Analysis of Damage inherent to Underground Blasting in the Neves Corvo Mine

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Abstract

Mining rock masses with explosives is an usual practice in the daily operations of an underground mine. However, this technique can influence the stability of the remaining rock mass and, consequently; force the use of artificial ground support techniques.

In order to explain (and quantify) the damage on the rock mass due to rock blasting it is necessary to characterize, from a dynamic point of view, these rock masses using retro statistical analyses, from the blasting of explosives. In addition to this in situ characterization, it is necessary to use geomechanical laboratorial test data to determine the values of compressive strength, densities and propagation velocity of longitudinal waves, on rock samples from the rock mass in analysis.

Thus, after the implementation of the in situ and laboratorial characterization, the adjustment of propagation laws, of vibration in rock masses, which are related to the damage is possible and the calculation of the damage equations is successful for different explosives.

Keywords: Explosives, Vibrations, Multiple Linear Regression, Damage, EDZ, Overbreak

1. Introduction

The prediction and control of damage to the rock mass is a very important factor to mining, with the possibility of optimization of each blast it is possible to increase the security of the workers, by lowering the instability of the rock mass, it is also possible to increase blasting efficiency and control the costs of blasting.

The damage that results from blasting depends of different geomechanical, rock dynamic strength, density and P wave propagation velocity. The damage also depends on the dimension of the blast charge and the type of explosive used, because of different properties.
2. Excavation Damage Zone (EDZ)

The damage resulting from the detonation of explosives, inside a underground gallery, gives rise to areas where damage occurs in various types and sizes. The zone of crushed rock and fracturing is designated by EDZ, which can occur in two ways, as overbreak and underbreak. These two forms are also called as DOW (Damage to the Opening Wall), which consists of the damage of a certain thickness of rock surrounding the blasting area. It is possible to observe these deviations in the following figure.

![Figure 1 – DOW - Damage to the Opening Wall (adapted from Torres, 2004)](image)

3. Prediction of EDZ

Currently, it is possible to evaluate the propagation of vibrations, in the immediate vicinity, of the blasting area, through various equations. However, the equation that has a greater consensus among the author's experts in the mining industry is due to Johnson (1971). This equation establishes that the vibrations in rock, with origin in blasting, affect a distance D (in meters) and is represented as follows:

\[ v = a \cdot Q^b \cdot D^c \]  
\( v \) represents the peak particle velocity (in m/s), \( Q \), the explosive charge detonated per delay (in kg) and "a", "b" and "c" are coefficients that depend on the properties of the rock and type of explosive.

The peak particle velocity, \( v \) (m/s), can be correlated with the dynamic tension (in Pa), \( \sigma_d \), the density of the rock (in kg/m³), \( \rho \), the speed of propagation of longitudinal waves, \( c_p \) (in m/s), using the following equation:

\[ \sigma_d = \rho \cdot c_p \cdot v \]  

However, if considered the tension (\( \sigma_d \)) as tensile strength, the peak velocity of the particles is considered as speed dribble criticizes. Thus correlating the equations mentioned above, it is
possible to obtain an equation to predict the extent of the damage caused (in meters), Dd, by underground rock blasting (Dinis da Gama, 1998):

\[ D_d = \left( \frac{\sigma_d}{\rho \cdot c_p \cdot a \cdot Q} \right)^2 \]  

(Equation 3)

Being that, \( \sigma_d \) represents the dynamic tension of rupture (transmitted to the rock, expressed in Pa), \( \rho \) the density of rocky mass (in kg/m3), \( c_p \) the velocity of propagation of P waves in the rock mass (in m/s), \( Q \) the explosive charge detonated per delay, (in kg) and that "a", "b" and "c" are constant dependent on the properties of the rock and the type of explosive.

![Transversal View](image1)

![Longitudinal View](image2)

Figure 3 - Thickness of rock damaged by underground blasting (adapted from Torres, 2005)

In order to be possible to determine the values of the coefficients a, b and c, in accordance with the conditions of the rocky mass, it is necessary to use techniques of retro statistical analysis (i.e., multiple linear regression), which are based on real data.

