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# EXPEDIENCY OF APPLICATION OF THE VERTICAL CONCENTRATED CHARGES TO DECREASE LOSSES OF ORE ON A LYING WALL OF DEPOSITS

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# ДОЦІЛЬНІСТЬ ЗАСТОСУВАННЯ ВЕРТИКАЛЬНИХ КОНЦЕНТРОВАНИХ ЗАРЯДІВ ДЛЯ ЗНИЖЕННЯ ВТРАТ РУДИ НА ЛЕЖАЧОМУ БОЦІ ПОКЛАДІВ

**Purpose.** Developing effective mining technologies of working with a roof fall of ore and adjacent strata for deposits of Kryvyi Rih iron ore basin.

**Methodology.** Mining-and-geological and design data of thick steep deposits of Kryvyi Rih iron ore basin are analyzed. Initial data for choosing mining methods for mineral deposits are established. Variants of mining technologies with scraping, rock ore drilling out by parallel fans of deep wells with formation of a vertical compensatory chamber in across and along the strike of a deposit are developed. The basic technical parameters of mining methods are substantiated including a level interval; height of an extraction of a sublevel; length of the block; distance from slusher drifts to developments of inset horizon; distance between final developments. Efficiency of application of the vertical concentrated charges at mines of Kryvyi Rih is proved.

**Findings.** The variant of caving system of ore and adjacent strata with downhole breaking of ore or combined by wells from drilling chambers and the vertical concentrated charges from a lying wall of a deposit is offered. Calculations of parameters of drilling-and-blasting for ore breaking by the vertical concentrated charges are performed. Parameters of breaking and the vertical concentrated charges are received.

**Originality.** Scientific novelty of the offered technology of mining with a roof fall of ore and adjacent strata consists in a substantiation of basic formulas of drilling-and-blasting.

**Practical value**. Effective engineering methods for working of deposits are developed. Calculation methods for parameters of drilling-and-blasting for working of reserves of ore which contact to a lying wall of steep deposits are developed.

**Keywords:** *ore losses, lying wall, mining method, the vertical concentrated charges*

**Introduction.** The problem which should be solved using the offered mining methods is efficiency and intensity of ore mining. Thus the given mining methods should answer as much as possible and effectively to geological conditions of burial of a deposit of Kryvyi Rih iron ore basin. Major factors which influence a choice of technology of underground extraction of a deposit include a deposit pitch angle, power of a deposit, durability of ore and soils of lying and trailing walls, firmness of soils of a lying and hanging side of a deposit.

Recently modern practice testifies, that deposits are more often to be developed with pitch angles of $\alpha = 50–60$ degrees. The given pitch angles are characteristic for deposits which are developed at mines such as "Oktiabrska", named after Lenin, "Rodina" (especially northern part of the deposit) of PJSC "Kryvbaszalizorudkom", at Artem–1 of PJSC "ArcelorMittal Kryvyi Rih", at Frunze and "Yuvileina" of PJSC "EVRAZ Sukha Balka".



Analyzing mining methods which have been applied recently, we may note that these are systems of sublevel caving of ore and adjacent strata which are accompanied by ways, methods, engineering solutions of improving indicators of ore mining [1].

So, the effective ore mining from rather flat deposits is quite a difficult engineering process. Complexity consists in the fact that the ore mining is accompanied by formation of losses of ore on a lying wall of a deposit.

Therefore, creation of effective ways and technologies of working deposits is an urgent scientific problem which has an important practical value.

**Analysis of the recent research and publications.** While working out the basic reserves of ore and crown pillars especially at pitch angles of a deposit of $\alpha = 50–60$ degrees using caving systems of ore and adjacent strata at mines of PJSC "EVRAZ Sukha Balka" and PJSC "Kryvbaszalizorudkom" considerable losses of ore remain on a lying wall of a deposit. So, it is necessary to pay special attention to effective extraction of a part of ore of a lying wall of deposits as these are the main losses of ore on the block.

