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Optimisation of Blasting in Mines: The Case of the M'HOUDATT Mine

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Abstract

Layout of blasting patterns appears to be a major issue for slope stability in the M’HAOUDATT highwall sector.

The M'HAOUDATT deposit has experienced landslides at the pit wall which occur after blasting.

The blasting operation is the first element in the process of granulometric reduction and plays a particularly important role in the stability of the slopes.

The objective of this paper is to limit the secondary fragmentation of large blocks that can be generated by blasting, and to significantly improve the working conditions of the loading and transport equipment of the blasted products.

Secondly, we plan to control the propagation of the shock wave and the nuisances generated by the operation, by meeting the regulatory requirements (in particular with regard to vibrations) and guaranteeing the safety of the operation;

The effect of slippage is an influential factor in the "sterile/mineral" ratio, which requires a reflection on the felling operation.

I. Introduction

The M'HAOUDATT deposit is a naturally rich iron ore deposit (hematite), located 55 km north-east of Zouerate-Mauritania.

The instability of the pit is located in the wall composed of a heterogeneous fracturing network, crossing a soft schistose lithology.

Following an analysis of the surveys of families of discontinuities, we found that the fracturing as a whole has the same geometric characteristics both at the surface and at depth;

The first phenomenon of instability in the M'HAOUDATT pit is exposed to the naked eye on the geological contact zones.

A combination of empirical and analytical calculations was carried out in order to dimension the angle of the step, the inter-ramp as well as the integrating slope of each pit face.

A resizing of the pit slopes was established according to a specific design based on the nature of the terrain, the geo-mechanical parameters and the characteristics of the rock that constitutes it.

These parameters are used in an empirical classification in order to assess the quality of the rock, and to take advantage of the correlation rules between the different methods to deduce the stability parameters.

These data have allowed the analysis of the failure mechanisms that can affect the slopes in an exhaustive way.

The interpretation of these analyses guided us to propose angles intended to ensure the stability of the slopes according to their safe orientations.

Finally, an analysis of the effect of blasting (the subject of this article) was carried out to determine the response of the rock mass to the type of explosive used. This analysis also allowed us to properly cut the pit slopes in order to avoid the painful consequences of blasting on the final pit faces.

II. Analysis of the Effect of the Production Fire

During visits to the M'HAOUDATT site, we found that the positioning of the blasting holes, their loading with explosives, and the undercutting of the loading shovels play a major role in the instability of the pit walls. For this reason, we will initiate this blast effect analysis to determine the appropriate parameters for the MH3 pit walls.

Abbreviation used

BHQ: Quartzite Hematite Bands
H: Hematite
Sch: Shale

Table 1: Mechanical parameters of MH3 rock

	Speed of sound (m/s)	Density (g/cm3)	Compressive strength single (MPa)	Indirect tensile strength (MPa) BRAIZILIAN Trial	Young's modulus (MPa)	Poisson's ratio	IS
BHQ	3933	3.08	148.6	19.5	47642,77	0.308	**6.19**
H	5231	4.56	222.7	10.4	124795,11	0.44	**9.28**
Sch	**3045**	**2.47**	**30.38**	**3.6**	**22900**	**0.2**	**1.27**

Table 2: Characteristics of the explosive

Designations	Density (g/cm3)	Detonation velocity m/s	Critical detonation diameter (mm)	Water resistance	Area of use
ANFO	0.8	3200	50-55	Low	Medium and soft rocks
Emulsions	1.3	5000	20-40	Excellent	Hard and wet rocks

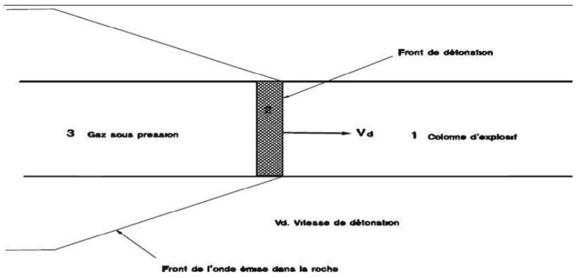
1. Explosive Work

An explosion is a phenomenon in which gases under pressure are generated and released in an extremely short time **[5]**. This phenomenon occurs when an explosive is detonated. In this case, a shock wave propagates through the explosive accompanied by an exothermic chemical reaction, releasing a large quantity of gas at high pressure and temperature.

