Controlled Trim-Blasting Model to Improve Stability and Reduce Vibrations at a Production Gallery of the San Ignacio de Morococha S.A.A. Mining Company

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Abstract. This paper presents a blasting method called controlled trim blasting, in which the rock mass of an unstable gallery where high levels of vibration have been detected is analyzed. This methodology comprises a drilling mesh with two-contour gallery assessment, producing its drilling machines and determining the type of explosive used and burden and spacing, which will be detonated after the internal blasting. Further, the internal blasting will possess its drilling machines, burden, spacing, and a second type of explosive. The separation of the gallery into smaller parts will improve the blasting, as verified in the recorded simulation. In addition, the rock-mass stability improves because the explosives used in the perimeter of the gallery are low-power with mild detonation pressure, which does not generate high levels of vibration. This is a practical and efficient method in areas where the rock mass is not good or there is a mixture of rock types.

1. Introduction
This document, has been written as a result of the deficiency generated by rock blasting in production galleries. Every time explosives are detonated in the gallery, the level of vibration generated affects the rock and its physical environment; therefore, it is necessary to provide greater support in the gallery, which leads to higher costs in the global production of the pit [1]. The intention is to use the trim-blasting method to reduce the blasting vibrations produced and generate greater stability in the gallery.

Therefore, a preliminary study is conducted on technical parameters such as the type of rock and its physical properties and dimensions of the gallery. Then, as per these results, a drilling mesh is constructed taking technical blasting considerations into account to correct the vibration levels by using either suitable explosives and an appropriately designed drilling mesh or the explosions delays necessary for blasting optimization and improving gallery stability, thus lowering mine support costs [2].

2. Theoretical Framework
The authors Bernaola Alonso, Castilla Gómez, & Herrera Herber [3], in their “Perforación y voladura de rocas en minería” (Drilling and blasting of rocks in mining) book, assert that a very important mine
exploitation factor is blasting and that it is closely related to the blowing techniques, drilling systems, controlled blasting, and the correct use of the explosives that are applied over the rock, thus leading to a generalized method of efficient drilling-mesh designs according to the type of rock mass, safety measures, and their influence on the rock during drilling and blasting.

To better understand this subject, the basic terms used in drilling, blasting, and geomechanics are described below, as define by Ames Lara & Ames Lara [4] in their article “Diseño de las mallas de perforación y voladura utilizando la energía producida por las mezclas explosivas” (Design of drilling and blasting meshes using the energy produced by explosive mixtures).

Blasting—The violent explosion in a gallery, front, chimney, cruise, etc. with assistance from explosives.

Density—The ratio of the volume and mass of a substance and that of an equal volume of another substance that is considered a model.

Detonation—Rapid and sudden explosion caused by a relatively stable explosive.

Vibrations—It is the progressive increase of the waves that elastically and plastically affect the mass in solid or liquid masses on a body.

Stability—Natural state of equilibrium of a rock mass where the vertical tensions are equal to the horizontal ones, not causing rocks to detach or fall.

Gallery—Mining work, where mines are excavated horizontally or almost horizontally with different sizes and shapes, serving as access and a path throughout the facilities and as a road to extract the minerals obtained.

3. State of the Art
The purpose of this research work is to determine the influence of the vibrations produced by blasting rocks in a gallery and how these vibrations affect the stability of the walls and ceilings, often requiring support techniques. Therefore, we must first identify the recurring problem: rocks falling in the blasting areas. Second, we proceed to assess an improved mesh drilling and controlled blasting method. The document by Salum & Murthy [5] debates the determination of the optimal round lengths of excavation in various kinds of rocks and control over tunnel excavation. The excavation sequence and requirements for the top header and bank are also addressed.

In the blasting operation process according to Xie, Lu, Gu, & Wang [6], shock, stress, and seismic waves develop later. Owing to the existence of these waves, the internal structure of the rock mass is inevitably influenced. The vibration speed exceeding a critical value can cause the formation of internal cracks in the rock mass, potentially damaging the protected structure. According to [7], when the blasting and explosive area is determined, the loading structure plays an essential role in blasting-energy transmission.

In the research by Ebadzadeh, Samareh, Esfami, Khoshrou, & Shahriar [8], from the first 11 controllable and uncontrollable parameters the influence of which on the speed of the seismic waves has been assessed by several researchers, the waves that match the propagation path corresponding to each of the 95 recorded in the seismic mapping on the geological and geometric model of the mine were selected.

In the research by Park, Kim, & Kwon [9], a sensitivity analysis of the parameters related to the reduction factor was conducted based on the intact rock; further, the properties in the soft explosion design show the variation of the factor of reduction. When increasing the constant value, the variation of the reduction factor was more significant.

4. Contribution
Considering the optimization and control of the explosions in the damaged zone of galleries to minimize the vibration and the damage in the rock and the design of an excavation method to reduce vibrations in difficult geological areas, the analysis of instability in underground gallery construction and the research study of the development of a damaged area and the influence of mechanical behavior in gallery construction.

The problem is the damage caused by the vibrations produced by rock blasting in the perimeter of the gallery. Considering this, the proposed model uses controlled trim blasting to minimize the
influence of vibrations and yield greater stability in the hanging wall, footwall, and perimeter of the gallery to improve security and lower mine support costs. A controlled blasting uses low-power explosive charges placed with a very small distance between one another and from the edges of the gallery profile. These charges are fired simultaneously to avoid over-breakage and cracks, obtain smooth profiles, and above all, improve stability.

