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New Model of Burden Thickness Estimation for Blasting of Open Pit Mines

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ABSTRACT

Suitable pattern design of drilling and blasting is very important in open pit mines. Using of explosive energy for rock fragmentation with minimum cost of production is one of the blasting purposes in open pit mines. The most important parameters of blasting are including diameter of hole, specific charge, burden thickness and suitable dimensions of rock fragmentation. In this paper, specific charge is calculated based on quality of rock mass and then based on definition of specific charge, maximum and minimum thickness of burden in open pit mines is calculated. In this paper, a new models of burden estimation based on quadratic equations is presented. Therefore, based on this new equations, other parameters of blasting are corrected. Also, the validation results of the new equations in this article show the new burden thicknesses have slightly differences with the experimental results. The maximum error of calculated burden is equal 3% based on obtained data. Therefore, the output results of these new equations can be reliable and accurate for calculations of the burden thickness.

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1. INTRODUCTION

Over the past three decades, significant progress has been made in the development of new technology in an attempt to reduce costs and increase efficiencies and productivities of blasting activities [1].

Drilling and blasting process is not used for the production of rigid materials that is not economically and technically possible to excavate in open quarry industry. The production of aggregate starts with drilling and blasting and ends with loading, transportation, and size reduction. In quarry blasting, it is very important to estimate the average heap size distribution beforehand for creating blast designs resulting quarry operations with the least cost [2–8].

Drilling and blasting costs constitute up to 30% of the total operational costs in open pit mines, which will be increased up to 50% by adding more oversize parts and the requirement of secondary blasting. Hence, the specification of rock fragmentation after blasting such as shape and size is by far one of the most important parameters in product optimization in mineral industry [9].

Overall, mining production cycle could be divided into two groups main and auxiliary. The main production cycle is including drilling, blasting, loading and haulage. Accordingly, it is necessary to have a suitable pattern for drilling and blasting of mining, especially for open pit mines. Using of explosive energy for rock fragmentation with minimum cost of production is one of the blasting purposes in open pit mines. The other aims of blasting are reduction of resultant damages of ground vibration and air blast.

In blasting pattern of mines exist various parameters. The most important parameters are included specific charge and burden thickness. Therefore, the purpose of this paper is presentation new equations of burden thickness based on defining of specific charge.

Various theories were presented for designing of blasting pattern in open pit mines by many researchers. Some of the researchers are such as Anderson [10], Jimeno et al. [11], Ouchterlony [12], Ash [13], Rustan [14], Langfors and Kihlstrom [15], Sendlein et al. [16], Berta [17], Lilly [18], and Moomivand and Vandyousefi [19]. The most researchers believe that blasting pattern is calculated based on burden thickness because burden thickness is one of the most important parameters of blasting pattern in open pit mines. Burden thickness depends on various parameters. The most important parameters include characteristics of rock mass, diameter

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of hole, diameter of charge, rock density, charge density, bench height, specific charge, spacing, hole length, charge length, stemming length, under drilling.

Some of researchers such Berta [17], Lilly [18], and Moomivand and Vandyousefi [19] believed that burden thickness depends on the specific charge. Specific charge is determined based on characteristics of the rock mass. Experimental results of blasting in open pit mines confirm the above information. Accordingly, this paper is presented quadratic equations for determining of burden thickness based on the specific charge. Then the final results of these new equations are controlled by the experimental results of blasting in open pit mines.

2. MATERIALS AND METHODS

2. 1. Hypotheses

The most important of hypothesis for estimation of burden thickness of blasting in this paper is the concept of specific charge. The specific charge is one of the most important parameters in blasting mines. Accordingly, the amount of specific charge is better to calculate based on rock quality. For calculation of specific charge exists various methods. Three methods of energy transfer rule, blastability index and rock fragmentation index are more valuable of other methods because these three methods have been designed based on quality of rock mass.