**Unsolved aspect of the problem.** Thus, it is necessary to offer an advanced effective technology of working out deposits which is characterized by the big indicators of ore mining at breaking of ore by fans of deep boreholes or the vertical concentrated charges.

**Objectives of the article.** Analyzing mountain and geologic properties of ore and soils at PJSC "EVRAZ Sukha Balka" it is necessary to note that there are different forms of ore bodies with power of $m$ = 10–30 m and a pitch angle of $\alpha \geq 50$ degrees. Adjacent strata are not inclined to display of rock bumps, ore martite durability $f$ = 7–8, different firmness and fracturing degree. Relative density of ore is $\gamma_p = 3.75$ t/m$^3$. The deposit hanging wall is presented by jaspilites with an average factor of durability $f$ = 15. The lying wall is presented by soils of different durability $f$ = 8–12 to 14.

Working of deposits is performed in the following sequence: I – formation of horizontal compensatory space by millisecond-delay blasting of fans of boreholes from chisel drifts and fans of leveling boreholes from drilling chambers; II – breaking of boreholes of chisel orts; III – blasting of other volume of a massif by deep boreholes from drilling chambers.

Drilling of fans of deep boreholes is done by machine tools NKR-100 M. In coordinates, charges of explosive substances (explosives) are located in the drilled bunches of deep boreholes of drilling chambers which are located on deposit flanks, at length of block $L$ = 60 m through the calculated size of distance between working faces of deep boreholes and $a$ = 3 m.

The special attention is to be focused on breaking rocks of a lying wall which change their properties with fall of mining operations [2]. So, for the set conditions it is necessary to offer effective technology of working out blocks to improve indicators of an ore mining [3].

**Presentation of the main research.** The substantiation of height of a fulfilled sublevel occurs according to a deposit pitch angle. Thus it is known that specific absolute losses of ore on a lying wall of a deposit change in direct ratio to differences of pitch angles $\alpha_p$ of a deposit and release of broken ore $\alpha_r$. With the height of subvel increasing over 25 m, losses of ore on a lying wall of the deposit increase almost by three times, and with increasing difference of pitch angles of a deposit and an ore drawing they increase only by 2 times.

While working out deposits of Kryvyi Rih iron ore basin with design sizes of the block: length $L$ = 60 m, subvel height $h_s$ = 40 m, level interval $H_l$ = 80 m, as side apply carrying out additional final developments on contact to deposit lying wall is applied as the basic way to prevent losses of ore on lying wall of a deposit. The given way is characterized by substantial increase in specific expenses preparatory and access roads.

The authors offer to use the technology of sublevel caving of ore and adjacent strata with a height of subvel $h_s$ = 25 m based on known mining-and-geological data of a deposit for working out the block of ore. This will provide the minimum formation of losses of ore on the lying wall of the deposit (Figs. 1 and 2). As precautionary means of reduction of losses of ore on the lying wall of the deposit, it is recommended to apply breaking by the vertical concentrated charges to move the ore which remains on the lying wall of the deposit. It can be used as supplementary to the process or separately depending on a deposit pitch angle on corresponding sublevels.

The authors offer to apply the most effective way of initiation of boreholes in a fan of counter initiation during longhole stoping. At such a way of initiation better cracking is provided in the zone between boreholes. It is expedient to apply counter initiation by priming cartridges with electric detonators and SIN detonators to maintain high speed of detonation of blasthole charges. Priming cartridges with electric detonators can be placed only in a borehole mouth while priming cartridges with SIN detonators can be placed both in a borehole mouth and in its end. The following cartridges and trotyl blocks are applied for priming cartridges: patronize explosive substances from ammonite AM #6ZHV in polyethylene packing. Initiation of blasthole charges is carried out both by means of priming cartridges with electric detonators and with UNS–SH detonators with wave guides. These systems of initiation are applied at as the most safe and technological all mines of Kryvyi Rih, Zaporizhzhya Iron Ore Combine, etc.

