Seismic analysis of vibration induced by rock blasting in underground mining

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ABSTRACT: Vibrations from a rock blasting can cause catastrophic damage in areas near and far from the source. Understanding their behavior in the rock mass and how their properties can be interpreted in favor of the blasting plan has been a great challenge faced in the Brazilian underground mines, due to a considerable number of detonations that occur daily and lack of valorization of this technique.

This paper will present a study case contain details about the rock mass considering the geomechanical parameters and rock strength. The entire discussion will be based on the monitoring plan, methodology, from the instrumentation campaigns on confined blasting to the technical recommendations of the observed interpretations. Finally, the equivalent attenuation curve will be discussed from the data collected and a technical recommendation to minimize the risk of displacement of rock blocks on the region of influence induced by blasting.

1 INTRODUCTION

The detonation represents one of the most important unit operations in all underground mining operations, where is quest a good fragmentation of the material and a good adherence of the planned advance, which is in development or in mining.

Vibration monitoring using velocity sensors (geophones) allows advantages in the detailed understanding of the detonation due to the possibility of quantifying the particle velocity levels that causes the detonation of a known explosive charge, as well as knowing the relative efficiency of each charge operation, its interaction with the adjacent charge holes and the general behavior of the fire plane with the rock mass.

Thus, vibration monitoring has been used as a blasting diagnostic tool, where an adequate interpretation of the seismogram allows determining the degree of interaction between the variables of a detonation, making it possible to evaluate blasting in an incorrect sequence of holes, dispersion of defined delay times, poor detonation of charges, instantaneous detonations, and detonations by sympathy.

The vibrations produced by the detonation, and the knowledge of the geomechanical properties of the rock mass, allow to estimate the probability of causing damages in the adjacent rock mass. High vibration levels cause damage to the rock mass, producing new fractures or reopening pre-existing discontinuities. The vibration, in this context, can be considered as an effort or deformation of the rock mass (Garrido, 2007).

2 OBJECTIVE

This work presents the seismographic results of monitoring detonation of development and mining (fans and slots) at the Cuiabá Mine, owned by AngloGold Ashanti.

The objective of this study is the elaboration of an attenuation curve for the blasting operations in the rock mass of the Serrotinho, Fonte Grande, Galinheiro and Balancão ore bodies, in order to understand the propagation of vibration in this study environment.

To find basic understanding of the behavior of the vibrations in the lithologies Carbonate-quartz-epitoto-chloroxist (MANX), quartz-carbonate-sericita-schist (X2CL); Banded Iron Formation (BIF) and Carboniferous Shale (XG), nineteen seismographic instrumentation campaigns were carried out, totaling 57 points.

The final products of the project will be to define a maximum charge per delay (MCD), at a given distance (D), for each lithotype, seeking to guarantee the least possible damage in nearby excavations, or adjacent pillars.

3 METHODOLOGY

For the monitoring campaigns of the detonations were used seismographs of engineering, duly calibrated.

The method of reading adopted by the seismograph varied in the trigger with lower limit between 0.51 to 2.0 mm/s and recording time varied according to the maximum delay time of each blasting, due to the fire plan adopted in each slot, fans or face of development.

The location of the monitoring points and the location of the blasting with their respective distances were made through a laser distance meter. From the blasting site, the first seismograph was installed at a certain distance, and then the others were installed at various distances.

As a reference, topographic plugs located near the monitoring points were used and measurements were taken from them using the laser distance meter.

For a data collection standard per monitoring campaign, a procedure developed by MecRoc Engenharia was followed, as detailed in the subitems below.

3.1 *Charging data*

The information collected in the field is of extreme importance, since it is the actual data of the charging, from which the premises for the interpretation of the data acquired by the seismographs will be realized.

With this data, and with the monitoring of the charging operation, it is possible to illustrate a profile of the distribution of the charge per hole, in addition to a sketch showing the distribution of the hole, as shown in Figure 1.

A map showing the locations of the geophones and their distances to the emitting source was generated for each blasting, as shown in Figure 2.

