Application of Comminution Theory for Analyzing Linear Underground Works Through Cylindrical Cuts

Adam Mak Brayam Urquizo Araujo, Hugo Damian Aval, Christian Pelaez Rosas, Yessica Idrogo Zamora, Eduardo Porras Oscco, Robert Navarro

Subject: Tunnels and Materials Movement

School of Mining Engineering

Faculty of Geological, Mining and Metallurgical Engineering

National University of Engineering

Summary

The following research work is based on the explanation of the comminution theory along with the crushing criterion (boev and sahpiro 1987), adapted and applied in the blasting in underground mining, using the mathematical model of comminution that is based on the Reduction and fragmentation of the rocky massif, related to the energy consumed and the size of fragments produced, we will take advantage of the fact that this theory has the virtue of relating the geomechanical characteristics of the rocks and the explosive, being these important factors in the blasting, this Will help us to optimize subsequent processes, thus improving the economic, social and environmental.

Introduction

Mining, which over time, has achieved economic, social and environmental development of countries immersed in this industry. At the moment it is the activity that greater profitability generates in our country, for that reason we opted to develop this project in order to contribute with the constant development of this one.

Seeing the importance of optimizing processes subsequent to blasting, we chose to explain the theory of comminution complemented by the triturability applied to underground mining with the aim of generating greater savings in production. Many studies have already been made of the rock breaking process, mentioning some authors (Langefors and Kihltrons, 1976, Shemiakin, 1963, Bond, rittinger, etc.).

In the mathematical model of the reduction theory is based on the reduction of size, taking advantage of the energy necessary to produce fractures of the rocks, considering dynamic loads and assuming that the fragmentation of the rocky massif is due to tensile stresses, being the energy Necessary to produce the fracture of the rocky mass that that is stored in the same material during its elastic deformation until its point of rupture.

Therefore, in the reduction should be quantified the relationships between energy consumed and size of fragments produced; Based on four important variables of the fragmentation: Rock hardness, in situ fracture, specific explosive energy and firing geometry; So we complement this theory with the triturability theory, initially to determine the burden in the first quadrangle, followed by the theory of

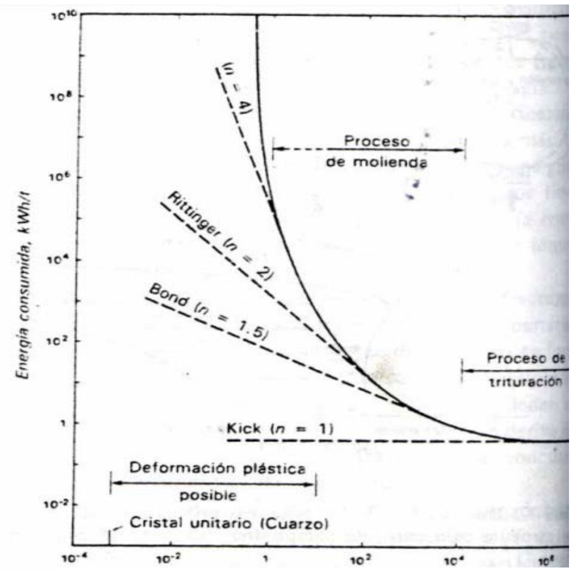
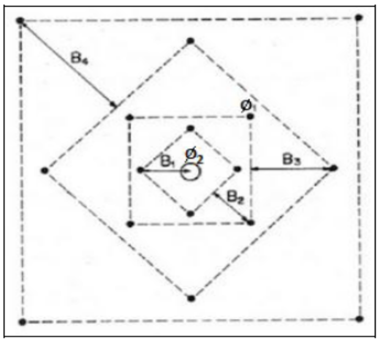


Figure 1: Relationship between energy and size comrproposed by bond

The triturability theory effectively gives us the first burden, it is also able to validate what in 1963 was specified by Lnagefors and khiltrons. The following figure represent the Relationship between energy and size proposed by bond



