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ENVIRONMENTALLY FRIENDLY TECHNOLOGIES OF INTEGRATED OPEN PIT-UNDERGROUND MINING

Mykola STUPNIK[1], Vsevolod KALINICHENKO[2], Olena KALINICHENKO[3], Oleksandr SHEPEL[4], Volodymyr PILCHYK[5]*

[1]Kryvyi Rih National University, Faculty of Mining and Metallurgy, KryvyiRih, Ukraine
[2]Kryvyi Rih National University, Faculty of Mining and Metallurgy, KryvyiRih, Ukraine, kalinichenko@knu.edu.ua
[3]Kryvyi Rih National University, Faculty of Mining and Metallurgy, KryvyiRih, Ukraine
[4]Kryvyi Rih National University, Faculty of Mining and Metallurgy, KryvyiRih, Ukraine
[5]SE "Eastern Mining and Processing Plant", Zhovti Vody, Ukraine

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Abstract: *Kryvyi Rih iron ore basin is one of Ukraine's oldest. Over 150 years of open pit mining has resulted in significant areas of arable land disturbed by open pits, dumps and tailings facilities. In Kryvyi Rih region, operation of open pits, dumps and tailings facilities results in worsened environmental conditions.*
Deep open pits and high dumps change the topography of the region. Open pits, dumps and tailings facilities not covered with vegetation contribute to bad air pollution by emitting large amounts of dust.
To settle the environmental issues and preserve the nature in the basin, gradual transition from the technology of open-pit mining to integrated open pit-underground and subsequent underground mining is developed and proposed.
In addition, the present paper addresses one of the main problems of geomechanical stabilization of the rock massif when constructing underground mines in areas of possible influence of open pit fields, and studies issues of controlling the stress-strain state of the rock massif during transition from the open-pit to integrated technology of deposit mining.
The research conducted enables substantiation of technologies involving formation of internal waste rock dumps during integrated open pit-underground mining. The paper presents the results of the research on the stress-strain state of the massif during transition from the open-pit to integrated mining technology and proposes environmentally friendly technologies of integrated open pit-underground mining of deposits with waste disposal in the worked out space of underground mines and open pits.
The results obtained are highly relevant and very important in both scientific and practical fields.
Keywords: *integrated open pit-underground mining, ore, environmentally friendly technologies, deposit, geomechanical stabilization, stress-strain state of the rock massif*

1. Introduction

Kryvyi Rih iron ore basin is one of Ukraine's oldest. Over 150 years of open pit mining has resulted in significant areas of arable land disturbed by open pits, dumps and tailings facilities.

Every year, thousands of tons of dust from open pits, dumps and tailings facilities worsen the state of the environment and pollute the air in Kryvyi Rih region.

Deep open pits and high dumps change the topography of the region. Open pits, dumps and tailings facilities not covered with vegetation contribute to bad air pollution by emitting large amounts of dust.

Thus, development of environmentally friendly technologies for integrated open pit and underground mining of deposits is an urgent scientific and practical task which is important for further sustainable development of mining regions of Ukraine.

* Corresponding author: Vsevolod Kalinichenko, Kryvyi Rih National University, Faculty of Mining and Metallurgy, Contact details:11 Vitalii Matusevych Str., KryvyiRih, 50027, Ukraine, kalinichenko@knu.edu.ua; Tel.: +380-67-56-82-260

2. The choice of object to study

Modern advances in mining technologies enable introduction of innovative mining processes which until recently were considered impossible in the mining industry [1, 2, 3].

In the context of an increase in the depth of deposit mining and deterioration of mining and geological characteristics of deposits, the toughening of environmental requirements for mining technologies has led to the search for new technological iron ore extraction flowsheets [4, 5, 6].

The present article deals with ways to solve the main problems of sustainable development of mining regions, in particular Kryvyi Rih iron ore basin.