The detonation propagates through the explosive with a speed greater than that of sound. Initially, the explosive is in the temperature conditions. Pressure and detonation wave, mass volume T0, P0**,** V0. At the end of the reaction, the reaction products are at conditions T1, V1 **[3]**.

In the Z3 zone (figure below): Decomposition gases expand and contribute to the mechanical effects of the explosion.

Figure 1: Propagation of the detonation wave



The economic objectives to be met when fragmenting a rock mass, as indicated by Harries and Mercer.

- Zone 1: the explosive before reaction
- Zone 2: chemical reaction zone
- Zone 3: Reaction product zone

The energy released by an explosive during detonation takes two forms: shock energy, carried by a stress wave and transmitted to the surrounding rock, and gas energy, which manifests itself as high gas pressure and temperature.

2. Rock Removal

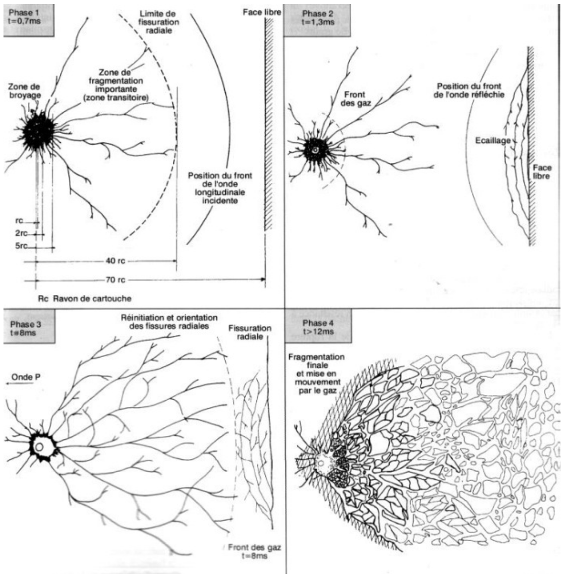
The process of explosive fracturing is based on the combined action of the shock wave and the explosion gases **[7]**. The detonation is not an instantaneous phenomenon, but the two stages that constitute it have very different durations: the shock wave phenomenon is very short compared to the action of the gases. Although these phenomena are not totally independent, their action can be presented in two main phases, as illustrated in the following figure:

- A **dynamic** phase, during which different phenomena can be distinguished, relating to different areas of the rock mass:
  - the shock wave generates, first of all, in a regime that can be assumed to be hydrodynamic, a compression wave, which will generate stresses greater than the compressive strength of the rock. This state of stress will crush the rock into fine particles in a zone around the hole known as the "crushing zone". However, the stresses decrease very quickly: at short distances (3 to 5 times the cartridge radius rc), the stresses are less than the compressive strength
  - Radial cracks are then created: the shock wave loses intensity, but the tangential stresses it creates are still sufficient to fracture the rock by tangential tensile stresses. Despite a decrease in 1/r3 in the crushing zone and in $1/r^2$ thereafter, the stresses remain higher than the tensile strength of the rock, in a zone called the transitional zone (between 20 and 50 rc). Beyond this zone, no significant microscopic cracking occurs: this is the seismic zone. The wave contributes to the weakening of the massif, but without affecting its overall structure through pre-cracking;
  - the last phenomenon of the dynamic phase involves traction waves: the shock waves initially created will encounter free surfaces (typically the front to be knocked down or the discontinuities of the massif) on which they will split into a transmitted wave and a reflected wave. The distribution between the transmitted and reflected energies depends on the ratio of the impedances of the two media. In

the case of a rock-air interface, this reflection is almost total. The initial compressional wave is reflected into a traction wave. This reflected wave generates tensile stresses in the rock mass, which will exceed the mechanical characteristics of the rock and cause cracking, called spalling, in a zone close to the interface. In addition, the reflected waves, by propagating, will reset the cracks created by the first phase;

- A **quasi-static** phase, which is the last stage of blasting: the stress waves have played their role, cracking or weakening the massif, the trapped explosion gases will be able to relax, continuing their propagation and action. They filter into the discontinuities, possibly participating in the cracking, and above all setting the whole in motion.

Figure 1: Development of fracture and fracturing in the rock face



In the radial cracking zone, the rock is subjected to tangential tensile stress in addition to compressive stress; radial cracks develop around the cavity until the tangential stress becomes less than the dynamic tensile strength of the rock. This can cover distances of up to 50 of the critical diameter of the detonation.

