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THE EFFECT OF BLASTING ON FALLS OF GROUND IN UNDERGROUND MINES

Batista, G.A.P.

AngloGold Ashanti, Crixás, GO, Brazil

Da Silva, J.H., Ramires, J.E.F., Carvalho, A.S. and Campos, M.P.

AngloGold Ashanti, Crixás, GO, Brazil

Gontijo, A.A. and Matos, A.R.

MecRoc Engenharia, Belo Horizonte, MG, Brazil

ABSTRACT: The rockfalls are recognized as the main cause of accidents at underground mining activities and are denominated as Fall of Ground. Aiming to reach a high level of risk management, real rockfalls examples will be expose as the developed methodology for risk prevention at the Mineração Serra Grande, located in the city of Crixás, in the state of Goiás, in central Brazil, and operated by AngloGold Ashanti. The result has shown the possibility to identify instability potential targets and by applying abacuses and modeling, is possible to manage these locals aiming to minimize the risks caused by rockfalls. The attenuation rule model proposed for this mine presents a good equivalence of 93% with the correlation coefficient. Defining the minimum vibration level for forming instable blocks is possible to determine the blast influence, turning possible to manage the project from an efficient and safe perspective. Therefore, this article aims to contribute for mineral operations management on reducing rockfalls hazards.

1. INTRODUCTION

The vibrations caused by the drill and blats process are a matter of concern due the structural damage they cause in the rock mass.

The vibrations are transmitted in all directions and aiming the prediction of risks and vibrations control, the Law of Attenuation can be used since it is able to predict vibration levels based on field data acquired through the seismographic monitoring.

The seismographic monitoring is a key tool as intended to measure vibrations propagation within the rock mass. Engineering seismographs can operate continuously over a period or make sporadic measurements.

The attenuation law model is based on the parameters from the particle velocity measurements obtained through the seismographic readings and the scaled distance, since it registers the blast charges in the same instant as the blast epicenter distance, making it possible to identify damaged targets. Therefore, the construction of a graphic, relating the values of particle velocity and the scaled distance, constitutes the Model of Attenuation Law.

Another factor that influences vibrations is the highest charge of explosive inserted in the drilled holes, called maximum charge per delay (CME). It can be a single or several holes loaded and blasted simultaneously, through an arrangement determined by the position of the delays in the holes.

This study aims to present the attenuation curve in addition to understand the vibration propagation within the rock mass, being this factor one of the main causes for blocks disarticulation inside the mines. Thus, the seismographic results from the blast monitoring from the underground mine called Mina Pequizão from Mineração Serra Grande will be presented as a case study through presenting the calibration results of the model presented.

The Serra Grande Pequizão Mine is operated by AngloGold Ashanti, in the city of Crixás, at Goiás state, in central Brazil. The underground operations have been conducting their excavations at depths ranging from 300 to 800 m as discussed by Batista & Campos, 2015.

2. OBJECTIVES

Historically, mining has been one of the riskiest activities in its exercise. Mining workers are expose to a number of workplace hazards that may be associated with accidents caused by electric shocks, explosions, choking, rockfalls, noise, dust exposure, poor lighting, ventilation deficiency among others, characterizing mining as one of the risk activities (Groves *et al.*, 2007).

In recent years, there were significant reductions in the rate of injuries and fatal accidents in this field. This is due to the health and safety advances in operations around the globe and better management of the workforce conditions since they access the underground mines every day. Aiming to make mining a safer environment through implementing security policies and taking actions that should always be monitored and controlled.

Rock falls are recognized as the main cause of accidents in underground mining activity. Most of the time rockfalls occurs due to the vibrations from the blasts. Therefore, it is necessary to understand the level of vibration supported by the rock mass in function of its geomechanical characteristics.

This article presents an approach of how it is possible to manage mining areas that are affected by the blasts and cause rockfalls responsible for work accidents by using the methodology of the seismic wave attenuation.

3. METHODOLOGY

The methodology is divided into two stages:

Obtaining the attenuation curve:

The first step is grounded on obtaining the rock mass vibration attenuation curve and its equation. For this purpose, a GeoSonics 3000 EZ PLUS engineering seismograph was used to determine the peak particle velocity (PPV). The maximum load per delay (CME) was determined in the blasting plan carried out at the Pequizão Orebody and the monitored distance was obtain using the Studio-3 modelling software from Datamine.