4. Case Study Neves Corvo Mine

The Neves Corvo Mine is located in Portugal near the village of Castro Verde, district of Beja, and produces Copper and Zinc. Geologically, the Neves Corvo mine, is located Neves Corvo is located in the western part of the Iberian Pyrite Belt (IPB) that extends for approximately 230 km, over a width ranging from 35 km to 50 km, through southern Spain into Portugal. The Neves Corvo deposits are located near the top of a dominantly volcanic sequence of the VSC, which consists of two chemically distinct intervals of felsic volcanics separated by shale units, with a discontinuous black shale horizon immediately below the massive sulphide lenses. The thickness of the VSC in the Neves Corvo area is approximately 300m. (SOMINCOR, 2011)
To be able to apply the study of blast damage at the Neves Corvo Mine was necessary to determine geomechanical variables, in particular the tensile strength, P wave velocity, density and the coefficients a, b, c and d.

The first 3 variables were obtained using geomechanical laboratory tests, being that the coefficients a, b and c were obtained by retro statistical analysis of blasts monitored in the Neves Corvo Mine.

Thus the following results were achieved for the variables mentioned above:

Table 1 - Results of the laboratory tests, of each type of Rock

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Tensile strength (MPa)</th>
<th>P Wave Velocity (m/s)</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shale</td>
<td>32,50</td>
<td>3014</td>
<td>2705</td>
</tr>
<tr>
<td>Shale with Chalcopyrite</td>
<td>63,03</td>
<td>3989</td>
<td>2705</td>
</tr>
<tr>
<td>Massive Sulphides</td>
<td>175,73</td>
<td>6162</td>
<td>4320</td>
</tr>
</tbody>
</table>

To obtain the coefficients a, b and c, the retro statistical analysis was divided by blast location, type of explosive and by charge undifferentiated or charge differentiated by detonation pressure, in this last case a new coefficient was added, coefficient d.

With the retro statistical analysis the following results were obtained:

Table 2 - Results of Linear regressions of undifferentiated charge

<table>
<thead>
<tr>
<th>Situations</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>1</td>
<td>8,649</td>
<td>0,343</td>
<td>-1,784</td>
<td>0,938</td>
</tr>
<tr>
<td>Lombador</td>
<td>2</td>
<td>3,606</td>
<td>0,388</td>
<td>-1,611</td>
<td>0,915</td>
</tr>
<tr>
<td>Subtek Charge</td>
<td>3</td>
<td>60,117</td>
<td>0,039</td>
<td>-1,958</td>
<td>0,936</td>
</tr>
<tr>
<td>Senatel PowerPac</td>
<td>4</td>
<td>1,101</td>
<td>0,632</td>
<td>-1,548</td>
<td>0,997</td>
</tr>
<tr>
<td>Subtek Eclipse</td>
<td>5</td>
<td>269,153</td>
<td>0,444</td>
<td>-2,335</td>
<td>0,925</td>
</tr>
</tbody>
</table>

Table 3 – Results of Linear regressions of charge differentiated by detonation Pressure

<table>
<thead>
<tr>
<th>Situations</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>1</td>
<td>92,683</td>
<td>0,103</td>
<td>-2,016</td>
<td>-7,535</td>
</tr>
<tr>
<td>Lombador</td>
<td>2</td>
<td>2529,300</td>
<td>-0,465</td>
<td>-2,235</td>
<td>-14,124</td>
</tr>
<tr>
<td>Subtek Charge</td>
<td>3</td>
<td>0,070</td>
<td>0,282</td>
<td>-1,221</td>
<td>423,165</td>
</tr>
<tr>
<td>Senatel PowerPac</td>
<td>4</td>
<td>0,903</td>
<td>0,677</td>
<td>-1,552</td>
<td>0,512</td>
</tr>
<tr>
<td>Subtek Eclipse</td>
<td>5</td>
<td>The program does not consider the variable P to decline, due to the reduced number of measurements</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Through the analysis of the results obtained with the linear regressions it is possible to conclude that the best way to get the constants of the terrain of the Neves Corvo Mine, and characterize the same, is through the division, of the values to be applied to the linear regressions, by type of explosive used, because in this way it is possible to obtain correlation coefficients above as well as a better analysis of the weighting P. Although the situations 1 and 2 have a correlation coefficient high, when comparing the values of load undifferentiated with the load differentiated it is possible to observe that the constant b is negative and this cannot happen because it means that most load leads to a lower damage. Thus only will be considered for implementation in the formulas of damage situations 3, 4 and 5.

5. Damage Equations

After gathering all the data of the variables it is possible to apply this variables in the equation 3 and obtain damage equations to the differentiated and undifferentiated charges.

