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A model to calculate blasting costs using hole diameter, uniaxial compressive strength, and joint set orientation

by A. Ghanizadeh Zarghami*, K. Shahriar†, K. Goshtasbi‡, and A. Akbari§

Synopsis

Calculation of the blasting costs plays a significant role in blast pattern design and reduction of the final extraction cost of minerals. Blasting costs include drilling costs, blasting materials costs, and additional costs of blasting operations. We assessed information from three copper mines in Iran, and found that there is a significant relationship between blasting costs and hole diameter. A relationship was derived to calculate blasting costs per cubic metre as a function of hole diameter, bench height, uniaxial compressive strength, joint set orientation, the cost of drilling, and the unit cost of explosives. This model will enable engineers to estimate blasting costs prior to designing the blast pattern. Based on the model, an increase in the rock strength and the angle between the bench face and the main joint set will increase the blasting cost. On the other hand, the costs will decrease when the hole diameter increases for every range of uniaxial compressive strength.

Keywords

Blasting cost, hole diameter, uniaxial compressive strength, joint set, Iran copper mines.

Introduction

Reduction of the operating costs is of great importance with respect to the final costs of the product. The ability to estimate blasting costs before designing blast patterns enables design engineers to choose suitable blast-hole diameters and other crucial parameters of the blast design (Ghanizadeh Zarghami, 2005). Specific charge and specific drilling are two substantial factors concerning blast pattern design that influence blasting costs (Ghanizadeh Zarghami *et al*., 2017). The hole diameter is generally regarded as a crucial parameter in designing blast patterns (Ostovar, 2013). In the same vein, this study, proposes several models to estimate blasting costs as a function of hole diameter and other parameters, including uniaxial compressive strength (UCS).

Research objective

Blasting models have been formulated by applying technical and economic information on blasting operations at three large copper mines in Iran, namely Sungun, Miduk, and Chah-Firouzeh (Figure 1), After determining the hole diameter and rock uniaxial compressive strength, it will be possible to calculate blasting costs for these three mines and similar operations.

Various investigations have been conducted with the aim of reducing blast operation costs. Afum and Temeng (2014) explored various parameters affecting drilling cost and blast optimization in a gold mine in Ghana. At this mine, blasting was done in three different blocks. The blasting and crushing costs were affected by parameters such as the ground conditions and blast pattern. The model was employed in order to regulate the costs by testing suggested patterns. The results indicated a decrease of between 5.3 and 12.2% in ore costs and between 2.9 and 14.8% for waste costs.

Adebayo and Akande (2015) investigated the effects of drilling in terms of blast-hole deviation and muck-pile loading costs for six scenarios at Hwange Colliery, Zimbabwe. The study showed that the drilling and operational costs were in the range of US$0.13–7.53 per m^3. Ancillary costs of drilling increased from US$1.7 to US$4.2 per m^3 with an increase in blast-hole deviation from 7% gradient to 21%.

Adebayo and Mutandwa (2015) evaluated the relationship between blast-hole deviation, fragment size, and fragmentation cost. The use of ANFO, heavy ANFO, and emulsion explosives in holes 191 mm and 311 mm in diameter was compared using six scenarios. The results showed that as blast-hole deviation increases the mean fragment size decreases and the cost of drilling and blasting increases. Increasing the hole diameter from 191 mm to 311 mm increased the blast fragmentation.

* *Department of Mining Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran.*

† *Department of Mining and Metallurgy Engineering, Amir Kabir University, Iran.*

‡ *Department of Mining Engineering, Faculty of Engineering, Tarbiat Modares University, Iran.*

§ *Department of Mining Engineering, Islamic Azad University of Tehran Central, Iran.*

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Figure 1—Perspective views of Sungun, Miduk, and Chah-Firouzeh copper mines

Nenuw and Jimoh (2014) designed and optimized the blasting parameters to reduce the damaging effects and blasting costs by using Langfors and other common blast formulae. In this study, which was conducted at four mines, parameters such as burden, spacing, bench height, hole diameter, the number of holes, bottom charge, and total charge per hole were examined and the planned and actual costs calculated. The actual costs of blasting material were higher than the calculated cost, which required modification and revision.

Cunningham (2013) investigated four key parameters that determine the ability to design an effective blast in terms of delay timing and cost. These parameters included heave control and monitoring, hole diameter, and explosive type.

Strelec, Gazdek, and Mesec (2011) designed an optimized blast pattern to reduce drilling costs. The blast fragmentation was optimized by applying the calibration factors in the Kuz-Ram model.

Eloranta (1995) showed, by comparing the loading costs of materials to the blasting costs, that due to the increase in specific explosive charge in large-diameter holes, the blasting costs have a strong inverse correlation with the specific explosives charge. Increasing the specific explosives charge by 15% increased the shovel and crusher efficiencies by 5%, resulting in an overall reduction in operating costs.

Blasting blocks information

More than 4600 records of blasting operations at Sungun, Miduk, and Chah-Firouzeh from 2012 to 2014 were collected. Incorrect and unreliable records were deleted and finally, 2414 blasts with limited back break, air blast, ground vibration, oversize, and destructive effects were selected. Basic information on the blasting operations, including drilling costs, blasting material, and blast block geometry for the three mines is shown in Table I (Ghanizadeh Zarghami, 2017).

In Table I, the mines are categorized according to rock strength. The drilling cost per metre is considered according to the contractor price, and the cost for ANFO is based on the purchase price, transport, and delivery to the mine. The types of rocks blasted are shown in Table II.

The choice of effective parameters

The large number of factors and the complicated iterations make it impossible to determine the theoretical consumption of explosives at the present level of development in blasting theory. Thus, recourse is made either to practical data or to empirical formulae that generalize blasting practice in application to drifting (Pokrovsky, 1980). In the present research, four important parameters: hole diameter, UCS, joint set orientation, and bench height were selected for calculating blasting cost. These parameters could be easily calculated by the engineers and ultimately aid in estimating the blasting costs.

