EFFICIENCY INCREASE IN MINING OF HIGH-GRADE IRON ORE DEPOSITS WITH SOFT ORES

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ABSTRACT

The article provides a geomechanical substantiation of the mass around the preparatory workings of the Yakovlevo deposit of high-grade iron ores using the finite element method implemented in the Simulia Abaqus software package. The simulation considered two schemes of transition from a layered system to a chamber one with enlarged geometric parameters of polygonal mine workings. The results of numerical simulation of the stress-strain state are obtained for various types of ores and are represented in the diagrams of the distribution of the main normal maximum stresses and configurations of the limiting condition zones of the mass around the workings/chambers at various stages of mining. The geomechanical justification of the safe parameters of the polygonal-shaped chambers confirmed the possibility of switching to the mining of martite and hematite-martitic iron ore reserves by an option of a layer system with larger chambers. The use of the obtained results on high-grade iron ore deposits with soft ores will increase the productivity, efficiency, and safety of mining.

Keywords: deposit, mine, iron ore, rock mass, mining methods, soft ore.

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1. INTRODUCTION

Currently, the content of iron in the developed deposits in Russia is low and is on average 30%, while having significant reserves of high-grade ores with an iron content of at least 60%.

A promising direction for the iron ore sub-sector development is the development of deposits of high-grade iron ores (up to 70% of iron) located in the area of the Kursk magnetic anomaly. [1]
The Yakovlevo deposit of high-grade iron ores of the Kursk magnetic anomaly is unique in its sources and in the content of iron in the ore.

The Yakovlevo deposit is one of the largest among the proven sources of high-grade ores with the highest iron content (the pure iron content is up to 70%) and the lowest content of harmful impurities (sulfur, phosphorus, etc.).

In the geological structure of the deposit, two different genetic complexes of rocks are distinguished: a Precambrian crystalline basement and a thick stratum of sedimentary horizons overlapping it. Crystalline rocks are represented by plagiogranites and metamorphic rocks - schists, ferruginous quartzites, phyllite schists. [2]

The Yakovlevo deposit is unique among iron ore deposits of the world in ore sources, peculiarities of hydrogeological and mining conditions (steeply falling thick reservoir, represented up to 50%) with loose and semi-loose ores, with a tensile strength of uniaxial compression of 0.3 to 3 MPa and high-pressure water-bearing strata.

Structurally, the deposit is a synclinal fold, the western wing of which coincides the Yakovlevo tape of ferrous quartzites. The inclination of strata composing the deposit is northeastern, monoclinic, with the dip angle of 60-70º, the strike is northwest at the azimuth angle of 320º.

High-grade iron ores are a product of weathering of ferrous quartzite. They form continuous sheet-like deposits, with the width in the range from 200 m to 600 m. Their thickness varies from 20 m to 250 m or more.

The ore deposit has a variable configuration. Carbonatization occurring in the ore deposit results in the development of dense, hard ores, coinciding with the upper part. The zone of loose ores spreads mainly in the thickest mineralization areas in the middle part of the deposit. [3]

The deposit sidewall is comprised of phyllitic quartz-sericite, chlorite-sericite schists, and the footwall of the deposit is the sandstone-slate formation. In the deposit footwall, there is an extensive field of plagiogranites.

In the hanging (eastern) wall of the ore body of the Yakovlevo deposit, folded structures with discontinuity of rocks are clearly traced. Disruptive disturbances have the character of fault-shifts and form numerous crushing zones. In the southeastern part, the structure is complicated by tectonic disturbances. High-grade iron ores are characterized by intensive fracturing, decompression, and loading-out, leading to loss of stability in mine workings.

Complex mining and hydrogeological conditions for the development of the Yakovlevo field with the presence of weak unstable loose iron ores and seven high-pressure water-bearing strata determined the use of a layered development system with the laying of a worked out area at the first stage of field development, which allows extracting of up to 98% of iron ore reserves. However, the low productivity of labor forces looking for more efficient versions of the development system. [4]

2. METHODS

It is proposed to use a chamber system of development with the formation of polygonal-shaped cleaning chambers in order to increase the productivity, efficiency, and safety of high-grade iron ore mining of the Yakovlevo mine. First of all, it is necessary to study the change in the stress-strain state of the ore and backfill mass, considering their physical and mechanical properties, the initial stress state, the order of cleaning operations and the stability of the excavations (Figure 1).
Figure 1 Schemes of chamber development systems with polygonal chambers. Stages of work 1-5.

a - scheme of transition from the layered development system to the chamber system, the chambers height is 12 m; b - scheme of transition from the layered development system to the chamber system, the chambers height is 16 m.

The finite element method implemented in the Simulia Abaqus software complex is used to study the stress-strain state of the mass around the preparatory workings.

The simulation considers two schemes of transition from a layered system to a chamber one with increased geometric parameters of polygonal mine workings.

