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Large Diameter Holes Presplitting

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Abstract Increasing the diameter of drill holes is an option to increase the tonnage in open-pit mines. This explains the appearance of unexpected disorders during drilling and blasting, the consequences of which classically take the form of both instability in the pit walls and collapses affecting the surface. Here, the phenomena observed are located between the slopes of the M'HAOUDATT pit. The disorders inherent in large-scale mining appear on the pit walls. The company operating the pit exploits the benches only with large diameter drills. The objective of this work is to find an optimal method to minimize the effects of the vibration of the blast on the pit of M'HAOUDATT in order to reward the absence of the Presplitting machines. Proposals to limit the effects of blasting were discussed in two aspects, such as reducing the tonnage of explosive in the holes or finding a way to reduce the diameter of the hole, which is considered inappropriate to create stable fronts. We conclude that it is preferable to play on the diameter of the hole and to concentrate on this direction in order to come up with a method to replace the absence of pre-splitting machines in the mine. The method of borehole diameter reduction is considered new for the pit operators. Therefore, it will not be effective in the test phases despite the relevant results after the front blasting. It is important to note the difficulties of replacing small drilling machines in open-pit mines. The implication is the efficiency of the method, the right way of execution and the training of the mine personnel.

Keywords M'HAOUDATT, Open Pit, Slope Stability, Presplit, Drill, Blast, Explosive, ANFO

1. Introduction

The determination of an optimal slope angle of an open pit, before its opening, is effectuated by taking into account geological and geotechnical parameters, necessary for the stability analysis [1].

The stability angles of the M'HAOUDATT pit are determined through an incomplete geotechnical model, due to the absence of a solid recognition method. Some parameters are therefore estimated.

During the deepening of the pit, new information was collected [2]. The analysis of the stability of the slopes requires a detailed examination of the geological and geotechnical parameters of the rock mass. Indeed, these parameters influence the design of slopes, particularly in open pit mines [3, 4].

Slope stability is always influenced by the damage caused by blasting. This damage is evaluated by a damage factor [5]. The factor depends on the degree of perturbation to which a rock mass of variable geological strength index (GSI) is susceptible due to blast damage and stress relaxation caused by pit excavation [6, 7].

It describes the extent to which intact rock modulus is affected [8]. Such degradation of rock modulus and strength can result either from an increase in fracture frequency or from fracture expansion. Both phenomena can be caused by blasting [9].

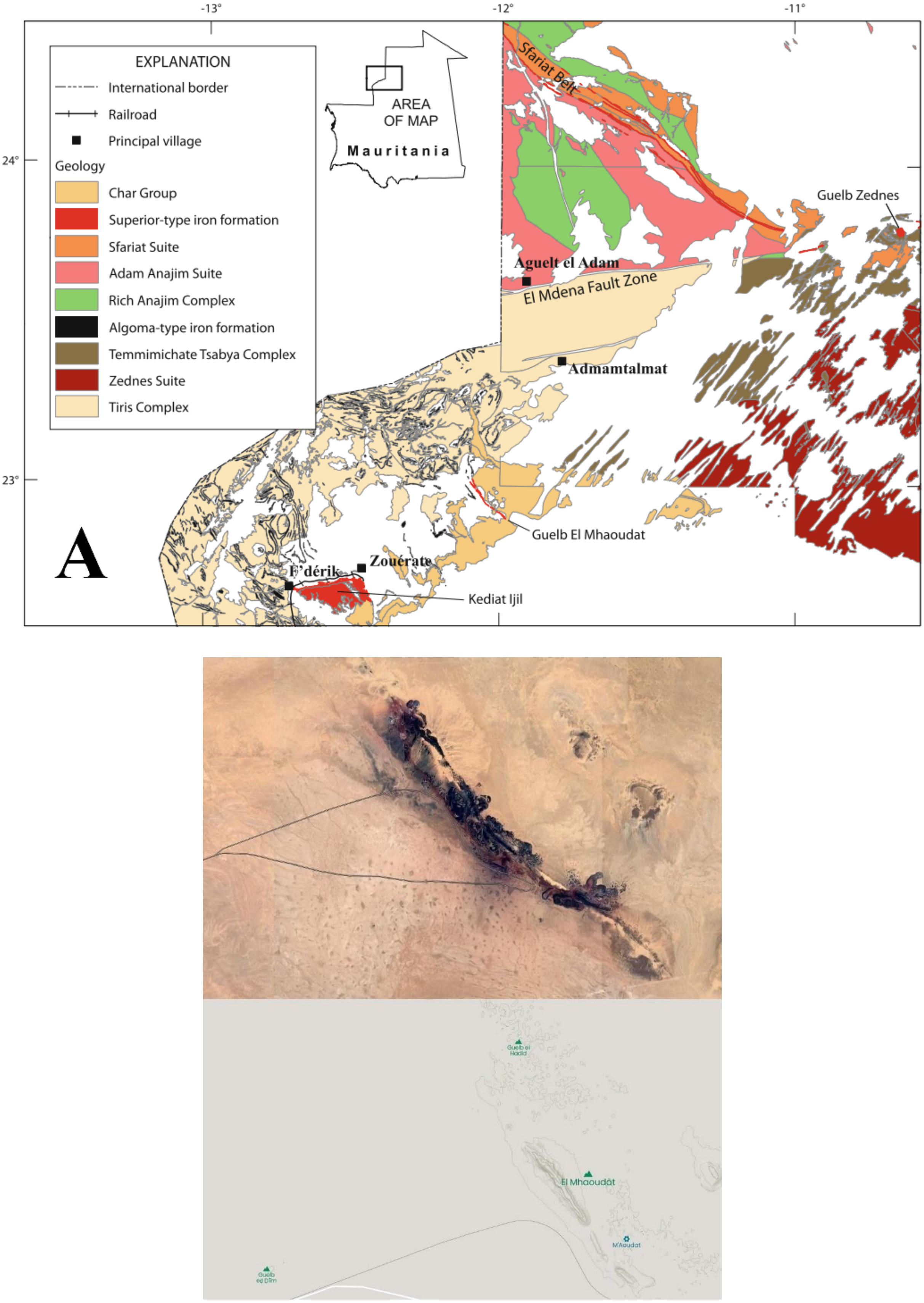


Figure 1. (A) Geographical zone of M'HAOUDATT, (B) Overview of the M'HAOUDATT chain

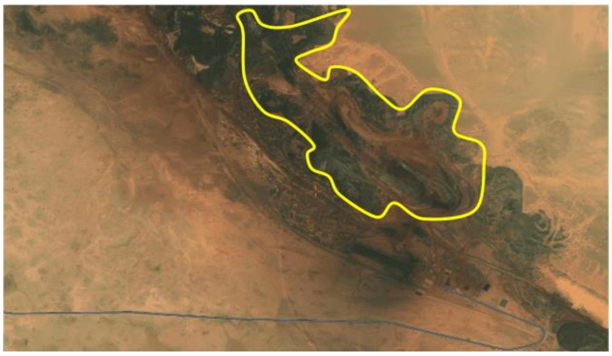


Figure 2. MH3 Pit

2. Case Study: M'HAOUDATT Pit

The M'HAOUDATT chain is located 55 km from the town of Zouerate in northern Mauritania (Figure 1A). The chain is formed almost entirely of Banded Iron Formation, with some quartzite and schist units (Figure 1B). One of the pits in the chain that is currently being mined is MH3 (M'HAOUDATT3) (Figure 2).