2. 1. 1. Energy Transfer Rule

Berta [17] presented his famous equation based on the energy transfer rule between explosive and rock. Berta [17] calculated specific charge of blasting based on Equation (1). This equation was defined based on requirement energy for rock fragmentation and released energy of the explosive. Berta [17] suggests that blasting burden thickness is calculated based on Equation (2). This equation has determined based on a full charge per hole for a square pattern.

$$q = \frac{s\,E_s}{\eta_1\,\eta_2\,\eta_3\,E_e} \tag{1}$$

$$B = \varphi_c \sqrt{\frac{\pi\,D_c}{4\,q}} \tag{2}$$

$$s = \frac{64}{D_{Max}} \tag{3}$$

$$\eta_1 = 1 - \frac{(I_2 - I_1)^2}{(I_2 + I_1)^2} \tag{4}$$

$$\eta_2 = \frac{1}{[e^{\frac{\varphi_h}{\varphi_c}}] - (e-1)} \tag{5}$$

$$I_1 = D_e\,V_e \tag{6}$$

$$I_2 = D_r\,V_r \tag{7}$$

where,

q : Specific charge (kg/m^3)

s : Desired degree of fragmentation (m^2/m^3)

E_s : Rock specific surface energy (MJ/m^2)

η_1 : Impedance efficiency

η_2 : Coupling efficiency

η_3 : Energetic fragmentation transfer efficiency (15%)

E_e : Explosive specific energy (MJ/kg)

B : Burden thickness (m)

φ_e : Charge diameter (m)

D_e : Explosive density (kg/m^3)

D_{Max} : Maximum fragmentation dimension (m)

I_1 : Explosive impedance

I_2 : Rock impedance

D_r : Rock density (kg/m^3)

V_r : Voice velocity in rock (m/s)

V_e : Explosive velocity (m/s)

φ_h : Hole diameter (m)

2. 1. 2. Blastability Index

Lilly [18] presented his famous equation based on the blastability index. Lilly [18] calculated blastability index based on characteristics of the rock mass. The blastability index is calculated based on Equation (8) and so is specific charge based on Equation (9). The details of these parameters in blastability index have defined in Tables 1 to 5.

$$BI = \frac{1}{2}(RMD + JPS + JPO + SGI + HD) \tag{8}$$

$$q(\frac{kg}{ton}) = 0.004\ BI \rightarrow q(\frac{kg}{m^3}) = 0.004\,SG \times BI \tag{9}$$

TABLE 1. Rock Mass Description (RMD) [18]

Powdery/Friable	RMD = 10
Blocky	RMD = 20
Totally Massive	RMD = 50

TABLE 2. Joint Plane Space (JPS) [18]

Close (<0.1 m)	JPS = 10
Intermediate (0.1 to 1 m)	JPS = 20
Wide (>1 m)	JPS = 50

TABLE 3. Joint Plane Orientation (JPO) [18]

Horizontal	JPO = 10
Dip out of face	JPO = 20
Strike normal to face	JPO = 30
Dip into face	JPO = 40

TABLE 4. Specific Gravity Influence (SGI) [18]

SGI=25SG-50
SG is the density in (ton/m3)

TABLE 5. Hardness Description (HD) [18]

$E < 50$	$HD = \frac{1}{3}E$
$E > 50$	$HD = \frac{1}{5}C_0$
E : Young's modulus: GPa	C_0 : UCS : MPa

2. 1. 3. Rock Fragmentation Index Moomivand and Vandyousefi [19] presented his famous equation based on rock fragmentation index. They calculated rock fragmentation index based on characteristics of the rock mass [19]. The rock fragmentation index is calculated based on Equation (10) and so specific charge based on Equation (11) and so burden thickness on Equation (12). The details of these parameters in rock fragmentation index have defined in Tables 6 to 10.

$$RFI = DPA + DPS + DPO + RMD + UCS \tag{10}$$

$$q(\frac{kg}{m^3}) = 312.12\,SG \times RFI^{-2.082} \tag{11}$$

$$B = RFI \times \varphi_h \tag{12}$$

2. 2. The Proposed Method In this paper using of specific charge concept, useful tables of mines blasting and experimental valuable equations of blasting are used for mathematical analysis of burden thickness. Therefore, the proposed method for calculation of maximum and minimum burden thickness is a mathematical analytical method. In this method various models of blasting equations is investigated and then based on mathematical analysis method, optimum equation from among other equations is selected. This optimum equation is named as maximum and minimum burden thickness.

