UNDERGROUND MINING ENGINEERING - PODZEMNI RADOVI 24 (2014) 11-19 UDK 62
UNIVERSITY OF BELGRADE - FACULTY OF MINING AND GEOLOGY YU ISSN 0354-2904

Professional paper

FUNCTIONAL DEPENDENCE ON CONSTRUCTION COSTS OF HORIZONTAL MINING FACILITIES IN LEAD-ZINC ORE

ZAVISNOST TROŠKOVA IZRADE HORIZONTALNIH RUDARSKIH PROSTORIJA U RUDI OLOVA I CINKA

Doneva Nikolinka[1], Hadži-Nikolova Marija[1], Lutovac Suzana[2]

Received: May 12, 2014 **Accepted:** June 4, 2014

Abstract: This paper presents a methodology for determination of the two-parameter dependence on construction costs of horizontal mining facilities in the lead-zinc ore. Construction costs are shown as a function of the profile area on facilities and the degree of jointed on the rock, presented by the change in their uniaxial compressive strength.

Key words: profile, ore deposit, scientific research

Apstrakt: U ovom radu dat je način određivanja dvoparametarske zavisnosti troškova izrade horizontalnih rudarskih prostorija u rudi olova i cinka. Troškovi izrade su prikazani kao funkcija površine profila prostorije i stepena ispucalosti radne sredine-predstavljene preko promene jednoaksijalne pritisne cvrstoće stenske mase.

Ključne reči: profil, ležište, istraživanje

1. INTRODUCTION

Horizontal mining facilities, such as pits, crosscutting drifts, longitudinal drifts etc., can be constructed in surrounding rocks, underburden or usually overburden, also in the ore deposit. The route of horizontal mining facilities primarily depends on: physical and mechanical properties of surrounding rocks and ore deposits, as on the thickness and way of providing the ore body, the construction costs and the projected mining method.

It should be noted that within same types of rock exist zones with different structural characteristics, regardless where mining facilities will be constructed either in surrounding rocks or ore body. Different properties create a difference in stability of the rock material. Therefore, is essential for any rock type to determine its structural

[1] University ″Goce Delčev″, Faculty of Natural and Technical Sciences, Mining Institute, Krste Misirkov 10A, 2000 Štip, Republic of Macedonia, e-mail: nikolinka.doneva@ugd.edu.mk
[2] University of Belgrade – Faculty of Mining and Geology, Đušina 7, 11000 Belgrade, Serbia, e-mail: suzana.lutovac@rgf.bg.ac.rs

properties such as: discontinuity plane orientation, the degree of jointed on rock material, joint and joint family, as and stability of each block, located adjacent to underground facilities (Brady and Brown 2006).

2. CREATING A MATHEMATICAL MODEL ON HORIZONTAL MINING FACILITIES CONSTRUCTION IN LEAD- ZINC ORE

As earlier stated, this paper analyze horizontal mining facilities construction in the lead-zinc ore. Table 1 shows physical and mechanical properties of lead-zinc ore from the deposit "Sasa" M.Kamenica obtained by laboratory tests including: bulk density γ [MN/m^3], uniaxial compressive strength σ_c [MPa], tensile strength σ_t [MPa], cohesion C [MPa], angle of internal friction φ [°], Poisson`s coefficient ν and modul of elasticity E [MPa].

Table 1 - Physical and mechanical properties of anticipated rocks type

Description	γ [MN/m^3]	σ_c [MPa]	σ_t [MPa]	C [MPa]	φ [°]	ν	E [MPa]
Lead-zinc ore	0.0377	142	17.00	28.5	46.5	0.245	69500

In this mathematical model have been created nine variants, so that have been adopted three sizes of mining facilities profile (Figure 1) and three degrees of jointed rock type. This is given in Table 3.