3. Materials and Methods

The blasting anomalies led us to investigate the heart of the production chain in order to save the feasibility of the resources, both material and human, of the mine.

In this article, we were at the same distance between the productivity and the safety of the mine.

It was not easy to put the finger on the problem until after several experiments and concentration.

The exhaustive use of explosives in every blasting operation put us in front of a big question mark about the effect of blast waves on the stability of the pit.

The operator of the MH3 mine suffers from the method of blasting by the use of large diameter drilling machines.

This diameter which is around 311mm generates anomalies on the slope stability (difficulty of realizing the bench face angle and the safety berm) with regard to the safety of the pit and at the level of the feasibility of the pit resources, the blasting of large diameter creates a difficulty at the level of the selectivity of the mining resources (heterogeneity of the platforms resulting from the blasting).

The instability of the MH3 pit walls is frequently caused by a combination of the nature of the rock, its weathering and the geological structure of the massif, the orientation of the excavation walls and the damage caused during blasting.

The poor adaptation of the mining design, the misinterpretation of the geology of the rock mass and the difficulty to control the blasting around the final pit fronts represent the priority causes of the instabilities observed on the excavated pit fronts.

The stability of the pit walls was evaluated through appropriate software to clarify the difference between the excavated pit and its intended design.

During the stability analysis phase of the MH3 pit, the option of reducing the drilling diameters was always in front of us due to the large quantity of explosives used during each blast performed at the bottom of the pit. This diameter reduction requires a fictitious concentration due to the absence of adequate drilling machines equipped with this method.

And in front of the minimal choices, we were obliged to drill by the large diameter and to find an approach to reduce it in terms of measures or to play on the quantity of explosives intended for a better fragmentation.

This paper presents the results of the pit slope blasting optimization tests over a period of 4 months (March 2022 to June 2022).

4. Slope Stability Evaluation

Since it was mined, the MH3 pit has experienced severe instabilities which have resulted in perturbation of the production process. These instabilities occurred on the pit wall where the lithology is mainly formed by schists.

Table 1. Geotechnical parameters of the MH3 pit recommended by the geotechnical study in 2005

Pit	**MH3**	
Sector	Foot-wall	High-wall
Orientation	045DDR	220DDR
Bench height	12	12
Bench width	17.1	14.6
Bench face angle	56	79
Inter-ramp	41	59

Table 1 summarizes the geotechnical parameters of the MH3 pit, and the pit dimensions recommended by the 2005 geotechnical study are summarized in Table 2.

Table 2. Dimensions of the MH3 pit recommended by the geotechnical study in 2005

Dimensions of MH3 pit	**CNI 2005**
Depth (m)	190
Maximum length (m)	1920
Maximum width	310; 350

A conformity evaluation of the pit was carried out to investigate the condition of the benches in relation to the recommendations of the geotechnical investigation of the pit. A total of three (3) sections covering the MH3 pit were prepared (Figure 3).