The given technologies of underground extraction of steep ore deposits (Figs. 1 and 2) are given for PJSC "EVRAZ Sukha Balka". At the initial stage of mining of ore deposit, drivage of haulage gate and orts-arrivals with air raises is carried out. Then scraping developments take place from which formation of the vertical compensatory chamber across or along the strike of deposits is carried out. Breaking is carried out by sublevels with a height of 25 m that allows minimizing ore losses on the lying wall of the deposit.

Burden and distance calculation between working faces of boreholes is carried out according to Yu. P. Kaplenko's instruction "Choice of parameters of drilling-and-blasting at breaking of ores by deep boreholes".

Thus, if to apply breaking by the vertical concentrated charges, calculation of parameters of drilling-and-blasting has some features. Breaking by the vertical concentrated charges is done by the concentrated charges of the explosive substances placed in specially driven vertical workings. As the basic way, breaking by the vertical concentrated charges has an assignment for a roof fall of dead rocks of a lying wall of deposits (Fig. 3).

The massif of the block which is broken is divided into separate explosive blocks, each of them is blasted out by one or two charges generated in vertical workings. After a charging, the ore received at formation of vertical workings, is used for filling (backfilling) of a free part of a development. The rock cushion in a mouth of the rising provides complete isolation of all developments in the block from direct penetration of explosive gases. At explosion of a charge of explosive, the rock cushion is not thrown out in a development, and remains on a place. Due to this complete actuation of a charge of explosive in rising and penetrations of all the volume of explosive gases through a blasted out massif are reached.

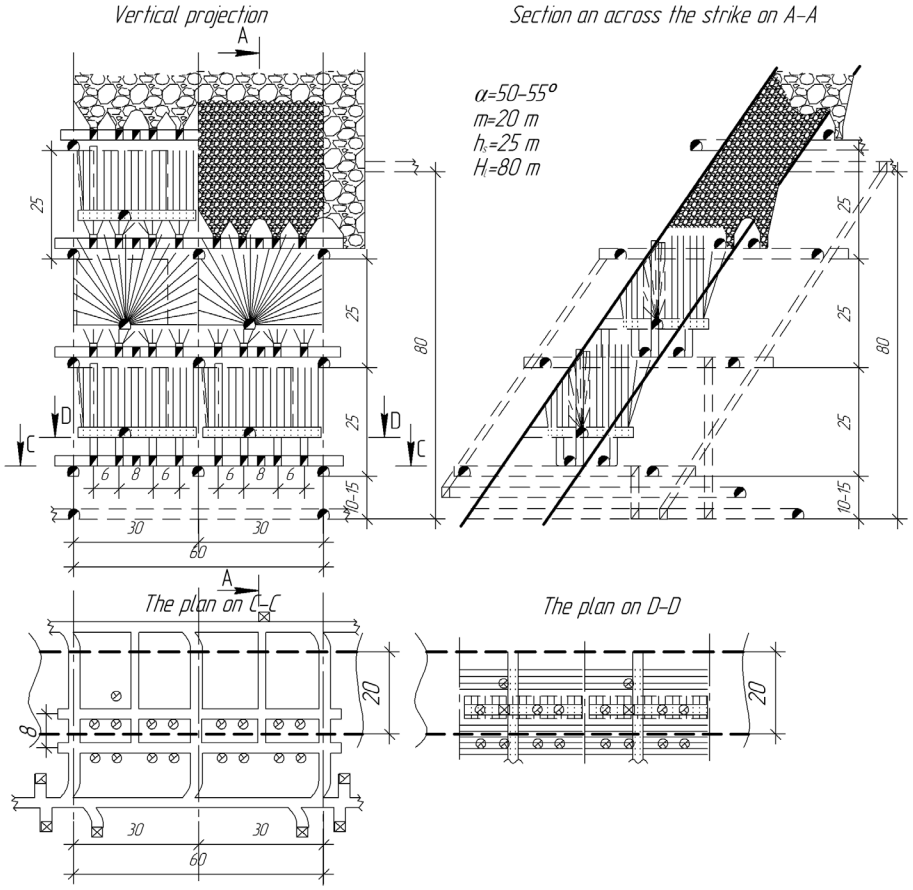


*Fig. 1. Technology of a sublevel caving of ore and adjacent strata with formation of the vertical compensatory chamber along the strike deposits*