3. Transfer of Detonation Energy

The work of the detonation pressure wave which is responsible for the fragmentation of the rock (DESIGN OF SURFACE BLASTS- **ASHUTOSH MISHRA**).

This pressure wave is calculated to evaluate their transfer by a CPF factor must be between [0.7; 1]

The pressure of the shock wave generated by the explosive is approximated by (CHAPMANN-JOUGUET) :

$$P = 2.5\, \rho\, D^2 10^{-6}$$

P: Detonation pressure in kbar

ρ: Specific gravity of the explosive

C: Detonation velocity in m/second

The detonation pressure can be expressed as a function of the detonation velocity according to some authors (The basic mechanisms in rock blasting. Proc of the 2nd cong. Of the Int. Soc. for Rock Mech **-Persson, P.A., Lundborg, N. and Johansson, C.H**):

$$P = \frac{4.18x10^{-7} DC^2}{1+0.8D}$$

P: Detonation pressure in kbar (1 kbar= 14,504 psi)
D: Specific gravity of the explosive
C: Detonation velocity in feet/second (1m=3.2808 feet)
According to the approach of Teller (1985): He defines the acoustic impedance Z of the rock:

$$Z = 1.31\, \rho\, \frac{V_s}{1000}$$

ρ: is the density of the rock
Vs: is the ultrasonic velocity in the rock in ft/s
It defines the characteristic factor CPF of the explosive:

$$CPF = \frac{Z}{P}$$

Where P is the detonation pressure in kbar.

This factor must be between:
0.7 < CPF < 1.

Table 3: Detonation energy transfer

					transfer of detonation energy			**transfer of detonation energy**		
					Z de la roche TELLER			Z de la roche TELLER		
Designations	Density g/cm3	Detonation speed ft/s	Detonation pressure (other authors)	Detonation pressure (CHAPMANN-JOUGUET)	BHQ	H	Sch	BHQ	H	Sch
					15,87	31,25	9,85	15,87	31,25	9,85
					CPF			CPF		
ANFO	0,8	10498,56	22,47	20,48	0,71	1,39	0,44	0,77	1,53	0,48
Emulsions	1,3	16404	71,68	81,25	0,22	0,44	0,14	0,20	0,38	0,12

The pressure increases as the velocity of detonation increases i.e. with Increasing the diameter of the felling holes.

We find that the Emulsion and ANFO explosives have a higher detonation velocity or density than is required to fragment the MH3 pit rocks, and the ANFO explosive has a lower detonation velocity or density than is required to fragment the hematite ore.

4. Energy Transfer in the Massif

This transfer is evaluated by an impedance ratio between the explosive and the fragmented rock:

$$\frac{E_{tr}}{E_i} = \frac{4Z}{(1+Z)^2}$$

With: Impedance $Z = \frac{\rho_e \cdot D}{\rho_r \cdot V_r}$ ratio (established by analogy).

ρ_e *et* D Density and detonation velocity of the explosive.

ρ_r *et* V_r Density and speed of wave propagation in rock.

This theory is thus based on a series of experimental measurements giving a range of interesting values for the impedance ratio Z. This Z value should be between 0.4 and 0.7 (experimentally established corrective coefficients).

$$0.4 < \frac{I_e}{I_r} < 0.7$$

Table 4: Energy transfer in the massif

Designations	**BHQ**		**H**		**Sch**	
	Z	**Transmitted energy**	**Z**	**Transmitted energy**	**Z**	**Transmitted energy**
ANFO	0,21	0,58	0,11	0,35	0,34	0,76
Emulsions	0,54	0,91	0,27	0,67	0,86	0,99

Based on a simulation on the I-BLAST software, for fragmentation by both types of explosives and the impedance ratio approach, we can therefore determine the types of explosives that can be used for foot shear at MH3. Considering these aspects, the only explosive that is a priori powerful enough is Emulsion.

However, the low Z value for the nitrate-oil raises the question of whether this explosive is really suitable for the type of rock mined in MH3. According to this approach, the energy developed by the ANFO explosive would be rather poorly transmitted to the rock mass. However, this study does not fully take into account the energy losses in the annular space for encartouchés; nitrate-oil, which is in bulk form, fills the hole completely, which could explain its good efficiency compared to other encartouché emulsions.