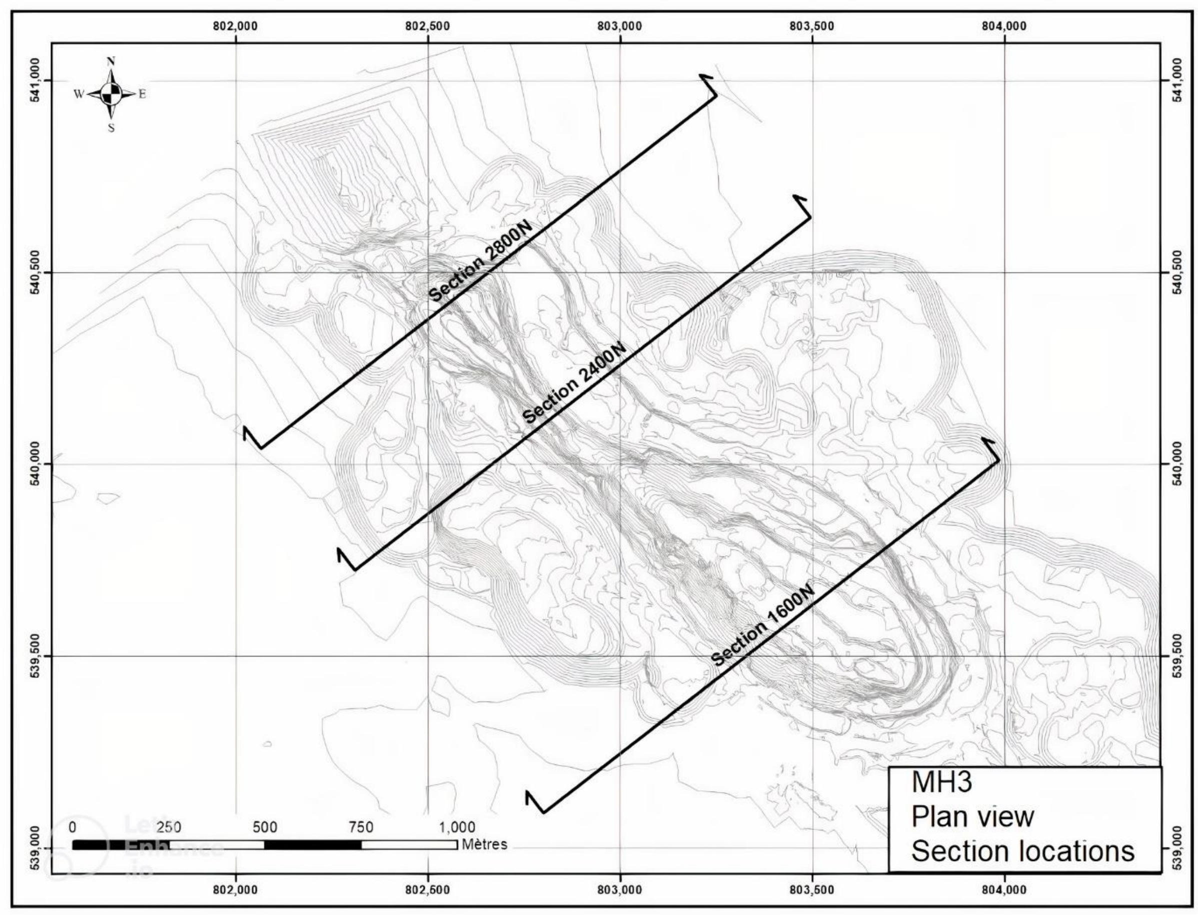
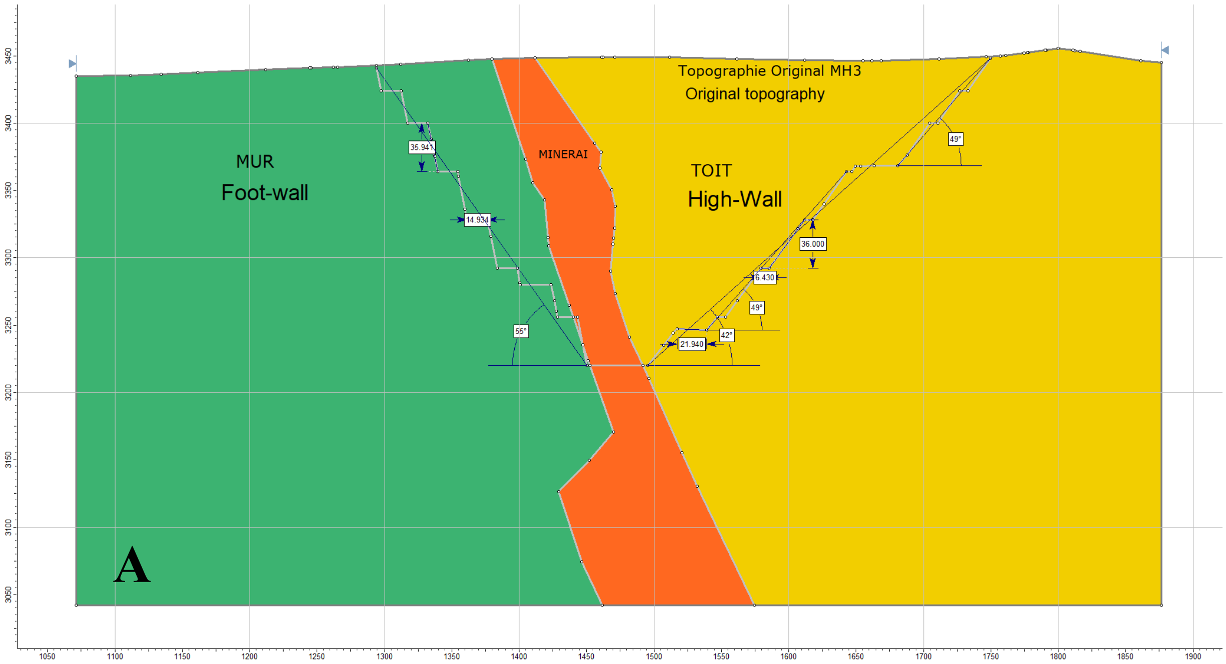


Figure 3. Location of the three sections of MH3 Pit

Section 1600N has received special attention in this article, as it contains an area of collapse, which is discussed in more detail in the next chapters. The analysis of the sections is illustrated in Figures 4-6.



B

Figure 4. State of MH3 pit slopes indicated by section: (A) 1600N Meas, (B) 1600 N mined