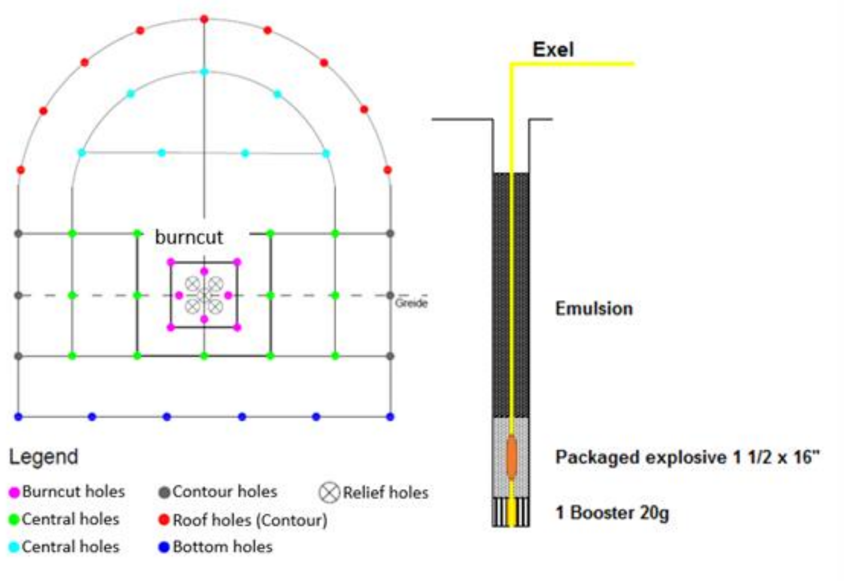

Figure 1. Development section (left) and charging components into the hole (right)

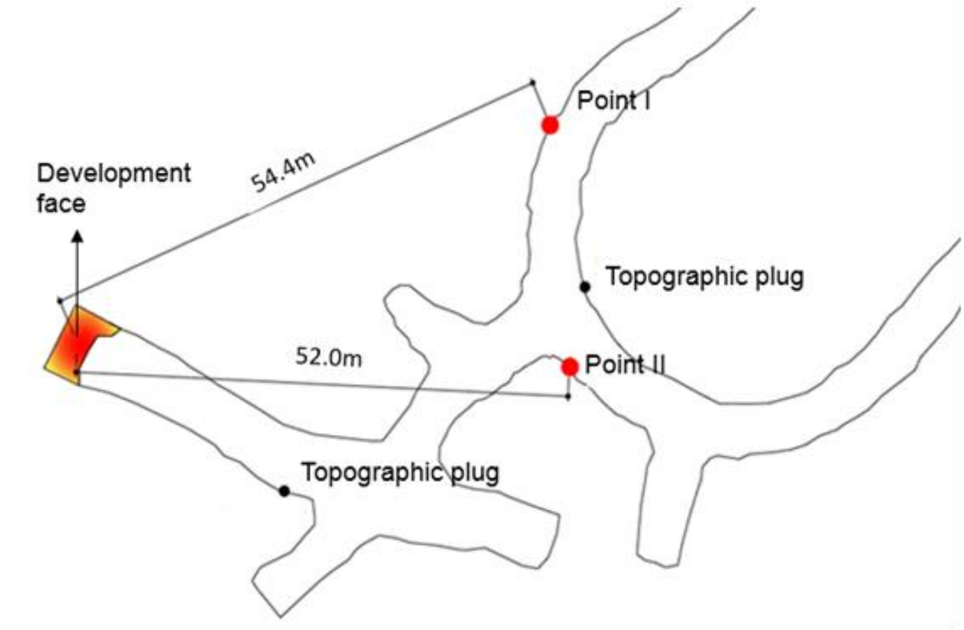

Figure 2. Location of monitoring points at a development blasting

3.2 *Seismic data*

In this work we will detail only the seismic data collected from confined blasting in the mining area. The analysis was done according to Figure 3, where the holes of the detonation with their respective delay, were aligned with the time of the pulses in the graph of the seismogram captured by the engineering seismograph.

In this way, it was possible to identify the holes detected in the seismogram and the undetected holes. Through the photo of the face of the detonation site, it was possible to represent these holes with different colors as shown in Figure 4.

