Estimation of Critical Distances to Avoid Failures in Detonators by Dynamic Pressure

Phol M. Llanos, National University of San Marcos
Lizbeth A. Escobar, National University of San Marcos
Maritza Y. Avila, National University of San Marcos

Abstract

In the blasting process in Open Pit mining, currently in Peru, the most used type of detonator is electronic because they provide greater safety and precision, leading to greater control in the fragmentation and vibration process. Another important characteristic is its resistance to external effects, among them, dynamic pressure, since it has a set of protections in its structure which varies according to the manufacturer, this allows it to be classified as the most resistant in the industry. However, in certain geological conditions such as the presence of discontinuities, ground water, voids and fill, the effect of the dynamic pressure will be greater, exceeding the resistance values of the detonator, existing the probability that the misfire will occur, which they represent a danger in mining as they can cause accidents.

That is why the present research work seeks to define critical parameters such as the time and critical distances between holes in different geological domains, taking into account the strength of the detonators, the diameter of the hole, length of charge, length of plug and density of the explosive. Faced with this problem, the need arises to use mathematical models for the effective prediction of stresses around a drill, such as the vibration modeling for near field proposed by Holmberg & Persson, based on this, the estimation of the stresses generated by an explosive charge on the adjacent detonators being evaluated in different ground conditions, which will be compared with the maximum efforts that the electronic detonators resist and thus obtain the critical parameters such as time and distance. For that, a data taken in the field through triaxial seismographs will be used, which were strategically located, taking into account the distance from the blast to the monitoring point, based on this, applying the predictive model the authors can find the values of the constants κ and α and perform the data extrapolation. In addition, the hydrodynamic model of Neyman will be used, which will help us to predict the extension of the damage zone that surrounds an explosive charge and with this will corroborate the results obtained from the Holmberg & Persson model, that based on these, it will be able to give scopes to improve the design and blast performance.

The application of these models will achieve the calculation of critical distances (H&P model 1.26m and the 1.49m Neyman Model) based on vibration parameters and damage control in the detonators are electronic for future designs and decision making, facilitating, and adding value to the company.

Introduction

Over the years, the use of technology has become more and more frequent both in surface mining and in underground mining and in the blasting process where new techniques allow increasing the amount of explosive energy that is applied in rock mass. Increasing the explosive energy per unit mass of surrounding rock in the hole multiplies all related physical variables. Taking this into account and establishing the conditions of the rock mass in conjunction with an inadequate blast pattern design, there is a probability of the occurrence of unwanted events such as misfires and this in specific cases is since the electronic detonator has undergone impact deformation of dynamic pressures, mainly due to the use of auxiliary holes due to deficiency in the main drilling. That is why making use of the mathematical model of Holmberg & Person and from a data obtained in the field, the PPV will be extrapolated and with the hydrodynamic model of Neyman it will corroborate the extrapolated data from the model to improve the process blasting and global operations guaranteeing optimal results.

In order to ensure that the implementation of this type of model will not have negative effects such as those indicated in the previous paragraph, a procedure has been defined to determine the dynamic pressure exerted between adjacent holes, this can be reliably reproduced in the field, providing information regarding how the behavior of these pressures influences under different blast configurations. That is why the present research work seeks to define critical parameters such as the time and critical distances between holes in different geological domains, considering the detonator strength, hole diameter, charge length, detonator length and explosive density. The results and analysis cannot be extrapolated to another rock mass, but they allow generating a design base for optimization work by increasing the explosive energy. These provide an antecedent regarding the factors that mainly affect the propagation of pressures and how influential the quality of the rock can be on them, technically valid for the sector in which they were taken, but represent, in turn, the bases and forms in which the phenomenon of pressure propagation occurs through the rocky mass.

Near field prediction model - Holmberg and Persson

It is called near field since the vibration monitoring is carried out near the holes where the fracturing of the mass occurs and where the equation must be modified to consider the long cylindrical shape of the load.

The Holmberg and Persson equation indicate that the factor has the greatest impact on peak vibration and damage is not the weight of the lag load but rather the linear load which is controlled by a combination of hole diameter and charge density.