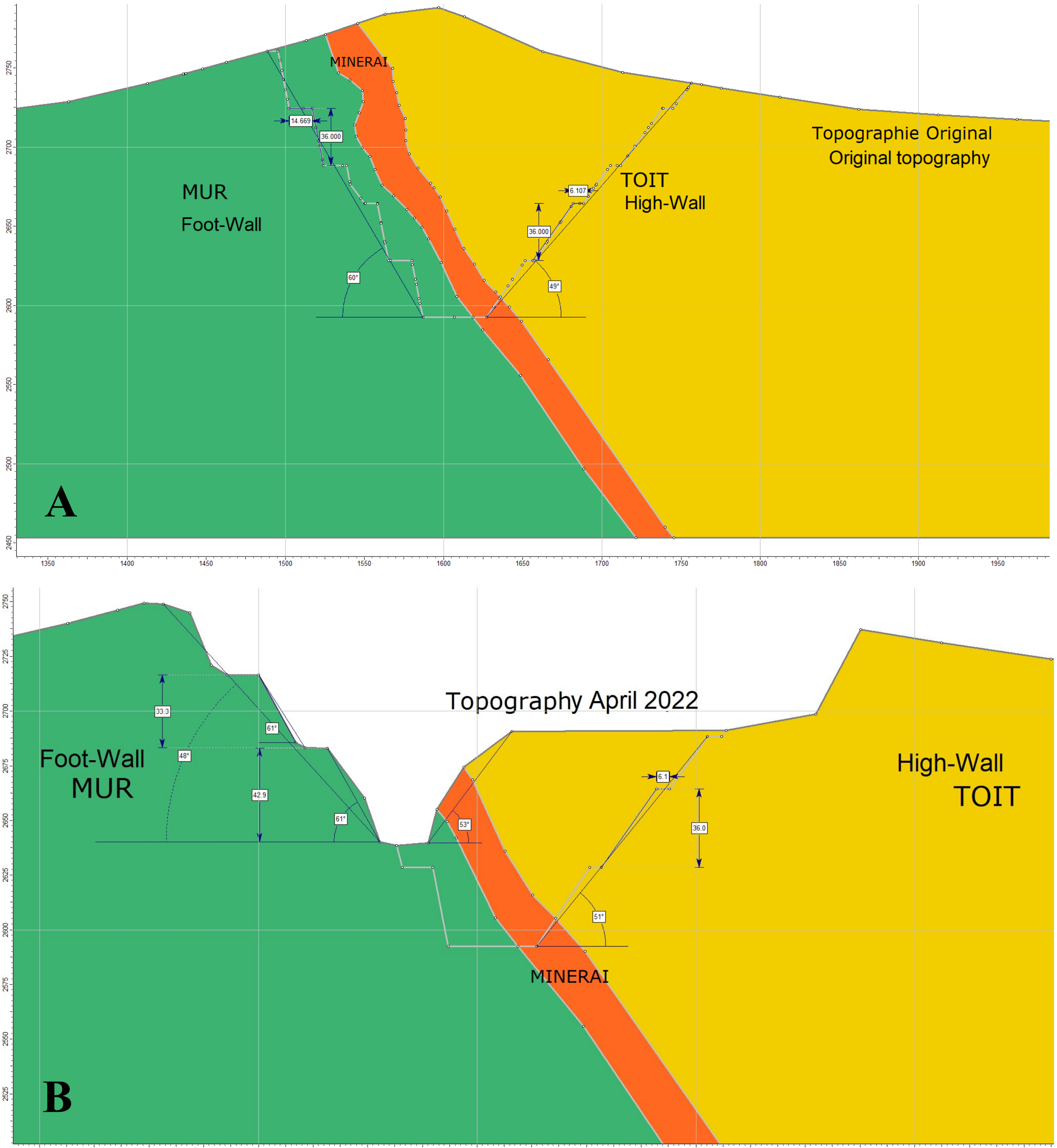


Figure 5. State of MH3 pit slopes indicated by section: (A) 2400N Meas, (B) 2400 N mined

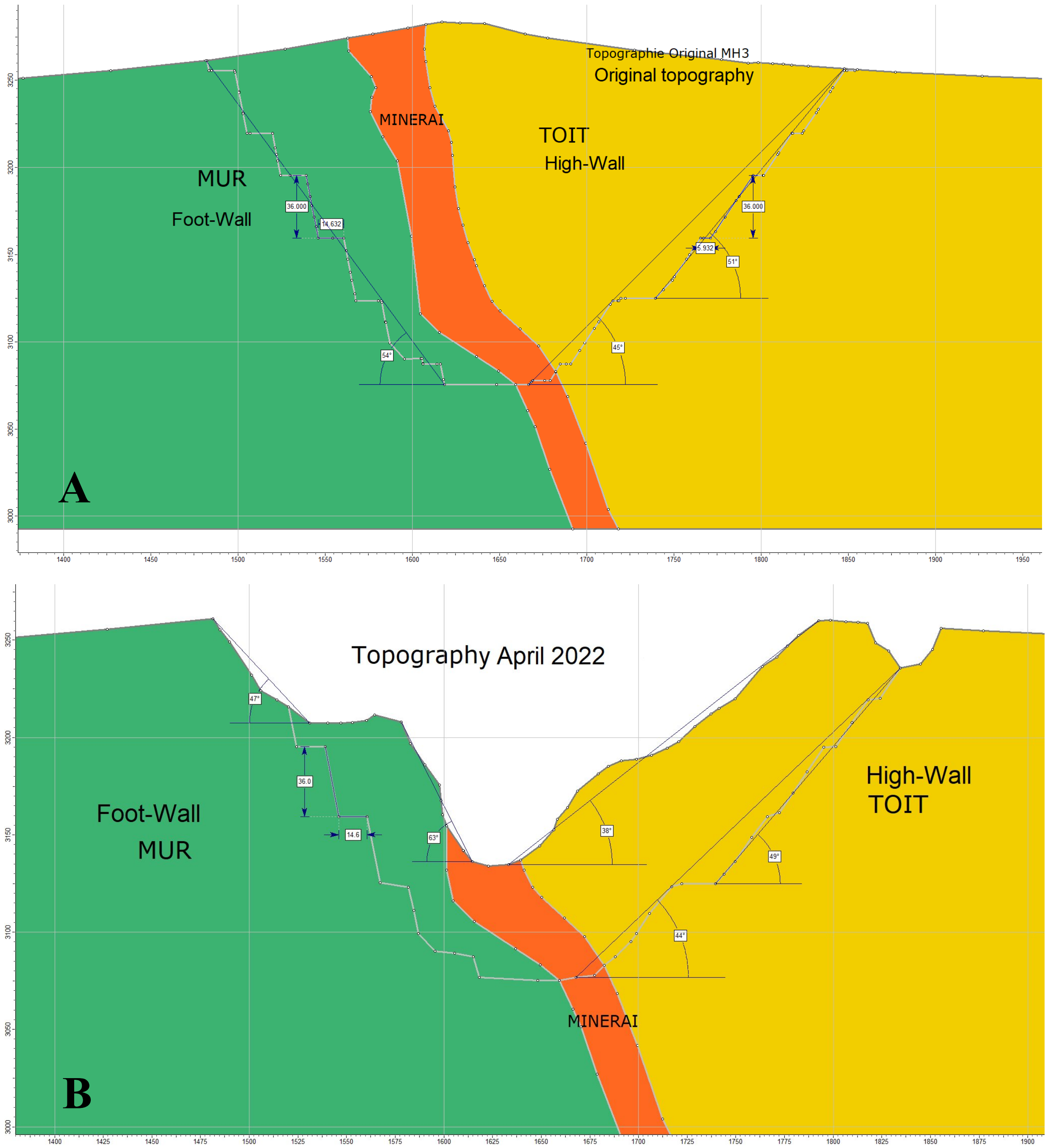


Figure 6. State of MH3 pit slopes indicated by sections: (A) 2800N Meas, (B) 2800N mined

The analysis of the various sections as constructed shows that the MH3 pit is not being operated within the parameters of the 2005 study (see Table 1). The main non-conformities noted are the absence of benches, the non-implementation of safety berms and the poor design of the inter-ramps.

The poor design of the benches poses a high risk of rocks falling to the bottom of the pit and projection to the site where employees and company equipment are located [10].

The overall slopes were checked for the 1600N, 2400N and 2800N cuts of the MH3 pit. The observations show that the overall slopes of the western wall of different sections vary from the recommended slope.

4.1. Platform Heterogeneity

After the loading of the fired products, it is always found that the platforms after the blast do not respect the expected pit levels.

More the problem of stabilities of front, we do not manage with the big dimeters to crush correctly the targeted toes.

This means that the mine is disturbed as much by the menace of security on the one side and the health of the deposit on the other side.