In the authors' opinion, the main way of sustainable development of the basin while preserving the nature of the region involves gradual transition from open pit mining of iron ore deposits to integrated open pit-underground and subsequent underground mining.

To accomplish this task, it is necessary to solve the problem of geomechanical stabilization of the rock massif when constructing underground mines in zones of open pit field influence.

The geomechanical condition of the rock massif is the main factor when selecting a mining technology and methods of mining minerals. The study of the stress-strain state and the value of actual stresses in the rock massif enables a general picture of the geomechanical condition of the massif at the stage of modern technology design [7, 8, 9].

Factors of the selected technology that influence the stress-strain state of the rock massif can be determined through modeling the geomechanical conditions under multifactorial dependences. When choosing a mining method, multifactorial modeling enables justification of the choice of the optimal technology for mining a deposit considering technological and environmental requirements [4, 5, 6].

Multifactorial modeling of transition from technologies of open pit mining of magnetite quartzites to those for integrated open pit and underground extraction of iron ore raw materials is the first task in shaping a new strategy for development of Kryvyi Rih iron ore basin. In the course of such modeling, a set of studies should be conducted to offer progressive, environmentally friendly combined technologies for mining magnetite quartzites [9, 10].

Such problems should be solved applying analytical methods of studying the rock massif, especially when dealing with dangerous zones of mutual influence of open pits and underground mine workings during mining the deposit by integrated open pit and underground methods [11, 12, 13, 14, 15].

The results of the research on combined technologies are necessary both at the design stage and further on when developing technologies for transition from open pit mining of mineral deposits to integrated open pit and underground extraction of iron ore raw materials.

A special task of such technologies consists in studying the possibility of disposing mining waste in the mined-out space of open pits. Such technologies can settle three main tasks:

– first, disposal of waste rocks in the mined-out space of open pits frees up large areas of arable land that are potentially allotted for dumps;

–second, filling up open pits potentially increases areas that can be used in economic activities in the future;

– third, absence of open pits and dumps improves the environment of the basin.

Thus, the present work aims to study the geomechanical condition of the rock massif during transition from open pit mining technologies to those of integrated open pit-underground and subsequent underground mining of iron ore raw materials, that enables solving an important problem of sustainable development of Kryvyi Rih iron ore basin and improving the environment of the region.

3. Research methods

To study the geomechanical condition of the rock massif by analytical methods, the software package "Ansys 22" is used to calculate the stress-strain state of the massif around open pits and underground mine workings and simulate the behaviour of the rock massif when applying combined mining methods.

The calculations are performed for the conditions of Kryvyi Rih iron ore basin, where magnetite quartzites are now mined by the open pit method.

The average depth of the open pit is accepted 350 m. At depths over 350 m, the cost of mining is equal to and sometimes exceeds the cost of the underground mining method. Considering the critical influence of open pit mining on the environmental condition of the basin, the optimal solution undoubtedly consists in transition to integrated open pit-underground and subsequent underground mining of magnetite quartzites.

Figure 1 presents the initial design model of combined open pit-underground mining for calculating stresses and strains in the combined massif during open pit-underground mining of the deposit applying the proposed technology with the initial stage of mining waste disposal in the mined-out space of the open pit.