At destruction of ore by means of the vertical concentrated charges the following parameters are considered: horizontal distance between charges ($a$); a burden ($W$); vertical distance between charges ($Z$); time of slowing-down of blasting of charges ($t$).

Vertical workings are done in diameter $d$ = 2.0 m. The height of a rock cushion is $h_{pp}$ = 6 m. Optimum time of slowing-down of blasting of charges makes $t$ = 27 ms.

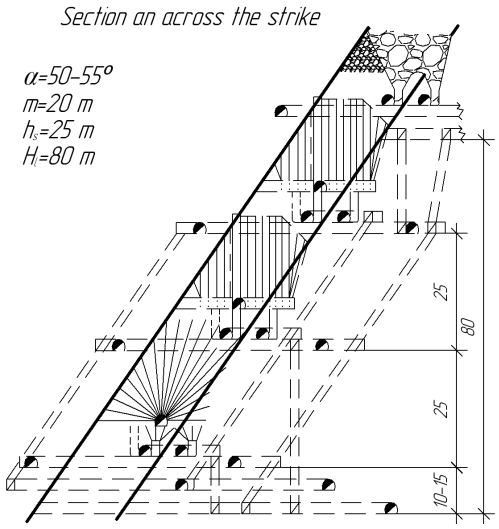


*Fig. 2. Technology of a sublevel caving of ore and adjacent strata with formation of the vertical compensatory chamber of the deposit across the strike*

At the initial stage of mining of ore deposit working of haulage gate and access crosscuts with air raises is performed. Then workings go in the following order: *1* – scraping subs; *2* – cone raises; *3* – final funnels; *4* – chisel drift in a lying wall of the deposit; *5* – horizontal compensatory space. The following stage is formation of vertical raise *7* from chisel drift *4* in which the concentrated charge of explosive is planted. Then there occur simultaneous millisecond-delay blasting of fans of deep boreholes *6* and vertical raise *7*, which displaces ore from a lying wall of the deposit which promotes reduction of losses of ore on a lying wall. The layer of ore which is dislodged has a length of 60 m, and a thickness of 25 m. For effective breaking, formation of four vertical concentrated charges in the blasted out block which are equally apart is sufficient. The maximum distance between the vertical risings equals 33 m. After blasting, dead rock 9 is spaced above the broken ore 8. Then release and delivery of broken ore are carried out.

The air cavity provides a longer term of time of action of shock waves on walls rising, a smaller zone of crushing of a massif in a near zone and a bigger zone of cracking distribution. The size of the air cavity makes $h_{ac}$ = 0.7 of the height of a column of explosive in the vertical concentrated charge.