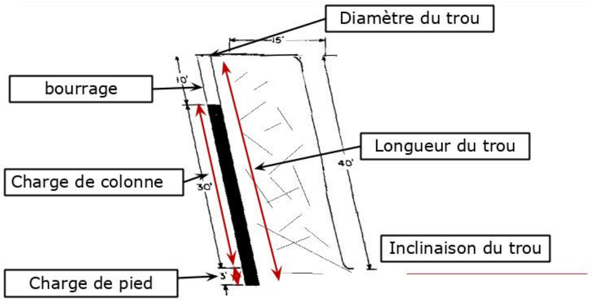
This study proposes a design for an adaptable firing plan for the MH3 pit. This design is found in detail in the body of the study.

III. Dimensioning of a Firing Plan Adaptable to the MH3 Pit

1) Mesh Calculation

Although there is no fundamental theory of explosive blasting, some rules exist for establishing a blasting pattern. Based on these rules of thumb (Study of rock fragmentation by means of explosives **- Rascheeff, 1973***)*, the blasting parameters developed in the rest of this section can be proposed.

Figure 3: Setting up a mesh hole



However, it is better to use the (**Livingston**) crater technique or the American Criteria for larger diameter explosions from 165 mm to 450 mm (The influence of delay timing on optimal fragmentation in electronic blasting. Proceedings of the 1st World Conference on Explosives and Blasting Technique, Balkema **Rossmanith, 2000).**

The proposed empirical approach takes into account the height of the step H, the compressive strength of the rock and the type of explosive used.

Table 7: Dimensioning of basic parameters

		Compressive strength (MPa)		
		<70	**70-180**	**>180**
	diameter d (mm)	**H/60**	**H/44**	**H/37**
ANFO	Bench Bq (m) Spacing E (m)	28*d 33*d	23*d 27*d	21*d 24*d
Emulsion	Bench Bq (m) Spacing E (m)	38*d 45*d	32*d 37*d	30*d 34*d
Tamping B (m)		T=0.7*Bq		
Over-fretting S(m)		J=Bq/3		

A.N:

Table 8: Calculation results

		step height H(m)		**12**
	Nature of the rocks	**Sch**	**BHQ**	**H**
	diameter (mm)	200	270	320
	diameter (inches)	7 ʼʼ $^{7/8}$	10 ʼʼ $^{5/8}$	12 ʼʼ $^{1/2}$
ANFO	Bench (m)	5,6	6,3	6,8
	Spacing (m)	6,6	7,4	7,8
	Tamping (m)	3,9	4,4	4,8
	Overfilling (m)	1,9	2,1	2,3
Emulsion	Bench (m)	7,6	8,7	9,7
	Spacing (m)	9	10,1	11,0
	Tamping (m)	5,3	6,1	6,8
	Overfilling (m)	2,5	2,9	3,2

2). Case Study

To size the following data set:

Table 9: Data from a felling flock

	ANFO			**EMULSION**		
	Sch	**BHQ**	**H**	**Sch**	**BHQ**	**H**
tonnage slaughtered (t)	26 096	41 969	128 135	47 302	76 620	159 293
Slice widening (m)	14	16	33	19	21	39

We calculate all the parameters of the adaptable firing plan:

Table 10: Calculation results

	ANFO			EMULSION		
	Sch	**BHQ**	**H**	**Sch**	**BHQ**	**H**
tonnage slaughtered (t)	26 096	41 969	128 135	47 302	76 620	159 293
volume of rock removed (m3)	10 565	13 626	28 100	19 151	24 877	34 933
the linear metre drilled (m)	14	14	14	15	15	15
Slice widening (m)	14	16	33	19	21	39
number of holes/row	3	3	5	3	3	4
advancement (m)	54	60	60	69	79	59
number of rows	9	9	8	9	9	6
length to be loaded (m)	10	10	10	9	9	8
volume of explosives/hole (m3)	0,312	0,567	0,785	0,289	0,514	0,697
powder factor (kg/m3)	0,564	0,818	0,987	0,458	0,632	0,703
Explosive charge/hole (kg/hole)	0,176	0,463	0,775	0,133	0,325	0,490
tonnage of explosives required (t)	0,250	0,453	0,628	0,376	0,668	0,906
tonnage of explosives required (kg)	250	453	628	376	668	906

3). Pre-cutting

Pre-cutting with explosives is the first time the charges are fired to create a crack that will stop the propagation of vibrations to the mass.

The creation of such a row helps to protect the catchment benches on the desired levels, to keep the frontage intact in place.