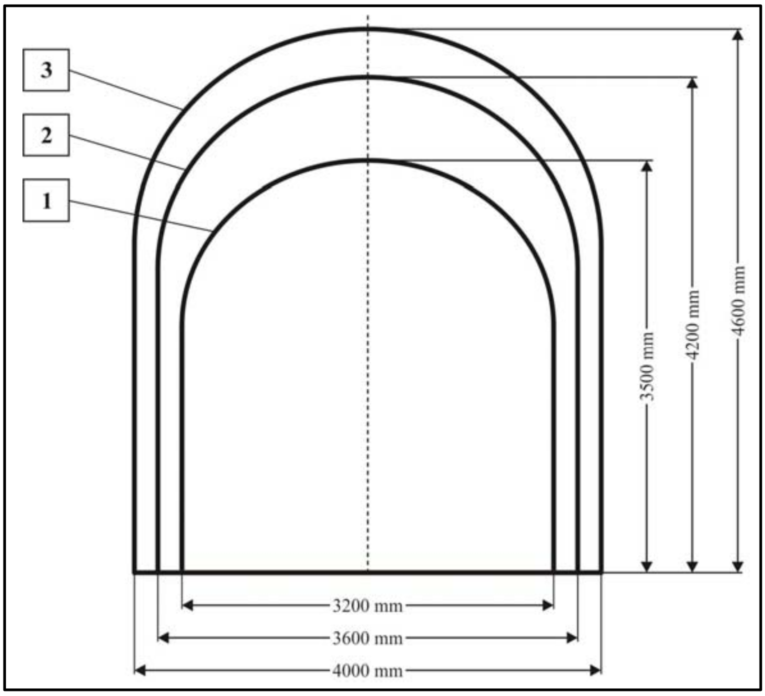

Figure 1 - Adopted size of underground mining facilities profile

Uniaxial compressive strength of three degrees jointed was calculated by following formula:

$$\frac{\sigma_{csm}}{\sigma_c} = e^{-0.008 \cdot J_f}, \qquad [\text{MPa}] \tag{1}$$

where are:
σ_{csm} - uniaxial compressive strength of rock material, [MPa];
σ_c - uniaxial compressive strength of intact rock, [MPa];
J_f - joints factor.

$$J_f = \frac{J_n}{n \cdot r} \tag{2}$$

where are:
J_n - joints number per 1m, [no./m];
n - inclination parameter, depending on the inclination of joints plane by major effective principal stresses (Table 2);
r - factor of joints, $r = \tan\varphi$.

Table 2 - Parameter on joint inclination

Angle on joint orientations, β	0	10	20	30	40	50	60	70	80	90
Parameter on joint Inclination, n	0.82	0.46	0.11	0.05	0.09	0.30	0.46	0.64	0.82	0.95

Table 3 - Variants of horizontal mining facilities in model

Rock type	**Uniaxial compres strength of intact rock σ_c [MPa]**	**Spacing of joints l [m]**	**Number of joints per 1m J_n [no./m]**	**Factor of joints J_f**	**Uniaxial compresive strength of rock mass σ_{cm} [MPa]**	**Anticipated cross-section [m^2]**	**Tag in model**
Lead-zinc ore	142	0.65	1.54	29.22	112	10.10	A1
						13.73	A2
						16.68	A3
		0.50	2.00	37.99	105	10.10	B1
						13.73	B2
						16.68	B3
		0.40	2.50	47.49	97	10.10	C1
						13.73	C2
						16.68	C3

So the degree of jointed rock material and size of mining facilities profile presents variants in the mathematical model. To obtain data that can be compared, other influential parameters in the mining construction system is needed to be same in all mining facilities (Донева, 2011).

Construction system includes these fixed parameters:

- Cross-sectional shape of mining facilities - horse - shoe shaped;
- The average depth of same route - 500 m;

- Work management - related technological cycle will be apply, with precisely defined of work operations duration;
- Drilling and blasting will be applied as construction method of mining facilities (Doneva et al. 2013).