1	2	3	4	5	6	7	8	9	10	11	12	13	Nº Furo
0	750	1450	2150	2850	3550	4250	4950	5650	6350	7050	7750	8450	Esperas (ms)

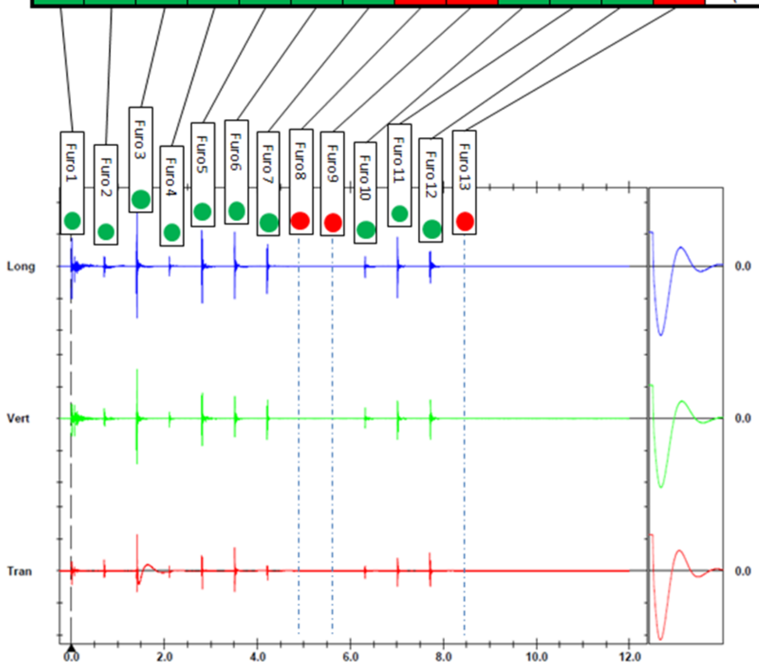

Figure 3. Seismogram of one confined mining blasting

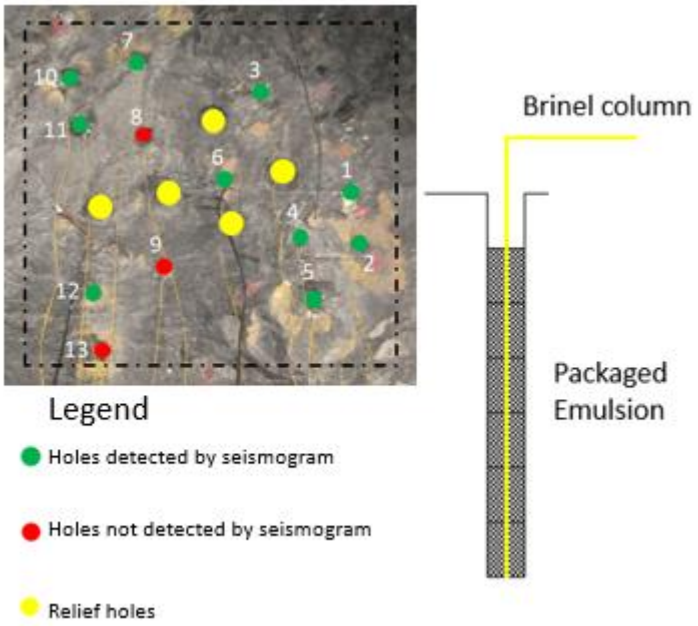

Figure 4. Slot blasting sketch (left) and charging components into the holes (right)

3.3 *Wave attenuation*

The wave attenuation in a rock mass consists of an intrinsic property of the spread environment, where its definition is conditioned in vibration values (PPV). According to Lima and Silva (2006), Yang et. Al. (2014) and Silva (2006) The traditional model to investigate the mitigation law is based on a regression analysis, being expressed by the equation:

$$PPV=k\,X\left(\frac{d}{\sqrt[2]{Q}}\right)^{-\alpha} \quad (1)$$

where PPV= Peak Particle Velocity (mm/s); K e α = Constants representants of the confinement and mass characteristics; d = Distance between the explosive charging and the monitoring point; and Q = Maximum charge per delay (kg).

