quartzite deposit is mined by the integrated open pit-underground mining system with room ore extraction under protection of an artificial barrier pillar made of the consolidating backfill, and stage II of creating an internal waste rock dump in the pit shell.

Fig. 6 shows distribution of principal stress isolines in the massif when a magnetite quartzite deposit is mined by the integrated open pit-underground mining system with room ore extraction under protection of an artificial barrier pillar made of the consolidating backfill, and stage III of creating an internal waste rock dump in the pit shell.

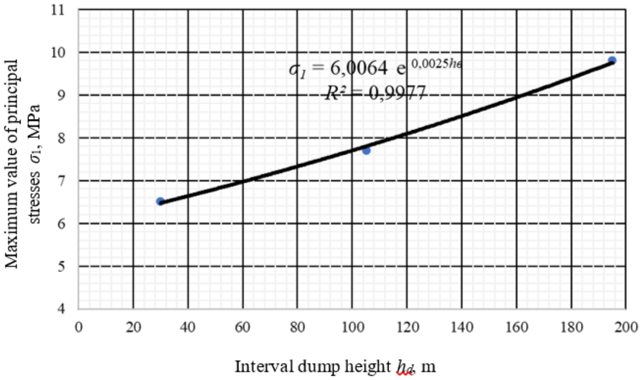

Fig. 6. Shows distribution of principal stress isolines in the massif when a magnetite quartzite deposit is mined by the integrated open pit-underground mining system with room ore extraction under protection of an artificial barrier pillar made of the consolidating backfill, and stage III of creating an internal waste rock dump in the pit shell.

The height of the stage III internal waste rock dump is 195 m. In this case, the maximum value of principal stresses in the artificial massif of the barrier pillar made of the consolidating backfill will be equal to $\sigma_1 = 9.8078$ MPa (Fig. 7). At the same time, when making backfill mixtures, it is necessary to pay attention to the final strength of the consolidating backfill, considering the barrier pillar life.

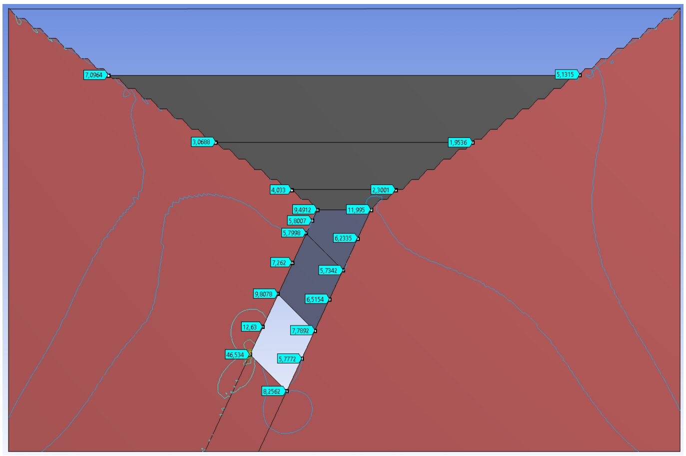

Fig. 7. Distribution of principal stress isolines in the massif when a magnetite quartzite deposit is mined by the open pit-underground mining system with room ore extraction under protection of an artificial barrier pillar made of the consolidating backfill, and stage III of creating an internal waste rock dump in the pit shell.

The maximum value of principal stresses in the artificial massif of the barrier pillar made of the consolidating backfill for different heights of the internal waste rock dump can be determined by the expression

$$\sigma_1 = 6.0064\ e^{0.0025 h_в};$$

$$R^2 = 0.9977,$$

where σ_1 is the maximum value of principal stresses, MPa; h_d is the height of the internal waste rock dump, m.

5 Conclusions

The paper emphasizes that due to long-term open pit iron ore mining, significant areas of arable are occupied by open pits, dumps, and tailings storage facilities and have become unsuitable for agricultural use and sometimes for human habitation. Thousands of tons of dust from open pits, dumps and tailings storage facilities deteriorate the environmental conditions.

Several hundred-meter-high dumps change the surface topography, turning the steppe region of Ukraine into a foothill-like one. At the same time, open pits-canyons, which are not covered with vegetation, are significantly heated in summer and contribute to emissions of large amounts of dust into the surrounding air. Gradual transition from open pit to integrated open pit-underground and subsequent underground mining technologies is proved to be one of the main ways to preserve natural resources.

Determination of the geomechanical state of the massif during transition from the open pit to integrated mining technology is the main task of the present research. The finite element method based on the Ansys 22 software package is used as the main tool for studying stresses and strains.

The paper presents the results of calculating stress fields in the rock massif when applying room mining systems under the pit bottom and backfilling the worked-out rooms with consolidating backfill mixtures. To reduce the negative environmental impacts and to provide rational use of the daylight surface, the authors propose to form an internal waste rock dump.

Numerical results of the research and visual diagrams of distribution of principal stress isolines in the massif under different options of integrated open pit-underground mining of the magnetite quartzite deposit are presented. Transition to underground mining is carried out by means of the room mining system under protection of an artificial barrier pillar made of the consolidating backfill.

The paper also presents the results of modeling the options with the subsequent stages of creating the internal dumps of different heights at the pit bottom. The dependency of the values of principal stresses in the artificial massif of the barrier pillar made of the consolidating backfill for different heights of the internal waste rock dump is established.

It is recommended to consider the final strength of the consolidating backfill when forming backfill mixtures, paying attention to the barrier pillar life.

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