3. PARAMETERS OF WORK OPERATIONS

Blast holes diameter is ø 45 mm for all variants, except central blank (ø 64 mm). The prismatic cut was also applied, while blasting was performed using AMONEKS 3 explosive, product by "Trayal" corporation, Kruševac, R.Serbia. In auxiliary and cuts blast holes cartridges with ø 38 mm will be used, while in flaking, ø 28 mm. Calculated parameters of drilling and blasting are given in Table 4.

After each blasting, a break of 30 minutes is needed when work area is absolve from dangerous gases of blasting using local ventilation systems. Ventilation parameters are given in Table 5.

Input parameter of loading and transportation is quantity on the bulk material produced during one blasting. Average distance LHD machine is 100 m, while on the mine truck is 800 m. These parameters are given in Table 6.

Shotcrete with a thickness (3 cm) that is determined calculating underground pressure and resistance of shotcrete and rock arch is used as supporting materials (Донева et al. 2008). Supporting parameters are given in Table 7.

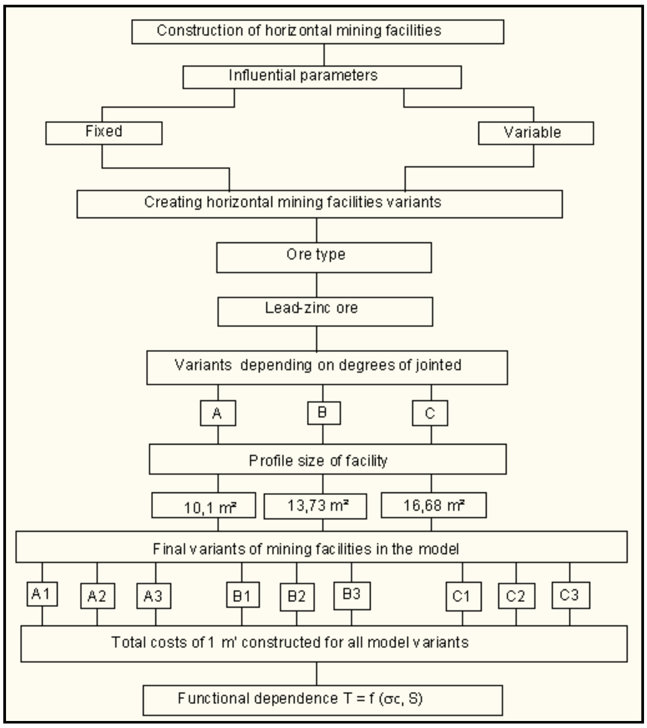

Figure 2 - Mathematical model

Table 4 - Driling and blasting parameters

No.	Parameters	Unit	Variants								
			A			B			C		
			Sub-variants			Sub-variants			Sub-variants		
			A1	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2**	**C3**
1.	Number of blast holes	piece	33	39	46	33	39	46	32	38	45
2.	Cuts	piece	8	8	8	8	8	8	8	8	8
3.	Auxiliary	piece	8	12	17	8	12	17	7	11	16
4.	Flanking	piece	16	18	20	16	18	20	16	18	20
5.	Length of blast hole	m	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
6.	Advance length for one blasting	m	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
7.	Total time for drilling and blasting per m	h/m	1.94	2.20	2.50	1.94	2.20	2.50	1.90	2.17	2.45
8.	Toatal quantity of explosive per one blasting	kg	62.40	75.20	90.50	55.20	65.60	78.00	53.20	63.60	76.00
9.	Usage of explosive per 1m drift	kg/m	27.13	32.70	39.35	24.00	28.52	33.91	23.13	25.65	33.04
10.	Normative of shifts for drilling and blasting	shift/m	0.97	1.1	1.25	0.97	1.1	1.25	0.95	1.09	1.23