3.4 *Damage to the rock mass*

Regard the rock mechanics, it should be evaluated which influence of the explosives across the surrounding of the blasting location. To do so, it should be accumulated data collected with geophones and thus seek to interpret them with existing theories.

3.4.1 *PPV minimum criteria*

One way of assessing the maximum extent of the damage zone, where preexisting rock fractures can propagate and dilate under the influence of relatively low levels of vibration, can be expressed by the equation:

$$PPV_{mínimo} = \frac{0{,}021\sigma_1}{V_p \cdot \rho_R} \quad (2)$$

where PPVmin. = Minimum particle velocity causing extension and dilation of preexisting fractures (mm / s); σ 1 = Principal stress at estimated rupture for intact rock (Pa); ρR = Density of intact rock (g/cm³); and Vp = Wave propagation speed (m/s).

Information needed to determine the minimum PPV, such as: lithography, UCS, Barton Q, rock mass depth and intact rock density, were obtained by the rock mechanics team of Cuiabá Mine. According to Barton (2002), the velocity of propagation was estimated through the Barton Abacus, using the depth of the rocky mass and the Q of Barton (Figure 5).

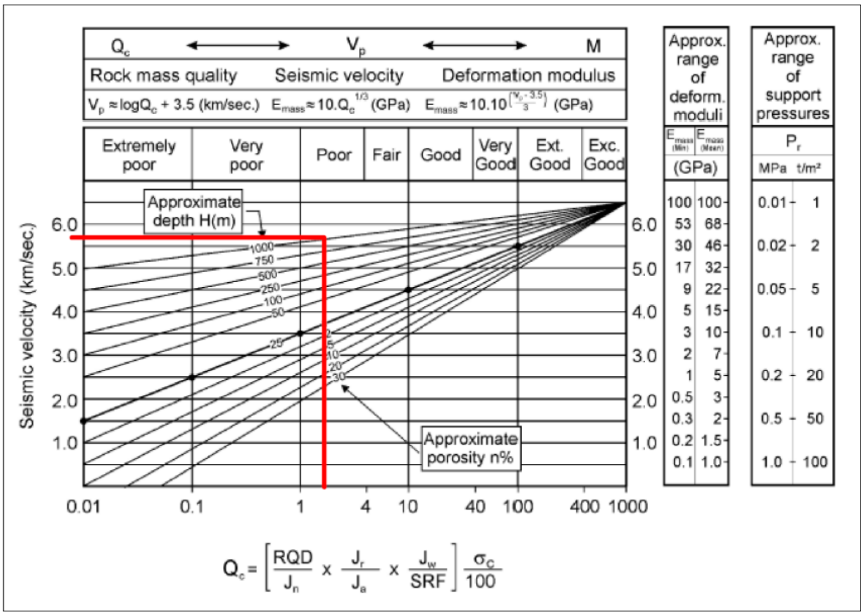

Figure 5. Barton Abacus - Definition of Vp (wave propagation velocity), according to depth and quality of rock mass "Q".

4 RESULTS

For the graphs of this chapter, it is worth mentioning the concept of PVS - Peak Vector Sum or Resultant Particle Velocity, which consists of the maximum value obtained by the vector sum of the three simultaneous orthogonal components of particle vibration velocity considered over a given time interval. Peak vector sum (PVS) is often used in relation to PPV because it reflects the effect of the other two components (Bollinger, 1980).

The models are generated by the statistical fit that describes the average data population, which means that 50% of the data is below the curve that represents the model and the remaining 50% are above the curve.

Mathematically correct, however, it means that there is a probability that 50% of an explosive charge will produce a level of vibration that exceeds that predicted by the model, a situation that leaves the model useless for practical purposes, particularly for projects aimed at controlling the vibration and damage. Therefore, it is recommended to raise the attenuation curve to a 95% confidence interval, covering a larger amount of data, thus making it more reliable to estimate the vibrations.

The definition of the attenuation curve uses two parameters as the main ones, being: distance between the origin of the detonation and the seismographic reading point and maximum charge per delay, however, other variables in the detonation process cause changes in the determination of the curve and its consequent dispersion (Dowding, 1985). Among these, it is possible to emphasize variation in the characteristics of the waiting times, geological conditions, type of explosive, spacing, spacing, buffer, free face wave reflection and others.