“We will not achieve greater results using a burden greater than 2Ø while the diameter of the opening is too small, so that the only effect would be the plastic deformation; Even if the burden is smaller Ø would cause sintering of the fragmented rock (Figure 3). For this reason, the distance between the relief bore and the holes in the first section must not exceed 1.7 ° in order to obtain a satisfactory exit”

Figure 2: Start of four sections; Source, manual drilling and blasting- López Jimeno

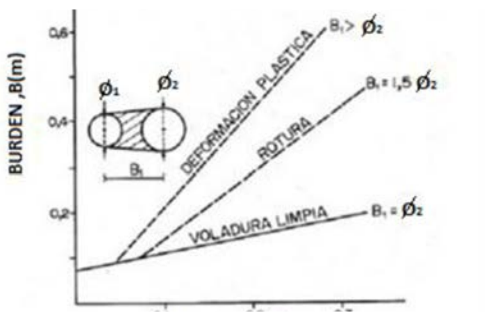


Figure 3: Ratio of the diameter of the drill with the burden to obtain a good blast; Source, manual drilling and blasting- Lopez Jimeno

Using random number generation parameterized in the generation of our dating, in order to simulate and using JK simblast software to estimate the concentration of energy in our mesh, we explain the development of the problem.

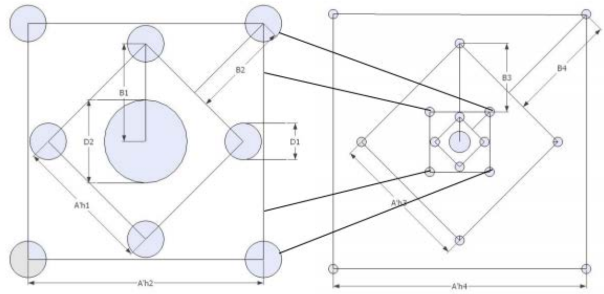


Figure 4: Design of the part of the start of the perforation mesh

Presentation of the problem

Blasting is one of the stages of great importance in the mining process, and the good results of this process depend to a great extent on the degree of fragmentation of the rock mass, as well as on the geomechanical characteristics of the rock mass. It is necessary to emphasize that these good results will influence to a great extent in the successful performance of the subsequent mining operations.

Currently, mining companies do not apply any mathematical model at the time of rock blasting, they are based only on the experience of the engineer in charge of carrying out the operation.

In the constant study it is shown that the application of mathematical models can optimize or improve any mining operation. Thus, based on the above, this work aims to use one of the many mathematical models as it is the model of the theory of comminution, mathematical model that will help greatly in the fragmentation of the rock.

Problem formulation

General problem

Will the use of the mathematical model generate an optimization in the other processes?

Specific problems

1) How to adapt the theory of reduction that is used in underground to underground?
2) How will we complete the theory of comminution with the triturability theory?
3) How will we generate our field data that we need for the development of the project?

General and specific objective

General objective

Analyze and adapt the theory of comminution in underground mining**.**

Specific goal

1) Break the rock efficiently, economically and environmentally.
2) Complement the comminution theory with the criterion of triturability to underground mining designing cylindrical cuts.
3) Determine if mesh design influences rock fragmentation
4) Determine how this theory helps.
5) To determine the factors that directly influence the application of the comminution theory.

Description of the solution.

Parameters to consider:

- **Rock parameter:**

They are uncontrollable variables (resistance to compression, tension, friction, etc.)

- **Explosive Parameter:**

Controllable variables such as physical and chemical properties (density, detonation velocity, pressure, sensitivity, etc.)

- **Charging parameter:**

They are also controllable variables at the time of the design of the drilling and blasting mesh (drill diameter, drill length, confinement, coupling, etc.)