This line eliminates micro-fracturing which can develop over time into a family of ruptures responsible for block collapse.

The layout of the holes and the geometry of a flight at the final face should be done with the tightening of the hole mesh of the rows closer to the final pit face to spare the casing area as much as possible.

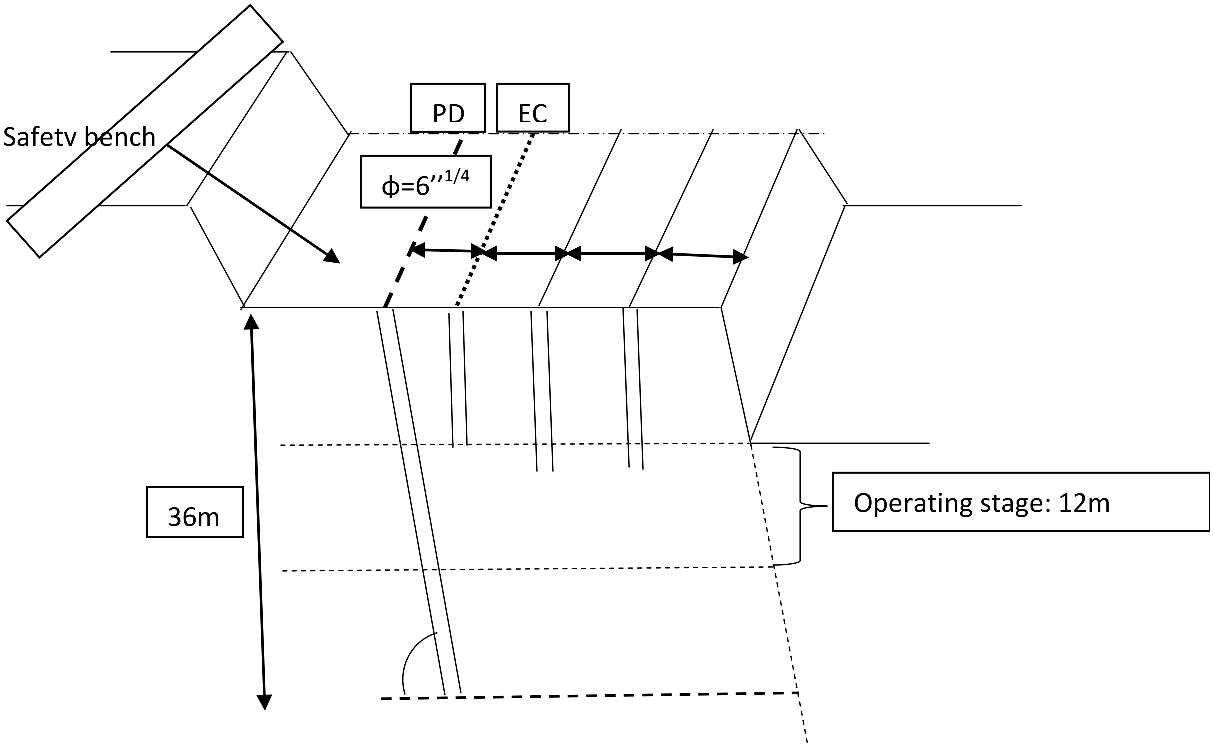
This layout must be carried out according to the different lithological facies existing in the pit.

The diameter of the holes in this line is estimated by $\Phi p = 4.5$ inches in the pit roof and by $\Phi p = 4$ inches in the wall.

The last row should be drilled without overdrilling, separated by a distance of 2 m from the pre-cut line loaded with 80% of the normal load.

There is a delay of 160ms between the jumping of the pre-cutting row and the main firing. Once this row is completed and the blast is effective, a new free surface will be created for the next row, and so on until the last row is fired.

Figure 4: 12m Pre-cut system



Elements of Calculation

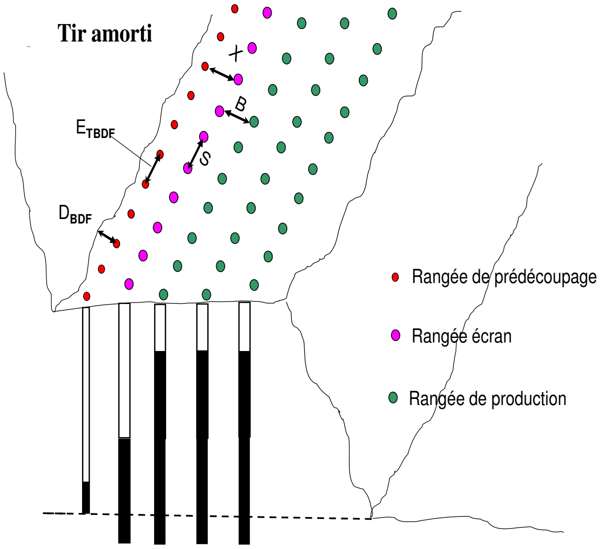
Table 11: Calculation of the parameters of a pre-cutting line

