IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Optimal mesh design methodology considering geometric parameters for rock fragmentation in open-pit mining in the Southern Andes of Peru

To cite this article: V Zamora-Paredes *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **758** 012015

IOP Conf. Series: Materials Science and Engineering **758** (2020) 012015 doi:10.1088/1757-899X/758/1/012015

Optimal mesh design methodology considering geometric parameters for rock fragmentation in open-pit mining in the Southern Andes of Peru

V Zamora-Paredes[1], L Arauzo-Gallardo[1], C Raymundo-Ibañez[2], Moises Perez[3]

[1] Ingeniería de Gestión Minera, Universidad Peruana de Ciencias Aplicadas (UPC), Lima 15023, Perú.
[2] Dirección de Investigación, Universidad Peruana de Ciencias Aplicadas (UPC), Lima 15023, Perú.
[3] Escuela Superior de Ingeniería Informática, Universidad Rey Juan Carlos, Mostoles, Madrid, España.
Email: carlos.raymundo@upc.edu.pe

Abstract. Blasting is one of the most important stages in the productive process of a mine due to its direct impact on rock fragmentation, which determines the degree of productivity of operations and the extraction costs generated. In this scenario, an optimized methodology is presented for designing blasting meshes by using mathematical models that help calculate the geometric parameters of a blasting mesh, such as burden, considering the variables of the rock mass and the type of explosive to measure its impact on rock fragmentation and loading productivity (tons/hour). The main advantage of this method is the reliability of the design, which takes into account a greater number of variables that influence fragmentation and uses the principle of distribution and amount of energy in an optimal way. The results obtained in the case of application show that a change in design (2.7 x 2.7 square mesh to 2.2 x 2.5 triangular mesh) reduces P80 by 65%, from 17 to 6 inches, approximately. Additionally, the results show that greater operational efficiency was achieved by increasing excavator productivity by approximately 15.6%.

1. Introduction

Currently, most mining companies seek significant unit cost savings in order to maintain a sustainable market position [1]. Because of this, continuous improvement processes are sought within mining operations under a holistic approach [2]. Fragmentation of blasting rocks has been studied because it can add great value by reducing costs, as it has a high impact on the productive and economic performance of loading, carrying (50–60% mine costs), crushing, and milling [3]. Several studies have been conducted to measure the relationship of these parameters with P80 (an indicator of the degree of fragmentation). However, an integrated approach is necessary in order to obtain more reliable results, since each mine has different characteristics in geological, structural, and operational areas [4], [5].
An optimal methodology that uses the Pearse mathematical model is proposed for the design of blasting meshes. The methodology is based on the principle of distribution and exploitation of the explosive energy within the drill, for which a triangular mesh model is proposed, depending on burden and spacing. To analyze the results, the Wipfrag software.

2. State of the art

IOP Conf. Series: Materials Science and Engineering **758** (2020) 012015 doi:10.1088/1757-899X/758/1/012015

2.1. Blasting mesh designs

Studies carried out to find solutions optimize rock fragmentation [6] determined the direct relationship between the resistance to the uniaxial compression of the intact rock and the power factor (amount of explosives used/tons of material in the mined bank), and the authors concluded that a greater power factor improves optimization, based on the theory of amount of energy required. Moving a step further, [7] analyzed rock mass, including intact rock and discontinuities, which affects energy distribution and the entire detonation process. The authors conclude, through fragmentation image analysis, that indicators such as the Bienowski rock mass rating and RQD must be present in the calculation of blast mesh designs in order to achieve the expected results.

2.2. Blasting mesh designs based on geometric parameters

Currently, all research allows current mines to use models such as Pearse (1955) and Langefors (1963) to determine geometric parameters such as burden, which serves as input for the calculation of spacing, block, and overdrilling. Considering the explosive factor, [8] proposed blasting mesh designs that take into account the implementation of higher energy explosives, which also use new geometric parameters, according to the areas of exploitation within the mine under study. The conclusion stated that a greater amount of energy and its better distribution are necessary to obtain optimal fragmentation in order not to have excessive costs in the drilling and blasting processes. Moreover, in [9] with the use of integral mesh designs, achieved more uniform fragmentation, contributing to an increase in loading, hauling, and milling performance.

3. Contribution

This research uses a methodology to perform reliable blasting mesh designs based on geometric design parameters, including loading, spacing, block length, overdrilling, and retardation times, taking into account the physical and mechanical properties of the rock mass, such as lithology, compressive strength, traction, and Deere RQD, in order to optimize rock fragmentation. This methodology is based on the principle of better distribution and greater amount of chemical energy used to fragment and displace the rock mass. For this, an equilateral triangular perforation is executed, as shown in Figure 1, which permits better distribution of the energy inside the blasting bank, a product of the existing geometric disposition. In (1), the geometrical relationship between burden and spacing is shown, and we can see how they impact energy distribution, affecting the coverage area.