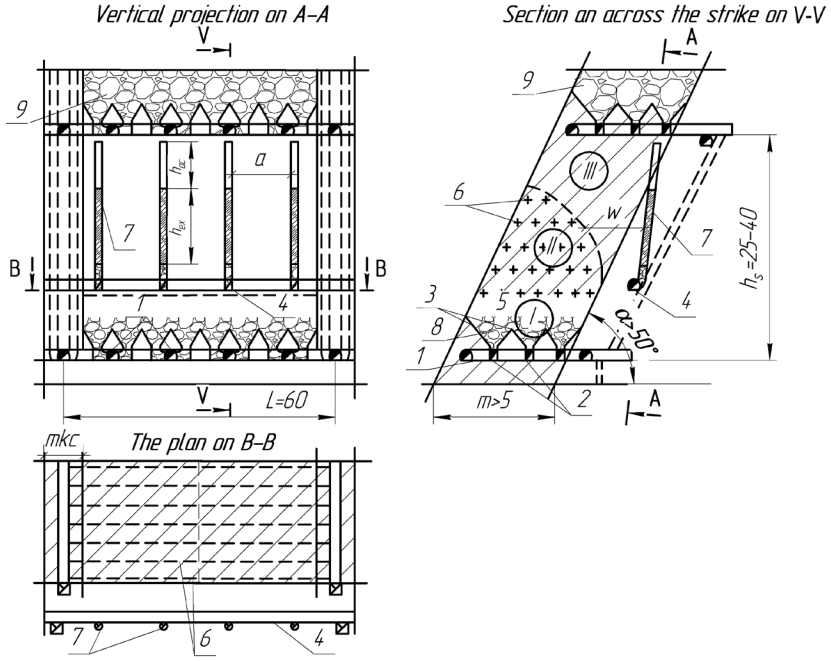


*Fig. 3. Mining method with breaking by bunches of deep boreholes and vertical compensatory chamber at "Yuvileina" mine of PJSC "EVRAZ Sukha Balka": a – horizontal distance between charges, m*

At calculation of parameters of drilling-and-blasting for ore breaking by the vertical concentrated charges the following formulas are used:

Critical speed of fragile destruction of ore equals m/s

$$u = 410 \cdot 10^{-2} \sqrt{\frac{10f}{\rho n}},$$

where $\rho_n$ is ore density, kg/m$^3$.

The horizontal distance between charges is defined by the formula, m

$$a = 1.07\left(\frac{3.62}{u} + 0.35h_{ex} - 0.0066h_{ex}^2 + \right.$$
$$\left. + 6.54d + K_1 \cdot 41.98d_{ave} - 8.01\right),$$

where $h_{ex}$ is the length of a charge, m; $d$ is the diameter of a charge, m; $d_{ave}$ is the average size of a piece of the crushed ore, m.

The burden is defined by the formula, m

$$W = 1.07\left(\frac{1.48}{u} + 0.174h_{ex} - 0.003h_{ex}^2 + \right.$$
$$\left. + 3.22d + K_2 \cdot 20.98d_{ave} - 3.471\right).$$

The vertical distance between charges is defined by the formula, m

$$Z = 1.07\left(\frac{1.32}{u} + 0.494h_{ex} - 0.005h_{ex}^2 + \right.$$
$$\left. + 2.34d + K_3 \cdot 16.11d_{ave} - 2.67\right),$$

where $K_{1,2,3}$ are correction factors; $K_1$ = 1.8 ÷ 2; $K_2$ = = 3.0 ÷ 4.0; $K_3$ = 3.0 ÷ 3.5.

Time of slowing-down of blasting of charges is calculated by the formula, ms

$$t = 0.154 \cdot \frac{\sqrt{\ln\left(\frac{2h_{ex}}{d}\right)} \cdot \left[\left(\sqrt{w^2 + h_{ex}^2}\right)^3 - h_{ex}^3\right]}{d \cdot h_{ex}},$$

where $w$ is a thickness of a blasted out layer, m.

The size of the vertical concentrated charge depends on product of expenses of explosive substances $q_o$ = = 2.1 kg/m$^3$, the thickness of a blasted out layer of ore, distances between charges $a$ = 32 m and charge distances $h_{ex}$ = 10 m and makes $Q_{ex}$ = 13708.8 kg. The size of quantity of ore in a blasted out layer at breaking is equal to the product of the geometrical sizes of the layer of ore.

Sequence of blasting of the vertical concentrated charges is as follows: within one explosive cycle simultaneously in a delay-action way through 27 ms the vertical concentrated charges formed of drift of the lying wall along the whole length of the block is blasted out. Breaking by the vertical concentrated charges is cheaper and more productive compared to downhole breakings.