TABLE 6. Discontinuity Plane Aperture (DPA) [19]

Close(<1 mm)	DPA = 8
Intermediate (1 to 5 mm)	DPA = 7
Intermediate ((5 to 50 mm)/full)	DPA = 6
Intermediate ((5 to 50 mm)/empty)	DPA = 5
Wide ((>50 mm)/full)	DPA = 4
Wide ((>50 mm)/empty)	DPA = 3

TABLE 7. Discontinuity Plane Spacing (DPS) [19]

Close (<0.1 m)	DPS = 12
Intermediate (0.1 to 1 m)	DPS = 7
Wide (>1 m)	DPS = 4

TABLE 8. Discontinuity Plane Orientation (DPO) [19]

Horizontal	DPO = 6
Dip out of face	DPO = 5
Strike normal to face	DPO = 4
Dip into face	DPO = 3

TABLE 9. Rock Mass Description (RMD) [19]

Powdery/Friable	RMD = 10
Blocky	RMD = 6
Totally Massive	RMD = 4

TABLE 10. Unconfined Compressive Strength (UCS) [19]

Close (<25 MPa)	UCS = 6
Intermediate (25 to 50 MPa)	UCS = 5
Intermediate (50 to 100 MPa)	UCS = 4
Intermediate (100 to 200 MPa)	UCS = 3
Wide (>200 MPa)	UCS = 2

3. RESULTS

3. 1. The Maximum and Minimum Thickness of Burden Mining experiences in last decade showed that it is better to use characteristics of rock mass for estimating the amount of the specific charge. Therefore, the new thickness of burden according to specific charge based on Equations (13) to (21) is calculated. These equations are stated as follows:

$$q = \frac{Q}{V} = \frac{\frac{\pi}{4}\varphi_c^{\,2} D_c L_c}{S\,B\,K} \tag{13}$$

$$L_c = H - S_t \tag{14}$$

$$H = \frac{K}{Sin\alpha} + U \tag{15}$$

$$S\,B = \frac{\pi\varphi_c^{\,2} D_c}{4\,q\,K}\left(\frac{K}{Sin\alpha} + U - S_t\right) \tag{16}$$

$$a = \frac{\pi\varphi_c^{\,2} D_c}{4\,q\,K} \tag{17}$$

$$S = k'\,B \tag{18}$$

$$k'\,B^2 = a\left(\frac{K}{Sin\alpha} + U - S_t\right) \tag{19}$$

$$U = (0.2 - 0.5)\,B \tag{20}$$

$$S_t = (0.7 - 1.3)\,B \tag{21}$$

where,

q : Specific charge (kg/m^3)

Q : Explosive weight (kg)

V : Blasting volume (m^3)

φ_c : Charge diameter (m)

D_c : Charge density (kg/m^3)

L_c : Charge length (m)

S : Spacing (m)

B : Burden (m)

K : Bench heights (m)

α : Hole slope in vertical direction (degree)

U : Under drilling (m)

S_t : Stemming (m)

H : Hole length (m)