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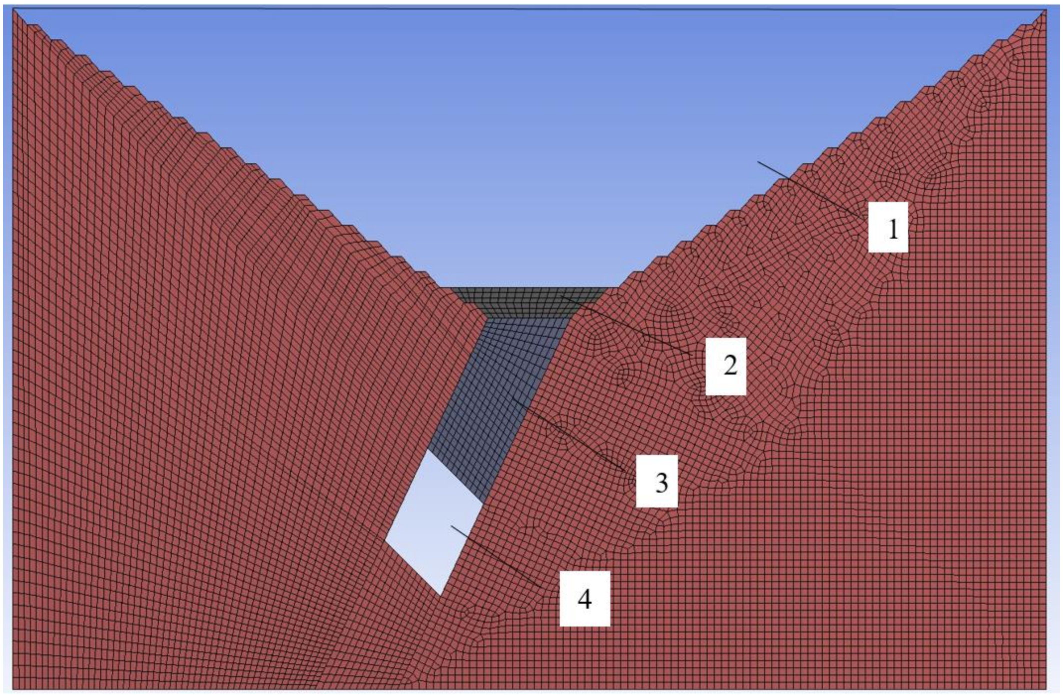

Fig. 1. Finite element grid for calculating stresses and strains in the combined massif at the initial stage of filling up the open pit; 1 – the open pit, 2 – waste rocks, 3 – the barrier pillar, 4 – the mined-out part of the ore deposit

The idea behind the presented design model of combined open pit-underground mining consists in dividing the massif into a finite element grid. The size of the initial design model is assumed to be adequate to the size of the area of applying the combined ore mining technology under study.

In this case, to build stress diagrams using the finite element method, the 3D model is divided into quadrilaterals with a side size of 5 m, (Fig. 2).

Figure 2 presents the initial design model of combined open pit-underground mining for calculating stresses and strains in the combined massif during open pit-underground mining of the deposit applying the proposed technology with mining waste disposal in the mined-out space of the open pit at the final stage of filling up the open pit.