	height H (m)		**12**	
	Wall		**Roof**	
	α (°)	**63**	**α (°)**	**73**
Diameter (m)	0,1016		0,1143	
Load height (m)	8,98		8,37	
Volume of explosives/hole (m3)	0,07		0,09	
Distance dp (m)	3,06		1,83	
Hole depth (m)	13,47		12,55	
Over depth (m)	1,5		0,5	
	ANFO	**EMULSION**	**ANFO**	**EMULSION**
Tonnage of explosives required (T)	0,058	0,095	0,069	0,112
Tonnage of explosives required (kg)	58,23	94,63	68,67	111,59
Specific consumption (t/m)	0,006	0,011	0,008	0,013
Specific consumption (kg/m)	6	11	8	13

4). Shooting in the Buff

This method consists of drilling five production rows on the clearing face (leading face of the shovel) followed by a screen row, and a pit edge pre-cutting row.

Figure 5: Design of the Cushioned Shot



The layout of the precut line depends on the $_{DBDF}$ distance which must be respected without any measurement error,

Note: In areas of low hardness resistance, the Pre-cut holes drilled on the edge of the pit contour will be left unloaded with explosives and tamping and serve as a free clearing face. The screen row holes are pulled towards the empty line, so that each screen row hole breaks the existing wall between two empty holes of the Pre-cut row.

