UNIVERSITY GOCE DELCEV - STIP
FACULTY OF NATURAL AND
TECHNICAL SCIENCES

ISSN:1857-6966

Natural resources and technology

No. 1 Volume XVI June 2022

UNIVERSITY "GOCE DELCEV" – STIP
FACULTY OF NATURAL AND TECHNICAL SCIENCES

Natural resources and technologies

JUNE 2022

VOLUME XVI

NO. 1

ISSN 1857-6966

NATURAL RESOURCES AND TECHNOLOGIES

Editorial Office
Goce Delcev University - Stip
Faculty of Natural and Technical Sciences

Contents

Manuscript received: 01.04.2022
Accepted: 03.05.2022

Natural Resources and Technology
Vol 16, No. 1, pp. 05 - 11 (2022)
ISSN 1857-6966
UDC: 622.272.063
DOI:https://doi.org/10.46763/NRT22161005m
Original research paper

UNDERGROUND MINING METHOD SELECTION ACCORDING TO NICHOLAS METHODOLOGY

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Abstract

The correct choice of the method of mining is of great importance, because it has a great impact on the total costs in the exploitation of mineral resources. The basic methodology for numerical ranking of mining excavation methods is the Nicholas methodology, according to which mining-geological factors of rock mass are taken into account. This choice of mining method is also called rational mining method selection.

In this paper, the methodology according to Nicholas will be applied for the selection of the method of mining excavation for a specific case, according to which it was obtained that the Cut and Fill mining method is the best ranked.

Key words: *mining method selection, rational selection, Nicholas methodology, mining-geological factors*

INTRODUCTION

The biggest problem that every researcher encounters at the beginning when researching the opening and operation of a new mine or analyzing an existing underground mine is the choice of the method of mining excavation. The greatest responsibility in choosing the method of excavation stems from the fact that the costs of excavation have the largest share in the total cost of mining. When making the final decision on which method of mining will be used, several factors should be taken into account, and they can be divided into three groups [1]:

- mining-geological factors, such as: geometry of deposit (general shape, ore thickness, dip, plunge, depth below the surface), rock quality (ore zone, hanging wall and footwall, i.e., rock substance strength, fracture spacing, fracture shear strength, rock quality designation, structures, strength, stress, stability), ore variability (ore boundaries, ore uniformity, continuity, grade distribution), quality of resource, etc.
- mining-technical factors, such as: annual productivity, applied equipment, health and safety, environmental impact, ore dilution, mine recovery, flexibility of methods, machinery and mining rate, and
- economic factors, such as: capital cost, operating cost, mineable ore tons, orebody grades and ore value.

The process of choosing a method of mining excavation can be divided into rational and optimal choice of method of mining excavation [2].

In the rational choice of the method of mining excavation, the methods of mining excavation are chosen according to the mining-geological factors. The purpose of this choice is to reduce the number of mining methods, which will be discussed in the next section.

There are several procedures for the choice, i.e., the selection of mining methods according to mining-geological factors, such as: the procedure according to Boshkov and Wright, Morrison, Nicholas, Laubscher, Hartman, UBC and others [3].

When a rational choice is made, i.e., the selection of the most acceptable methods of mining excavation according to mining-geological factors, the optimal choice, i.e., the selection of selected methods of mining excavation according to mining-technical and economic factors follows.

In this paper, the Nicholas methodology will be applied to choose the method of mining excavation according to mining-geological factors.

NICHOLAS METHODOLOGY

By selecting mining methods of excavation according to Nicholas [4, 5], with numerical ranking, the method or group of excavation methods that are suitable for the excavation of a given ore deposit is determined. The choice of excavation method is based on:

– deposit geometry and grade distribution,
– rock mechanics characteristics.

The adoption of parameters for the geometry of the ore body and grade distribution is done on the basis of the data shown in Table 1.