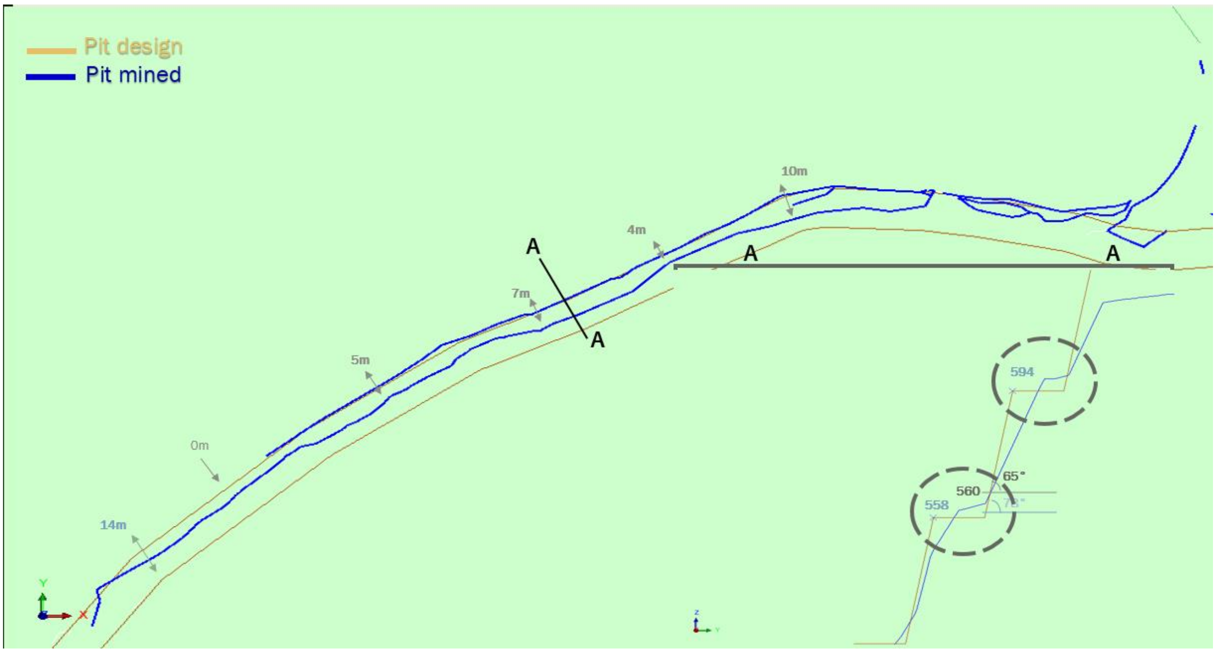


Figure 7. Berms above the level expected

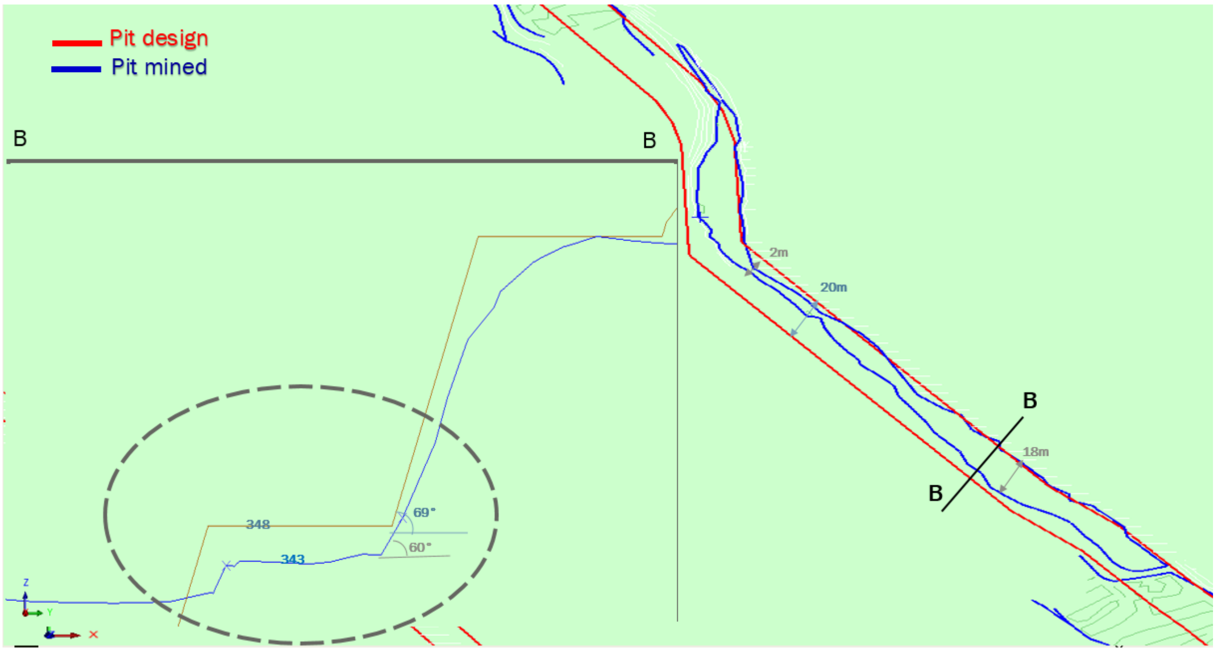


Figure 8. Berm below the level expected

Figure 7 shows that in the section AA you can observe that a portion of the berms is made on a higher level than its planned level.

On another berm of the pit, we encountered an exceeding of the planned level of the pit (Figure 8).

On-site observations concluded that the majority of the anomalies originated from the blasting methods next to the walls.

The non-control of the blasting with the large diameters imposes us to focus on a method of control of mining as much for the safety as for the productivity and the health of the deposit.

The effect of large diameter drilling impacts the safety and productivity of the pit, generating an unplanned strip ratio and causing instability of the MH3 pit walls.

This requires focus to minimize damage on the pit front [11].

5. Blast Damage Evaluation

The impacts of mining on the slope are very apparent by the existence and expansion of micro-fractures decreasing the strength and GSI modulus of the solid rock, including the creation of fissures on the pit fronts [12].

In the first step, we started by following the blasting operation from the implementation to the shooting. The parameters of the holes are summarized in Table 3.

Table 3. Parameter of the blast holes

Type of explosive	**ANFO**
Hole diameter	12’’$^{1/4}$
Hole height	12
sub-drill	3
Stemming	5

Figure 9 shows a MH3 pit wall implementation. This layout was shot a few days after it was drilled.