<u>Theory of Triturability</u>

Determination of crushing radius: Based on the static rock shear strengths and traction determined by laboratory tests, dynamic rock shear strengths and tensile strength were determined from Borovikov and Vaniagil (1974, 1995)

$$[\sigma^{d}_{traccion}] = K^{d}_{traccion}[\sigma^{e}_{traccion}]$$

$$[K^{d}_{traccion}] = 4.81 - 0.97 * 10^{-11} * \rho_{o} * V_{p}^{2}$$

Expression of Nurmujamedov, 1973.

$$[\sigma^{d}_{cort}] = 7[\sigma^{e}_{cort}]$$

1) $[\sigma^{d}_{traccion}]$: Dynamic tensile strength.
2) $[\sigma^{e}_{traccion}]$: Static tensile strength.
3) $[k^{d}_{traccion}]$: Coefficient of tensile dynamicity.
4) $[\sigma^{d}_{cort}]$: Dynamic shear strength.
5) $[\sigma^{e}_{cort}]$: Static shear strength.

The grinding, cracking and scraping radiuses are determined from the tensile and shear strength by three criteria:

1. Crushing Criteria $\sigma_{corymax} \approx [\sigma^{d}_{cort}]$
2. Fragmentation criterion $\sigma_{rmax} \geq [\sigma^{d}_{traccion}]$
3. Slope criterion $\sigma_{rmax} = [\sigma^{d}_{traccion}]$

We continue with the adaptation of the mathematical model of reduction to underground mining.

Theory of Comminution

The following mathematical relation gives the total energy per unit volume required to reduce “fragments” of rocks from a size “D” to a smaller one of size “d”.

$$\boldsymbol{ET = \frac{3}{4} * Std^{2} * \frac{(R+1)}{E} * D^{3}} \text{...... (1)}$$

WHERE:

ET: Total energy to reduce the rock from a size D to a size d (Joule / 〖m〗 ^ 3).

STD: Dynamic Rock Voltage Resistance (Pa)

E: Young (Pa) modulus of elasticity

A: D / d reduction ratio <d is data>

D: size of required fragments

$$D = \sqrt[3]{A * H * L_{Tal}}$$

Compared with the energy delivered by the detonation of an explosive mixture, 80% of the total:

Q = (Kcal / Kg)

(1 K Cal = 4186.8 Joules)

(1 joule = 〖10〗 〗 7 ergons)

Then the amount of explosive needed to fragment 1 m3 of rock from fragments of size D to size d. R = D / d will be:

$$W = \frac{3*10^{-2}*Std^2*(R+1)}{4*E*Q} kg\ explosivo..(2)$$

Height of the load:

$H_c = H_{tal} - B$ Or what is generally used

$$H_c = (H_{tal} - 10 * Ø)$$

Where:

H_c: Height of the load (m) ; H_{tal}: Drill depth ; B: Burden (m) ; Ø: Drill depth (m).

So:

On the other hand the amount of explosive required per drill will be:

$$Wb = \frac{(H_c)*\pi*Ø^2*\rho_e}{4000} \quad o \quad \frac{Wb}{tal} = H_c * D_c$$

Where:

Wb: Explosive amount per drill (Kg/tal)

H_c : Height of the load (m)

Ø: Diameter of the drill (mm)

ρ_e: Explosive density (gr/cm3)

D_c : Load density

$$D_c = \frac{\pi * Ø^2 * \rho_e}{40}$$

The number of required holes loaded with Wb Kg of explosives to fragment an area front AxL (m2) and the following mathematical relation gives Htal (m) depth into fragments of size d:

Nt= (Amount of explosive required)/(Wb/tal)

$$Nt = \frac{30 * Std^2 * \left(\frac{\sqrt[3]{H * L * A}}{d+1}\right) * A * H * L}{E * Q * H_c * Ø^2 * \rho_e}$$

Nt: Total number of bricks required

Std: Resistance to dynamic tension of the rock (Pa)

E: Modulus of elasticity of rock (Pa)

Q: Heat of explosion of explosive mixture (Joules)

ρ_e: Density of explosive (gr/cm3)

For the calculation of the burden we applied a mathematical model to design a mesh of drilling and blasting, calculating the area of influence by drill and was developed as follows

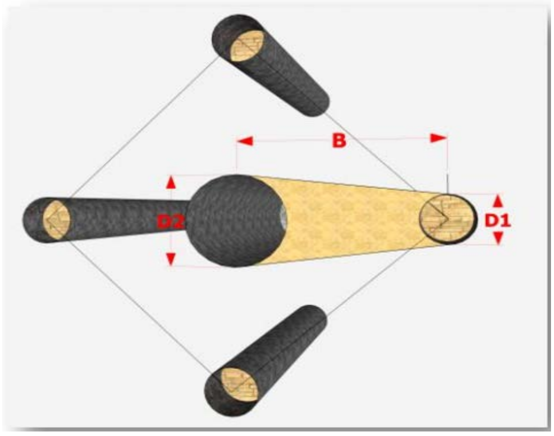


Figure 5: 3D view of relief drill and starter drills.