Table 1. Definition of Deposit Geometry and Grade Distribution [4, 5]

General shape	equi-dimensional	all dimensions are on the same order of magnitude
	platy-tabular	two dimensions are many times the thickness, which does not usually exceed 100 m
	irregular	dimensions vary over short distances
Ore thickness	narrow	< 10 m
	intermediate	10 ÷ 30 m
	thick	30 ÷ 100 m
	very thick	> 100 m
Plunge	flat	< 20º
	intermediate	20 ÷ 55º
	steep	> 55º
Depth below surface		
	/	provide actual depth
Grade distribution	uniform	the grade at any point in the deposit does not vary significantly from the mean grade for that deposit
	gradational	grade values have zonal characteristics, and the grades change gradually from one to another
	erratic	grade values change radically over short distances and do not exhibit any discernible pattern in their changes

Table 2. Rock Mechanics Characteristics [4, 5]

Rock Substance Strength	weak	< 55 MPa	
	moderate	55 ÷ 110 MPa	
	strong	> 110 MPa	
Fracture Spacing (Fracture Frequency)		No. of fractures / m	% RQD
	very close	> 16	0 ÷ 20
	close	10 ÷ 16	20 ÷ 40
	wide	3 ÷ 10	40 ÷ 70
	very wide	< 3	70 ÷ 100
Fracture Shear Strength	weak	clean joint with a smooth surface or filled with material with strength less than rock substance strength	
	moderate	clean joint with rough surface	
	strong	joint is filled with a material that is equal to or stronger than rock substance strength	

Note: *Deere rock mass classification [6]

The adoption of parameters for mechanical characteristics of ore, hanging wall and footwall is done on the basis of data shown in Table 2.

The Rock Substance Strength (Tab. 2) can be determined based on the value of the uniaxial compressive strength of the rock mass (σ_c, MPa).

The Fracture Spacing (Tab. 2) is defined by the number of fractures per meter and the RQD classification (Rock Quality Designation). The qualitative description of the rock mass fracture was obtained by defining the number of fractures per meter.

The Fracture Shear Strength (Tab. 2) is determined by observing the existing fracture systems.

For a given ore body, it is necessary to adopt parameters for deposit geometry and grade distribution, and rock mechanic characteristics (ore, hanging wall and footwall) according to the divisions shown in Table 1 and Table 2.

Based on the previously mentioned parameters for the ore body, the following excavation methods are selected:

1. Block Caving;
2. Sublevel Stoping;
3. Sublevel Caving;
4. Room and Pillar Mining;
5. Shrinkage Stoping;
6. Cut and fill Stoping;
7. Top Slicing;
8. Square Set Stoping;
9. Longwall Mining;
10. Open pit Mining.

The choice of excavation methods is made in such a way that for each method of excavation special point values are adopted, the sum of which gives the point value which is entered into a special table and, on the basis of those point values, the mining method is selected. It should be noted that this methodology does not choose the mining method for excavation, i.e., it does not favor any of the mining methods used in the excavation of a given ore body. The purpose of this selection is to single out all the favorable methods of mining excavation which, based on the characteristics of the ore body shown in Table 1 and Table 2, stand out as most efficient. The efficiency of a certain method of mining excavation, according to the mentioned methodology, is defined by the total point value. The highest total value of points indicates the most efficient method of excavation. According to this principle, the methods of mining excavation are ranked, and the results are shown in the table.

In case any method of excavation has a negative total point value, it should be eliminated as an unacceptable method of excavation of a given ore body.

The method of excavation, which has a total point value of zero (0), is not excluded, but its use for excavation of a given ore body is not recommended.

The group of possible excavation methods consists of excavation methods with total point values higher than the stated ones (conditionally less than 23).

The group of favorable excavation methods consists of excavation methods with total point values greater than 23 and which do not differ significantly from each other.

Excavation methods differ based on the cost of excavation, with some excavation methods low and some high [7]. The comparison of the relative cost of excavation for individual excavation methods, is based on the fact that each of the excavation methods is applied in conditions that suit it. For this purpose, it is necessary to take into account the mining-technical and economic factors, i.e., to make the optimal choice of the method of mining excavation [2].

CASE STUDY

This paper examines the active underground mine of lead and zinc, where a new part is opened and it is necessary to choose the appropriate method of excavation [2, 3, 8]. The input data for the ore deposit are given below.