This relation shows that the Peak Particle Velocity (PPV), at a point in space, is given by the location of this point with respect to the charge, the type of explosive and the geometry of the hole defined by the linear charge concentration "γ "(Kg / m), and more importantly, due to the attenuation characteristics of each rock mass in particular (constants K and α).

For this model it is considered that:
- The explosive charge column is divided into a series of infinitesimal charges.
- The vibration waves generated by each elemental charge obey the propagation equation.
- The PPV associated with each element is numerically additive.
- VOD is considered infinite.

Below is the equation for near field vibration prediction (Figure 1):

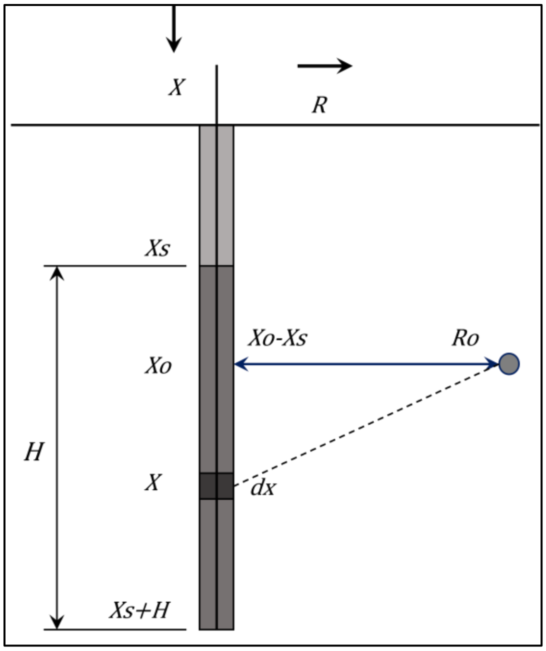

Figure 1. Near field vibration modeling

$$PPV = K\left[\left(\frac{\gamma}{Ro}\right)\left(arctan\left(\frac{H+Xs-Xo}{Ro}\right) + \arctan\left(\frac{Xo-Xs}{Ro}\right)\right)\right]^{\alpha} \qquad \text{Equation 1}$$

Where:
γ =linear load density (lbs/ ft) (kg / m)
Ro =horizontal distance from the load to the measuring point (ft) (m)
H =loading length (ft) (m)
Xs =cleat length (ft) (m)
Xo =measurement depth (ft) (m)
K =speed factor (depending on the source)
α =decay or attenuation factor (depending on the rock mass)

Neyman hydrodynamic model

In the development of the hydrodynamical model that seeks to determine the zones of crushing within the rock, it was assumed that the rock was isotropic, homogeneous, incompressible, and infinitely strong. Two of the characteristics of many real rocks, bonding, and anisotropy are not included.

If these two characteristics had been considered, great complexities would have been introduced so the results obtained with the models are for a generic rock with the assumed properties. In order to determine the crush dimensions in real rock mass, it is necessary to develop some correction factors developed knowing the seismic characteristics.
The maximum limiting velocity of the particles is a characteristic is a fundamental characteristic of the mechanical and structural properties of solid rock. Depending on the geological structure, it may be necessary to determine such limits in the various directions of anisotropy of the rock.
The process is described below:

- With the hydrodynamic model the authors can calculate isovelocity lines in the vicinity of the load. If the critical speed was known at which the failure occurs, it is possible to identify which of these curves describes the failure limit.
- In the field, a series of experiments are carried out where explosives of different lengths are used, and the damage zones and real velocity fields are measured. From these experiments, a set of curves like those obtained theoretically are constructed.
- By comparing the corresponding field and the results of the model, one can determine the similar coefficients.
- By applying the similarity coefficients to the model curves, curves are obtained that can be used for the design in the rock mass of interest.
- On the velocity field calculated for solid rock, the critical rupture velocities of the rocks can be plotted in the directions of the representative properties and in the direction of anisotropy. So, the surface that delimits the crushing zone is obtained.