Blasting pattern and cost calculations

The correct ratios between the geometric parameters of blasting patterns and hole diameter in the UCS range between 10 and 250 MPa and for the angle between the bench face and main joint set (γ) <90° and >90° were extracted from the blasting databases at the respective mines. These ratios are presented in Tables III and IV. In the same UCS range, more energy is required when γ is greater than 90° because the joint set dips in the opposite direction to the free face direction. Therefore, the specific charge and specific drilling, and blasting costs are higher for γ>90° than for γ<90° (Ghanizadeh Zarghami, 2017).

According to the rules of block theory, the angle between the bench face and the main joint set is important. This angle is located between the two normal vectors of the planes. In other words, γ is the same angle between the two planes and

Table I

Data of drilling costs, explosives, and bench geometry considering compressive strength

Mine	Chah-Firouzeh	Miduk	Miduk and Sungun	Sungun
UCS (MPa)	10–70	70–120	120–180	180–250
Length of block (m)	70	70	70	70
Width of block (m)	150	150	150	150
Bench height (m)	15	15	15	15
ANFO density (t/m^3)	0.88	0.88	0.88	0.88
Volume of block (m^3)	157 500	157 500	157 500	157 500
Drilling cost (US$/m^3) (6 inches diameter in 2017)	4.5	5.4	6.48	7.77
Price of ANFO (2017) (US$/kg)	0.73	0.73	0.73	0.73

Table II

Rock types at the three case study copper mine

No.	Mine	Rock type	Description	UCS (MPa)
1	Miduk	Waste	Andesite	70–120
2	Miduk	Mixed	Andesite and granodiorite	120–180
3	Miduk	Ore	Granodiorite	120–180
4	Sungun	Waste	Trachyte	180–250
5	Sungun	Ore	Monzonite	120–180
6	Chah-Firouzeh	Waste	Alluvium	10–70

Table III

Ratios between the geometric parameters of the blasting pattern and the hole diameter for γ<90°

UCS	10–70 MPa			70–120 MPa			120–180 MPa			180–250 MPa		
Range	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
B/Dh (m/in)	0.99	1	0.99	0.915	0.945	0.93	0.882	0.918	0.9	0.821	0.859	0.84
S/Dh (m/in)	1.29	1.31	1.3	1.185	1.195	1.19	1.082	1.118	1.1	0.941	0.979	0.96
T/Dh (m/in)	0.89	0.91	0.9	0.825	0.855	0.84	0.792	0.828	0.81	0.731	0.769	0.75
J/Dh (m/in)	0.24	0.26	0.25	0.255	0.285	0.27	0.282	0.318	0.3	0.281	0.319	0.3

Table IV

Ratios between the geometric parameters of the blasting pattern and the hole diameter for γ>90°

UCS(MPa)	10–70 MPa			70–120 MPa			120–180 MPa			180–250 MPa		
Range	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
B/Dh (m/in)	0.699	1.161	0.93	0.599	1.201	0.9	0.81	0.87	0.84	0.76	0.8	0.78
S/Dh (m/in)	1.18	1.2	1.19	0.899	1.301	1.1	0.94	0.98	0.96	0.794	0.866	0.83
T/Dh (m/in)	0.828	0.852	0.84	0.78	0.84	0.81	0.725	0.775	0.75	0.47	0.93	0.7
J/Dh (m/in)	0.24	0.3	0.27	0.299	0.301	0.3	0.28	0.32	0.3	0.27	0.33	0.3

it is a necessary factor for writing the equation of plane, dip, and dip direction of the plane. The dip and dip direction of the main joint set and bench face are of importance to present the equation of their plane. Equation [1] demonstrates the plane equation and Equation [2] represents the coordinates of normal vector through dip and dip direction (Dehghan, 2001). Figure 2 shows the layout of the angles and plane.

$$AX + BY + CZ = D \quad [1]$$

$$A = \sin\alpha \sin\beta$$
$$B = \sin\alpha \cos\beta \quad [2]$$
$$C = \cos\alpha$$

In Equation [2], α indicates the dip and β represents dip direction relative to north. Equation [3] is used to measure the angle between the two planes (γ).

$$P_1(\alpha_1,\beta_1) \rightarrow \hat{n}_1 = (A_1, B_1, C_1)$$
$$P_2(\alpha_2,\beta_2) \rightarrow \hat{n}_2 = (A_2, B_2, C_2) \quad [3]$$
$$y = \cos^{-1}\left(\frac{A_1,A_{2,}B_1,B_{2,} + C_{1,}C_{2,}}{\sqrt{(A_1^2 + B_1^2 + C_1^2)(A_2^2 + B_2^2 + C_2^2)}}\right.$$

All blasting costs were modelled in the Comfar technical and economic analysis software and the cost per cubic metre broken was calculated. As presented in Table V, 87% of the blasting operation costs depends on the cost of ANFO and drilling costs. Equation [4] shows the cost of blasting operations according to specific drilling, specific charge, the price per kilogram of ANFO, and drilling cost per metre (Ghanizadeh Zarghami, 2017).

$$C_1 + C_2 = 87\%BC, BC = (1/0.87)(C_1 + C_2), \quad [4]$$
$$BC = 1.15(P_A \times SC + P_D \times SD)$$

In Equation [4], parameter C_1 represents ANFO cost, C_2 represents drilling cost, *BC* represents blasting cost per cubic metre, P_A the price of ANFO per kilogram, P_D the price of drilling per metre, *SC* the specific charge (kg/m3), and *SD* the specific drilling (m/m3).

Tables VI to IX show the burden, spacing, stemming, and sub-drilling considering the rock strength with γ<90° and γ>90°. At the studied mines, hole diameters of 6 to 6.5 inches are used. The burden parameter, spacing, stemming, and sub-drilling in zone classification of UCS were calculated according to joint set orientation with a hole diameter of 6 inches (152.4 mm).

Discussion and review

Factors in the blasting operation costs include blasting material costs and auxiliary costs such as staff wages, transportation, storage, and overhead costs. The bulk of the costs includes the blasting costs and consists of the drilling costs and the cost of ANFO. Finally, considering the contractor costs, the blast side cost was equal to 15% of the total cost.