Based on Equations (19) to (21) four various models for burden equations are obtained. These equations are stated as follows:

a. the first model

$$\left.\begin{array}{l} U = 0.2\,B \\ S_t = 0.7\,B \end{array}\right\} \rightarrow k'\,B^2 = a\,(\frac{K}{\operatorname{Sin}\alpha} - 0.5\,B) \tag{22}$$

b. the second model

$$\left.\begin{array}{l} U = 0.2\,B \\ S_t = 1.3\,B \end{array}\right\} \rightarrow k'\,B^2 = a\,(\frac{K}{\operatorname{Sin}\alpha} - 1.1\,B) \tag{23}$$

c. the third model

$$\left.\begin{array}{l} U = 0.5\,B \\ S_t = 0.7\,B \end{array}\right\} \rightarrow k'\,B^2 = a\,(\frac{K}{\operatorname{Sin}\alpha} - 0.2\,B) \tag{24}$$

d. the fourth model

$$\left.\begin{array}{l} U = 0.5\,B \\ S_t = 1.3\,B \end{array}\right\} \rightarrow k'\,B^2 = a\,(\frac{K}{\operatorname{Sin}\alpha} - 0.8\,B) \tag{25}$$

Based on Equations (22) to (25), two different models for burden equations are obtained. These equations are stated as follows:

a. the maximum thickness of burden

$$\begin{array}{l} k'\,B^2 = a\,(\frac{K}{\operatorname{Sin}\alpha} - 0.2\,B) \rightarrow \\ k'\,B^2 + 0.2\,a\,B - \frac{a\,K}{\operatorname{Sin}\alpha} = 0 \end{array} \tag{26}$$

b. the minimum thickness of burden

$$\begin{array}{l} k'\,B^2 = a\,(\frac{K}{\operatorname{Sin}\alpha} - 1.1\,B) \rightarrow \\ k'\,B^2 + 1.1\,a\,B - \frac{a\,K}{\operatorname{Sin}\alpha} = 0 \end{array} \tag{27}$$

The maximum and minimum thicknesses of burden based on Equations (26) and (27) are calculated. These equations are quadratic equations. Accordingly, the average thickness of burden based on Equation (28) can be calculated.

$$B_{ave} = \frac{B_{Max} + B_{Min}}{2} \tag{28}$$

Researchers believe to achieve optimum blasting pattern is necessary to the amount of K/B became between 3 till 4. Accordingly, the thicknesses of burden based on Equations (29) to (32) could be calculated.

$$\left.\begin{array}{l} K = 3B \\ a' = \frac{\pi\,\varphi_c{}^2\,D_c}{4\,q} \\ k'\,B^2 = a\,(\frac{K}{\operatorname{Sin}\alpha} - 0.2\,B) \\ k'\,B^2 = a\,(\frac{K}{\operatorname{Sin}\alpha} - 1.1\,B) \end{array}\right\} \rightarrow \left\{\begin{array}{l} 3k'\,B^2 = a'\,(\frac{3}{\operatorname{Sin}\alpha} - 0.2) \\ 3k'\,B^2 = a'\,(\frac{3}{\operatorname{Sin}\alpha} - 1.1) \end{array}\right. \tag{29}$$

$$\rightarrow \left\{\begin{array}{l} B_{Max} = \sqrt{\frac{a'}{3k'}\,(\frac{3}{\operatorname{Sin}\alpha} - 0.2)} \\ B_{Min} = \sqrt{\frac{a'}{3k'}\,(\frac{3}{\operatorname{Sin}\alpha} - 1.1)} \end{array}\right. \tag{30}$$

$$K = 4B \rightarrow \left\{\begin{array}{l} 4k'\,B^2 = a'\,(\frac{4}{\operatorname{Sin}\alpha} - 0.2) \\ 4k'\,B^2 = a'\,(\frac{4}{\operatorname{Sin}\alpha} - 1.1) \end{array}\right. \tag{31}$$

$$\rightarrow \left\{\begin{array}{l} B_{Max} = \sqrt{\frac{a'}{4k'}\,(\frac{4}{\operatorname{Sin}\alpha} - 0.2)} \\ B_{Min} = \sqrt{\frac{a'}{4k'}\,(\frac{4}{\operatorname{Sin}\alpha} - 1.1)} \end{array}\right. \tag{32}$$