$$\bar{L} = \frac{L\,[m]}{d\,[m]} \qquad \text{Equation 2}$$

$$v_s = \frac{\bar{L} + \sqrt{1+\bar{L}^2}}{-\bar{L} + \sqrt{1+\bar{L}^2}} \qquad \text{Equation 3}$$

$$P = d\sqrt{\frac{\rho_{ex} * q_{ex}}{8\rho_r * v_s}}\,\left[\frac{m^2}{s}\right] \qquad \text{Equation 4}$$

Where:

L = charge length (m)
d = charge diameter (inch) (m)
P = constant (m^2/s)
ρ_{ex} = equivalent explosive density (kg/m$^)$
q = specific energy of the explosive (m^2/s^2)
v_s = relative velocity potential at the hole wall

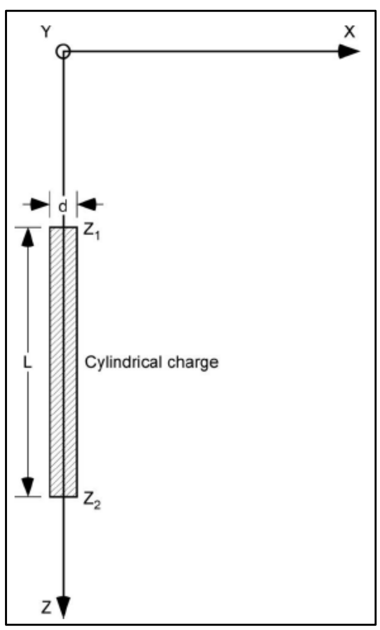

Figure 2. Coordinate system for a cylindrical charge in an infinite medium.

Calculation on the X axis:

$$V_x = P.x.\left\{[\,(z_1 - z)^2 + x^2 + y^2]^{\left(-\frac{1}{2}\right)}.\left[\,z_1 - z + ((z_1 - z)^2 + x^2 + y^2)^{\left(\frac{1}{2}\right)}\right]^{(-1)} - [\,(z_2 - z)^2 + x^2 + y^2]^{\left(-\frac{1}{2}\right)}.\left[\,z_2 - z + ((z_2 - z)^2 + x^2 + y^2)^{\left(\frac{1}{2}\right)}\right]^{(-1)}\right\} \quad \text{Equation 5}$$

Calculation on the Y axis:

$$V_y = P.y.\left\{[(z_1 - z)^2 + x^2 + y^2]^{\left(\frac{-1}{2}\right)}.\left[\,z_1 - z + ((z_1 - z)^2 + x^2 + y^2)^{\left(\frac{1}{2}\right)}\right]^{(-1)} - \,[\,(z_2 - z)^2 + x^2 + y^2]^{\left(\frac{1}{2}\right)}.\left[\,z_2 - z + ((z_2 - z)^2 + x^2 + y^2)^{\left(\frac{1}{2}\right)}\right]^{(-1)}\right\}\Bigg\} \quad \text{Equation 6}$$

Calculation on the Z axis:

$$V_z = P\ .\left\{[\,(z_2 - z)^2 + x^2 + y^2]^{\left(-\frac{1}{2}\right)} - [\,(z_1 - z)^2 + x^2 + y^2]^{\left(-\frac{1}{2}\right)}\right\} \quad \text{Equation 7}$$

$$V_p = \sqrt{{V_x}^2 + {V_y}^2 + {V_z}^2}\ \left[\frac{m}{s}\right] \quad \text{Equation 8}$$

Where:

V_p= peak velocity
V_x= velocity in the x direction
V_y= velocity in the y direction
V_z= velocity in the z direction
P = constant (m^2/s)

Demonstration of the Approach

The simulation was developed in an area of potassium granodiorite for having more geological and geotechnical information. This information was obtained from a copper open pit mine in Peru.