The cost of drilling operations and consumed specific costs were calculated through burden, spacing, stemming, and sub-drilling. Parameter calculations and the operational costs in rocks with UCS of 10 to 70 MPa and hole diameters of 2 to 16 inches are presented in Table X, for γ<90°.

According to Table VI, for γ>90°, the same calculations were carried out based on Table X, the results of which, along with the results of calculations for γ<90°, are shown in Figure 3.

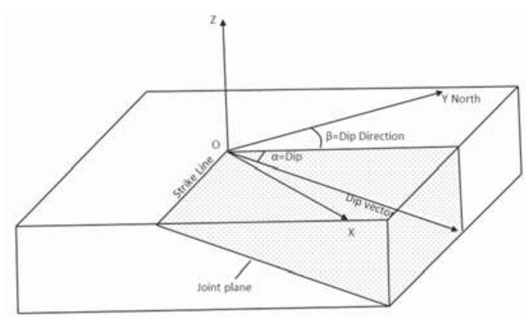


Figure 2—Layout of the angles and plane (Dehghan, 2001)

Table V

The ratio of ANFO costs and drilling costs to the total blasting costs

No.	Mine	Type	Year	Blasting cost (1000 Rials/m3)	Production volumes (m3)	ANFO cost + drilling cost (1000 Rials) (A)	Drilling cost (1000 Rials)	ANFO cost (1000 Rials)	Total blasting cost (1000 Rials) (B)	Ratio A/B
1	Miduk	Waste	2012	13.67	3 931 645	48 863 950	16 528 950	32 335 000	53 739 619	91%
2	Miduk	Waste	2013	14.83	2 460 168	33 736 800	10 861 800	22 875 000	36 487 558	92%
3	Miduk	Waste	2014	14.07	1 021 837	12 349 950	3 627 450	8 722 500	14 377 475	86%
4	Miduk	Mixed	2012	14.32	1 952 261	23 644 850	8 024 850	15 620 000	27 959 571	85%
5	Miduk	Mixed	2013	15.42	2 802 693	38 499 100	11 924 100	26 575 000	43 215 594	89%
6	Miduk	Mixed	2014	13.27	5 981 862	72 757 900	22 107 900	50 650 000	79 380 906	92%
7	Miduk	Ore	2012	15.05	1 430 466	15 393 550	5 176 050	10 217 500	21 529 271	72%
8	Miduk	Ore	2013	21.81	1 010 146	13 553 350	4 679 100	8 874 250	22 027 611	62%
9	Miduk	Ore	2014	18.79	1 002 165	11 914 000	3 939 000	7 975 000	18 831 301	63%
10	Sungun	Waste	2012	32.18	624 178	18 668 700	6 610 950	12 057 750	20 085 600	93%
11	Sungun	Waste	2013	34.62	147 914	3 914 725	1 410 450	2 504 275	5 120 925	76%
12	Sungun	Waste	2014	40.21	315 153	11 390 050	4 014 000	7 376 050	12 672 690	90%
13	Sungun	Ore	2012	13.52	7 698 287	101 487 100	35 356 350	66 130 750	104 078 530	98%
14	Sungun	Ore	2013	14.19	6 777 431	93 713 950	32 721 450	60 992 500	96 188 900	97%
15	Sungun	Ore	2014	14.37	6 562 884	91 971 600	31 918 800	60 052 800	94 300 530	98%
16	Chah-Firouzeh	Waste	2012	18.12	2 702 430	45 956 250	15 142 500	30 813 750	48 973 369	94%
17	Chah-Firouzeh	Waste	2013	15.32	3 742 393	54 760 000	21 303 750	33 456 250	57 345 636	95%
18	Chah-Firouzeh	Waste	2014	13.39	3 098 502	39 060 050	13 063 800	25 996 250	41 480 320	94%
*In 2017: $1 = 37 000 Rials Iran's currency is the Rial									Mean:	87.01%

Table VI

Blast pattern parameters at Chah-Firouzeh copper mine, UCS 10–70 MPa and hole diameter 6 inches

Variable parameters of blast pattern	Ratios UCS = 10–70 Mpa (γ<90°)		Computational v alues Dh = 6 in	Ratios UCS = 10–70 Mpa (γ>90°)		Computational values Dh=6 in
Burden	B/Dh	0.99	5940	B/Dh	0.93	5580
Spacing	S/ Dh	1.3	7722	S/ Dh	1.19	7142
Stemming length	T/ Dh	0.9	5346	T/ Dh	0.84	5022
Sub drilling length	J/ Dh	0.25	1485	J/ Dh	0.27	1618

Dh=Hole diameter B=Burden S=Spacing T=Stemming j=Sub-drilling

Table VII

Blast pattern parameters at Miduk copper mine, UCS 70–120 MPa and hole diameter 6 inches

Variable parameters of blast pattern	Ratios UCS = 70–120 Mpa (γ<90°)		Computational values Dh = 6 in	Ratios UCS = 70–120 Mpa (γ>90°)		Computational values Dh=6 in
Burden	B/Dh	0.93	5580	B/Dh	0.9	5400
Spacing	S/ Dh	1.19	7142	S/ Dh	1.1	6588
Stemming length	T/ Dh	0.84	5022	T/ Dh	0.81	4860
Sub drilling length	J/ Dh	0.27	1618	J/ Dh	0.3	1782

Dh=Hole diameter B=Burden S=Spacing T=Stemming j=Sub-drilling

Table VIII

Blast pattern parameters at Miduk and Sungun copper mine, UCS 120–180 MPa and hole diameter 6 inches

Variable parameters of blast pattern	Ratios UCS = 120–180 Mpa (γ<90°)		Computational values Dh = 6 in	Ratios UCS = 120–180 Mpa (γ>90°)		Computational values Dh=6 in
Burden	B/Dh	0.9	5400	B/Dh	0.84	5040
Spacing	S/ Dh	1.1	6588	S/ Dh	0.96	5746
Stemming length	T/ Dh	0.81	4860	T/ Dh	0.75	4486
Sub drilling length	J/ Dh	0.3	1782	J/ Dh	0.3	1799