The obtained results are presented graphically, where the peak particle velocity (PPV) represented by the vibration levels are correlated with the scaled distance. The scaled distance consists in the correlation between the monitored distance and the maximum load per delay (CME), and it is defined by the scaled distance (DE) equation, Eq. (1):

$$DE = \frac{D}{(CME)^{0.5}} \qquad (1)$$

Where "D" is the distance between the monitoring point and the detonation (m) and "CME" is the maximum load per delay (kg).

The mathematical expression that comprises the law of attenuation is describe as Eq. (2):

$$PPV = K(DE)^{-b} \qquad (2)$$

Where PPV is the peak particle velocity (mm/s), DE is the step distance ($m/kg^{0.5}$), the coefficient "K" is related to the intensity of the seismic energy that is transferred to the terrain, and "b" is associated with lithological and structural variations of the local lithotypes, where the seismic wave passes being a measure from the reduction of the particle velocity intensity along the distance as discussed by Rosenhaim, 2005.

From these analyzes is established the graphic of the particle vibration velocity, as a function of the scaled distance and determining the coefficients "K" and "b".

Determination of the minimum PPV parameter:

The second step presents the rock parameters to determine the minimum velocity of the peak particle.

Rock parameters such as Modulus of Elasticity (E), Uniaxial Compressive Strength (UCS), Mean Propagation Rate and Rock Density were obtain by laboratory tests. It is also possible to obtain propagation velocity as described by Barton, 2009. Rock Quality, Seismic Velocity, Attenuation and Anisotropy, where theoretical propagation velocity abacuses are presented in relation to mass quality.

The minimum PPV will be obtained from the literature based on the methodology proposed by Ryan and Harris, 2000. The minimum PPV can be determined by the resistance of the Rock Mass - UCS_{MR} in MPa (σ1), Propagation Rate in m/s (Vp) and Rock Density in g/cm3, as described below, in Eq. (3):

$$PPV_{minimum} = \frac{0.021\sigma_1}{V_p\ \rho_R} \qquad (3)$$

In relation to the literature, it is observe that for different authors there is a great variability regarding the damage criterion, probably due to the use of intact rock data. In this work, the UCS_{MR} is being used aiming not neglect the influence of rock blasts, since most of the blocks are limited by them. Thus, the values will be obtain using the RocLab software from Rocscience Inc., based on the Geological Strength Index (GSI) classification from Hoek and Marinos, 2000.

4. RESULTS

The understanding of the waves attenuation within the rock mass is pretty important for the predictability of the possible impacts in the nearby excavations. In this item, the results obtained from the calculation of the attenuation curve will be present, as the correlation between the maximum load per delay (CME) and the PPV for typical the lithology of the Pequizão Orebody denominated Carbonaceous Schist (GXN).

Two engineering seismographs were used to monitor vibration and noise generated by detonations. A total of 45 events were registered, from which 32 were used to construct the attenuation curve, since some data were not possible to correlate with the blasts events due the interference of other unpredicted blasts next the area.

Seismographs were installed aligned but with different distances, in order to capture more than one event and to determine the decay of the vibration levels within the rock mass as the distance increases from the blast. Therefore, to determine the seismic wave attenuation, the Table 1 presents the data from the seismic monitoring conducted at the Pequizão Orebody.

Table 1. Seismograph Data

Serra Grande Mining	Peak Particle Velocity (mm/s)	Scaled Distance (m/kg^0.5)	ID number
Pequizão Orebody	3.18	34	3
	2.92	35.2	4
	72.64	3.4	5
	11.18	9.2	6
	5.27	14.5	7
	3.68	14.2	8
	24.51	5.6	9
	1.65	25.7	10
	1.4	44.5	11
	0.64	49.1	12
	5.1	13	14
	5.7	10.9	15
	5.9	12.1	16
	3.8	14.5	17
	6.4	9.7	18
	8.6	10.3	19
	41.6	3	20
	38.8	4.7	21
	49.3	3.3	22
	41.4	2.5	23
	47.6	3.2	24
	53.7	3.7	25
	36.6	2.9	27
	61.2	1.9	28
	135	1.4	29
	122	1.9	30
	10	7.8	33
	16.8	8.4	34
	11.4	11.8	40
	43.9	4.9	42
	12.5	5.4	43
	45.7	2.4	44

Figure 1 illustrates the attenuation curve elaborated with the monitoring data. The elaborated curve presents a reliability of 93%, turning possible to determine the "K" coefficient related to the intensity of the seismic energy being transfer through the rock mass and the "b" coefficient associated to the local lithotype composing the rock mass. Thus, the values obtained for K = 212.99 and for b = 1.37.