Calculation of the Burden with a new theory: This design method is born from the following illustration 6.

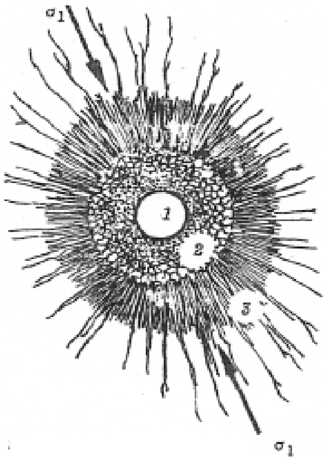


Figure 6 : Influence area of a drill after blasting.

- In zone 1, it is the diameter of the drill, zone 2 is the zone sprayed by the explosive and zone 3 is the area of influence of the drill after a coladura
- The new theory calculates the thickness fractured by the explosive and then demonstrates the burden.
- Its basis of this theory is the resistance of materials, rock mechanics, explosive parameters and drilling.

Formulation of the mathematical model used for the calculation of the burden.

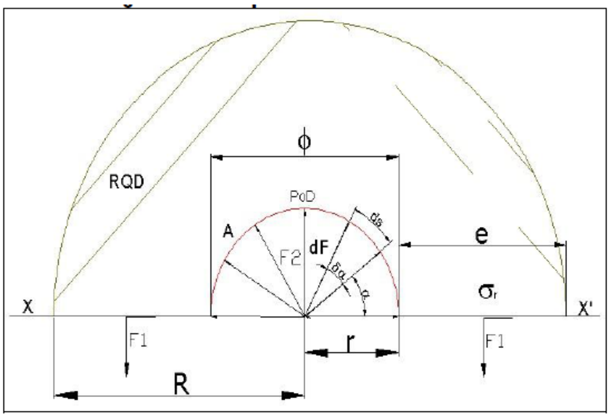


Figure 7: Area of influence of a drill.

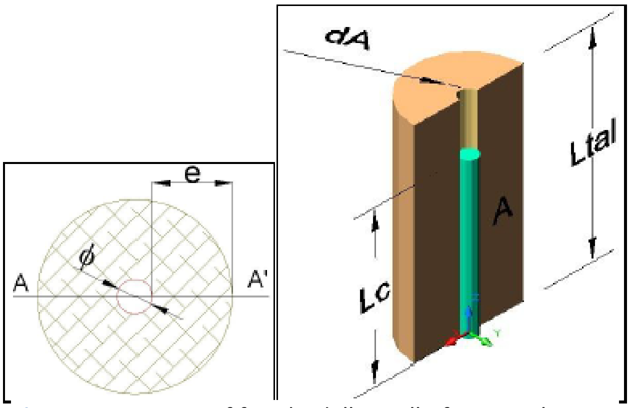


Figure 8: Diagram of free body''D.C.L'' of cut A-A '

Resolving the balance of forces.

$$\sum Fv = 0$$

$$-2F_1 + F_2 = 0$$

$$\boldsymbol{F_2 = 2F_1 \ldots (1)}$$

We determine F_2 from Figure 8.

$$dF_2 = 2dF_2 sen\alpha + 2dF_2 cos\alpha$$

The dF_2 depends on the detonation pressure, the charge factor (Fc) and the area difference. From D.C.L

$$dF_2 = P_oD * Fc * dA$$

$$dF_2 = P_oD_{tal} * dA$$

But (dA) is a function of the length of the drill and its ds.