Dh=Hole diameter B=Burden S=Spacing T=Stemming j=Sub-drilling

Table IX

Blast pattern parameters at Sungun copper mine, UCS 180–250 MPa and hole diameter 6 inches

Variable parameters of blast pattern	Ratios UCS = 180–250 Mpa (γ<90°)		Computational values Dh = 6 in	Ratios UCS = 180–250 Mpa (γ>90°)		Computational values Dh=6 in
Burden	B/Dh	0.84	5040	B/Dh	0.78	4680
Spacing	S/ Dh	0.96	57468	S/ Dh	0.83	4961
Stemming length	T/ Dh	0.75	4486	T/ Dh	0.7	4165
Sub drilling length	J/ Dh	0.3	1799	J/ Dh	0.3	1778

Dh=Hole diameter B=Burden S=Spacing T=Stemming j=Sub-drilling

Table X

Calculations of blasting parameters and costs with UCS 10-70 MPa and hole diameter of 2 to 16 inches

10-70 MPa		Dh (in)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ratio is rounded (m/in)		Dh (mm)	50.8	76.2	102	127	152	178	203.2	228.6	254	279.4	304.8	330.2	355.6	381	406.4
B/Dh	0.99	B (mm)	1980	2970	3960	4950	5940	6930	7920	8910	9900	10890	11880	12870	13860	14850	15840
S/Dh	1.3	S (mm)	2574	3861	5148	6435	7722	9009	10296	11583	12870	14157	15444	16731	18018	19305	20592
T/Dh	0.9	T (mm)	1782	2673	3564	4455	5346	6237	7128	8019	8910	9801	10692	11583	12474	13365	14256
J/Dh	0.25	J (mm)	495	742.5	990	1237.5	1485	1732.5	1980	2227.5	2475	2722.5	2970	3217.5	3465	3712.5	3960
SC (kg/m^3)			0.32	0.3	0.29	0.27	0.26	0.24	0.229	0.214	0.199	0.184	0.1694	0.154	0.139	0.124	0.109
SD (m/m^3)			0.2	0.09	0.05	0.03	0.02	0.02	0.014	0.011	0.009	0.008	0.0065	0.006	0.005	0.004	0.004
Drilling cost (1000 $)			141	63.5	36.3	23.6	16.6	12.4	9.635	7.724	6.346	5.319	4.532	3.915	3.421	3.02	2.69
ANFO cost (1000 $)			37	35.2	33.5	31.8	30	28.3	26.57	24.83	23.09	21.36	19.618	17.88	16.14	14.41	12.67
The lateral blast costs the equivalent of 13% of the total (1000 $)			26.6	14.8	10.5	8.3	7	6.11	5.43	4.883	4.416	4.001	3.6226	3.269	2.935	2.614	2.304
Blasting operation total cost (1000 $)			204	114	80.3	63.7	53.7	46.8	41.63	37.44	33.85	30.68	27.773	25.07	22.5	20.04	17.67
Blasting operation total cost ($/m^3)			1.3	0.72	0.51	0.4	0.34	0.3	0.264	0.238	0.215	0.195	0.1763	0.159	0.143	0.127	0.112

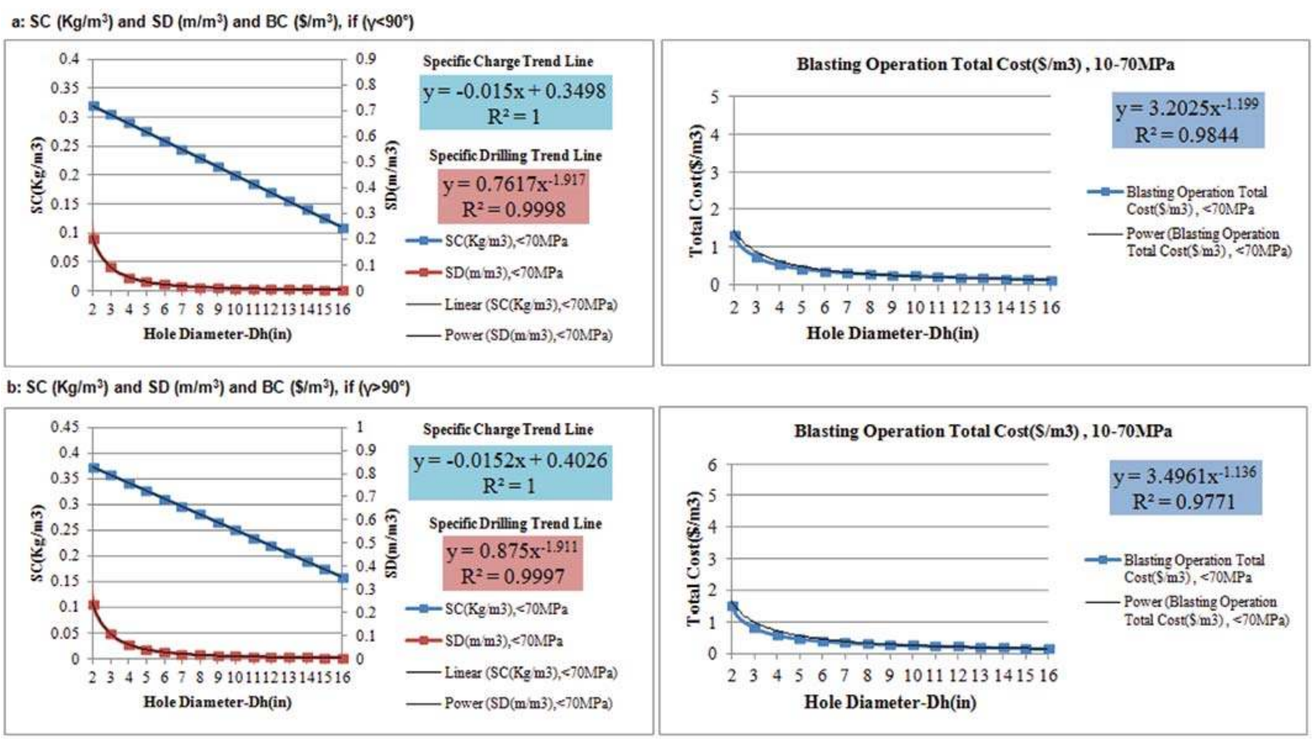


Figure 3—Relationship between of specific charge (SC), specific drilling (SD), and blasting costs considering hole diameter in the UCS range of 10-70 MPa for γ<90° and γ>90°