Therefore, the area of each drill is represented in (2). The influence area of the explosive per drill is represented in (3). The coverage percentage of the explosive per drill is *I1*=90.69% (4).

$\frac{S}{B} = \frac{2R}{\sqrt{3}R} = 1.15; \quad R = \frac{B\sqrt{3}}{3}$ (1)	$A_E = \pi * R^2$ (3)
$A_H = 2R\left(\sqrt{3}R\right) = 2\sqrt{3}R^2$ (2)	$\%I = \frac{\pi * R^2}{2\sqrt{3}R^2} * 100\% = 90.69\ \%$ (4)

Area F_1, where there is no interaction between the explosives of the drills on the triangular mesh, is

$$F_1 = A_T - 3A_S = \frac{2R * R\sqrt{3}}{2} - \frac{3\pi * R^2 * 60}{360} = \sqrt{3}R^2 - 1.57R^2 = 0.1621R^2 = 0.054\, B^2 \quad (5)$$

where B is the burden, S is spacing, R is the radius of influence of the drill, and F1 is the area where there is no interaction of drill holes in triangular mesh during blasting.

On the other hand, Figure 2 shows a square mesh design, which is used in medium open-pit mining operations and quarries, because it allows a reduction in drilling and blasting costs. However, the geometric influence of burden and spacing negatively impacts fragmentation, because the percentage of explosive coverage per drill is less than that of a triangular mesh.

Area F2, where there is no interaction between the explosives of the drill the triangular mesh, is equal to where *% I2* = 78.54%.

$$F_2 = A_C - 4\,A_S = (2R)^2 - 4 * \frac{\pi * R^2 * 90}{360} = 4R^2 - 3.14R^2 = 0.8585 * \left(\frac{B}{2}\right)^2 = 0.2146\, B^2 \quad (6)$$

IOP Conf. Series: Materials Science and Engineering **758** (2020) 012015 doi:10.1088/1757-899X/758/1/012015

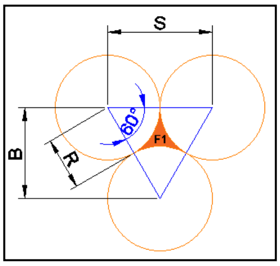

Figure 1. Triangular mesh design

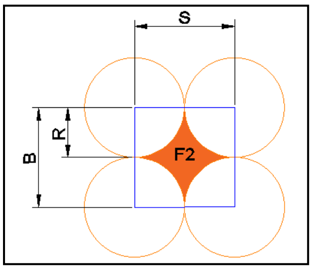

Figure 2. Square mesh design

where F2 is the area where there is no interaction of square mesh holes during blasting. It is determined that the percentage of explosive coverage per drill in a triangular mesh is 12% higher than in a square mesh and that F1 > F2 is, therefore, more likely to result in finer rock fragments.

When using the equilateral triangular mesh, the best use of chemical energy is achieved with a spacing/burden ratio equal to 1.15.

The research methodology is shown in Figure 3 and begins with the comparison of mesh designs (square and triangular). From this, it is concluded that the triangular pattern generates a better energy distribution, which favors the optimization of rock fragmentation.

