

## ГЕОТЕХНОЛОГИЯ. ГОРНЫЕ МАШИНЫ

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### Pillar dimensions optimization in room-and-pillar mining in underground mines

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#### Abstract

**Research objective** is to optimize pillar dimensions in room-and-pillar mining in underground mines.

**Methods of research** include analyzing theory and practice in this field and carrying out engineering forecast for the prospects of room-and-pillar mining.

**Results.** The article explains the urgency of pillar dimensions optimization aimed at ensuring personnel, equipment and subsoil safety. The article shows the role of mining-geological and technological factors that weaken the rock mass and introduces the resulting coefficient of pillar design diameter increase for a pillar within the stress-strained rock mass system. Formulas are presented calculating safe pillar increase parameters to compensate for its weakening caused by the manifestation of natural and man-induced factors of various origins. The order of weakening coefficients quantitative values is determined based on specific mining conditions and established regularities, including those depending on probabilistic indices. Weakening coefficients have been characterized considering the data about the factors behaviour. The dependence between the pillar strength and the pillar base strength has been extended. The role of stresses crucial for the pillars is revealed, and an algorithm for their forecast based on probable mathematical models is recommended.

**Conclusions.** Based on this study data, pillar dimensions in room-and-pillar mining in underground mines can be optimized. It is recommended to use the research results when designing an ore extraction technology and adjusting the development parameters.

**Keywords:** ore pillar; underground mining; rock mass; strength; failure; stresses; calculation algorithm; safety; ore quality; room-and-pillar mining.

**Introduction.** The needs of the industrial society grow urging to solve the problem of metal supply which the industry is currently faced with.

The mining development direction based on intensified field development processes, increased ore production through the use of high-performance equipment and reserves geometrization, used to be a priority but fell short of expectations. This is due to the fact that increased impoverishment is not compensated for by increased recovery during ore processing [1–3].

In complex conditions of ore localization, primarily non-ferrous, rare and noble metals, it is impossible to implement this development direction. Therefore, to increase the efficiency of subsoil use, alternative ways of modernizing mining technology without heavy equipment are being searched for [4–7].

Ore production performances are developed and their quality is improved through the reserves of mining and related works organization [8–11].

The ore bodies that make up the deposits of non-ferrous, rare and noble metals are characterized by inconsistent occurrence parameters and high contrast of mineralization, which provokes selective mining of high-value reserves. The host rock is generally stable with significant roof rock outcrops. However, managing their condition requires knowledge of the stress state of rock mass.

As the mining depth grows, ore mining conditions become more complicated. Thickness reduction, angle of incidence variability, faults and pinches necessitate greater mine working dimensions and protective pillars or artificial concrete massifs, which requires a situational approach to the problem of managing mineral raw materials recovery.

As a result of mining, a stress field arises in the rock mass. It is formed under the influence of the occurrence depth, tectonic activity, anisotropy and rock elasticity, gases and groundwater pressure, etc. In rocks with a strength of 50 to 150 MPa in the zone of fractured rock, the weakening coefficient decreases. Within the zones, a zone of weakening is recorded. Within this zone, rock strength decreases dramatically.

Taking into account and applying the properties of ore-hosting heterogeneous solid rock is the main condition for ore mining efficiency improvement [12–14].

Basic aspects of metal deposits underground mining have been studied by specialists. However, mining in the zones of tectonically faulted rock masses should be investigated, and the patterns of interaction between natural and man-induced factors should be interpreted.

Improving the technology of underground mining of ores in the conditions of complex deposits is an urgent scientific and practical issue of our day, which is associated with the problem of preserving the environment in the mining area.

**Research objective** is to optimize pillar dimensions in room-and-pillar mining in underground mines.

**Methods of research.** The objective is achieved by an integrated method which analyses the theory and practice of room-and-pillar mining when mining solid minerals by an underground method.

The main method of research includes analyzing theory and practice in this field and carrying out engineering forecast for the room-and-pillar mining prospects.

**Results.** In room-and-pillar mining, ore pillar dimensions must ensure the safety of mining operations. Increased pillars result in the undesirable loss of ore and metal. It is especially undesirable when extracting mineral rich areas. So, the problem of optimizing the pillar dimensions is an urgent scientific and practical task.

The pillar radius is determined from the expression:

$$R = \sqrt[5]{\frac{S^2 H^2 \gamma^2 K_{\text{safety}}^2 h}{2\pi^2 \delta_{\text{compr}}^2 \cdot 100^2}}, \quad (1)$$

where  $S$  is the roof area per pillar,  $\text{m}^2$ ;  $H$  is the depth of mining,  $\text{m}$ ;  $\gamma$  is the specific gravity of the overlying rock,  $\text{t}/\text{m}^3$ ;  $K_{\text{safety}}$  is the factor of safety that compensates for the impact of rock mass weakening factors which depend on the mining-geological and technological conditions of complex host rock development;  $h$  is the pillar height,  $\text{m}$ ;  $\sigma_{\text{compr}}$  is the compressive strength of the pillar,  $\text{MPa}$ .