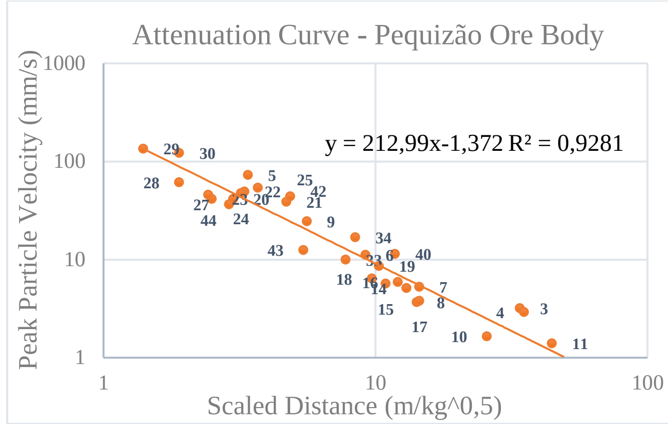

Fig. 1. Attenuation curve for the Pequizão Mine - Mineração Serra Grande.

To determine the minimum PPV, histograms were generated from the mine database, a total of 21 samples were used to define the Uniaxial Compressive Strength and 18 tests for the mass propagation velocity, as the results can be seen below (Fig. 2 and Fig. 3).

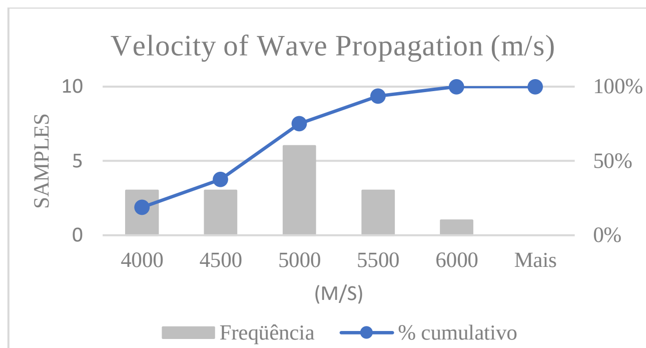

Fig. 2. Velocity of Wave Propagation of lithology GXN at Pequizão Mine.

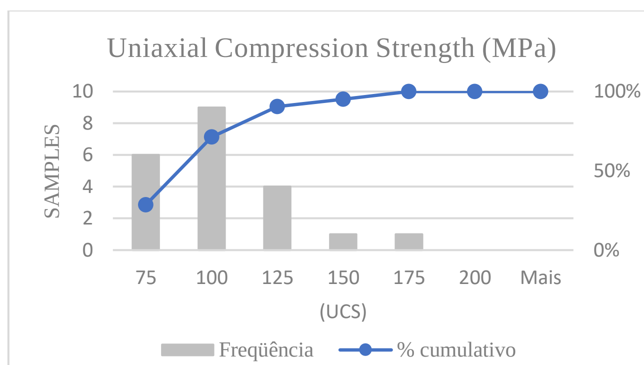

Fig. 3. Uniaxial Compression Strength of lithology GXN at Pequizão Mine.

The values of UCS_{MR} were obtained with the software RocLab of Rocsciense. For this, GSI classification was generate in which the value 70 was adopted after the analysis of the geotechnical database, obtaining a value of 29.6 MPa.

Table 2 shows the summary of the values used to determine the minimum PPV. The result states that the propagation velocity of 45mm/s has the potential to generate unstable blocks on the surface of the excavation.

Table 2. Parameters to determine the PPVmin.

Parameters to determine the PPVmin.	
Lithology	GXN
Velocity of propagation (m/s)	5000
UCS Rock Mass (Mpa)	29.6
Tensile strength (Mpa)	3.0
Rock Density (g/cm3)	2.78
Minimum PPV (mm/s)	45

By adopting a fixed limit value for particle velocity levels, in the case of 45mm/s, reference values can be obtained for the maximum load per delay (CME), to be used over the preset distance. In the following table, some maximum CME values for certain distances based on the attenuation of the Mine wave are presented.

Table 3. Influence on the unstable rock blocks generation based in the maximum load per delay.