$$dA = L_{tal} * ds$$

$$ds = r_e * d\alpha$$

Replacing and integrating.

$$\int dF_2 = \int_0^{\pi} 2 * P_oD_{tal} * L_{tal} * r * sen\alpha\, d\alpha + \int_0^{\pi} 2 * P_oD_{tal} * L_{tal} * r * cos\alpha d\alpha$$

$$\boldsymbol{F_2 = 2 * P_oD_{tal} * L_{tal} * r} \ldots\ldots (2)$$

We determinate F_1 from the ilustration ; F_1 depends on the compressive strength of the rock or mineral (σ_r), R.Q.D and the area of rupture (A).

$$F_1 = \sigma_r * RQD * A$$

Dónde: A=e*L_{tal}

$$\boldsymbol{F_1 = \sigma_r * RQD * e * L_{tal}} \ \ldots\mathbf{.(3)}$$

Replacing

(3),(2) en (1) nos queda:

Where $r = \frac{\emptyset}{2}$

$$e = \frac{P_oD_{tal} * \emptyset}{2 * \sigma_r * R.Q.D} \ \ldots\ldots(4)$$

Min Tube (Tmin):$T_{min} = \frac{e}{Fs}$

Burden for a safety factor (Fs).

$$Bn = \frac{2e}{Fs} + \emptyset \ldots (5)$$

Burden nominal "Bn", its general formula, We replace (4) en (5).

$$\boldsymbol{Bn = \emptyset * \left(\frac{P_oD_{tal}}{Fs * \sigma_r * RQD} + 1\right)}$$

Bn: Nominal Burden (m)

Sn: Nominal spacing (m)

Ø: Drill Diameter (m)

P_oD_{tal}: Drill detonation pressure (kg/cm^2)

RQD: Quality Indication of the Rock

σ_r: Resistance to compression of rock or mineral

(kg/cm^2)

Fs: Safety factor

P_oD_{tal}: Drill detonation pressure.

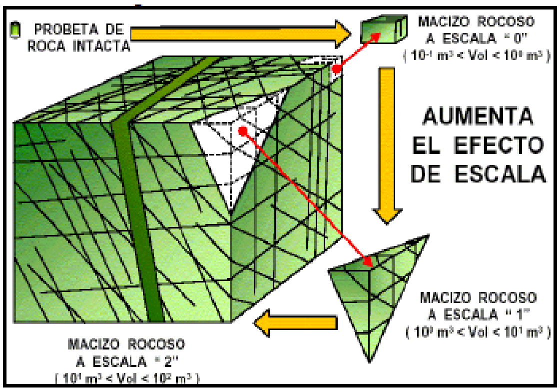
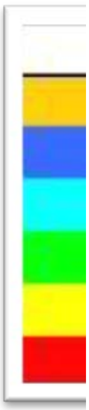


Figure 9: Block of rocky massif; Source, Geomecanich.



Figu
re1

0: Constants of safety factor for different burdens

$$P_oD_{tal} = 0.25 * 10^{-5} * Pe * VoD^2$$

Fc: Load factor; Is a function of the volume of the drill and the volume of the explosive inside the drill.Fc = <1

$$F_C = \frac{V_C}{V_{tal}} = \frac{\pi * Ø^2 * L_e * N_{cartuchos}}{\pi * Ø_{tal}^2 * L_{tal}}$$

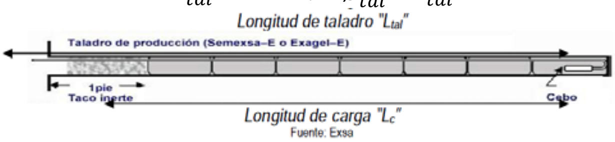


Figure 11: Charged drill.