Geological factors

- The platy-tabular lead-zinc ore body;
- The surrounding rocks: footwall – slate and hanging wall – slate;
- The average thickness of the ore body is 15 m (thickness ranges from a few meters to 30 meters);
- The average plunge is 37° (from 25 to 49°);
- The depth below surface is 500 meters;
- The grade distribution is erratic.

Rock mechanics characteristics

Mechanical characteristics of the ore

- Volume mass of ore is 3,5 tons per meter cubic;
- The average compressive strength of the ore is 93 MPa (the compressive strength ranges from 46 to 140 MPa);
- The average number of fractures per meter is 4 (the number of fractures per meter ranges from 3 to 5);
- The average value of the RQD index is 77% (the value of the RQD index ranges from 74 to 80%);
- The average value of the RMR index is 84%;
- The fractures are clean joint with a smooth surface or filled with material with strength less than rock substance's strength.

Mechanical characteristics of the hanging wall

- Volume mass of hanging wall (slate) is 2,7 tons per meter cubic;
- The average compressive strength of the hanging wall is 78 MPa (the compressive strength ranges from 31 to 125 MPa);
- The average number of fractures per meter is 9 (the number of fractures per meter ranges from 8 to 10);
- The average value of the RQD index is 58% (the value of the RQD index ranges from 56 to 60%);
- The average value of the RMR index is 65%;
- The fractures are clean joint with a smooth surface or filled with material with strength less than rock substance's strength.

Mechanical characteristics of the footwall

- Volume mass of footwall (slate) is 2,7 tons per meter cubic;
- The average compressive strength of the footwall is 79 MPa (the compressive strength ranges from 33 to 125 MPa);
- The average number of fractures per meter is 8 (the number of fractures per meter ranges from 6 to 10);
- The average value of the RQD index is 59% (the value of the RQD index ranges from 58 to 60%);
- The average value of the RMR index is 66%;
- The fractures are clean joint with a smooth surface or filled with material with strength less than rock substance's strength.

Based on the given input data on the deposit geometry and grade distribution and rock mechanical characteristics of the ore and adjacent rocks (hanging wall and footwall), Table 3 is completed.

Table 3. Input data for the selection of the method of mining excavation according to Nicholas

Parameters for the deposit geometry and grade distribution	
General shape	platy-tabular
Ore thickness	intermediate
Plunge	intermediate
Depth below surface	provide actual depth
Grade distribution	erratic
Rock mechanical characteristics	
Ore	
Rock Substance Strength	moderate
Fracture Spacing	wide
Fracture Shear Strength	weak
Hanging wall	
Rock Substance Strength	moderate
Fracture Spacing	close
Fracture Shear Strength	weak
Footwall	
Rock Substance Strength	moderate
Fracture Spacing	close
Fracture Shear Strength	weak

As it is an underground lead and zinc mine, i.e., underground exploitation of metal mineral raw materials, the mining method of excavation is not taken into account: Longwall Mining and Open pit Mining.

After the calculation according to this methodology, the following order was obtained for the methods of mining excavation (Tab. 4):

Table 4. Ranking of mining methods according to Nicholas

Serial number	Mining method	Total value points	Rank
1	Block Caving	23.5	4
2	Sublevel Stoping	13.4	8
3	Sublevel Caving	21.5	5
4	Room and Pillar Mining	19.7	7
5	Shrinkage Stoping	24.0	3
6	Cut and fill Stoping	33.2	1
7	Top Slicing	20.7	6
8	Square Set Stoping	31.2	2

Table 4 shows that the Cut and fill Stoping method has the highest value (Fig. 1), which is the most efficient method of excavation.

The first four best ranked methods of mining excavation can be singled out as favorable methods of mining excavation for application in this case. The group of favorable mining methods includes the following mining methods:

1. Cut and fill Stoping,
2. Square Set Stoping,
3. Shrinkage Stoping, and
4. Block Caving.

These methods of mining excavation can be taken into account in the optimal choice of mining methods based on mining-technical and economic factors, which will be the subject of research in the next study.