For other rock strengths in the three mines, the tables of calculated blast parameters and diagrams are presented together. Table XI lists the parameters and blasting costs in rock with a strength of 70–120 MPa and with hole diameters of 2 to 16 inches.

According to Table VII, for γ>90°, the same calculations were carried out based on Table XI, the results of which, along with the results of calculations for γ<90°, are shown in Figure 4.

Table XII shows the parameters and blasting costs in rock with the strength of 120 to 180 MPa and hole diameters of 2 to 16 inches.

According to Table VIII, for γ>90°, the same calculations were carried out based on Table XII, the results of which, along with the results of calculations for γ<90°, are shown in Figure 5.

Table XIII shows calculations of parameters and blasting costs in rock with strength between 180 to 250 MPa and hole diameters of 2 to 16 inches.

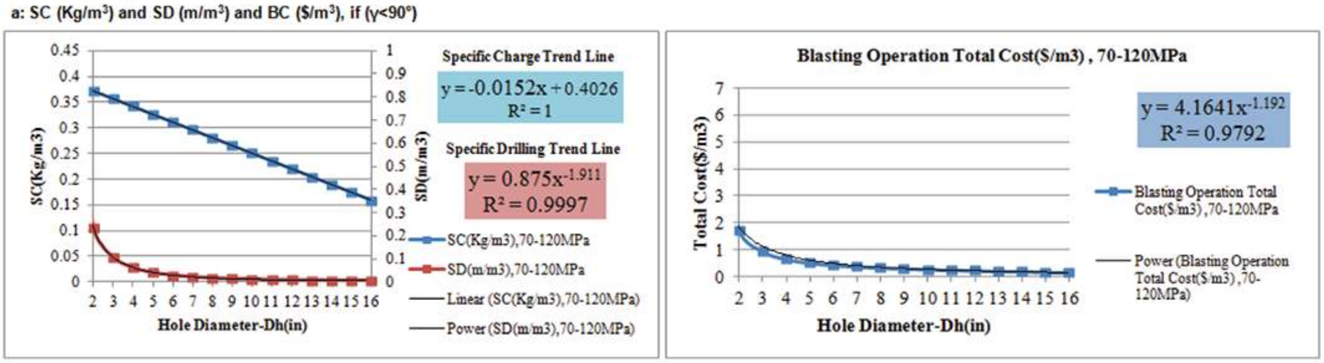
According to Table IX, for γ>90°, the same calculations were carried out based on Table XIII, the results of which, along with the results of calculations for γ<90°, are shown in Figure 6.

Table XI

Calculations of blasting parameters and costs with UCS 70-120 MPa and hole diameter of 2 to 16 inches

70-120 MPa		Dh (in)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ratio is rounded (m/in)		Dh (mm)	50.8	76.2	102	127	152	178	203.2	228.6	254	279.4	304.8	330.2	355.6	381	406.4
B/Dh	0.93	B (mm)	1860	2790	3720	4650	5580	6510	7440	8370	9300	10230	11160	12090	13020	13950	14880
S/Dh	1.19	S (mm)	2380.8	3571.2	4761.6	5952	7142.4	8332.8	9523.2	10713.6	11904	13094.4	14284.8	5475.2	6665.6	17856	9046.4
T/Dh	0.84	T (mm)	1674	2511	3348	4185	5022	5859	6696	7533	8370	9207	10044	10881	11718	12555	13392
J/Dh	0.27	J (mm)	539.4	809.1	1078.8	1348.5	1618.2	1887.9	2157.6	2427.3	2697	2966.7	3236.4	3506.1	3775.8	4045.5	4315.2
SC (kg/m^3)			0.372	0.357	0.342	0.326	0.311	0.296	0.281	0.266	0.250	0.235	0.220	0.205	0.189	0.174	0.159
SD (m/m^3)			0.234	0.106	0.061	0.039	0.028	0.021	0.016	0.013	0.011	0.009	0.008	0.007	0.006	0.005	0.005
Drilling cost (1000 $)			195.07	88.20	50.46	32.84	23.18	17.31	13.46	10.80	8.89	7.46	6.36	5.50	4.81	4.25	3.79
ANFO cost (1000 $)			43.09	41.33	39.57	37.81	36.04	34.28	32.52	30.75	28.99	27.23	25.46	23.70	21.94	20.17	18.41
The lateral blast costs the equivalent of 13% of the total (1000 $)			35.72	19.43	13.50	10.60	8.88	7.74	6.90	6.23	5.68	5.20	4.77	4.38	4.01	3.66	3.33
Blasting operation total Cost (1000 $)			273.88	148.96	103.53	81.24	68.10	59.32	52.87	47.79	43.56	39.88	36.59	33.58	30.76	28.09	25.53
Blasting operation total cost ($/m^3)			1.74	0.95	0.66	0.52	0.43	0.38	0.34	0.30	0.28	0.25	0.23	0.21	0.20	0.18	0.16

a: SC (Kg/m^3) and SD (m/m^3) and BC ($/m^3), if (γ<90°)



b: SC (Kg/m^3) and SD (m/m^3) and BC ($/m^3), if (γ>90°)