Figure 6 below allows to compare the attenuation curve determined in the Devine model for the three detonation domains of the study in question: Fans, Development, Slot.

The attenuation curve was determined using the PVS Resulting Particle Velocity (Peak Vector Sun) and the actual maximum charge per delay for the blasting.

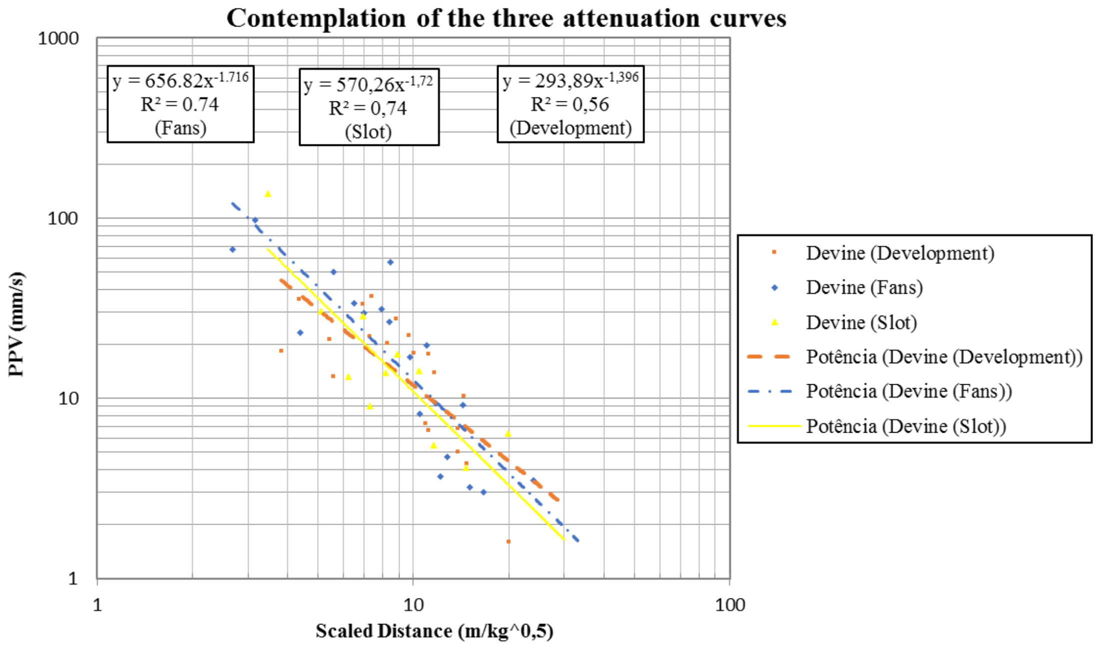

Figure 6. Attenuation curve for each type of blasting operation

From these data, local attenuation coefficients of the rock mass were obtained.

A PPVmin was calculated to each lithograph, the XG equal to 74.9 mm/s; MAN, equal to 132,61 mm/s and BIF 216,7 mm/s.

After the attenuation analyzes and the definition of PPVmin, three abacuses were constructed that correlate the explosive kilo x distance x vibrations for each equation of the attenuation curve, e one elaborated for the development is showed in Figure 7 (MecRoc, 2019).