Table 5 - LVS parameters

No.	Parameters	Unit	Profile size 1	Profile size 2	Profile size 3
1.	Fan type Zitron 7-30/2	piece	1	1	2
2.	Power of electric motor of the fan	kW	30	30	2 x 30
3.	Operation pressure - H_v	Pa	2,674	743	1,064
4.	Flow fan - Q_v	m^3/s	9.3	12	22
5.	Air quantity of work face - Q_e	m^3/s	8.86	11.74	20.98
6.	Diameter of pipeline - d	m	0.7	1	1.2
7.	Length of one pipe	m	1	1	1

Table 6 - Parameters for loadiing and transportion

No.	Parameters	Unit	Variants								
			A			B			C		
			Sub-variants			Sub-variants			Sub-variants		
			A1	A2	A3	B1	B2	B3	C1	C2	C3
1.	Volume of the bulk material from one blasting	m^3	36.6	50.0	60.4	36.6	50.0	60.4	36.6	50.0	60.4
2.	Material weight of one blasting	t	92.0	125.2	152	92.0	125.2	152.0	92.0	125.2	152
3.	Bucket capacity of LHD machines	m^3	1.9	2.7	4.8	1.9	2.7	4.8	1.9	2.7	4.8
4.	Total time for loading and hauling material per one blast with LHD machine	min	89.8	86	58.7	89.8	86	58.7	89.8	86	58.7
5.	Mine truck capacity	t	15.4	20	30	15.4	20	30	15.4	20	30
6.	Total time for hauling material per one blast with MT	min	104	115.3	88.8	103.7	115.3	88.8	104	115.3	88.8
7.	Total time for loading and hauling in hours per 1m drift	h/m	1.4	1.47	1.09	1.4	1.47	1.09	1.4	1.47	1.09
8.	Normative of wages for loading and hauling	shift/m	0.47	0.49	0.36	0.47	0.49	0.36	0.47	0.49	0.36

Table 7 - Supporting parameters

No.	Parameters	Unit	Variants								
			A			B			C		
			Sub-variants			Sub-variants			Sub-variants		
			A1	A2	A3	B1	B2	B3	C1	C2	C3
1.	Radius of cavity	m	1.6	1.8	2.0	1.6	1.8	2.0	1.6	1.8	2.0
2.	Radius of plastic zone	m	1.65	1.85	2.06	1.71	1.92	2.14	1.78	2.00	2.22
3.	Support resistance	MPa	4.4	4.4	4.4	3.6	3.6	3.6	3.0	3.0	3.0
4.	Resistance of rock arch	MPa	10.4	10.4	10.4	9.0	9.0	9.1	7.6	7.6	7.6
5.	Resistance of shotcrete	MPa	0.17	0.16	0.14	0.23	0.21	0.19	0.29	0.26	0.23
6.	Usage of cement per 1m drift	kg/m	110	127	140	147	169	187	183	212	234
7.	Usage of send per 1m drift	m^3/m	0.31	0.35	0.39	0.41	0.47	0.52	0.51	0.59	0.65
8.	Usage of accselerator per 1m drift	kg/m	6	7	7	8	9	10	9	11	12
9.	Total time of supporting per 1m	h/m	0.34	0.37	0.39	0.4	0.45	0.48	0.47	0.52	0.57
10.	Normative of shits for supporting	shift/m	0.17	0.18	0.20	0.20	0.22	0.24	0.24	0.26	0.28

4. CONSTRUCTION COSTS OF NINE FACILITIES VARIANTS

Based on calculation parameters and price of materials, the cost of mechanization and gross shifts, construction costs by working operations as well as total costs were obtained (Table 8).