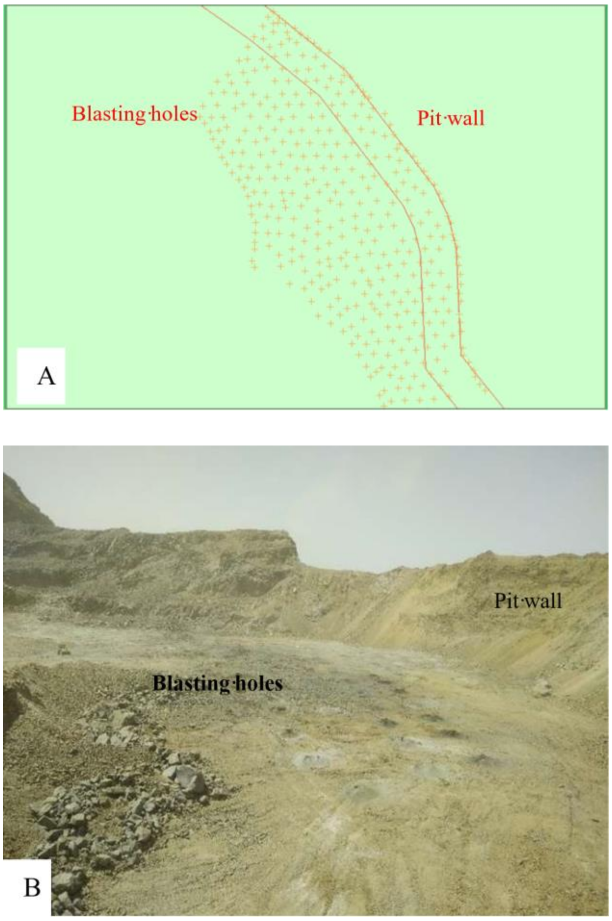


Figure 9. MH3 pit border implementation: (A) numeric implementation, (B) onsite implementation

When drilling on the pit wall side, the cleaning of the platform and the fronts next to it must be ensured. Although it is important to ensure the cleaning of the bench toes.

Figure 10 shows that these corrections have not been respected, which will influence the loading method.

During the loading of the excavated platform, a deviated fracture was found on the pit slopes. This fracture was scanned and surveyed at the request of the monitoring team (Figure 11).

Figure 10. Blasting results

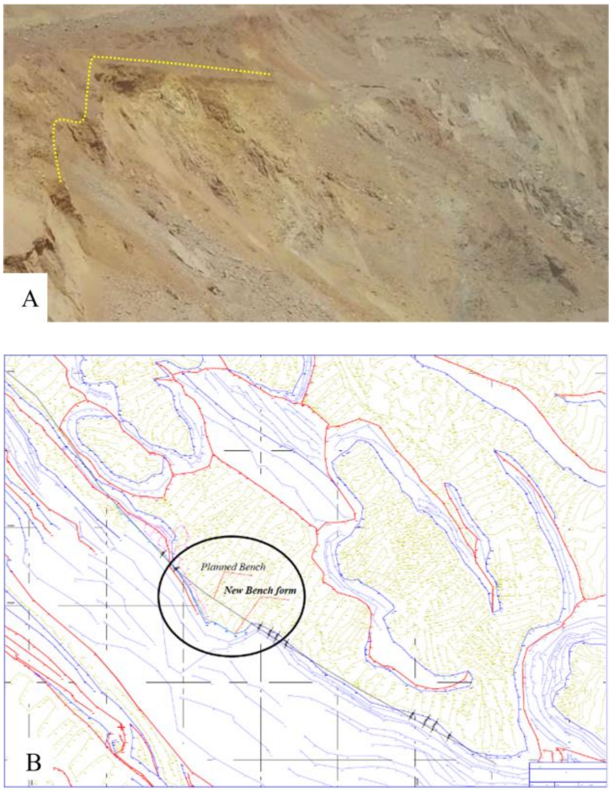


Figure 11. (A) Form of the rupture observed on the front, (B) topographic surveys of the slip

5.1. Analysis of the Pit Wall Failure

The blast-induced fracture is located in the middle of section 1600N in Figure 3, at the location of a ground instability that is affecting ore production in the MH3 pit (Figure 12).

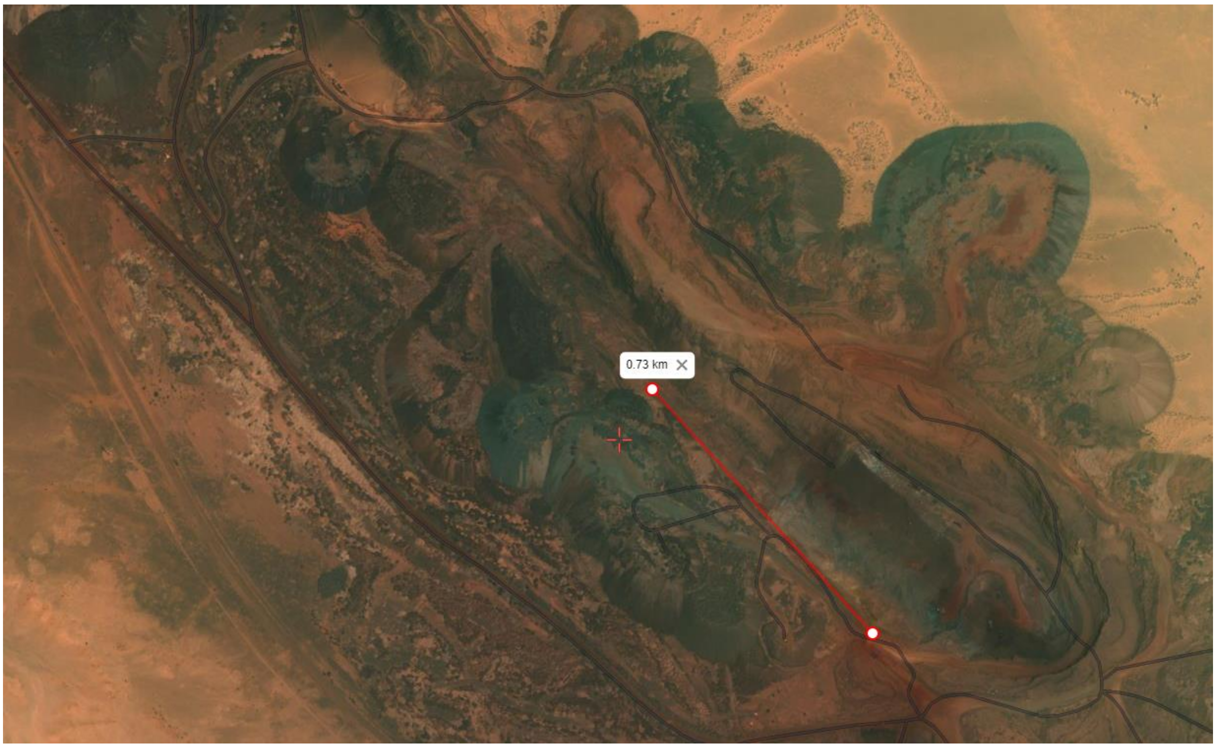


Figure 12. Overview of the length of the instability

Figure 10 shows an unstable kilometer distance on the pit wall due to the effect of lithology degradation influenced by the blast energy.

The unstable zone is subjected to a blasting front analysis to evaluate the impact of blasting next to the pit border [13].