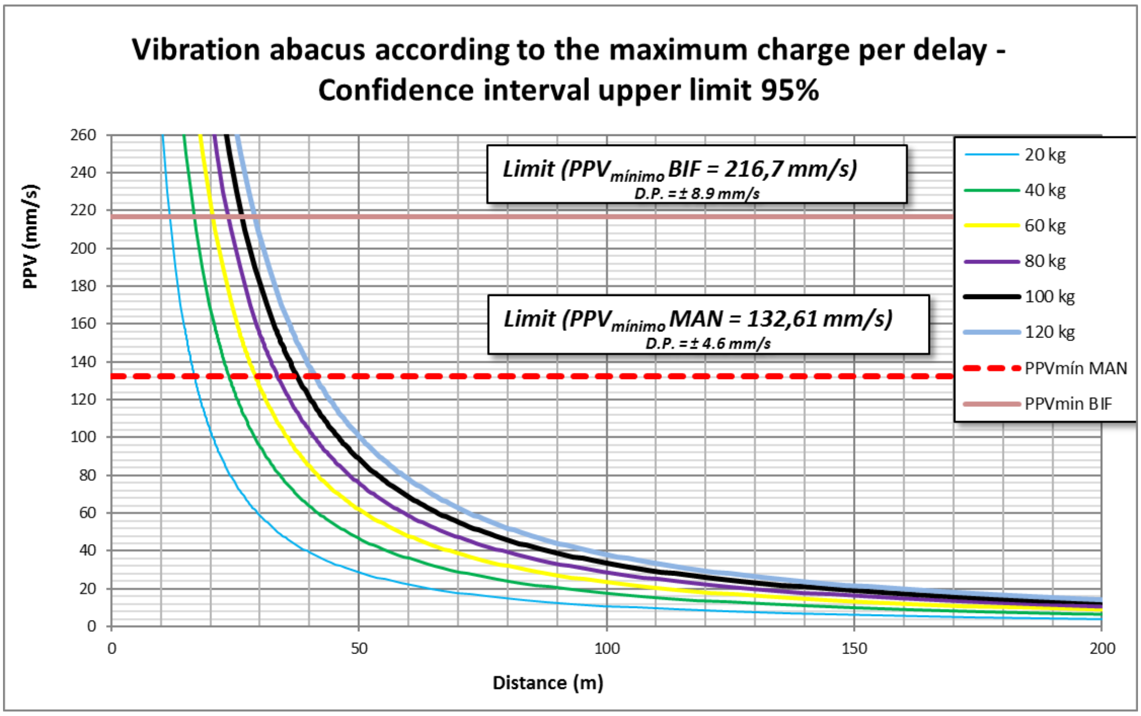

Figure 7. Vibration abacus according to the maximum charge per delay - Confidence interval upper limit 95%

5 CONCLUSIONS

The detonation activities represent an opportunity for operational improvement and technical evolution in mining, since many of the current routines are mostly derived from empiricism. Certainly, such knowledge has already allowed and still allows to add value, however, can be optimized in geotechnical, safety and financial aspect in optimizing costs from the material and rework perspective.

All the field work performed to determine the attenuation curve in different situations was demonstrated with acceptable reliability, R^2 higher than 74% for the fan and slot curves, whereas for the development curve it presented a 56% R^2, however, a continuous data collection should be followed to maximize the results and benefits of this study.

By the critical evaluation of the developmental detonation seismographs, it is noticed in two situations that some holes detonated in the correct time, however, did not transmit energy in the surrounding rock mass nor the distance that it should fracture. This evidence demonstrates that previous charges are already enough to open the face, a fact that reiterates the relevance of the practices of control of diversion of drilling and / or revision of the design of fire plan. By monitoring it is believed both opportunities can be worked out.

For fan detonations, the profiling of the holes should be used as instruments to understand the behaviors evidenced. It is noteworthy for this process that during the detonation process some holes in the sequence of the same process may tend to displace, because of the vibration, towards the floor, canceling some holes.

For the detonations of slot, it was observed that the number of holes not detected in the seismograms presented a high index, that is, in 51 holes charged, only 28 were detected in the seismograms. Such scenario highlights the criticality of this detonation and the real need for the application of profiling and proper slot drilling planning to be performed.

6 FUTURE WORK

It is noticed the need to increase the interpretation of the effect of the detonation in the rock mass, therefore, a study using near-field seismographs associated with the use of calibration instruments as micro cameras for monitoring holes will be conducted.

Further detailing of seismograms through signature hole analysis will allow to define for each lithograph the minimum delay times required, thus avoiding impacts of detonation quality and the nesting rock.

The increase in the quality control of the explosives in the operation shows an opportunity, so the control of the VOD (Velocity of Detonation) will allow indirect monitoring of the explosive efficiency since this parameter is determinant of the detonation pressure and consequent vibration to the rock mass.

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