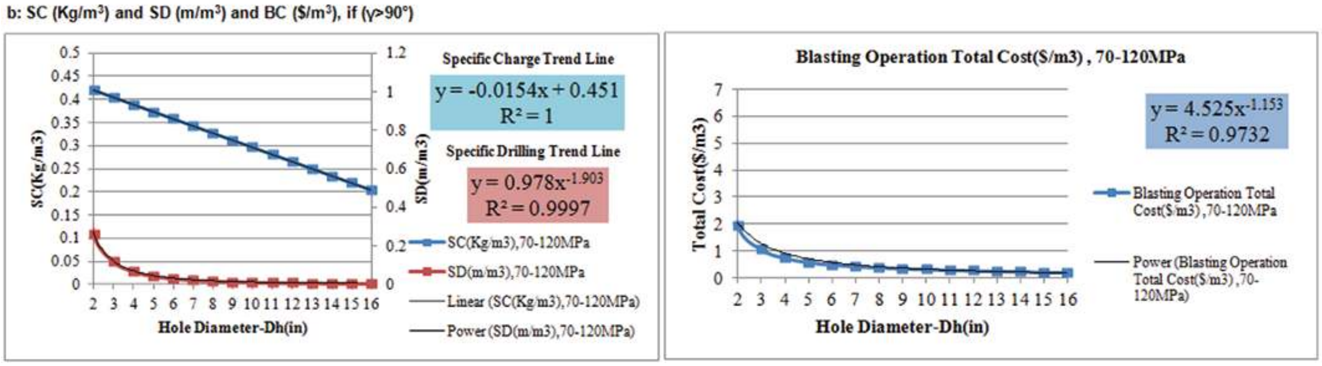


Figure 4—Relationship between specific charge (SC), specific drilling (SD), and blasting costs considering hole diameter in the UCS strength range (70-120 MPa) for (γ<90°) and (γ>90°)

Table XII

Calculations of blasting parameters and costs with UCS 120-180 MPa and hole diameter of 2 to 16 inches

120-180 MPa		Dh (in)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ratio is rounded (m/in)		Dh (mm)	50.8	76.2	102	127	152	178	203.2	228.6	254	279.4	304.8	330.2	355.6	381	406.4
B/Dh	0.9	B (mm)	1800	2700	3600	4500	5400	6300	7200	8100	9000	9900	10800	11700	12600	13500	14400
S/Dh	1.1	S (mm)	2196	3294	4392	5490	6588	7686	8784	9882	10980	12078	13176	14274	15372	16470	17568
T/Dh	0.81	T (mm)	1620	2430	3240	4050	4860	5670	6480	7290	8100	8910	9720	10530	11340	12150	12960
J/Dh	0.3	J (mm)	594	891	1188	1485	1782	2079	2376	2673	2970	3267	3564	3861	4158	4455	4752
SC (kg/m³)			0.42	0.40	0.39	0.37	0.36	0.34	0.33	0.31	0.30	0.28	0.27	0.25	0.24	0.22	0.20
SD (m/m³)			0.26	0.12	0.07	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Drilling cost (1000 $)			263.16	119.19	68.30	44.51	31.47	23.53	18.33	14.73	12.13	10.19	8.70	7.53	6.60	5.84	5.21
ANFO cost (1000 $)			48.66	46.87	45.08	43.30	41.51	39.73	37.94	36.15	34.37	32.58	30.79	29.01	27.22	25.44	23.65
The lateral blast costs the equivalent of 13% of the total (1000 $)			46.77	24.91	17.01	13.17	10.95	9.49	8.44	7.63	6.97	6.42	5.92	5.48	5.07	4.69	4.33
Blasting operation total Cost (1000 $)			358.59	190.97	130.39	100.98	83.93	72.74	64.71	58.51	53.47	49.19	45.42	42.02	38.89	35.96	33.19
Blasting operation total			2.28	1.21	0.83	0.64	0.53	0.46	0.41	0.37	0.34	0.31	0.29	0.27	0.25	0.23	0.21