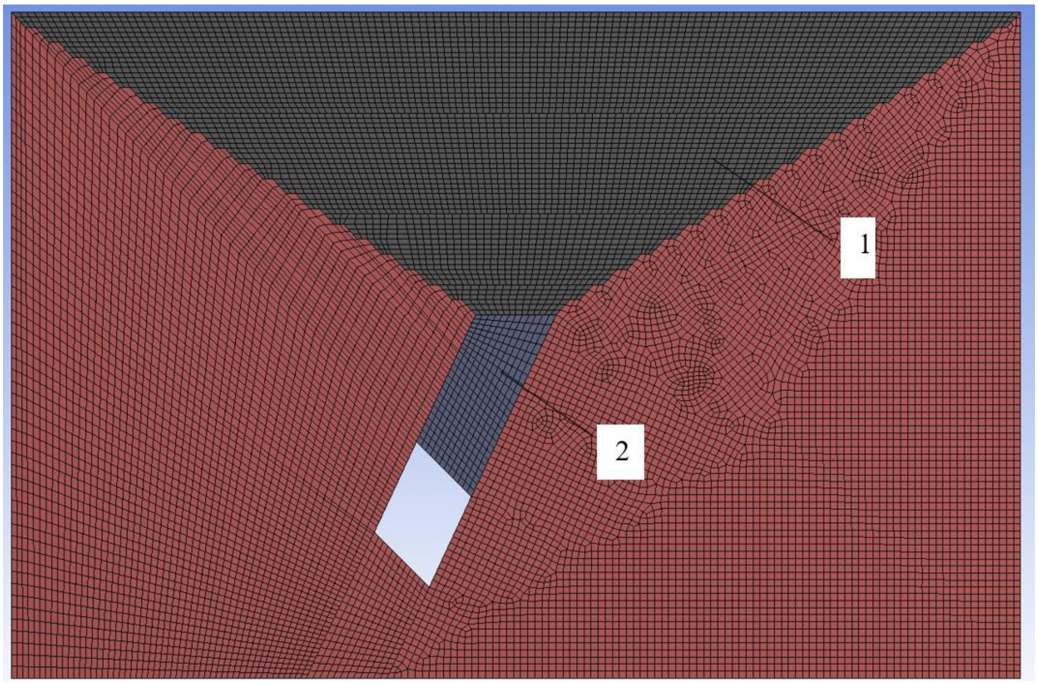

Fig. 2. Finite element grid for calculating stresses and strains in a combined massif at the final stage of filling up the open pit; 1 – the open pit at the final stage of filling it up with waste rocks, 2 – the barrier pillar

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4. Research results

The authors research on the problems of controlling the stress-strain state of the rock massif during transition from the open pit to complex technology of deposit mining.

The technologies for creating internal waste rock dumps when applying integrated open pit-underground mining methods are studied and substantiated.

Figure 3 visualizes distribution of principal stress isolines in the massif in the case of open integrated pit-underground mining of a magnetite quartzite deposit with the room ore mining system and creation of a barrier pillar in the combined massif at the initial stage of filling up the open pit with waste rocks.