Table 1. The physical properties

Properties	Units	Value
E: Young's modulus	-	15.0
u: Poisson's ratio	-	0.24
d: rock mass density	kg/m3	2570
UCS	Mpa	20.3

Table 2. Explosive properties and Blasthole measurements

Properties	Units	Value
Hole length	m	15
Diameter of the charge,	inch	5
Length of the charge	m	8.6
Density, EQ 82	g/cc	1.1
Diameter of the charge,	kJ/kg	3280

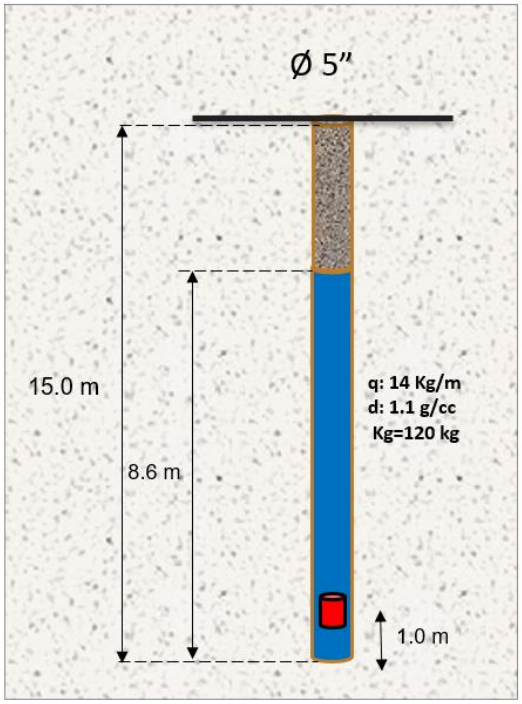

Figure 3. Blasthole Design and Properties

First, the P-wave velocity was calculated from the geomechanically data to have a simulation of monitoring points, to have a simulation of PPV values, stresses as a function of distance. Obtaining some values with which it was carried out an exponential regression, since this better describes the attenuation of planar sine waves. Once the model was performed, the distances which generates stress values close to the dynamic resistance of the detonator was calculated. It must take into account that there are pre-existing conditions of porosity, saturation and failure, in addition to it was considered the factor of 25% to the fitted curve.

$$Vp = \sqrt{\frac{E}{d} * \frac{1-u}{(1+u)*(1-2u)}} \qquad \text{Equation 9}$$

Where:
u = Poisson’s ratio
E = Young’s modulus of elasticity
d = rock mass density (kg/m3)

$$Vp = \sqrt{\frac{15 * 10\hat{}9}{2570} * \frac{1 - 0.24}{(1 + 0.24) * (1 - 2 * 0.24)}}$$

$$Vp = 2623\ m/s$$

Because of the presence of failures, therefore an additional percentage of 20% was taken, in that case it was obtained:

$$Vp = 2098\ m/s$$

Holmberg and Persson model

For the H&P model it is necessary to have the factors k = Speed Factor and α= Attenuation Factor.