Calculations of parameters of drilling-and-blasting at breaking by the vertical concentrated charges are resulted in the summary Table.

**Conclusions.** Practical application of the offered advanced technologies of working rather flat deposits using mining methods with a sublevel caving of ore and adjacent strata with breaking of ore by fans of deep wells or the vertical concentrated charges which at most correspond to difficult geological conditions of burial of a deposit, allow improving efficiency and intensity of ore mining, reducing iron ore losses on a lying wall of a de-

*Table*

Parameters of drilling-and-blasting

| # | The parameters | Value |
|---|---|---|
| 1 | Maximum burden VKZ, *W*, m | 21 |
| 2 | The maximum horizontal distance between charges, *a*, m | 33 |
| 3 | The maximum vertical distance between charges, *z*, m | 22 |
| 4 | Ore outcrop from 1 m of a workings, t/m | 222 |
| 5 | Specific expenses of explosive for breaking of vertical concentrated charge, kg/t | 1.06 |

posit, improving ore production cost, in general, within the system.

The following directions of research and topical problems which represent, according to the authors, the greatest theoretical and practical interest are distinguished:

1. Further improvement and the change of mining methods applied in the industry with a sublevel caving of ore and adjacent strata, more effective systems with application of new engineering and technical solutions for the purpose of increasing concentration of mining operations are planned.

2. Substantiation of introducing modern highly effective productive loading and drilling equipment in all operating processes as much as possible to provide continuous ore mining from blocks and, above all, to increase productivity of extraction of ore.

3. Thick loading and drilling equipment at Kryvyi Rih mining basin with constantly increasing high rock pressure requires to solve a problem of expedient application of the equipment paying attention to advantages and disadvantages, equipment cost, as well as cost of spare parts, expenses for its maintenance and operating repair.

4. While placing highly effective productive loading and drilling equipment into operation, the substantiation of expediency of face ore drawing, or definition of optimum and effective release of broken ore with defining a necessary diameter of final developments is necessary.

5. While solving problems of reducing losses of ore on the block, in particular, on a lying wall, it is necessary to consider possibility of breaking ore with application of the vertical concentrated charges not only in rocks of a lying wall, but of the whole block, which will provide reduction of the expense for preparatory and access workings; moreover, the total length of chisel developments and an expense for their maintenance will decrease.

6. An obligatory condition is development of calculation methods for parameters of drilling-and-blasting at breaking by the vertical concentrated charges for working reserves of ore of steep and flat deposits.

7. Development of highly technological ways of complete destruction of ore in place on which the vertical concentrated charges are directed as well as the prevention of pressing and caking of broken ore operate.

8. The analysis of character of crushing of broken ore by vertical concentrated charges and ways of improvement of fundamental crushing of ore at breaking due to increase in density of charges of alternative brands of explosives.

9. As conformity to underground conditions at formation of the ascending rising the substantiation of application of the equipment "Rhino 408H" is planned.

10. In laboratory conditions on models from equivalent materials which are as much as possible approached to real industrial conditions, the phenomenon of seismic influence at breaking of the vertical concentrated charges on the block blasted out is to be simulated.

11. The analysis and expediency of technology of breaking a massif with vertical concentrated charges with the previous shielding of the block which is blasted out at working of deposits in certain mining conditions which demand restrictions of blasting a mass of explosives on seismicity, preventing destruction of big masses of adjacent strata.

12. Based on results of laboratory research the basic dependences are to be received on which efficiency of application of breaking by the vertical concentrated charges is estimated.

13. Definition of the main dependences which influence length of movement of ore from a lying wall into a zone of release of steep and flat deposits is one of directions of the further research.

14. Further it is planned to change and improve profoundly parameters of existing mining methods with a sublevel caving of ore and adjacent strata based on a major factor of influence of a pitch angle of a deposit according to which excavation methods, deliveries and transportations of minerals are chosen.