In room-and-pillar mining, numerous factors influence the strength of pillars holding the roof of rooms. They should be taken into account when assessing pillar bearing capacity. These factors are: fracturing of the ores that build up the pillar, the angle of dip

of the deposit, time change in rock physical and mechanical properties, reduction in pillar strength caused by mine workings, etc.

The factor of safety can be interpreted as the resulting coefficient that increases pillar design diameter:

$$\sum_{i=1}^n \Delta D_i = 3.29 \sqrt{0.111 D_{\text{ore}}^2 \sum_{i=1}^n (1 - K_i)^2}, \quad (2)$$

where  $\sum_{i=1}^n \Delta D_i$  – is pillar increase to compensate for its weakening caused by  $n$  factors;

$D_{\text{ore}}$  is the diameter of an ore pillar neglecting the weakening factors;  $K_i$  is the coefficient introducing the  $i$ -th weakening factor into the calculation.

Design diameter of an ore pillar:

$$D = D_{\text{ore}} \left( 1 + 3.29 \sqrt{0.111 \sum_{i=1}^n (1 - K_i)^2} \right). \quad (3)$$

Weakening coefficients are determined based on specific mining conditions or established patterns. Some weakening coefficients depend on probabilistic indices including:

- reduced pillar dimensions relative to design indices to reduce the loss of metal with an increased risk of its failure;
- reduced pillar strength caused by excavation, aimed at improving the ventilation, for example;
- the weakening effect of drilling and blasting that depends on the type and properties of drilling equipment, explosives and firing devices; in shallow blast-hole blasting, pillar dimensions are increased by 0.3 m on each side, and under longwall stoping, pillar dimensions are increased according to full-factorial calculations;
- reduced pillar parameters ratio or height-to-width ratio, resulting in the weaker effect of the mine working within the pillar on the pillar strength;
- the dip of the ore body for pillars along the strike, as well as for square or circular pillars, weakens their strength by:

$$K_{\alpha}'' = \frac{\eta \sin \alpha}{\cos \beta \sin(\alpha - \beta)}, \quad (4)$$

where  $\alpha$  is the angle of dip of the ore deposit, degrees;  $\eta$  is the coefficient of lateral thrust;  $\beta$  is the pillar axis angle of underlay to the ore body incidence plane up the dip.

The other group of weakening coefficients is determined based on probabilistic mathematical models considering data on the behaviour of factors, namely:

- ore fracturing in the pillar body; the impact of the ore fracturing on pillar bearing capacity is manifested by weakening surfaces, weakening zones and reduced pillar strength;
- time change in the physical and mechanical properties of rocks; under a sufficiently long load action, it reduces the strength by almost 2 times compared to the conditional instantaneous strength;
- the presence of interlayers and inhomogeneous pillar structure that reduces its bearing capacity; the impact of interlayers should be considered if the interlayer thickness reaches 0.05 of the pillar height.

The strength of the pillar base has a significant impact on the strength of the pillar. If the base is weak, the bearing area of the pillar tends to decrease due to the formation

of spalls along its faces. Reduced strength of the base rocks to 0.1 of the initial pillar strength reduces its strength by approximately 35%; for 0.3, the decrease will be 10%. The pillar strength does not decrease if the strength of the base rocks exceeds the index of 0.3 of the pillar strength.

The main parameter that determines the pillar state under extreme load are the stresses at which the rock mass fails (Figure 1).