Table 3. H&P model parameters

Parameters	Valor
K	273
α	1.29

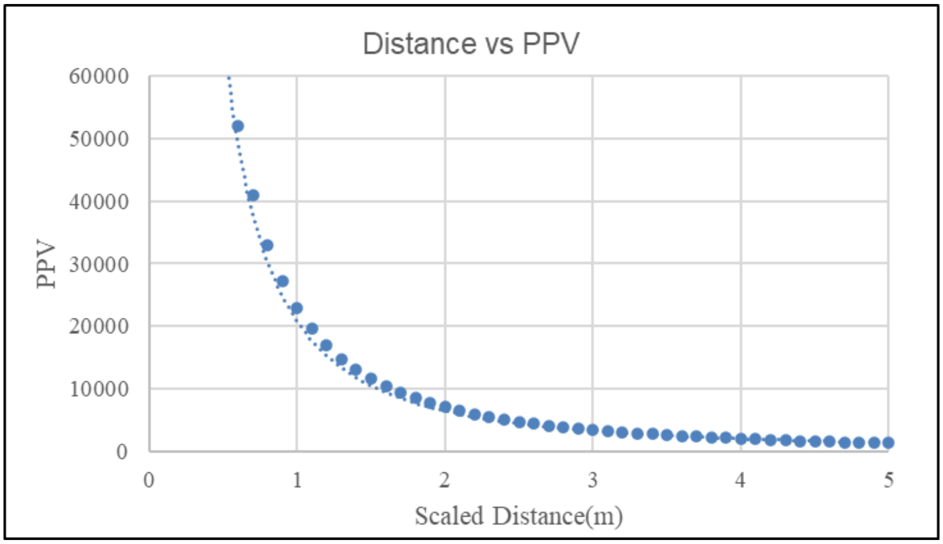

Figure 4. PPV estimation using the H&P model

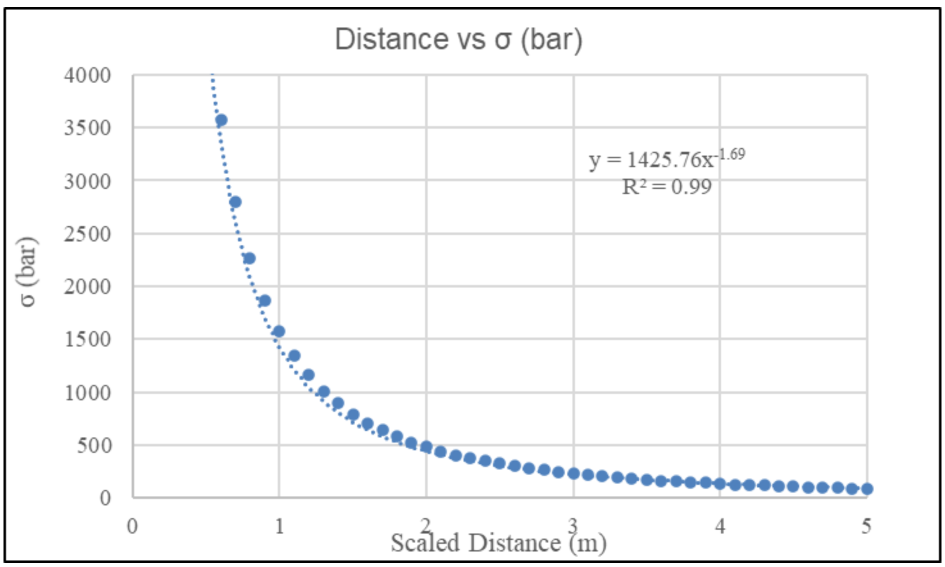

Figure 5. Stress estimation using the H&P model

Holmberg and Persson model fit

Linear regression was developed, and a better fit curve was obtained. The form of the initial stress model was:

$$\text{Stress} = k * D^{\alpha} \qquad \text{Equation 10}$$

Once the adjustment factor has been considered to have a bandwidth of 99% of the data, it was obtained:

$$\text{Stress} = 1.25 * k * D^{\alpha}$$

Figure 5 shows the two correlations that were developed, both to the initial model of efforts, and to the model adjusted with a factor of 25% to have a confidence of 99%, that is, 99% of the data are represented by our model, this that corroborated with the value of our coefficient of determination of 99%.