Coefficient k' in Equations (26) and (27) is one of the important parameters in drilling pattern because this coefficient shows the angle amount of free face with spacing and burden. Usually the drilling pattern is displaying in various models such a square, rectangular or triangular. Accordingly, this factor is estimated as follows:

a. Square and Rectangular pattern

In this model, k' factor is estimated based on Figure 1 and Equation (33) as follows:

$$\left.\begin{array}{l} k' = \frac{S}{B} \\ \operatorname{Cot}\beta = \frac{S}{B}) \end{array}\right\} \rightarrow k' = \operatorname{Cot}\beta \tag{33}$$

b. Triangular pattern

In this model, this factor is estimated based on Figure 1 and Equation (34) as follows:

$$\left.\begin{array}{l} k' = \frac{S}{B} \\ \operatorname{Cot}\beta = \frac{S/2}{B}) \end{array}\right\} \rightarrow k' = 2\operatorname{Cot}\beta \tag{34}$$

β: The angle is between free face with spacing and burden

Other parameters of blasting in open pit mines are estimated based on Equations (35) to (42). These equations are stated as follows:

$$U = 0.3\,B_{ave} \tag{35}$$

$$H = \frac{K}{\sin\alpha} + U \tag{36}$$

$$L_c = \frac{4\,Q}{\pi\,\varphi_c^{\,2}\,D_c} \tag{37}$$

$$S_t = H - L_c \tag{38}$$

$$Q = q\,S\,B\,K \tag{39}$$

$$Q = \frac{s\,E_s}{\eta_1\,\eta_2\,\eta_3\,E_e}\,S\,B\,K \tag{40}$$

$$Q = 0.004\,SG\ BI\,S\,B\,K \tag{41}$$

$$Q = 312.12\,SG \times RFI^{-2.082}\,S\,B\,K \tag{42}$$

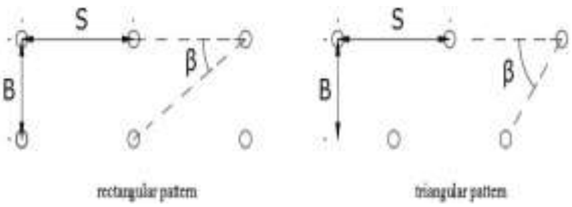

Figure 1. Various models of drilling pattern

3. 2. The Validation of the New Burden Thickness

For validation of the new burden thickness in Equations (26) to (28) is used optimum experimental data of blasting pattern in various open pit mines. Accordingly, this validation is performed in two different models such as the data of useful tables and optimum experimental data of blasting pattern in some open pit mines of Iran. They are discussed as follows:

3. 2. 1. The Data of Useful Tables This validation is performed based on the data of useful tables which published in the textbook of the blasting in mines by Hossaini and Poursaeed [20]. Accordingly, the summary of useful tables' data are presented in Table 11 and the results of new burden thickness and other blasting parameters have been presented in Table 12. Also, the comparison of these results has been presented in Table 13. Based on Table 13, difference of results are slight.

3. 2. 2. The Data of Some Open Pit Mines of Iran This validation is performed based on optimum experimental data of blasting pattern in some open pit mines of Iran. Based on this, the summary of data of blasting in some open pit mines of Iran are presented in Table 14. The results of the new thickness of burden and other blasting parameters are summarized in Table 15. Based on Table 15, difference of results are slight.