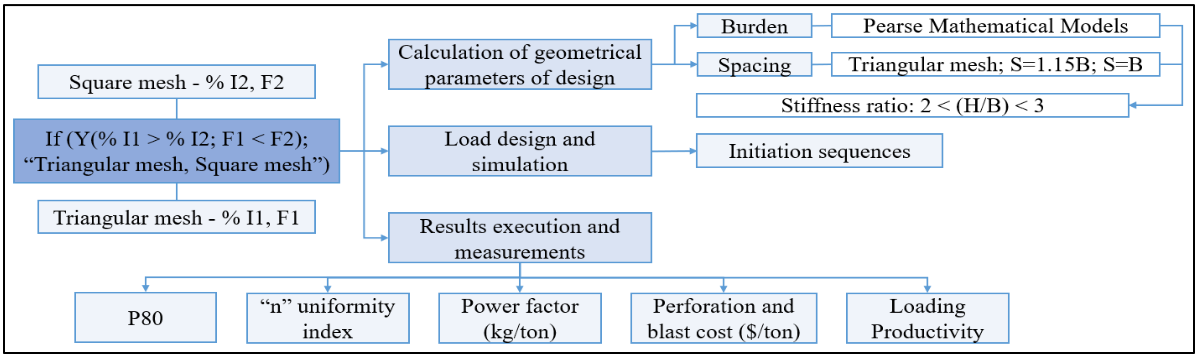

Figure 3. Conditional flow chart of mesh design

Among the indicators to be evaluated is P80, as a measure of rock fragmentation, based on the granulometric curves of Kuz Ram. This varies between 0.6 and 2.2; a value close to the lower limit means that there is a variable percentage between fine and coarse fragments. Conversely, a value close to the upper limit indicates that the stack of material has fine or coarse fragments. Furthermore, the power factor (kg/tons) is evaluated in order to obtain the relationship between the quantity of explosive used and the fragmentation of rocks in P80 and to evaluate the quantity of energy used.

4. Validation

4.1. Case study

The investigation was conducted in a medium-sized mining operation (approximately 800 tpd), which exploits copper ore using the open-pit method in the Southern Andes of Peru. The deposit is located in the Tacaza volcanic formation. Table 1 presents the physical and mechanical properties of the rock mass. In order to achieve the objectives proposed in this paper, a field study was carried out on 10 blasting banks in an open-pit mine in the Andes of Peru.

In Table 2, a comparative table is presented with the mesh design parameters using a square mesh pattern with an empirical model (baseline) and the equilateral triangular pattern with a mathematical model (proposed methodology) in order to obtain an optimal and reliable result involving the largest number of variables for the design.

Table 1. Characteristics of the rock mass in the area under study

Domain	Lithology	t/m^3	Rc (MPa)	Rt (MPa)	RQD %
III-B	Tuff breccia and andesite augitic	2.1	90.2	9.02	50

IV-A	Feldspatic Andesite	2.5	107.2	10.72	42
I-B	Reworked tuff	1.8	9.61	0.98	15

Table 2. Design parameters of the conventional mesh and the proposed mesh

Parameters	Units	Square mesh -empirical model	Triangle mesh–mathematical model
Drill diameter	mm	101.6	101.6
Bank height	m	5	5
Burden	m	2.7	2.2
Spacing	m	2.7	2.5
Length of block	m	1.0	1.5
Over perforation	m	0.3	0.5
Stiffness ratio		1.85	2.27
Type of initiation		Pyrotechnic detonators	Pyrotechnic detonators
Power factor	Kg/t	0.26	0.36
Retardation times between rows	ms	25 t 42	17 to 25
Retardation times between drills	ms	17	17

5. Results

Below is a summary of the results for each of the lithologies, n estimate of unit costs in the drilling and blasting process, and measurement of the variations with the proposed new mesh design. Figure 4, shows that an optimal fragmentation was obtained, according to those compared to the baseline, where the fragments exceeded 11 inches, which was the limit standard for the concentrator plant.
Table 3 compares both the mesh designs in terms of $PR_{80}R$, uniformity index, power factor, unit cost of drilling, and blasting. Comparisons are also made at the loading stage to measure the performance of excavators during the mining cycle, as shown in Table 4.

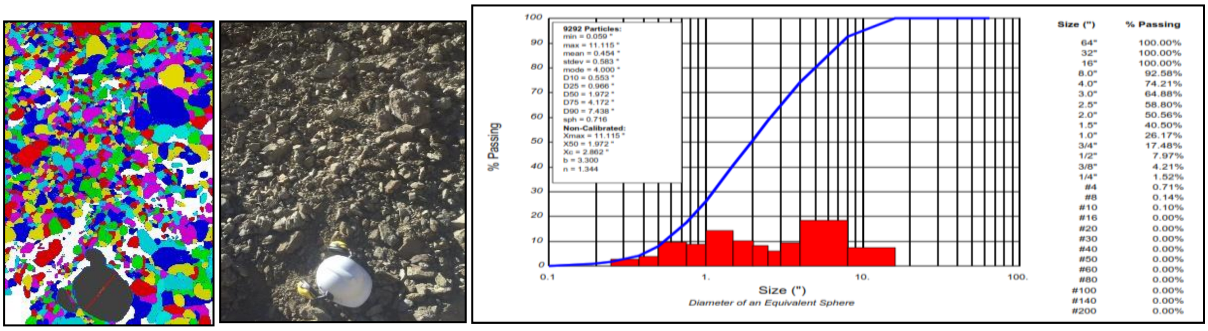

Figure 4. Kuz Ram granulometric curve

Table 3. Comparative indices of fragmentation, and drilling, and blasting costs

Model	Unit	Baseline	Proposed design
Type		CAT 336D2L	
Capacity	m^3	2.6	2.6
Filling factor	%	80	90
Density	ton/m^3	2.3	2.3
Sponging		1.2	1.2
Cycle	seg	40	35
Productivity	ton/hour	358.8	403.7