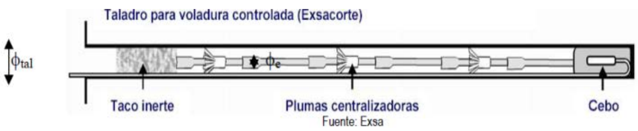
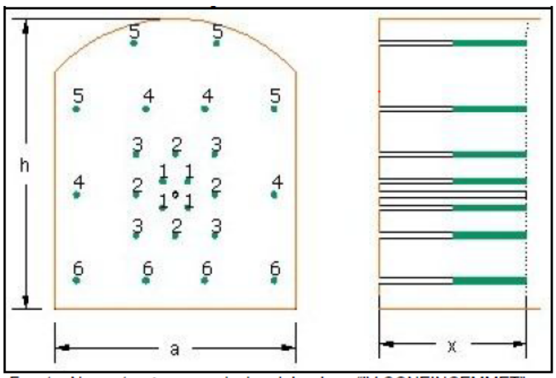


Figure 12: Drills desviation

Ideal Burden"Bi"



Fi Fuente: Nueva teoría para calcular el burden, "IV CONEINGEMMET" en Huancayo 2003

$$Bi = Bn - Dp$$

Dp is the deviation of the drill to be used in the mining plan.

Ae: The coupling is a function of the diameter of the explosive and diameter of the drill, where:

$$A_e = \frac{Ø_e}{Ø_{tal}}$$

The number of drills can also be calculated using software, designed by programmer Edson Jesus Quispe

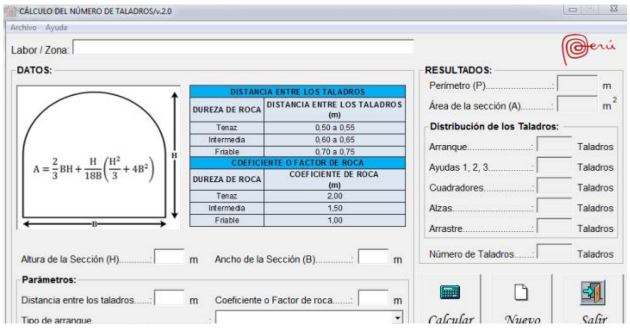


Ilustración 14: Software used for comprobate the number of drills.

Ilustración 15: Isometric Sight of front´s perforation

Application of the theory of comminution in fronts:

Case 1: Mining Company Volcan, Cerro de Pasco, using emulsions

Date provided by Ing. Herman Flores

Figure 16: Front view and profile of a drill net.

1.1. - Field data

MINING WORK: 16848-8S

SECTION: 3.50m x 3.0m

DIAMETER TAL: 2 "Ø

PROF. PERFORATION: 3.20 m with 12'

1.2.- Geomechanical characteristics of rocks**:**

ROCK TYPE: I

HARDNESS: HIGH

DYNAMIC TENSIONAL RESISTANCE: 126.5 MPa

YOUNG DYNAMIC ELASTICITY MODULE E = 20000 Mpa

1.3.- Characteristics of the explosive: Obtained from Exa.

SEMEXA EMULSION E65 1 ½ "X 12" DENSITY q = 1.14 gr / cc EXPLOSION HEAT: Q = 935 Kcal / kg SIZE OF FRAGMENTATION REQUIRED D = 0.20 m (width of the grid)

Calculate the mesh of drilling and blasting with the reduction theory complemented with the triturability and mesh design with burden calculation knowing the area of influence of a drill and evaluate results.

SOLUTION

a) Calculate of the relationship of reduction R:

$$R = \frac{D}{d}$$

Section area: 3.5m*3.0m*3.20m= 33.6 m^3

$D^3 = 33.6m^3$ ^ d=0.20 m

$$R = \frac{\sqrt[3]{33.6}}{0.20} \approx 16$$

a) Calculate of the energy required to breakthe hard rock with a granulometry of 0.20m maximum.