TABLE 11. The pattern blasting of useful tables [20]

Num	φ_h (mm)	α (degree)	D_c (kg/m^3)	q (kg/m^3)	K (m)	B (m)	S (m)	H (m)	U (m)	S_t (m)
1	45	72	850	0.27	4	1.70	2.15	4.75	0.5	1.70
2	45	72	850	0.32	5	1.65	2.05	5.75	0.5	1.65
3	51	72	850	0.27	5	2.00	2.50	5.85	0.6	2.00
4	51	72	850	0.37	6	1.80	2.25	6.85	0.55	1.80
5	64	72	850	0.30	7	2.45	3.05	8.10	0.75	2.45
6	64	72	850	0.44	8	2.10	2.60	9.10	0.65	2.10
7	76	72	850	0.32	8	2.80	3.50	9.25	0.85	2.80
8	76	72	850	0.47	9	2.40	3.00	10.20	0.70	2.40
9	89	72	850	0.35	9	3.15	3.95	10.45	0.95	3.15
10	89	72	850	0.47	10	2.80	3.50	11.40	0.85	2.80
11	102	72	850	0.35	11	3.60	4.50	12.65	1.10	3.60
12	102	72	850	0.51	12	3.10	3.85	13.60	0.95	3.10
13	115	72	850	0.56	14	3.35	4.20	15.75	1.00	3.35
14	127	72	850	0.40	14	4.20	5.25	16.00	1.25	4.20
15	127	72	850	0.61	16	3.55	4.45	17.90	1.05	3.55
16	152	72	850	0.50	16	4.60	5.75	18.25	1.40	4.60
17	152	72	850	0.56	20	4.45	5.55	22.45	1.35	4.45

18	200	72	850	0.69	20	5.20	6.50	22.65	1.55	5.20
19	200	72	850	0.74	24	5.10	6.40	26.85	1.55	5.10

TABLE 12. The results of the new burden thickness in the first model

Num	φ_h (mm)	α (degree)	q (kg/m^3)	K (m)	B_{Min} (m)	B_{Max} (m)	B_{ave} (m)	$\frac{S}{B_{ave}}$	$\frac{U}{B_{ave}}$	$\frac{S_t}{B_{ave}}$
1	45	72	0.27	4	1.567	1.943	1.755	1.265	0.30	0.92
2	45	72	0.32	5	1.524	1.783	1.654	1.242	0.30	0.93
3	51	72	0.27	5	1.828	2.225	2.027	1.250	0.30	0.92
4	51	72	0.37	6	1.672	1.925	1.799	1.250	0.30	0.93
5	64	72	0.30	7	2.258	2.672	2.465	1.245	0.30	0.93
6	64	72	0.44	8	1.978	2.235	2.107	1.238	0.30	0.93
7	76	72	0.32	8	2.589	3.065	2.827	1.250	0.30	0.93
8	76	72	0.47	9	2.256	2.555	2.406	1.250	0.30	0.93
9	89	72	0.35	9	2.898	3.428	3.163	1.254	0.30	0.93
10	89	72	0.47	10	2.621	2.988	2.805	1.250	0.30	0.93
11	102	72	0.35	11	3.368	3.944	3.656	1.250	0.30	0.93
12	102	72	0.51	12	2.930	3.305	3.120	1.242	0.30	0.93
13	115	72	0.56	14	3.175	3.547	3.361	1.254	0.30	0.94
14	127	72	0.40	14	3.987	4.607	4.290	1.250	0.30	0.93
15	127	72	0.61	16	3.394	3.760	3.577	1.254	0.30	0.94
16	152	72	0.50	16	4.316	4.942	4.629	1.250	0.30	0.93
17	152	72	0.56	20	4.250	4.710	4.480	1.247	0.30	0.94
18	200	72	0.69	20	4.917	5.553	5.235	1.274	0.30	0.94
19	200	72	0.74	24	4.879	5.380	5.130	1.255	0.30	0.94