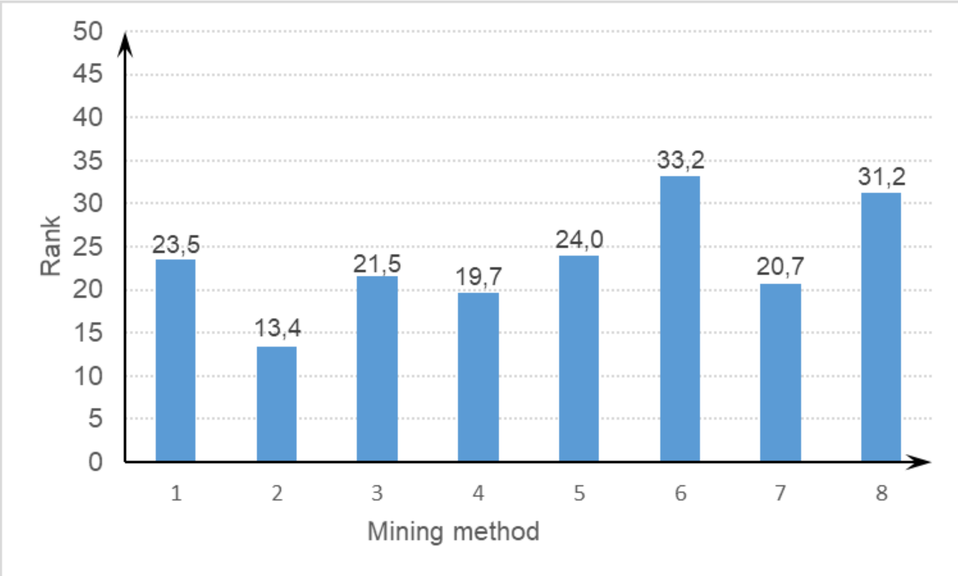

Figure 1. Ranking of mining methods

CONCLUSION

The correct choice of the method of mining excavation for underground exploitation has a very large impact on the performance, costs of ore exploitation, the size of losses and dilution of ore, as well as the financial effects that will be realized later.

Due to the great importance for the correct choice of the method of mining excavation, this issue has been studied by several authors. As a common phase of the procedures proposed by individual authors, two phases can be distinguished: rational choice of the method of mining excavation and optimal choice of the method of mining excavation.

There are several procedures for rational selection, i.e., the choice of mining methods according to mining and geological factors, such as: the procedure according to Boshkov and Wright, Morrison, Nicholas, Laubscher, Hartman and others.

This paper uses the procedure of rational selection of the mining method according to Nicholas, which is the basic procedure for numerical ranking of mining methods and determining the most efficient method, as well as a group of favorable methods for excavation of a given ore body.

We have selected the first four best ranked mining methods as favorable mining methods for use in this case and they can be used for optimal selection of mining methods, which will take into account mining-technical and economic factors.

When deciding which method of mining to use, as many factors as possible that influence the choice of method of mining should be taken into account. If there are several relevant factors, the chosen method of mining excavation will be more suitable for specific mining-geological, mining-technical and economic factors.

Multi-criteria optimization methods enable the choice of the method of mining excavation, taking into account a number of influencing factors, and thus enable the selection of the most appropriate method of mining excavation for a specific case, which will be the subject of research in the next study.

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ИЗБОР НА РУДАРСКА ОТКОПНА МЕТОДА ЗА ПОДЗЕМНА ЕКСПЛОАТАЦИЈА СПОРЕД МЕТОДОЛОГИЈАТА НА NICHOLAS

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Резиме

Правилниот избор на рударска откопна метода е од многу голема важност, бидејќи има големо влијание врз вкупните трошоци при експлоатација на минералната суровина. Основна методологија за нумеричко рангирање на рударските откопни методи е методологијата според Nicholas, според која се земаат во предвид рударско – геолошките фактори на карпестата маса. Овој избор на рударска откопна метода, уште се нарекува и рационален избор на рударска откопна метода.

Во овој труд ќе биде применета методологијата според Nicholas за избор на рударска откопна метода за конкретен случај, според која е добиено дека Методата за откопување со засипување на откопаниот простор е најдобро рангирана.

Клучни зборови: *избор на рударска откопна метода, рационален избор, методологија на Nicholas, рударско-геолошки фактори*