Table 4 shows the rock parameters adopted by the company operating the MH3 pit.

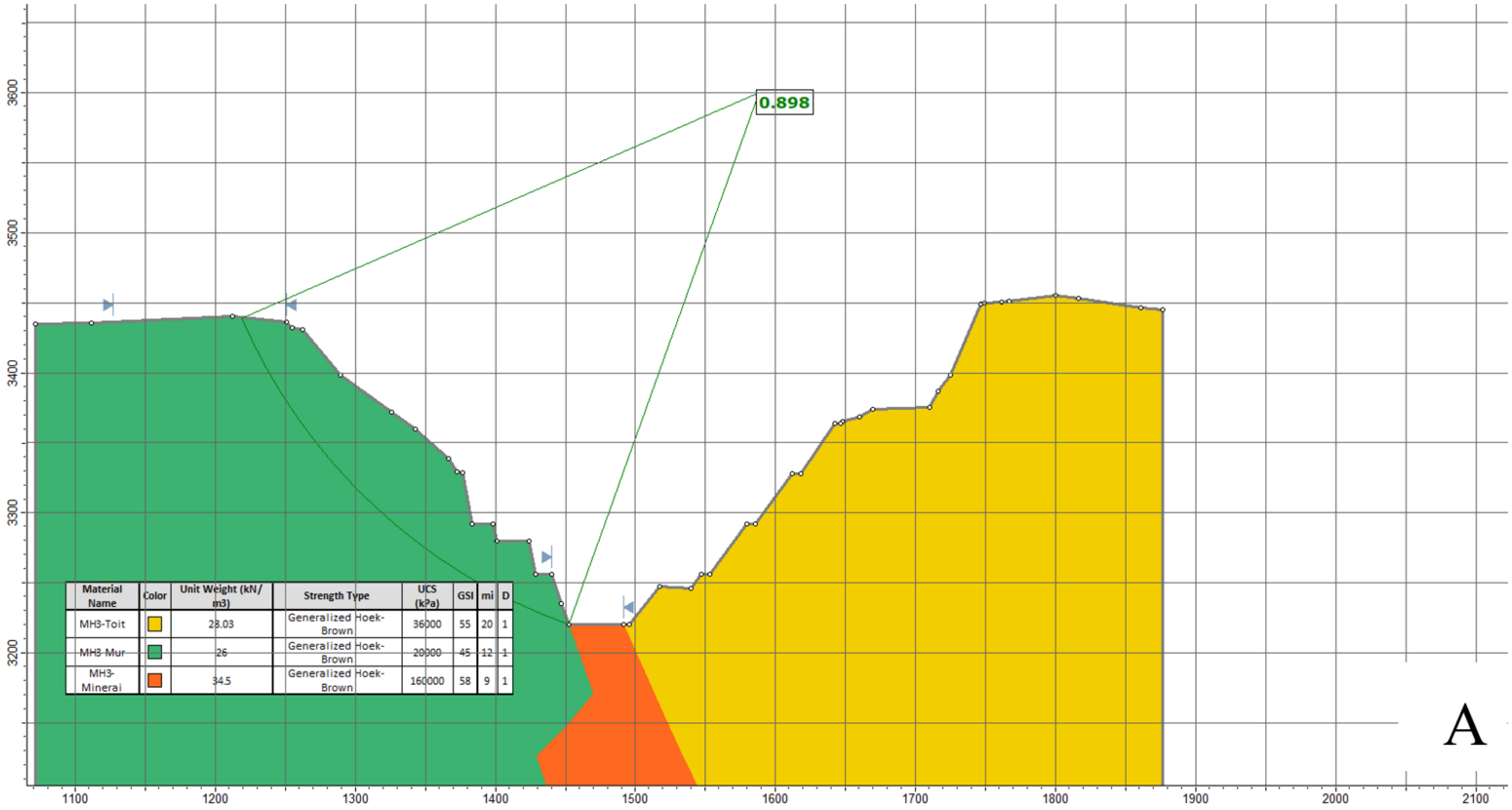
This analysis is based on the perturbation factor D, which depends on the degree of perturbation to which the rock mass is likely to be subjected due to damage from blasting and stress relaxation caused by pit excavation.

It varies from zero (0), for a confined and completely non-disturbed rock mass, to one (1) for disturbed rock masses [14].

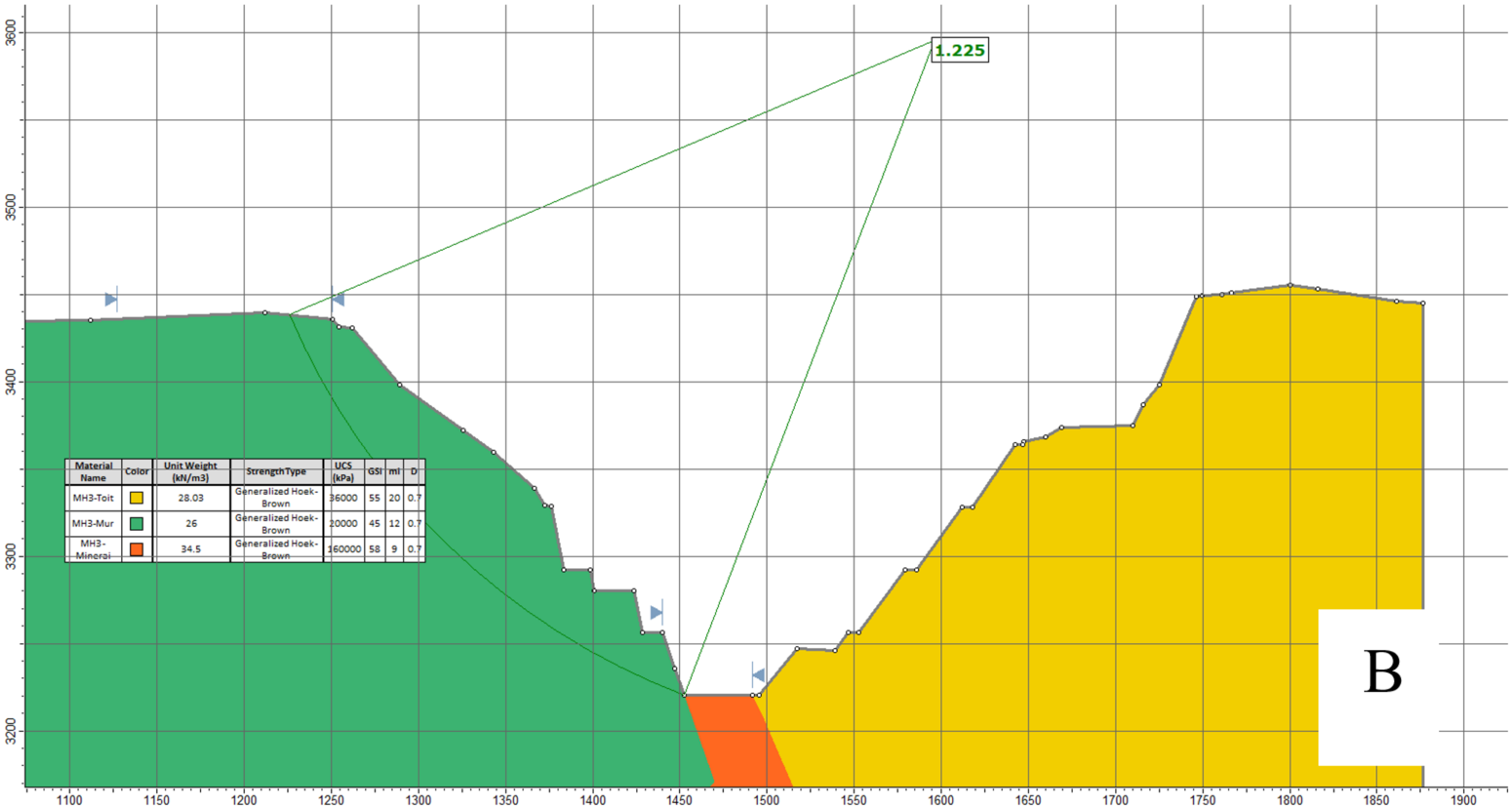
Two cases were simulated according to this perturbation coefficient (Figure 13).