TABLE 13. The comparison of results in the first model

Num	φ_h (mm)	Δ_B (m)	Δ_B (%)	$\frac{S}{B}$	$\frac{\Delta S}{B}$	$\frac{U}{B}$	$\frac{\Delta U}{B}$	$\frac{S_t}{B}$	$\frac{\Delta S_t}{B}$
1	45	-0.055	3.24	1.265	0	0.294	-0.006	1	0.080
2	45	-0.004	0.24	1.242	0	0.303	0.003	1	0.070
3	51	-0.027	1.35	1.250	0	0.300	0.000	1	0.080
4	51	0.001	0.06	1.250	0	0.306	0.006	1	0.070
5	64	-0.015	0.61	1.245	0	0.306	0.006	1	0.070
6	64	-0.007	0.33	1.238	0	0.310	0.010	1	0.070
7	76	-0.027	0.96	1.250	0	0.304	0.004	1	0.070
8	76	-0.006	0.25	1.250	0	0.292	-0.008	1	0.070
9	89	-0.013	0.41	1.254	0	0.302	0.002	1	0.070
10	89	-0.005	0.18	1.250	0	0.304	0.004	1	0.070
11	102	-0.056	1.56	1.250	0	0.306	0.006	1	0.070
12	102	-0.02	0.65	1.242	0	0.306	0.006	1	0.070
13	115	-0.011	0.33	1.254	0	0.299	-0.001	1	0.060
14	127	-0.09	2.14	1.250	0	0.298	-0.002	1	0.070
15	127	-0.027	0.76	1.254	0	0.296	-0.004	1	0.060

16	152	-0.029	0.63	1.250	0	0.304	0.004	1	0.070
17	152	-0.03	0.67	1.247	0	0.303	0.003	1	0.060
18	200	-0.035	0.67	1.250	0	0.298	-0.002	1	0.060
19	200	-0.03	0.59	1.255	0	0.304	0.004	1	0.060

TABLE 14. The blasting pattern in some open pit mines of Iran [19]

Num	Mine name	φ_h (mm)	α (degree)	q (kg/m^3)	K (m)	B (m)	S (m)
1	Iron stone of Jalalabad	165	90	0.600	12	4.20	5.30
2	Iron stone of Choghart	165	90	1.300	12.5	3.00	4.00
3	Limestone of pirbakran	105	90	0.35	8	3.50	4.50
4	Limestone of Abelu	89	90	0.408	10	3.00	3.43
5	Limestone of Asgarabad	101.6	80	0.778	10	2.74	2.74
6	Limestone of Korehblagh	63.5	90	0.487	10	2.20	2.20
7	Chalk stone of Shireki	76.2	90	0.620	10	2.32	2.32
8	Chalk stone of Eivavgholi	64	90	1.030	10	1.50	1.50

TABLE 15. The results of the new burden thickness in the second model

Num	Mine name	q (kg/m^3)	K (m)	B_{Min} (m)	B_{Max} (m)	B_{ave} (m)	$\frac{S}{B_{ave}}$	$\frac{U}{B_{ave}}$	$\frac{S_t}{B_{ave}}$
1	Iron stone of Jalalabad	0.600	12	3.921	4.703	4.312	1.262	0.30	0.93
2	Iron stone of Choghart	1.300	12.5	2.810	3.156	2.983	1.333	0.30	0.94
3	Limestone of pirbakran	0.35	8	3.073	3.845	3.459	1.286	0.30	0.92
4	Limestone of Abelu	0.408	10	2.282	3.282	3.054	1.143	0.30	0.93
5	Limestone of Asgarabad	0.778	10	2.529	2.889	2.709	1	0.30	0.93
6	Limestone of Korehblagh	0.487	10	2.067	2.296	2.182	1	0.30	0.94
7	Chalk stone of Shireki	0.620	10	2.180	2.439	2.310	1	0.30	0.93
8	Chalk stone of Eivavgholi	1.030	10	1.490	1.603	1.547	1	0.30	0.94