The activities performed according to the problem assessment and solution requirements are as follows:

- To identify the type of rock found in the gallery and its physical properties
- To determine the gallery area
- To identify the accessories required
- To collect drilling data such as drilling mesh, drilling diameters, drilling lengths, load, spacing, and use of relief bores
- To collect blasting data, such as the type of explosive used, and quantity of explosives
- To indicate the sequence of ignition, rock movement, power factor, and load factor
- To determine new data based on mine data that may help develop the controlled-blasting model
- To assess the controlled blasting model through simulation software

Table 1. Data Collected

| Gallery Width    | 4.5 M |
|------------------|-------|
| Gallery Height   | 4.5 M |
| Drilling Length  | 3.50 M|
| Actual Drilling Length | 3.15 M |
| Rock type        | Granite |
| Rock density     | 2.5 Tn/m³ |
| Production bore  | 50 mm |
| Relief bore      | 102 mm |
| Bieniawski classification | 41 RMR Class III |
| Bores used       | 51 bores |
Number of Bores = 45 bores

Then, we only consider the cutting area and proceed to calculate the area, perimeter, and number of bores.

\[ S = \frac{B \times H}{2} \times (8 + \pi); \quad S = \frac{3.5 \times 4.0}{12} \times (8 + \pi); \quad S = 13.00 \text{ m} \]  

\[ P = \sqrt{13.00} \times 4; \quad P = 14.42 \text{ m} \]  

Number of bores = \( \frac{P}{d_t} + (C \times S) = \frac{14.42}{0.62} + (1.5 \times 13.00) = 43 \text{ bores} \)

Then, the load and spacing, amount of charge per bore, and type of explosive to be used are developed.

| Cut section | Burden value | Section side |
|-------------|--------------|--------------|
| First       | B1 = 1.5 x D2 | B1 x \( \sqrt{2} \) |
| Second      | B2 = B1 x \( \sqrt{2} \) | 1.5 x B2 x \( \sqrt{2} \) |
| Third       | B3 = 1.5 x B2 x \( \sqrt{2} \) | 1.5 x B3 x \( \sqrt{2} \) |
| Fourth      | B4 = 1.5 x B3 x \( \sqrt{2} \) | 1.5 x B4 x \( \sqrt{2} \) |

Table 4. Load quantity

| Type of rock | Factor | Drill | N° bore | Load (kg) | Improved Load (kg) | Explosives per bore (calculation) | Cartridges per bore (improved) | #Total cartridges | TOTAL LOAD |
|--------------|--------|-------|---------|-----------|-------------------|-----------------------------------|-------------------------------|------------------|-----------|
| Very         | 1.5 to 1.8 | Relief | 3.00   | 0.00    | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Difficult    | 1.3 to 1.5 | Boot   | 3.00   | 1.33 x 1.50 | 2.00 | 5.42 | 5.50 | 16.50 | 5.99 |
| Easy         | 1.1 to 1.3 | Aids  | 17.00   | 1.33 x 1.20 | 1.60 | 4.34 | 4.50 | 76.50 | 27.15 |
| Very Easy    | 1.0 to 1.2 | Quarry | 6.00   | 1.33 x 0.90 | 1.20 | 3.25 | 3.50 | 21.00 | 7.19 |
|              |         | Upper | 8.00   | 1.33 x 0.60 | 1.20 | 3.25 | 3.50 | 28.00 | 9.58 |
|              |         | Puling | 6.00   | 1.33 x 1.00 | 1.33 | 3.62 | 4.00 | 24.00 | 7.98 |
|              | Total No. of bores | 43.00 | | | | | | | 166 | 57.89 |

Finally, after completing the entire calculation process for the cut of the internal gallery, we proceed to conduct the same process in the contour for controlled trim blasting.

Number of bores = 45 bores
Spacing = 0.31 m
Burden = 0.40 m
Trimming area = total area - new area = 18.80 - 13.00 = 5.80 m²
Load factor = 1.3
Actual Length = 3.15
Volume = Area \times \text{Actual length} = 5.80 \times 3.15 = 18.27 m³
Load quantity = Volume \times \text{load factor} = 18.27 \times 1.3 = 23.75 kg \times \text{shot}
Load per hole = Load quantity / Number of bores = 23.75 / 45 = 0.53 kg/bore
ton = Volume \times \text{Density} = 18.27 \times 2.5 = 45.68 ton
Explosive: Exadit 45 weight 0.076 g - 328 per box
Number of cartridges = \( \frac{\text{Load per bore}}{\text{weight}} \times \text{number of bores} = \frac{0.53}{0.076} \times 45 = 313.8 \) cart.

In the simulation, the quantity of explosives will be considered not only in the cut but also in the trim area. In addition, the production and relief diameters, spacing, actual perforation length per bore, distribution of the bores in the drilling mesh and type of explosive used in each blasting will be required.

The number of bores in the determined mesh will be carried out using the simulation software.
6. Conclusions

- The controlled trim-blasting model was efficiently developed by reducing the vibrations in the hanging wall, footwall, and contours of the gallery using parameters that can be measured according to the characteristics that are available in the production gallery at the San Ignacio de Morococha SAA mining company.

- Some of the effects of the implementation are as follows: the working time improved because pneumatic bore and support work were conducted after the blasting; the reduction of the high costs involved in the making of support of any type; and the improvement in the drilling mesh in the production gallery.

- As shown in Figure 10, the contours have not been damaged, nor has breakage been caused, thus improving the stability of the rock mass while reducing the vibrations to a level that renders a stable gallery with little or almost no support.

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