Table 4. Comparative productivity between the designs presented

Description	Unit	Square mesh	Triangle mesh
Average volume per blast	m^3	4200	4200
Tons	ton	8880	8880
No. of drills	tal	108.00	133.00
Unit cost per perforation	$/ton	0.10	0.13
Unit cost per blast	$/ton	0.32	0.36
Power factor	kg/ton	0.24	0.36
Average P80	inch	17.0	6.0
Uniformity index		1.0	1.4

6. Data analysis

Table 5 shows the average results of the 10 blasting operations in ore banks, where the average mesh design is 2.0 x 2.50 m, resulting in P80 of 5.9 inches and uniformity index “n” of 1.5, which indicates a large percentage of material with similar size of fine fragments. Additionally, higher productivity compared with blasting with square mesh designs are obtained, as the fragmentation obtained is finer, which allows the loading of ore in less time and with a higher filling factor in the excavator buckets.

Table 5. Comparative productivity between the designs presented

Statistics	Burden (m)	Espacing (m)	P_{80} (inches)	n	Power factor (kg/t)	T/hour - excavator	Perforation cost ($/t)	Blasting cost ($/t)
No. of samples	10	10	10	10	10	10	10	10
M ńimum	2.1	2.4	4.0	1.3	0.35	403.0	0.11	0.35
Maximum	2.3	2.55	7.0	1.8	0.38	435.0	0.15	0.39
Medium	2.2	2.5	5.9	1.5	0.37	416.2	0.13	0.37
Standard deviation	0.07	0.06	0.94	0.13	0.01	9.73	0.01	0.01

7. Conclusions

The research concludes that triangular mesh designs and mathematical models are favorable for rock fragmentation due to better energy distribution. In addition, this impacts the unit costs of drilling and blasting but allows an increase in the productivity of the loading equipment, which, in turn, decreases hauling cycles (fixed time), impacting the reduction of loading and hauling costs. This generates greater profitability in the mining operation.

- Triangular mesh designs generate a better use of energy in the drill compared with square meshes (+15.68%). The area of non-interaction is reduced by 75 %, which favors rock fragmentation.
- The power factor increases by 50% due to greater number of holes drilled in a triangular mesh and decrease in burden and spacing.
- Average P80 is reduced by approximately 65%, from 17 to 5.9 inches.
- Drilling and blasting costs increased due to higher steel consumption and power factor (+30% and +12% respectively).
- Loading productivity increased by 15.61% (ton/hour).

8. References

[1] D. Whittle, “CHAPTER 10.2: Open-Pit Planning and Design.”
[2] D. Murr, Workman Lyall, J. Eloranta, and P. Katsabanis, “Blasting Influence on comminution,” in SAG Conference, 2015, pp. 1–21.
[3] E. Rybinski et al., “Optimisation and Continuous Improvement of Antamina Comminution Circuit,” in SAG Conference, 2011, p. 19.
[4] P. K. Singh, M. P. Roy, R. K. Paswan, M. Sarim, S. Kumar, and R. Ranjan Jha, “Rock fragmentation control in opencast blasting,” J. Rock Mech. Geotech. Eng., vol. 8, no. 2, pp. 225–237, Apr. 2016.
[5] G. L. Gomes-Sebastiao and W. W. De Graaf, “An investigation into the fragmentation of blasted rock at Gomes Sand,” J. South. African Inst. Min. Metall., 2017.
[6] F. Mohamed, A. Hafsaoui, K. Talhi, and K. Menacer, “Study of the Powder Factor in Surface Bench Blasting,” Procedia Earth Planet. Sci., 2015.
[7] K. Nur Lyana, Z. Hareyani, A. Kamar Shah, and M. H. Mohd. Hazizan, “Effect of Geological Condition on Degree of Fragmentation in a Simpang Pulai Marble Quarry,” Procedia Chem., vol. 19, pp. 694–701, Jan. 2016.
[8] A. Aguirre, “Optimización de parámetros de tronadura en función de explosivos de alta energía en Sociedad Contractual Minera El Abra,” Universidad de Chile, 2016.
[9] P. Zuñiga, “Diseno de tronaduras y su impacto en el costo mina de Compañía Minera Cerro Negro,” Universidad de Chile, 2015.