Table 8 - Total construction cost

Const. costs [€/m]	A1	A2	A3	B1	B2	B3	C1	C2	C3
Costs for drilling and blasting	151.5	169.4	187.9	148.1	164.8	181.8	146.7	163.4	180.5
Costs of ventilation	16.0	21.7	34.9	16.1	21.8	35.2	16.2	21.9	35.4
Costs of loading and transportation	108.7	114.3	106.6	108.7	114.3	106.6	108.7	114.3	106.6
Costs of supporting	65.4	74.2	81.9	75.6	86.0	94.9	85.8	97.7	107.9
Costs of auxiliary w. operations	34.0	34.9	37.3	33.2	35.4	37.7	34.0	36.4	38.8
Total construction cost of 1m horizontal mining facilities [€/m]	375.6	414.4	448.6	381.6	422.3	456.3	391.3	433.7	469.3

5. FUNCTIONAL DEPENDENCY

Based on calculated construction cost of horizontal mining facilities, using a computer program OM Explorer, upgrade on the Excel program, a two-parameter functional dependence of construction costs have been established: from the rock type and the profile size in the following form:

$$z = c + a \cdot x + b \cdot y \tag{3}$$

Where as:
x - uniaxial compressive strength of rock mass [MPa];
y - profile size of facility [m^2],
presents independent variables, while
z - construction cost of horizontal mining facility [€/m],
is dependent variable
c - constant;
a, b - constants before independent variables.

Following values of coefficients are obtained:

$c = 388.702$

$a = -1.154$

$b = 11.395$

$$z = 388.702 - 1.154x + 11.395y$$

This functional dependence is shown graphically on Figure 3.

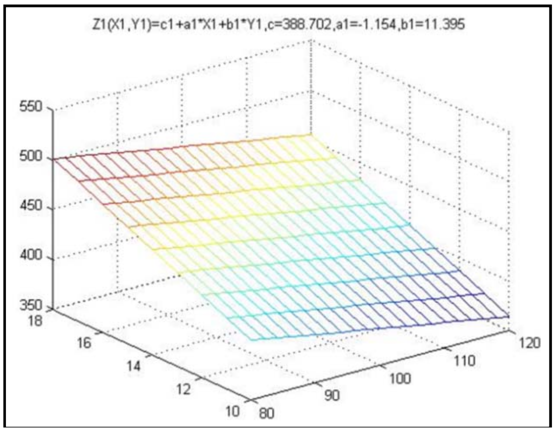

Figure 3 - Two-parameter functional dependence of construction costs

Table 8 and Figure 1 show that with increasing strength, costs will be decreased, while they will be increased in case of increasing profile size.

6. CONCLUSION

This scientific research indicates that different strength properties of rock material and size profiles lead to differences in construction costs on horizontal mining facilities.

Therefore is essential during projecting mining facilities to pay attention on selection of optimal route and determination of optimal profile size in terms of construction costs, as well as from the aspect of continuous production at the mine.

ACKNOWLEDGEMENT

This paper was realized as a part of the project "Research on possibility of AT (Advanced Technology) rockbolting application in mines for the purpose of work safety increase and production efficiency" (TR 33025) financed by the Ministry of Education, Science and Techonological Development of the Republic of Serbia within the framework of Programme of research in the field of technological development for the period 2011-2015.

REFERENCES

[1] BRADY, B. and BROWN, E.T (2006) *Rock mechanics for underground mining*. Queensland: University of Western Australia.

[2] ДОНЕВА, Н. et al. (2008) Компаративна анализа за подградување на хоризонтална рударска просторија со еластична и дрвена подграда. *II стручно советување на тема: Технологија на подземна експлоатација на минерални суровини - ПОДЕКС '08*, *М. Каменица*, *декември 2008.* Скопје: Здружение на рударски и геолошки инженери на Република Македонија, pp. 89-103.

[3] ДОНЕВА, Н. (2011) *Методологија за утврдување на функционалната зависност на трошоците од видот на работната средина и големината на профилот при изработка на хоризонтална рударска просторија*. (PhD), Универзитет „Гоце Делчев“ Штип.

[4] DONEVA, N. et al. (2013) Construction of horizontal mining facilities through schist's massive. In: *Proceedings of the 5th Jubilee Balkan Mining Congress, Ohrid, September 2013*. Skopje: Association of Mining and Geological Engineers of Macedonia, pp. 721-725.