We use the formula of the Conminution theory erg units.

$$ET = \frac{3 * (126.5 * 10.197 \frac{Kgf}{cm^2})^2 * (16+1) * 33.6 * 10^6 cm^3)}{4 * 20000 * 10.197 \frac{Kgf}{cm^2}}$$

$$ET = \frac{2851250294 * 10^6}{815760} (Kgf.cm)$$

$$ET = 3495.207284 * 10^6 * 9.80665N * 10^{-2} m$$

$$ET = 34276.27451 * 10^4 N.m$$

N.m=JOULE ^ 1 Joule= $10^7 ERGIOS$

$$ET = 3.42 * 10^{15} Ergios$$

b) Calculate of the energy diven by the explosive SEMEXA E65 1 ½" X 12"

$$\Delta E = 0.7Q = 0.7 * 935 \frac{Kcal}{Kg} = 655 \frac{Kcal}{Kg}$$

$$\Delta E = 655 \frac{Kcal}{kg} * 4.1868 * 10^{10} \frac{ergios}{kg}$$

$$\Delta E = 2.74 * 10^{13} \frac{ergios}{kg}$$

c) We calculate the total amount of the emulsion

1 kg emulsión SEMEXSA E65 $2.74 * 10^{13}$ $ergios$

X $3.42 * 10^{15} Ergios$

X ≈ 125 kg de emulsión

d) Calculation of drilling and blasting meshes

i) Calculation of the amount of emulsion per bore

$$QE = \frac{nQ^2}{4} \times 100\ cm \times 0.9 \frac{gr}{cc} = 1838\ {}^{gr}/_{m}$$

QE = 1,8 kg/m

ii) Calculation of the amount of emulsion per bore

Effective length = 3.20 m

Load length = 0.7 x 3.0 m = 2.10 m

$$\frac{Kg\ expl}{tal} = 2.10 \times 1.8.\frac{kg}{m} = 3.78\ {}^{kg}/_{tal}$$

iii) Calculation of the number of drill loaded

$$\#tal = \frac{125\ kg}{3.78\ {}^{kg}/_{tal}} = 33\ tal$$

33 tal cargados + 1 vacíos

iv) Number of cartridges / cut

$$\frac{3.78\ kg/tal}{0.39\ kg/cart} = 10\ cart/tal\quad (corte)$$

v) Calculation of drilling and blasting mesh S / B = 1,25

$$B_n = \emptyset \times \left(\frac{P_0 D \times A_e \times F_c}{f_s \times \sigma_r \times RQD} + 1\right)$$

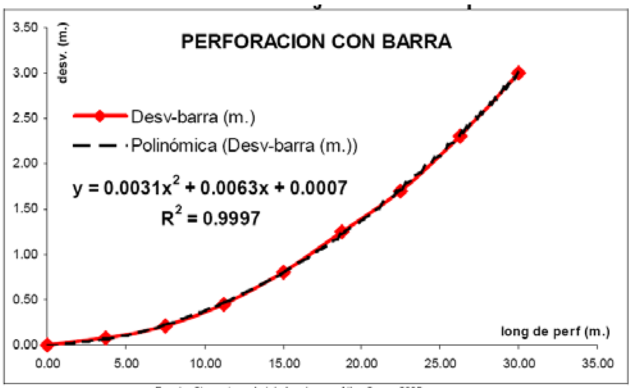
$$B_{start} = 0.0508 \times \left(\frac{54022.5 \times 0.591 \times 0.75}{6 \times 917.745 \times 0.9} + 1\right) = 0.296\ m$$

$$B_{help} = 0.0508 \times \left(\frac{54022.5 \times 0.591 \times 0.75}{5 \times 917.745 \times 0.9} + 1\right) = 0.3453\ m$$

$$B_{sub-help} = 0.0508 \times \left(\frac{54022.5 \times 0.591 \times 0.75}{4 \times 917.745 \times 0.9} + 1\right) = 0.4189\ m$$

$$B_{contour} = 0.0508 \times \left(\frac{54022.5 \times 0.591 \times 0.75}{3 \times 917.745 \times 0.9} + 1\right) = 0.5417\ m$$

e) Drill Bypass with Bar



x = Longitud efectiva = 3.2 m

$$y = 0.0031(3.2)^2 + 0.0063(3.2) + 0.0007 = 0.0526$$

$$B = B_n - y$$

Figure 16: Desviation of the drill rod according to its length

$$B_{help} = 0.2927\ m$$

$$B_{sub-help} = 0.3663\ m$$

$$B_{contour} = 0.4874\ m$$