15. Choice and substantiation of a necessary height of subvel while mining steep and flat deposits of low thickness.

16. The direction of the further research consists in improving parameters of explosives and substantiating application of alternative explosives at ore breaking.

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**Мета.** Розроблення ефективної технології розробки з обваленням руди та вміщувальних порід для умов відпрацювання покладів Криворізького залізорудного басейну.

**Методика.** Проаналізовані гірничо-геологічні та проектні дані потужних крутоспадних покладів Криворізького залізорудного басейну. Встановлені вихідні дані для вибору системи розробки родовищ корисних копалин. Розроблені варіанти технологій розробки зі скреперною доставкою, розбурюванням рудного масиву паралельними віялами глибоких свердловин з утворенням вертикальної компенсаційної камери вхрест простягання та за простяганням родовища. Обґрунтовані основні технічні параметри системи розробки: висота поверху; висота виймального підповерху; довжина блоку; відстань від виробок скреперування до виробок прийомного горизонту; відстань між випускними виробками. Обґрунтована ефективність застосування вертикальних концентрованих зарядів (ВКЗ) на шахтах Кривого Рогу.

**Результати.** Запропонований варіант системи розробки з обваленням руди та вміщувальних порід зі свердловинною відбійкою руди або комбіновано свердловинами з бурових камер і вертикальними концентрованими зарядами з лежачого боку покладу. Наведені розрахунки параметрів буропідривних робіт для відбійки руди вертикальними концентрованими зарядами. Отримані параметри відбійки та зарядів ВКЗ.

**Наукова новизна.** Наукова новизна запропонованої технології розробки з обваленням руди та вміщувальних порід полягає в наведенні основних формул буропідривних робіт.

**Практична значимість.** Розроблені ефективні інженерні методи відпрацювання покладів. Розроблена методика розрахунку параметрів буропідривних робіт для умов відпрацювання запасів руди, що контактують з лежачим боком крутоспадних покладів.

**Ключові слова:** *втрати руди, лежачий бік, система розробки, вертикальні концентровані заряди, Кривбас*

**Цель.** Разработка эффективной технологии отработки с обрушением руды и вмещающих пород для условий залежей Криворожского железорудного бассейна.

**Методика.** Проанализированы горно-геологические и проектные данные мощных крутопадающих залежей Криворожского железорудного бассейна. Установлены исходные данные для выбора системы разработки месторождений полезных ископаемых. Разработаны варианты технологий разработки со скреперной доставкой, разбуриванием рудного массива параллельными веерами глубоких скважин с образованием вертикальной компенсационной камеры вкрест простирания и по простиранию месторождения. Обоснованы основные технические параметры системы разработки: высота этажа; высота выемочного подэтажа; длина блока; расстояние от скреперных выработок до выработок приемного горизонта; расстояние между выпускными выработками. Обоснована эффективность применения вертикальных концентрированных зарядов (ВКЗ) на шахтах Кривого Рога.

**Результаты.** Предложен вариант системы разработки с обрушением руды и вмещающих пород со скважинной отбойкой руды или комбинированно скважинами из буровых камер и вертикальными концентрированными зарядами с лежачего бока залежи. Приведены расчеты параметров буровзрывных работ для отбойки руды вертикальными концентрированными зарядами. Получены параметры отбойки и зарядов ВКЗ.

**Научная новизна.** Научная новизна предложенной технологии разработки с обрушением руды и вмещающих пород состоит в обосновании основных формул буровзрывных работ.

**Практическая значимость.** Разработаны эффективные инженерные методы отработки залежей. Разработана методика расчета параметров буровзрывных работ для условий отработки запасов руды, которые контактируют с лежачим боком крутопадающих залежей.

**Ключевые слова:** *потери руды, лежачий бок, система разработки, вертикальные концентрированные заряды, Кривбасс*

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