Lithology	Distance (m)	Max. charge per delay – CME (kg)
GXN	20	40
	30	90
	40	160
	50	250
	60	360

According to the analysis in Table 3, it is possible to verify that the CME values influences the generation of unstable blocks according to a limit distance from the blast. Thus, simulating a 90kg CME, within a 30-meter radius, unstable blocks will be generated and at the same time greater distances does not presents damages as the ones near the blasting. Therefore, in the prevention of accidents involving rockfalls caused by blast vibrations, activities such as inspection and scaling must happen in areas that are receiving vibrations higher than PPVmin.

Regarding this, the particle velocity abacus is generated as a function from the distance, quantifying the risk occurrence of blocks formation at the walls and backs of galleries and according to the PPVmin. In this abacus, it is possible to verify that for a CME of 25 kg unstable blocks can be generate within a radius up to 16m from the blasting heading, represented by the gray line. On the other hand, the red line has a CME of 125kg that can generate unstable blocks in a radius up to 35m distance.

It is important to highlight that this study is an opportunity to reinforce the necessity of improvements in scaling practices along primary and secondary development areas. Figure 4 shows the abacus of particle velocity in function of the distance.

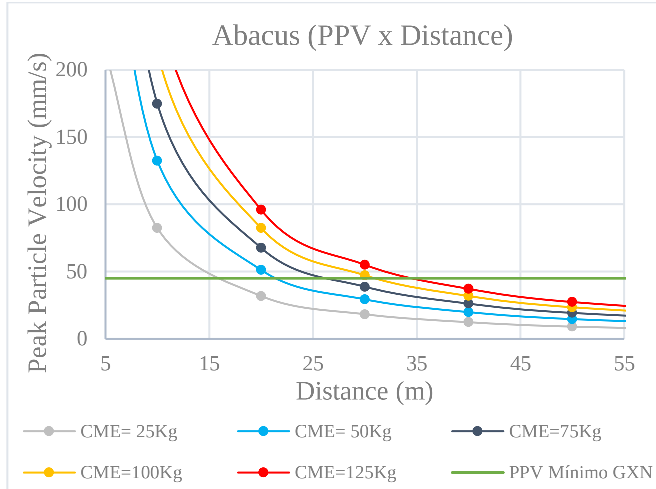

Fig. 4. Abacus of particle velocity as a function of distance.

At the project level, the BasRock GEM4D software interpolates the attenuation of the seismic wave bringing the ability to insert the constants "K" and "b" obtained through the analysis. Figure 5 shows a project in which it is possible to verify the wave attenuation on the surface of the excavation.

The colors from red to green represent seismic wave velocities above 40 mm/s, higher than the PPVmin obtained for this lithology - GXN. Thus, this region presents the potential of generating unstable blocks. This example illustrates the risk region not only in the gallery under development but also in the main access - primary ramp - due to the proximity of the blasting by the maximum charge per delay.

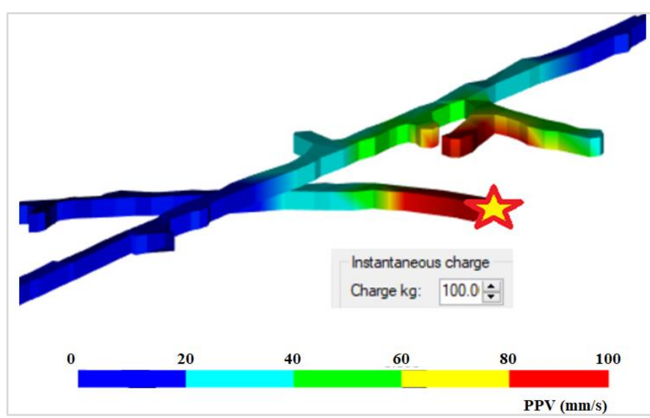

Fig. 5. CME-based particle velocity of the blasting and its influence on underground excavation.

Based on real events at the mine, two case studies will be presented that corroborate with the use of methodology. The first is ground on the fall of a rock block unexpectedly, determined as fall of ground (FOG), on 21 of February 2018.

The 260 kg block fell soon after the blast at a stope area, 42 m away, in which a maximum load per delay of 212.94 kg was use.

According to the analyzes, the vibration velocity at the FOG site was 60 mm/s (Fig. 6). Beside the fall of the rockfall, labors took turns working in a region with shotcrete support.