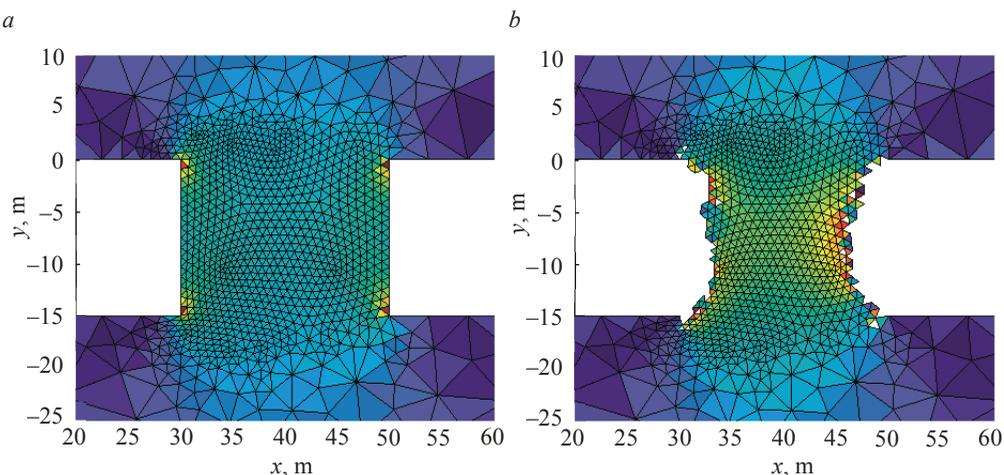


Figure 1. The process of pillar failing under the impact of stresses:

*a* – initial stage; *b* – final stage

Рисунок 1. Процесс разрушения целика под влиянием напряжений:

*a* – исходная стадия; *b* – конечная стадия

It is advisable to determine this parameter based on probabilistic mathematical models because even within the same extraction unit its values can differ significantly from each other.

This index is defined as the value of the upper confidence limit for random variables realization (critical stress values at which the rock sample failed):

$$\delta_{\text{compr}} = \delta_{\text{critical mean}} + t \frac{\sigma}{\sqrt{n}}, \tag{5}$$

where  $\delta_{\text{critical mean}}$  is the mean of critical stresses at which the rock sample failed;  $t$  is the Student's coefficient for small sample sizes  $n \leq 20$  with a probability of 0.99 for crucial measurements (in particular responsible for human safety);  $\sigma$  is the standard deviation of the accepted sample;  $n$  is the sample size.

The algorithm for calculating the dimensions of the pillar which provides a safe and efficient process of extraction is implemented in the following sequence:

- using  $\delta_{\text{compr}}$  values sampling data within the extraction unit,  $\delta_{\text{compr}}$  design index is determined as the value of the upper confidence limit of random variables realization (5);
- based on  $\delta_{\text{compr}}$  design index, according to the established dependencies (not given in this article), the weakening coefficients of the second group are determined;
- considering specific mining conditions, weakening coefficients of the first group are determined;
- the resulting coefficient of pillar design dimensions increase  $\sum_{i=1}^n \Delta D_i$  (2) is determined;

– the actual dimensions of an ore pillar are determined, which ensure efficient and safe ore mining by the room-and-pillar mining method (3).

The issues of rock mass state control optimization, including pillar dimensions in complex deposits underground development, were considered in the works of Russian and foreign specialists [15–18].

**Conclusions.** In room-and-pillar mining in underground mines, pillar dimensions are optimized based on analyzing the theory and practice and carrying out an engineering forecast of the prospects for its application.

The problem of pillar dimensions optimization is important because the personnel, equipment and subsoil safety must be ensured, particularly in the presence of mining-geological and technological factors that weaken the rock mass.

Pillar structure optimization within the framework of the rock mass state management program can be carried out when designing the ore mining technology and at the stages of deposit development.

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## К оптимизации размеров целиков при камерно-столбовой системе разработки на подземных рудниках

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### Реферат

**Цель работы** – оптимизация размеров целиков при камерно-столбовой системе разработки на подземных рудниках.

**Методика.** Анализ теории и практики по рассматриваемому направлению горного дела и инженерный прогноз перспектив применения камерно-столбовой системы разработки.

**Результаты.** Обоснована актуальность проблемы оптимизации размеров целиков для обеспечения безопасности занятого в производстве персонала, применяемой техники и недр. Показана роль ослабляющих массив факторов горно-геологического и технологического происхождения и приведен результирующий коэффициент увеличения расчетного диаметра целика, работающего в системе напряженно-деформированного массива. Представлены формулы расчета безопасных параметров увеличения целика для компенсации его ослабления от проявления природно-техногенных факторов различного происхождения. Определены значения ослабляющих коэффициентов по конкретным горнотехническим условиям и на основе установленных закономерностей, в том числе зависящих от показателей вероятностного характера. Дана характеристика ослабляющих коэффициентов с учетом данных о природе действия факторов. Детализирована зависимость прочности целика от прочности основания целика. Раскрыта роль критических для целиков напряжений и рекомендован алгоритм их прогнозирования на основе вероятностных математических моделей.

**Выводы.** Оптимизация размеров целиков при камерно-столбовой системе разработки на подземных рудниках может быть осуществлена с использованием данных настоящего исследования. Рекомендовано использовать результаты исследования при проектировании технологии добычи руд и корректировке показателей разработки.

**Ключевые слова:** рудный целик; подземная разработка; массив; прочность; разрушение; напряжения; алгоритм вычисления; безопасность; качество руд; камерно-столбовая система разработки.

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