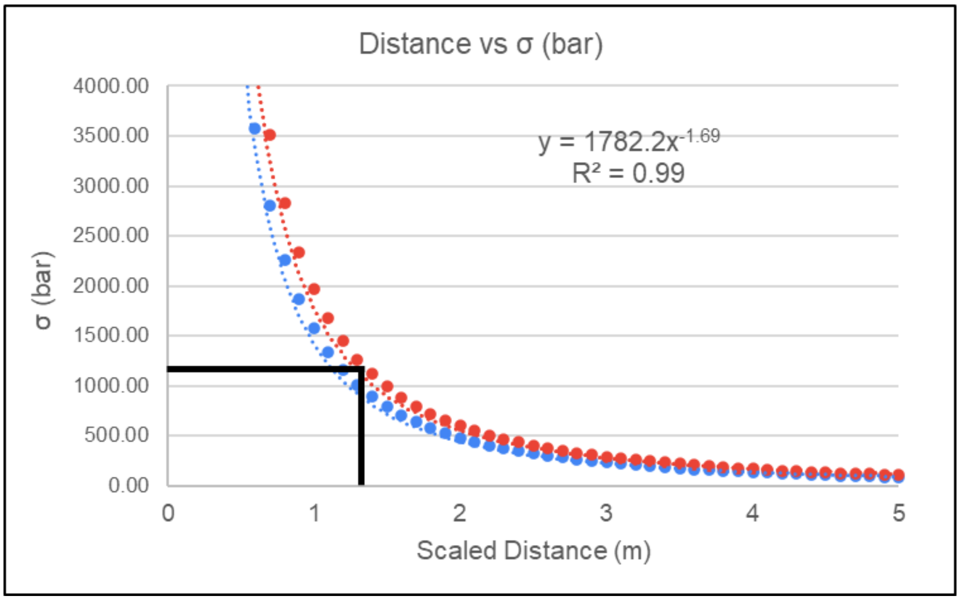

Figure 6. Fitting the Stress Estimate Using the H&P Model

Critical distance for the generation of the 1200 bar (120 MPa) of dynamic resistance of the detonator (technical data sheet i-kon^{TM} II). The previous graph shows the induced stresses and value of the dynamic resistance of the detonator 1200 bars, by intercepting these graphs, the value of 1.26 m was obtained. This indicates that at a distance less than 1.26 m, damage is generated in the electronic detonator due to the effect of dynamic pressure.

Critical distance = 1.26 m

To determine the critical time, it must replace in the following equation:

$$Critical\ time = \frac{Cd}{Vp} = \frac{1.26}{2098} * 1000\ (ms)$$
$$Critical\ time = 0.60\ ms$$

The result is that Vp takes 0.60 ms to travel the critical distance. At this value problems with the non-detonation of electronic detonators due to dynamic pressure failures were had.