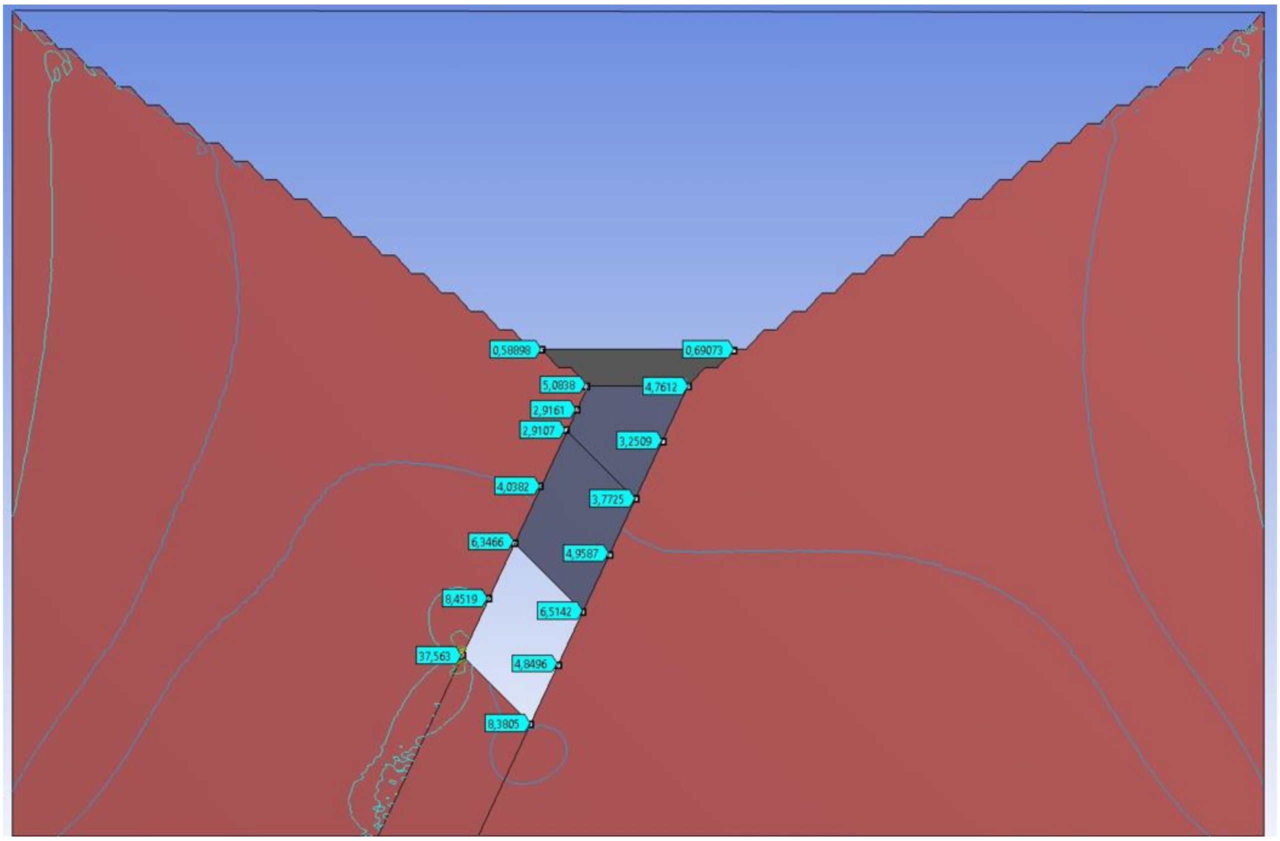

Fig. 3. Distribution of principal stress isolines in the combined massif at the initial stage of filling up the open pit with waste rocks

The research is conducted for conditions of creating of both an ore barrier pillar and an artificial barrier pillar from a consolidating backfill.

Underground extraction of magnetite quartzites is conducted by the room mining system. In the case of using an artificial barrier pillar from a consolidating backfill, the mining technology consists in the following.

After the complete drawing of the broken ore from the upper room, the mined-out space is backfilled with a consolidating backfill creating an artificial barrier pillar that separates the open pit mining operations from the lower room of the next underground level.

Further underground mining of minerals, magnetite quartzites in this case, is conducted by room mining systems under protection of an artificial pillar of a consolidating backfill.

In the case of creating an artificial barrier pillar from a consolidating backfill, formation of an internal dump for waste rocks or other mining wastes is conducted after the artificial barrier pillar acquires its design strength.

The analysis of the obtained calculations enables a general picture of stress field distribution in the combined massif.

The highest absolute value of stress is reached near the corners of the room.

Slight concentration of stresses is observed in the corners at the bottom of the room.

Significant maximum stresses σ1 in the corners of the room are explained by compressive stresses.

Depthwards into the ore massif, the stresses σ1 decrease, and their distribution pattern becomes more uniform.

The maximum value of stresses at the open pit bottom is 5.0838 MPa.

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When transiting from open pit to combined open pit-underground, or underground method of mining magnetite quartzites in Kryvyi Rih iron ore basin, the authors find it reasonable to support the following basic principles of developing transitional technologies.

Vertical shafts of the underground mine should be sunk in the footwall of the deposit.

According to the practice of underground mining of magnetite quartzites, the most rational height of the underground level should make 80 m – 90 m.

During the research, all the proposed design models are brought to a single modelling scale to enable studying the stress-strain state of the combined massif with high accuracy of the results obtained.

Figure 4 visualizes distribution of principal stress isolines in the massif in the case of integrated open pit-underground mining of a magnetite quartzite deposit applying the room ore mining method and creation of a barrier pillar in the combined massif at the final stage of filling up the open pit with waste rocks.