For the case of undifferentiated charge, the following equations were obtained:

Table 4 – Equations of damage as a function of Load undifferentiated

<table>
<thead>
<tr>
<th>Situation</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shale</td>
</tr>
<tr>
<td>Subtek Charge</td>
<td>$D_d = 3,998. Q^{0.020}$</td>
</tr>
<tr>
<td>Senatel PowerPac</td>
<td>$D_d = 0.436. Q^{0.408}$</td>
</tr>
<tr>
<td>Subtek Eclipse</td>
<td>$D_d = 6,074. Q^{0.190}$</td>
</tr>
</tbody>
</table>

In the case of charge differentiated by detonation pressure, to obtain the equation that allows the estimation of the damaged area, it is necessary to use the equation 3 and add two new variables, obtaining the following equation:

$$D_d = \left(\frac{\sigma_d}{\rho C_p A Q a P d}\right)^{\frac{1}{2}}$$  \hspace{1cm} (Equation 4)

Where a, b, c and d represent the coefficients of the rock mass calculated previously for various situations, Q represents the maximum charge per delay and P represents the weight of the detonation pressure.
For the case of differentiated charge, the following equations were obtained:

\[
\text{Table 5 – Equations of damage as a function of Load differentiated}
\]

<table>
<thead>
<tr>
<th>Situation</th>
<th>Rock Type</th>
<th>Schist</th>
<th>Schist with Chalcopyrite</th>
<th>Massive Sulphides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subtek Charge</td>
<td>(D_d = 0,037 \cdot Q^{0,231} \cdot P^{346,572})</td>
<td>(D_d = 0,027 \cdot Q^{0,231} \cdot P^{346,572})</td>
<td>(D_d = 0,024 \cdot Q^{0,231} \cdot P^{346,572})</td>
<td></td>
</tr>
<tr>
<td>Senatel PowerPac</td>
<td>(D_d = 0,384 \cdot Q^{0,436} \cdot P^{0,330})</td>
<td>(D_d = 0,300 \cdot Q^{0,436} \cdot P^{0,330})</td>
<td>(D_d = 0,278 \cdot Q^{0,436} \cdot P^{0,330})</td>
<td></td>
</tr>
</tbody>
</table>

Using the equations from table 5 it is possible to obtain a graph that represents the calculated damage for different charges and detonation pressure weights:

![Graph showing calculated damage vs. maximum charge per delay](image)

**Figure 4 – Damage in blasts with subtek charge, in shale, for different detonation pressure weights**

**5.1. Overbreak Adjustment**

The idea of creating an adjustment that allows the estimation of overbreak that can occur through underground blasting, since this estimation allows to reduce costs and increase revenue because it leads to a decrease in the use of explosives and allows the control of dilution. To study this hypothesis, and consequent implementation of linear regressions for the calculation of the adjustment, we obtained the following equation:

\[
\text{Overbreak} = A_1 \cdot D_{\text{calculated}}
\]

(Equation 5)
With the information from the overbreaks from October and November of 2013, gathered by the topography department from SOMINCOR, it is possible to obtain this adjustment.

Since the overbreak data is from blasting, with Subtek Charge, in shales the equation that can be applied to this adjustment is the equations from Situation 3.

Thus it is possible to obtain the following equation for differentiated charges:

\[
\text{Overbreak} = (0.017 \cdot Q^{0.231} \cdot P^{3.672})
\]

(Equation 6)

With the equation above it is possible to obtain a graph of calculated overbreak for different charges and detonation pressure weights.

6. Conclusions

Analysing all variants of tables 2 and 3, which are the results of linear regressions to undifferentiated and differentiated charges, it is possible to understand that the best way to characterize the damage derived from the use of explosives is the characterization of propagation as a function of the type of explosive used. Each type of explosive causes a characteristic reaction to the surrounding rock through the different pressures that act, therefore it is not sufficient to enter the simplified load.

The damage calculated is much higher than the measured overbreak and the creation of the overbreak adjustment allows the anticipation and control, to a certain extent, of the damage and the dilution that may result from the underground blasting. However this overbreak adjustment has more logic for blasts with Subtek Charge, since the blasts with Senatel PowerPac are loaded in vertical holes, it is not possible to obtain a surrounding area of damage around the bench. With this adjustment was obtained a good correlation coefficient so it is possible to estimate the overbreak.
7. References