The problem is solved in a flat setting, where the real mass is represented by a weighty finite area of width 750 m and height 200 m. The model dimensions were chosen taking into account the elimination of the influence of boundary conditions on the distribution of stresses and deformations around the workings. The workings soil of the protective overlap was located from the top of the model at a depth of 65 m, which corresponds to the thickness of the safety ore mine. The modeled portion of the mass was fixed from displacements along the model faces in perpendicular direction to the fixed faces.

The magnitude of vertical and horizontal stress was accepted in accordance with the previously performed calculations of the stress-strain state of the inhomogeneous ore mass and was $\sigma_y = 7$ MPa for vertical stress and $\sigma_x = 4$ MPa for horizontal stress.

An elastic-plastic model, based on the Coulomb-Mohr strength condition, is used to characterize the strength of rocks. [5]

The host ore mass is represented by a nonlinearly deformed isotropic medium with physicomechanical characteristics of iron-ore-martite ore. The physicomechanical characteristics of the ore mass and the packing material were taken from the results of laboratory and field mine studies carried out by VIOGEM and the St. Petersburg Mining University. [6, 7]
The results of numerical modeling of the stress-strain state were obtained for different types of ores, the height of the chambers was set at 12 m and 16 m. The results are represented by the diagrams of the distribution of the main normal maximum stresses and configurations of the zones of the limiting condition of the mass around the workings/chambers at various stages of mining.

At the first stage, the simulation of arched sectional workings was carried out, which will be used in the fans of holes drilling, with the subsequent breaking of ore in the chamber and its transportation.

In loose iron-ore-martite ores at the height of the chambers of 12 m and 16 m, intensive growth and subsequent closing of the limiting condition zones is observed, from which it can be concluded that the load-bearing capacity of the mining work in the form of falling out of the roof to the height of the worked chamber.

In iron-ore-martitic ores of medium density, with a chamber height of 12 m and 16 m, the local zones of the limiting state with the largest linear dimensions of 1.5 m and 0.2-0.3 m, respectively, are marked in the top of the excavations.

In dense iron-ore-martite ores with a chamber height of 12 m and 16 m, the local zones of the limiting condition with the largest linear dimensions of 0.35 m and 0.2 m, respectively, are marked in the top of the excavations.

At the stage of working out the chambers in the iron-ore-martite loose and medium-density ores, the separating pillar is in the limiting condition, which indicates the high probability of mining pressure in the form of inrushes and the ore slipping into the chamber (Figure 2, Figure 3).

![Figure 2 Simulation of the development stage of chambers.](http://www.iaeme.com/IJMET/index.asp)

Diagrams of the distribution of the main normal stresses in a mass of dense ore.

- **a** - the height of the chambers is 16 m;
- **b** - the height of the chambers is 12 m.
Figure 3 Simulation of the development stage of chambers.

Configurations of the limit condition zones.

a - the height of the chambers is 16 m; b - the height of the chambers is 12 m.

Local zones of the limiting condition with the largest linear dimension of 0.8-1.0 m are noted in dense iron-ore-martite ores in the contour mass of chambers.

In the iron-ore-martite dense ores, preparatory workings and separating pillars retain their stability. When conducting mining operations in loose and medium-density ores, it is proposed to ensure the stability of preparatory workings and separating pillars by installing a reinforcing fiberglass anchor support that increases the bearing capacity of the contour mass.

3. RESULTS

The geomechanical justification of the safe parameters of the polygonal-shaped chambers confirmed the possibility of switching to the mining of martite and hematite-martitic iron ore reserves by an option of a layer system with larger chambers.

The idea of the proposed mining method is the development of cross-rubbed cleaning chambers of a polygonal cross-section with the use of drill-haulage and ventilation-packing frames located in the base and roof of the chambers.

Chambers of adjacent floors are displaced half their width. The excavation of the ore is carried out progressively in a descending order under the protective overlap, using a drilling and blasting method of breaking. After harvesting the chipped rock mass, the chamber is laid with a hardening filling and the ventilation lining is left in the roof of the chamber as a result of underfilling. The width, the height of the chambers of the various bursts, the angle of inclination of the side walls of the chambers is determined from mathematical expressions,
starting from the stable span of the protective overlap, the width of the drill-delivering mouth and the angle of internal friction of the ore mass (Formula 1):

$$B < L_{stb}; \ h = \frac{B - b}{2 \cdot \text{ctg} \alpha}; \ h_1 \approx \frac{1}{2} B; \ h_2 \approx B; \ \alpha = 45 + \frac{\phi}{2},$$

where $B$ – chamber width, m; $L_{stb}$ – stable design span of the protective overlap, m; $h$ – chamber height, m; $b$– width of the delivery unit, m; $\alpha$ – the angle of inclination of the chamber walls, deg.; $h_1$ – height of the first floor chamber, m; $h_2$ – height of the second floor chamber, m; $\phi$ – the angle of internal friction of the ore mass, deg.