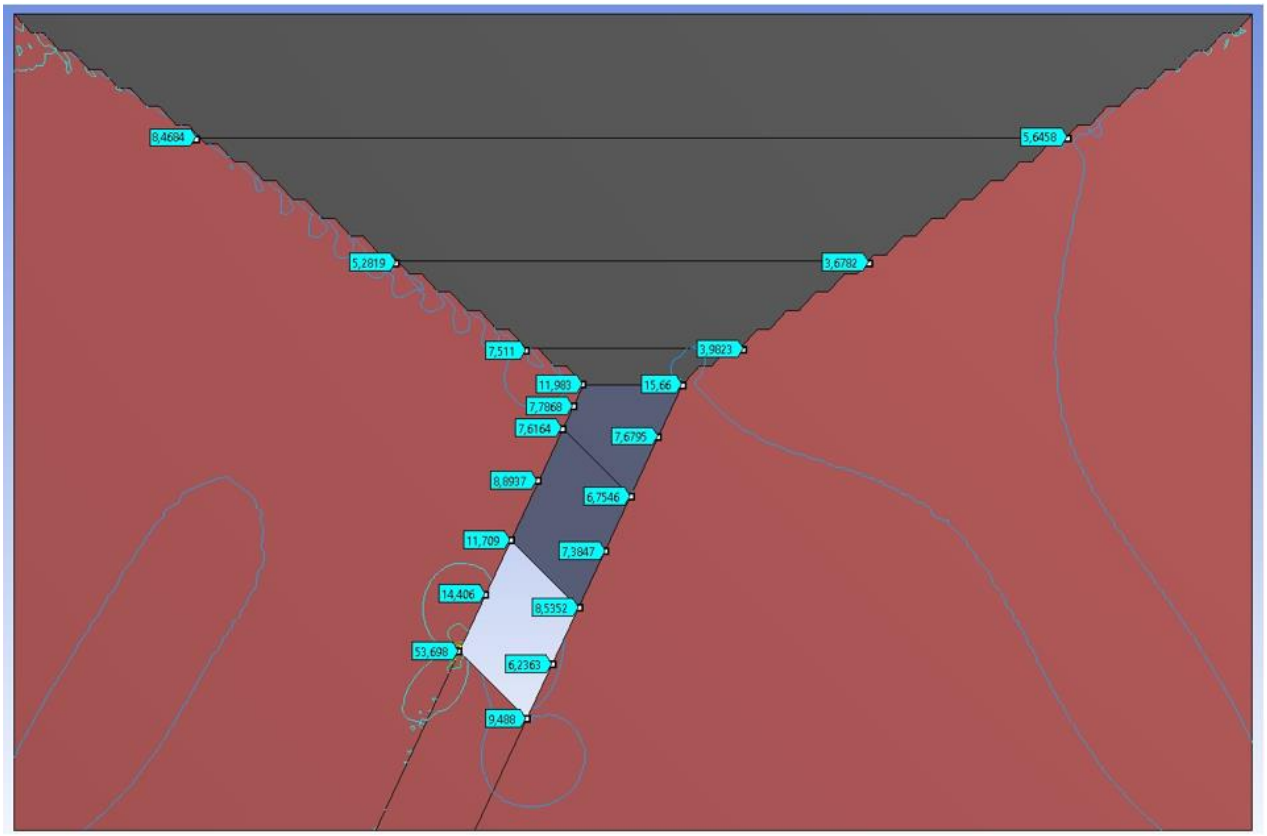

Fig. 4. Distribution of principal stress isolines in a combined massif at the final stage of filling up the open pit with waste rocks

When the open pit is completely filled with waste rocks, the maximum value of stresses at the bottom of the open pit increases to 15.66 MPa. But such stresses are observed in the footwall and are tangential to the artificial massif. Accordingly, the load from the column of waste rocks is redistributed mainly to the host rocks of the footwall.

Figure 5 shows the dependence of the value of maximum stresses in the combined massif on the height of the internal dump.

The maximum value of principal stresses in a combined massif that depends on the height of the internal dump can be determined by the equations 1.

$$\sigma_1 = 4{,}1757\ln(h_{id}) - 9{,}3295;\ R^2 = 0{,}9865 \qquad (1)$$

σ_1 is the maximum value of principal stresses, MPa; h_{id} is the height of the internal dump of waste rocks, m.