TABLE 16. The comparison of results in the second model

Num	Mine name	Δ_B (m)	Δ_B (%)	$\frac{S}{B}$	$\frac{\Delta S}{B}$
1	Iron stone of Jalalabad	-0.112	2.67	1.262	0
2	Iron stone of Choghart	0.017	0.57	1.333	0
3	Limestone of pirbakran	0.041	1.14	1.286	0
4	Limestone of Abelu	-0.054	1.41	1.143	0
5	Limestone of Asgarabad	0.031	0.66	1	0
6	Limestone of Korehblagh	0.018	0.60	1	0
7	Chalk stone of Shireki	0.01	0.36	1	0
8	Chalk stone of Eivavgholi	-0.047	1.25	1	0

4. DISCUSSION

The amount of specific charge is one of the main parameters for determining the burden thickness in blasting of open pit mines. The estimation of specific charge is better to do base on characteristics of the rock mass. Therefore, using of energy transfer rule, blastability index and rock fragmentation index are suggested for estimating the amount of the specific charge. The experimental results of blasting in open pit mines are confirmed the above subject.

Various equations have been presented based on blasting experiences that some of they are valuable. These equations have been shown in Equations (13) to (21). Using of mathematical science and conflation of Equations (13) to (21) with together are obtained very useful of results. Mathematical analysis of these equations causes to presentation of Equations (22) to (32) for burden thickness. Accordingly, in this paper has been presented new equations for estimation the maximum and minimum thickness of burden. These equations have designed based on the amount of specific charge according to Equations (26) to (28). The arrangement of the drilling holes in most of the previous methods is not clear perfectly. Therefore, in this paper for more clarity of above subject was presented k' factor in Equations (26) to (28).

5. CONCLUSION

Tables 13 and 16 show the validation results of the new equations in this article. The results of the new equations of burden thickness have slight differences with the experimental results. Based on Tables 13 and 16, the maximum error of burden is calculated to be 3%.

In some previous methods for estimation of burden thickness requires solving nonlinear equations but solving of quadratic equations is easier. Also these new equations depend on rock quality that is the advantages the projected model. Accordingly in this paper quadratic equations are presented.

Blasting pattern in open pit mines can display in various models such a square, rectangular and triangular. Based on this, arrangement of drilling pattern is very important for estimation of burden thickness. Therefore, in this article the coefficient k' was defined. This coefficient considers effects of arrangement of drilling pattern in estimation of burden thickness. Therefore, using the definition of k' coefficient in these new equations, it can be claimed that these new equations are considered as the most reliable mathematical equation for the accurate calculation of the burden thickness.

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Persian Abstract

چکیده

داشتن الگوی مناسب برای چالزنی و انفجار از ضروریات علم معدن‌کاری و بالاخص معادن روباز است. یکی از اهداف آتشکاری در معادن روباز به خدمت گرفتن انرژی حاصل از انفجار مواد منفجره برای خرد کردن سنگ با حداقل هزینه تولید است. مهمترین پارامترهای آتشکاری شامل قطر چال، خرج ویژه، ضخامت بارسنگ و ابعاد خردشدگی مناسب سنگ است. مقادیر پارامترهای آتشکاری به کیفیت توده سنگ بستگی دارد. در این مقاله بر اساس امتیاز حاصل از کیفیت توده سنگ و مقدار خرج ویژه در آتشکاری، مقادیر حداکثر و حداقل ضخامت بارسنگ در آتشکاری معادن روباز بر اساس یک معادله درجه ۲ محاسبه می‌شود. براساس برآورد ضخامت جدید بارسنگ سایر پارامترهای آتشباری محاسبه می‌شوند. اعتبارسنجی انجام شده در این مقاله بیانگر این مطلب است که نتایج حاصل از این معادله جدید اختلاف ناچیزی با مقادیر واقعی ضخامت بارسنگ معادن مختلف ارائه شده در جداول ۱۳ و ۱۶ دارد. حداکثر خطای محاسبه شده در این اعتبارسنجی معادله جدید برابر ۳ درصد است که بیانگر قابلیت اطمینان بالای این ضخامت بارسنگ جدید است.