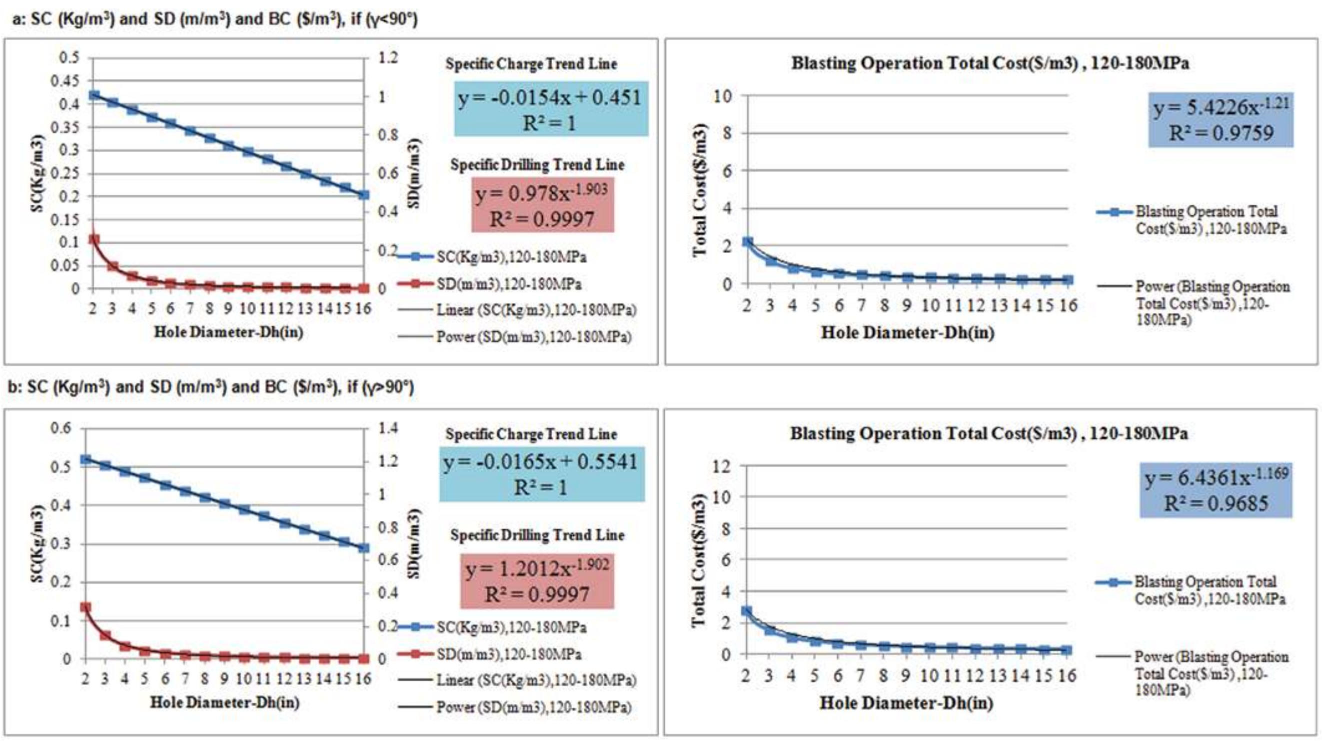


Figure 5—Relationship of specific charge (SC), specific drilling (SD), and blasting costs to hole diameter in the UCS range 120–180 MPa for γ<90° and γ>90°

Results of reviews

According to the research and the proposed models shown in the previous section, the relationship between the hole diameter and specific charge, specific drilling, and blasting costs for bench heights of 15 m in γ<90° and γ>90° are determined. The results are presented in Table XIV for the range of UCS considered.

Equation [5] shows the general equation of blasting cost, which is derived to calculate the blasting cost according to the hole diameter. In this equation, coefficients 'a' and 'b' are functions of bench height, UCS, join set orientation, the cost of drilling per metre, and the cost of ANFO.

$$BC = 1.15(P_A \times SC + P_D \times SD) = a(Dh)^{-b} \quad [5]$$

BC_e in Table XIV is the estimated blasting cost during 2017. If the price of ANFO and drilling cost are fixed, blasting engineers can use BC_e in Table XIV; otherwise, they can use BC for calculating blasting cost, which excludes a time-frame. However, they should determine P_A and P_D for every year.

According to Table XIV, blasting cost was calculated using the UCS, hole diameter, and joint set orientation for Sungun, Miduk, and Chah-Firouzeh. In this model the blasting cost was calculated for each blast block, which includes drilling cost, the cost of ANFO, and auxiliary charges for the blasting operation. It should be mentioned that the

Table XIII

Calculations of blasting parameters and costs with UCS 180-250 MPa and hole diameter of 2 to 16 inches

180-250 MPa		Dh (in)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ratio is rounded (m/in)		Dh (mm)	50.8	76.2	102	127	152	178	203.2	228.6	254	279.4	304.8	330.2	355.6	381	406.4
B/Dh	0.84	B (mm)	1680	2520	3360	4200	5040	5880	6720	7560	8400	9240	10080	10920	11760	12600	13440
S/Dh	0.96	S (mm)	1915.2	2872.8	3830.4	4788	5745.6	6703.2	7660.8	8618.4	9576	10533.6	11491.2	12448.8	13406.4	14364	15321.6
T/Dh	0.75	T (mm)	1495.2	2242.8	2990.4	3738	4485.6	5233.2	5980.8	6728.4	7476	8223.6	8971.2	9718.8	10466.4	11214	11961.6
J/Dh	0.3	J (mm)	599.76	899.64	1199.52	1499.4	1799.28	2099.16	2399.04	2698.92	2998.8	3298.68	3598.56	3898.44	4198.32	4498.2	4798.08
SC (kg/m^3)			0.52	0.50	0.49	0.47	0.45	0.44	0.42	0.41	0.39	0.37	0.36	0.34	0.32	0.31	0.29
SD (m/m^3)			0.32	0.15	0.08	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Drilling cost (1000 $)			388.10	175.80	100.75	65.68	46.44	34.73	27.05	21.74	17.91	15.05	12.85	11.13	9.75	8.62	7.70
ANFO cost (1000 $)			60.33	58.42	56.50	54.59	52.67	50.76	48.84	46.93	45.01	43.10	41.18	39.27	37.35	35.44	33.52
The lateral blast costs the equivalent of 13% of the total (1000 $)			67.26	35.13	23.59	18.04	14.87	12.82	11.38	10.30	9.44	8.72	8.11	7.56	7.06	6.61	6.18
Blasting operation total cost (1000$)			515.70	269.36	180.85	138.31	113.98	98.31	87.28	78.97	72.36	66.87	62.14	57.95	54.16	50.67	47.40
Blasting operation total cost ($/m^3)			3.27	1.71	1.15	0.88	0.72	0.62	0.55	0.50	0.46	0.42	0.39	0.37	0.34	0.32	0.30