Chambers adjacent to the working chamber must be filled with filling material that has gained normative strength or represents an undrawn part of the mass (ore pillar), to improve the safety of mining operations.

At the same time, due to the formation of a monolithic filling mass in the upper part of the cleaning chamber, it is possible to increase the load on the cleaning face.

Mining of the chambers in descending order allows excluding inrush in the roof of the chambers, which are directly under the safe overlap. The arrangement of the chambers in a checkerboard pattern increases the stability of the upper inclined walls of the chambers due to the arrangement of the half-chamber under the enclosed mass.

However, this arrangement of the chambers increases the load perceived by the ore inter-chamber pillar, which increases the probability of loss of the load-bearing capacity of the walls of the lower part of the chambers. They are of polygonal shape in order to prevent falling from the walls of the chambers, the angle of inclination of the walls depends on the angle of internal friction of the rocks of the mass.

The results of simulation of the stress-strain condition around the chambers and excavations in the ore mass showed that the stability of inter-chamber ore pillars is preserved in dense iron-martite ores. In the ore mass of medium and low density, the stability of the pillars and the roof of the workings is achieved by using fiberglass plastic anchors.

The low stability of the ore mass increases the risks of dumping in the roof of the chambers and the destruction of inter-ore lobbies. To improve the safety of mining operations, it is proposed that the cleaning chambers be refined. At the same time, the length of the holes is 6-15 m (in 3 m increments). The length of the stitch is determined by the technological parameters and the cycle time of the complete working of a chamber. The increase in the length of the excavation makes it possible to reduce the number of chambers that are under simultaneous development.

However, the preemptive working and laying of the chambers affect the ventilation of the unit. In this situation, the ventilation of the cleaning and preparatory workings has to be carried out by a dead-end scheme, thereby complicating the ventilation scheme and increasing the costs.

To ensure through ventilation of chambers and workings due to general depression, it is proposed to leave ventilating and packing ort in the pouched chambers. Fresh air from the drifts of the recumbent side is fed through the ventilation-packing and boring and delivering ortas into the cleaning chamber, and the exhaust air is removed through the artificially formed ventilating infill into the ventilation drift of the hanging side and further to the ventilation shaft.

In situations where the laying or chipped ore in the chamber prevents the passage of exhaust air from the drill-delivering ort to the ventilation-packing ort, it is necessary to apply a dead-end ventilation scheme using a local ventilation fan.
To reduce the total shrinkage of the filling mass, after working off and fixing the chamber for the entire thickness of the ore body, the venting-packing ort, and the jam before the drift of the recumbent side is to be completely laid. The transition to the next floor is carried out only after the set of a normative strength of the filling array.

Increasing the load on the face is achieved by spreading the technological processes of drilling and charging wells, delivering ore, and installing the laying pipeline in various workings within the cleaning chamber, and in various chambers within the same floor. Each site serves one production complex, consisting of a drilling rig and one or two loading and unloading machines. In case the length of the roll-out exceeds 300 m, the technological complex can be supplemented with dump trucks.

In order to ensure the safety of mining operations, the order of working out of the chambers provides for the presence of an interlock chamber with a width not less than the span of the treatment chamber.

4. DISCUSSION
The transition to a layered development system with the formation of cleaning chambers of increased polygonal size while processing reserves of martite and hematite-martitic iron ores of the Yakovlevo field will allow:

- reduce the volume of mining preparation work;
- minimize dilution and loss of ore;
- improve the safety of mining operations due to the lack of people in the bottom hole;
- to ensure the stability of the filling mass due to the contact interaction along the lateral faces of the adjacent chambers (tapes) of adjacent substages.
- increase technical and economic indicators of production, labor safety of miners and solve a number of related problems:
  - ensure the stability of the cleaning chambers by giving a polygonal shape and using the fastening of zones of potential inrush with fiberglass anchors;
  - carry out ventilation of the cleaning chambers and workings at the expense of general depression;
  - reduce the total shrinkage of the filling mass due to a two-stage filling of the used chambers.

5. CONCLUSION
The results of the studies presented in the article can be used by enterprises and organizations that design, build and operate underground workings of iron ore deposits and can be useful for scientific and engineering workers of enterprises, research and design institutes involved in the fixing and maintenance of mountain development in the development of ore deposits.

Further prospects for research are the development of new and improvement of existing geomechanical approaches to assessing the stability of mine workings of newly developed horizons of the high-grade iron ore deposits, taking into account changes in geological and hydrogeological conditions.

At the next stage of the study, it is planned to consider the design of the system and the organization of technological processes in mining operations, which will make it possible to increase the technical and economic parameters of the digging excavation by increasing the geometric parameters of the mine workings (while maintaining the safety of mining operations).
REFERENCES