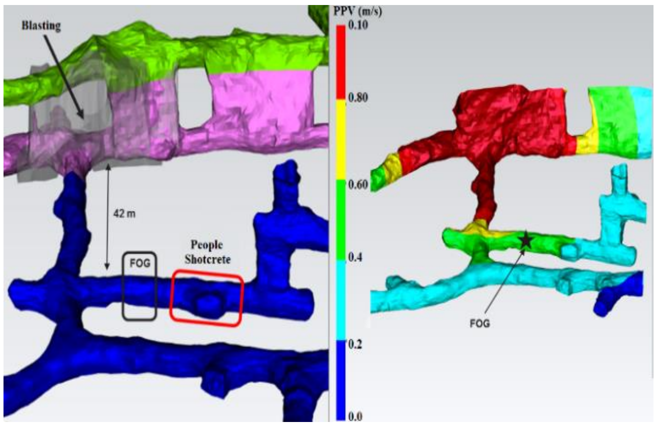

Fig. 6. FOG at 42 m away from the stope. Analyzes demonstrates vibration velocity of 60 mm/s at the event site.

The second example is based on the mining project with the ramp below the blasting region on 25 May of 2018. The simulation of attenuation of the seismic wave predicted the probability of rockfalls at a piece of the ramp, with propagation velocity up to 100 mm/s (Fig. 7).

The recommendation to use surface support was performed and the meshes were applied on the backs and walls. The whole part marked from green to red presented blocks hanging on the meshes during the following blast, with vibrations reaching a speed that exceeds 40 mm/s.

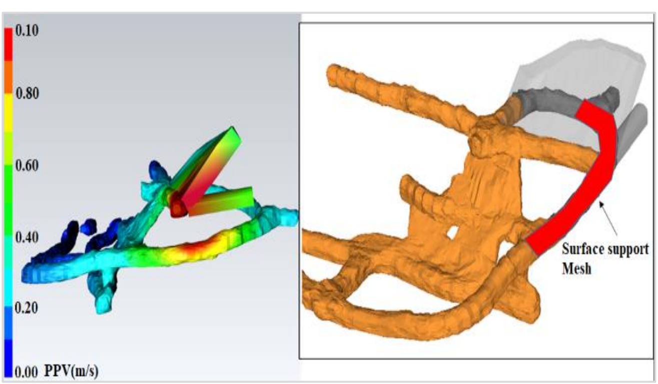

Fig. 7. Simulation of the seismic wave attenuation during rock blasting and its interference on the access ramp.

After this date the verification of the influence of the blast and their impact on rockfalls has been incorporated into the company Geotechnical Practice Code, in order to carry out the risk management and to recommend the appropriate support system. Figure 8 represents the methodology, indicating the likely regions that will be influenced by the rock blasting.

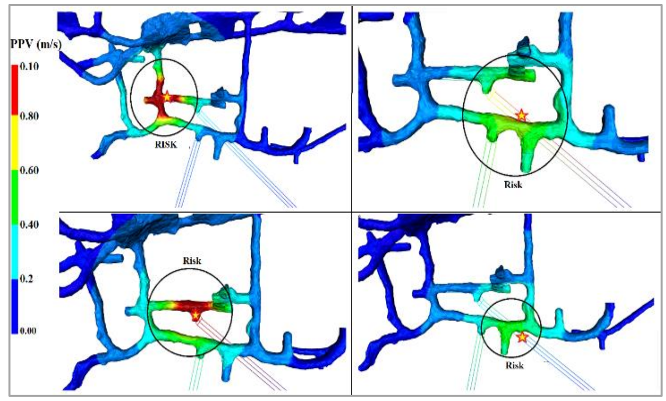

Fig. 8. Evaluation of developed galleries indicating regions of influence from the blasts.

5. CONCLUSION

The proposal of an attenuation curve for the blasting activities in the Serra Grande Mining was satisfactory for Pequizão Orebody. The proposed Attenuation Law model for this mine shows a good equivalence exposing a correlation coefficient of 93%.

Defining the minimum vibration level for rockfalls generation, and based on works related to the attenuation of the seismic wave, it is possible to determine the influence of the blasts, aiming to manage the project from an efficient and safe perspective.

One of the greatest risks to human life in mining activities, and one that must be avoid in underground mining practices, is allowing the formation of unstable blocks. Therefore, this article aims to contribute to the operational management of mining in order to influence the reduction of risks caused by rockfalls, as the practice of applying surface support is not a common practice in all underground mines.

It is recommended to test this methodology in other lithotypes from the Serra Grande rock masses, in order to understand how wave attenuation behaves in a different geological environment.

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