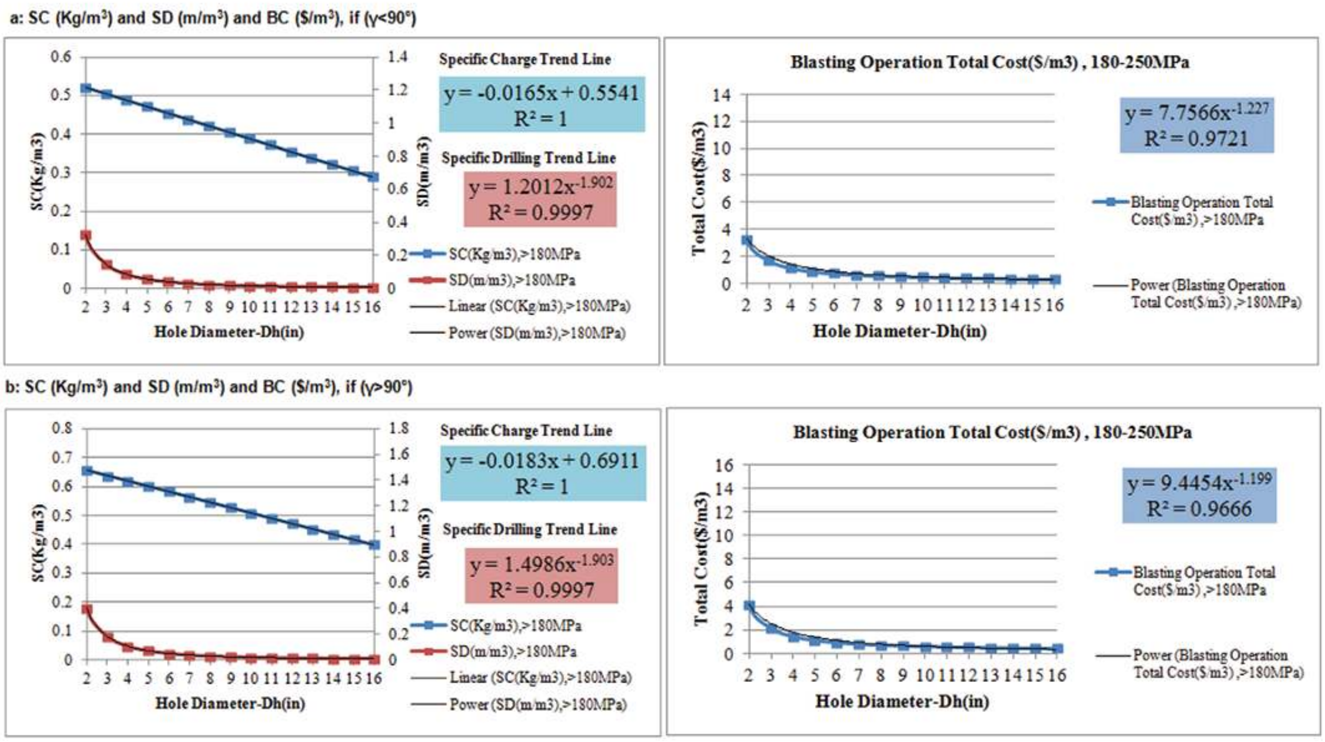


Figure 6 – Relationship of specific charge (SC), specific drilling (SD), and blasting costs considering hole diameter in the UCS range 180-250 MPa for γ<90° and γ>90°

blasting cost will increase with increasing rock strength and γ, and decrease with increasing hole diameter in all ranges of UCS.

Conclusion

Investigation of the blasting cost at Sungun, Miduk, and Chah-Firouzeh copper mines revealed that there is a relationship between hole diameter and blasting cost. Generally, the relationship can be expressed as $BC = a(D_h)^{-b}$, where D_h is the hole diameter in inches, BC is blasting cost in US dollars per cubic metre, and coefficients 'a' and 'b' are a function of bench height, UCS, joint set orientation, drilling cost per metre, and ANFO cost per kilogram. The bench height considered was 15 m. The values of coefficients 'a' and 'b' for various UCS ranges and values of γ (the angle between plane of the bench face and the plane of the main joint set) less than or greater than 90° are as follows.

Table XIV

Models for calculating blasting cost considering *in situ* rock USCS, hole diameter, and γ

UCS	(γ>90°), H = 15 m	(γ<90°), H = 1 5 m
10–70 MPa	$SC = -0.015(D_h) + 0.35$ $SD = 0.76(D_h)^{-1.9}$ $BC = 1.15(P_A \times SC + P_D \times SD)$	$SC = -0.015(D_h) + 0.4$ $SD = 0.87(D_h)^{-1.9}$ $BC = 1.15(P_A \times SC + P_D \times SD)$
	$BC_e = 3.2(D_h)^{-1.2}$	$BC_e = 3.5(D_h)^{-1.13}$
70–120 MPa	$SC = -0.015(D_h) + 0.4$ $SD = 0.87(D_h)^{-1.9}$ $BC = 1.15(P_A \times SC + P_D \times SD)$	$SC = -0.015(D_h) + 0.45$ $SD = 0.9(D_h)^{-1.9}$ $BC = 1.15(P_A \times SC + P_D \times SD)$
	$BC_e = 4.16(D_h)^{-1.2}$	$BC_e = 4.5(D_h)^{-1.15}$
120–180 MPa	$SC = -0.015(D_h) + 0.45$ $SD = 0.97(D_h)^{-1.9}$ $BC = 1.15(P_A \times SC + P_D \times SD)$	$SC = -0.016(D_h) + 0.55$ $SD = 1.2(D_h)^{-1.9}$ $BC = 1.15(P_A \times SC + P_D \times SD)$
	$BC_e = 5.4(D_h)^{-1.2}$	$BC_e = 6.4(D_h)^{-1.17}$
180–250 MPa	$SC = -0.016(D_h) + 0.45$ $SD = 1.2(D_h)^{-1.9}$ $BC = 1.15(P_A \times SC + P_D \times SD)$	$SC = -0.0186(D_h) + 0.7$ $SD = 1.5(D_h)^{-1.9}$ $BC = 1.15(P_A \times SC + P_D \times SD)$
	$BC_e = 7.75(D_h)^{-1.2}$	$BC_e = 9.4(D_h)^{-1.2}$

D_h: Hole diameter (in) *BC*: Blasting cost ($/m³) BC_e: Blasting cost estimated ($/m³) in 2017 *SC*: Specific charge (kg/m³) *SD*: Specific drilling (m/m³)
H: Height of bench (m) P_A: ANFO price ($/kg) P_D: Drilling price ($/m) γ : Angle between plane of bench face and the plane of main joint set

γ <90°:

UCS (MPa)	Coefficient *a*	Coefficient *b*
10–70	3.2	1.2
70–120	4.16	1.2
120–180	5.4	1.2
180–250	7.75	1.2

γ <90°

UCS (MPa)	Coefficient *a*	Coefficient *b*
10–70	3.5	1.13
70–120	4.5	1.15
120–180	6.4	1.17
180–250	9.4	1.2

This relationship shows that blasting costs will increase with increasing rock strength and γ value, but will decrease with increasing hole diameter in every range of UCS.

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