Figure 6: Pre-cutting test with empty holes

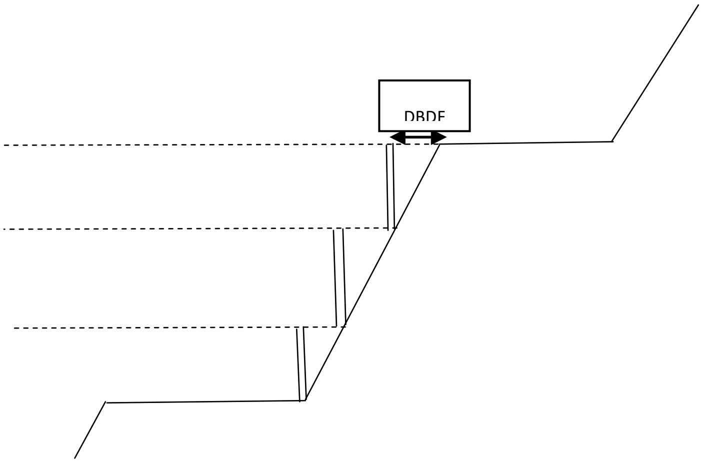


Figure 7: Damped firing pattern configuration

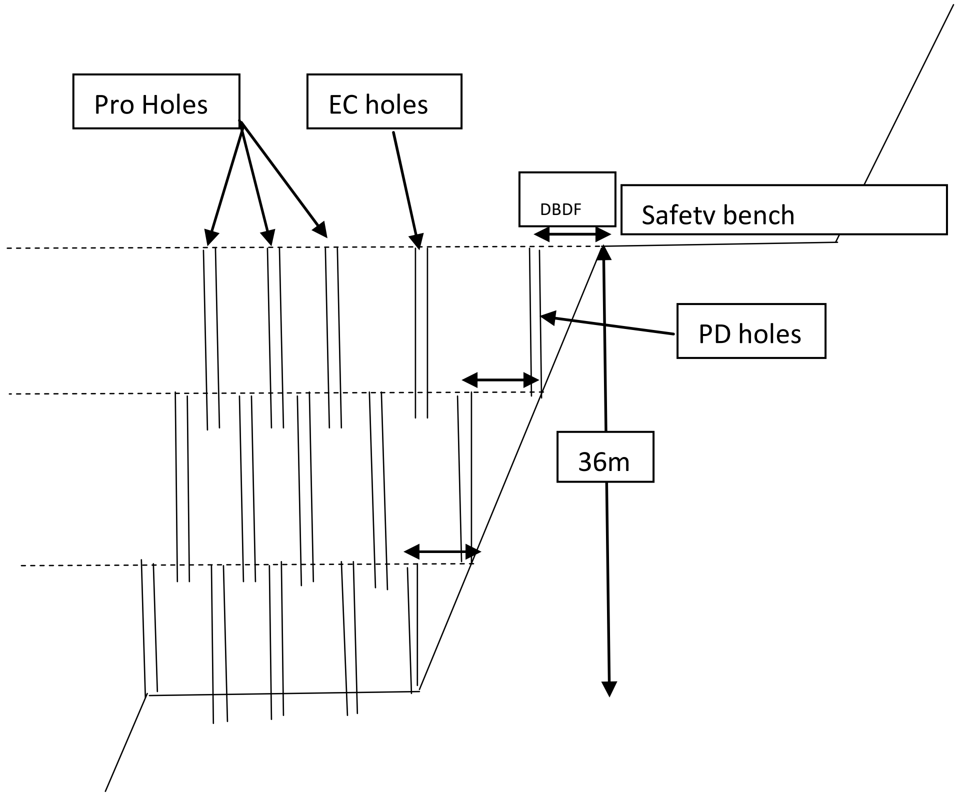
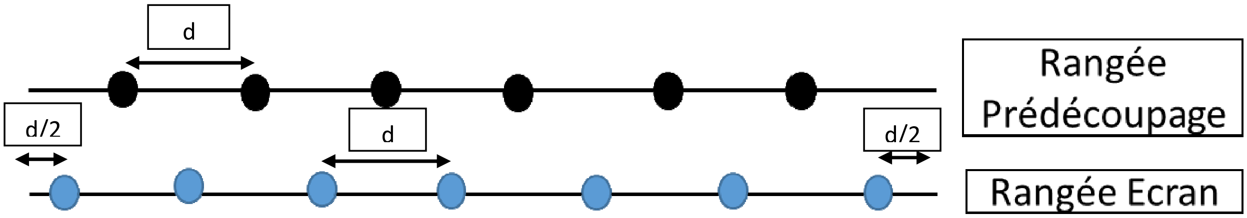


Figure 8: Empty hole pre-cut test



The amortization method is applicable if two conditions are met:

- Limit production rows to three rows
- Shooting at a clearance surface

NB: that firing without a clearing front, with the deflagration pointing upwards, generates :

- An important back effect;
- A bad platform after shooting;
- The need for ripping or breaking to achieve the desired level.

In addition to the cross-sections, the following outline highlights the main focus for reducing the negative impacts from blasting along the M’HAOUDATT hanging wall and other wall sectors.

i. Blast pattern layout along pit walls should be oriented with respect to the pit wall. Always locate the trim row first. The trim row should reflect the wall orientation. The ramining rows ar spaced with respect to the trim row location. Currently, the patterns ar surveyed with respect to the dig face, which causes inconsistencies with burden and spacing of blast holes nearest to the pit wall.

ii. The blast should be initiated to two free faces at the corner of the pattern.

iii. Avoid drop-cuts next to final walls. Instead, drop cut in the pit center, then establish haul ramps with blasting to free faces. This greatly reduces vibration to the final walls and avoids the practice of undercutting rock fabric

iv. The buffer row should be placed between the trim row and the first production row. The buffer row should have the same burden and spacing as production holes, with approximately 80% of the normal production charge.

Conclusion

The M'HAOUDATT pit is unstable due to the operating conditions and the lack of control of the blasting operation, which requires the operators to respect the geotechnical parameters.

The analysis of all the results allowed us to carry out an overall analysis and enabled us to determine that information on the characteristics of the rock mass and the explosive is essential for the effectiveness of the shots and the improvement of the fragmentation.

The use of previously fired flights as a clearance surface so that the maximum amplitude of the deformation wave is well distributed towards the edges of the pit.

The degree of fragmentation and distribution throughout the rock pile is a function of the method of initiation of the explosive and the parameters of the rock, as well as the parameters of the shot.

The reduction of the detonation energy sent to the rock mass is always controlled through the respect of recommended diameters of the drill holes by techniques can be developed for the optimum use of a drill hole in the economy of the shooting operations as a whole

This exhibition shows that the control of depth and load for all holes and the correct application of pre-cutting in areas containing highly stained talc becomes a necessity to prevent slippage and cracking of the walls.

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