Neyman hydrodynamic model

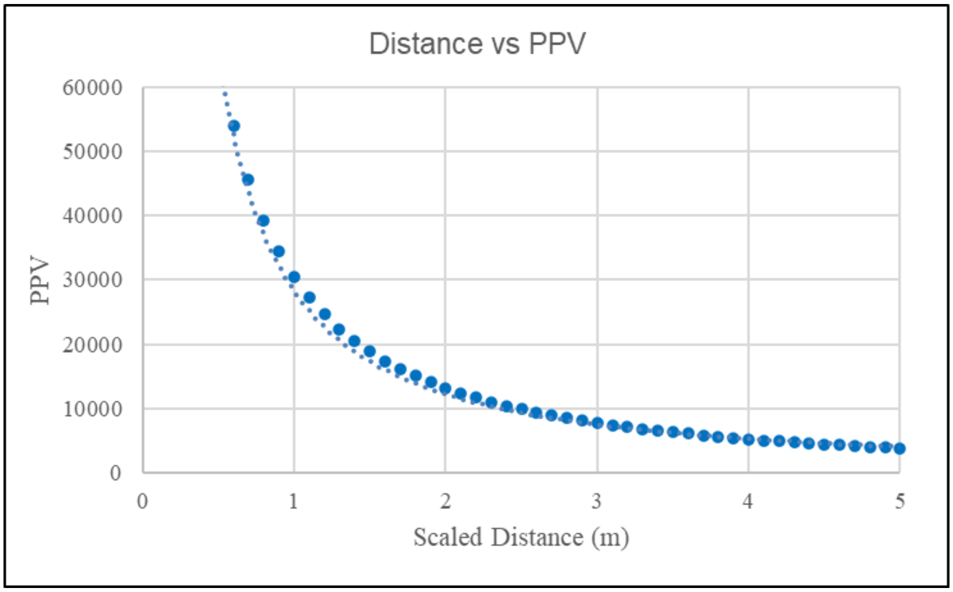

Figure 7. PPV estimation using the Neyman model

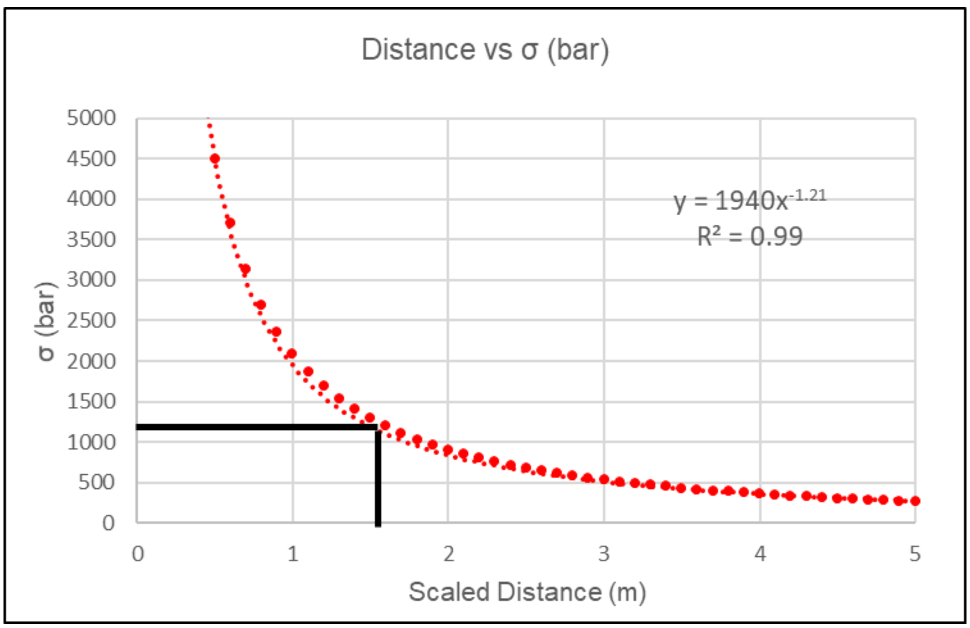

Figure 8. Stress estimation using the Neyman model

The Figure *8* shows the induced stresses and value of the dynamic resistance of the detonator 1200 bars (technical data sheet i-kon^{TM} II), by intercepting these graphs, it was obtaining the value of 1.49 m. This indicates that at a distance less than 1.49 m, damage is generated in the electronic detonator due to the effect of dynamic pressure.

Critical distance = 1.49 m

To determine the critical time, it must replace in the following equation:

$$Critical\ time = \frac{Cd}{Vp} = \frac{1.49}{2098} * 1000\ (ms)$$
$$Critical\ time = 0.71\ ms$$

The result is that Vp takes 0.71 ms to travel the critical distance. At this value problems with the non-detonation of electronic detonators due to dynamic pressure failures were had.

Results and discussion

The results obtained through the methods are theoretical. Both methods are 99% reliable. Demonstrating that the drill pattern designs of less than Critical Distance in the case of H&P model 1.26m and the 1.49m Neyman Model. Initiation problems were had. For this, it could use the simultaneous initiation in the drill pattern designs. Additionally, the authors could mention that the geological characteristics and structural conditions influence Vp.

Conclusion and Future Work

Through this methodology it can accurately estimate the stress values through the H&P and Neyman model, and it can also be adjusted through sensor tests, which is why they are methods that can be used in the face of resource limitations. Based on the results, it is concluded that a blast design with a distance less than the critical distance or with a very long delay time would generate excessive pressures in the Blasthole which can cause damage to the electronic detonator. It is important to bear in mind that the P wave velocity decreases according to the conditions of effective pressure, porosity, structural conditions, presence of water, etc. The value of Vp characterizes the rock mass and its conditions since its calculation is carried out based on the parameters of the rock mass. These methods, as it was saw in the application of the research, have different results, not so distant. Therefore, with a sensor test it could be determined which of these best fits the studied terrain

Acknowledgements

Our special thanks to Eng. Luis Huaroc Rojas and our faculty advisor Eng. Magali Arroyo, for their unconditional support and guidance during this research work.

References

Benites, A. G. (2017). "The minimum distance between holes to avoid damage to electronic detonators by dynamic pressure, in Lagunas Norte mine": 34-37

Kuznetsov, V.M. 1974. “Hydrodynamic calculation for ejection blasting by long charges”. Soviet Mining Science, pp. 292-295.

International Society of Explosives Engineers. (2011). “ISEE Blasters' Handbook”. Cleveland, Ohio: International Society of Explosives Engineers.