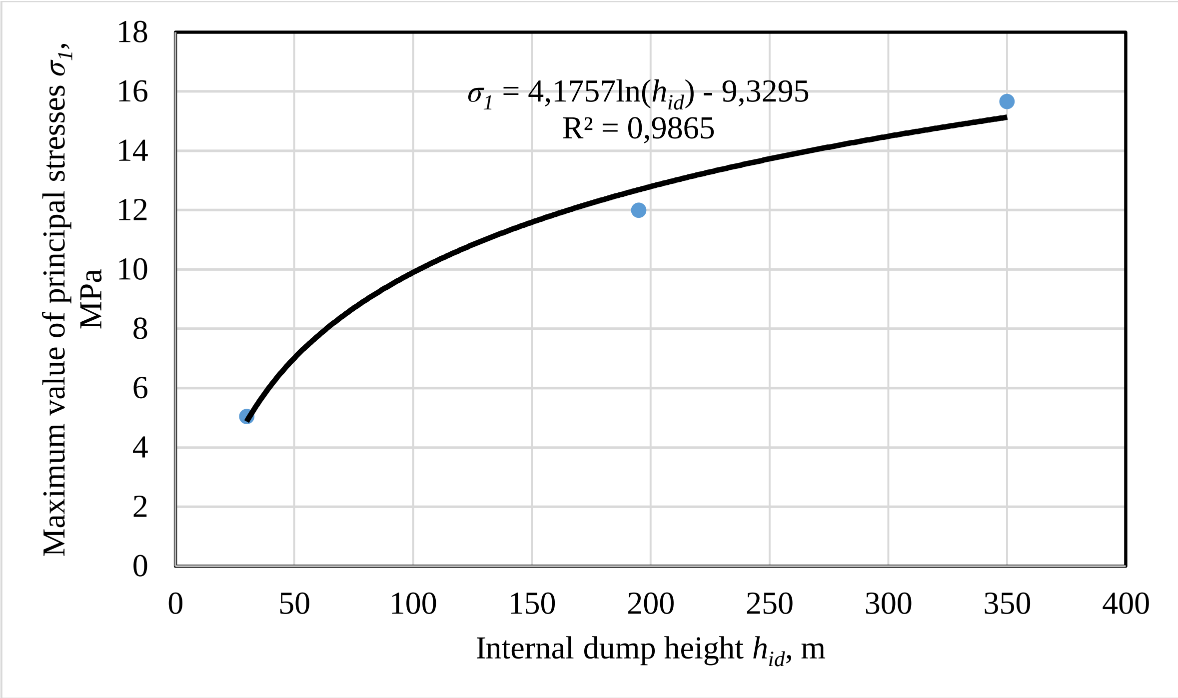

Fig. 5. Dependence of the value of maximum stresses in a combined massif on the height of the internal dump

The complete filling up of the open pit with waste rocks frees up large areas of fertile agricultural land that are potentially alloted for new dumps.

In addition, filling up the open pit shell with waste rocks and subsequent reclamation of the restored surface will partially restore the safe environmental state of the mining basin.

5. Conclusions

The stress-strain state of the rock massif during transition from open pit mining of iron ore deposits to integrated open pit-underground and subsequent underground mining of minerals is studied. Expediency of this transition considering the geomechanical condition of the massif is proved.

The conducted studies enable recommending environmentally friendly integrated technologies for open pit-underground mining of deposits with solution of the following problems: disposal of waste rocks in the mined-out space of open pits, which frees up large areas of arable land potentially alloted for dumps; return of industrial territories to economic activities by filling up open pits with mining waste and their subsequent reclamation; improvement of the environment of the basin due to absence of open pits and dumps.

The results obtained are relevant and possess important scientific and practical significance.

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