Table 4. Geotechnical parameters of the MH3 rock.

Rock type	**Banded Hematite Quartz**	**Quartzite**	**Schiste**
Unit weight (KN/m^3)	34.5	28	26
UCS (Kpa)	160	36	20
Base Friction Angle	36	36	
GSI	58	55	45
D	1	1	1
MR	375	375	675
mb	0.448	0.804	0.236
s	0.009	0.006	0.0001



Material Name	Color	Unit Weight (kN/m3)	Strength Type	UCS (kPa)	GSI	mi	D
MH3-Toit	🟨	28.03	Generalized Hoek-Brown	36000	55	20	1
MH3-Mur	🟩	26	Generalized Hoek-Brown	20000	45	12	1
MH3-Minerai	🟧	34.5	Generalized Hoek-Brown	160000	58	9	1



Material Name	Color	Unit Weight (kN/m3)	Strength Type	UCS (kPa)	GSI	mi	D
MH3-Toit	🟨	28.03	Generalized Hoek-Brown	36000	55	20	0.7
MH3-Mur	🟩	26	Generalized Hoek-Brown	20000	45	12	0.7
MH3-Minerai	🟧	34.5	Generalized Hoek-Brown	160000	58	9	0.7

Figure 13. (A) MH3 pit walls with a coefficient D = 1, (B) MH3 pit wall with a coefficient D = 0.7

For the perturbation coefficient close to 1, the FOS is always lower than 1(0.89), which means that it is unstable (Figure 13A). While the same wall uses the same parameters but with a Perturbation factor of 0.7, the FOS is 1.225, which is considered stable (Figure 13B).

This shows the importance of controlling the blasts, especially near the ultimate walls [15].

5.2. Influence of the Blasting Holes

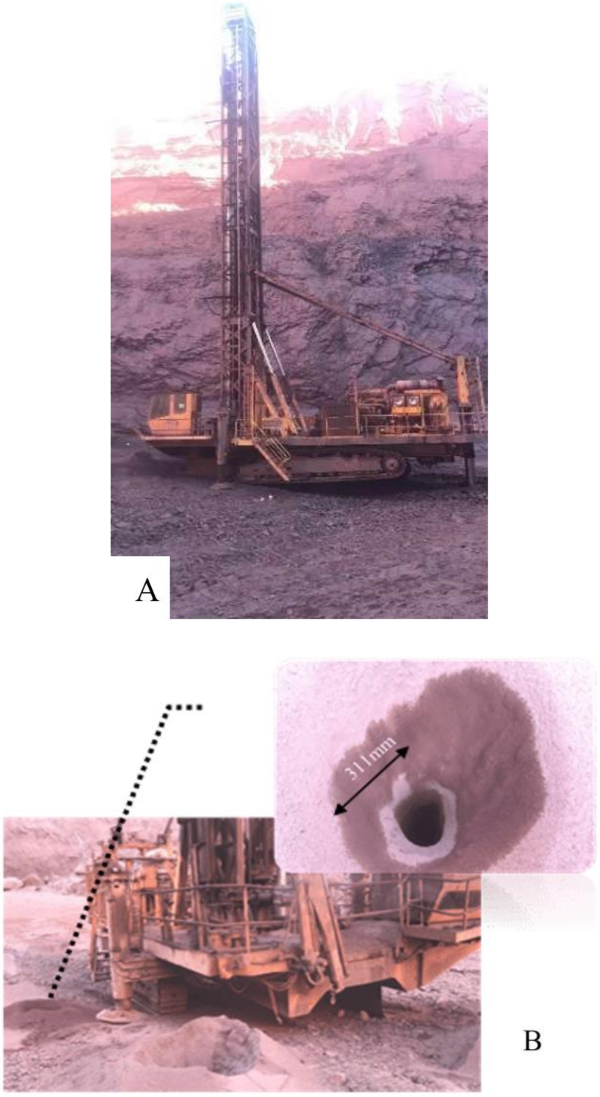


Figure 14. (A) Drill machine at MH3, (B) Form of the drilling holes

The result is that the large-scale blasting carried out on the wall of the MH3 pit caused a part of the wall of the pit by the amplitude of the reaction forces. We can interpret that this instability comes from the high pressure explosion gases which are considered responsible for the expansion of the joints (confinement).

During the investigations, it was clear that the pit wall was influenced by the diameter of the drill holes (Figure 14).

It is important to adjust the diameter of the hole to reduce the radius of high-intensity vibrations or dynamic stresses because the linear charge in the vicinity of an explosive column is expressed in mass of explosive per meter of column length.

Experience shows through “(1),” that the explosive loading density (ƒ) varies as a function of hole diameter (d) [16, 17]:

$$ƒ=0.3404xD^2xd_e \tag{1}$$

ƒ: loading density of explosives (Kg/m)
D: diameter of the hole (mm)
d_e: density of the explosive (g/cm^3)

Table 5 summarizes the characteristics of the ANFO explosive used at the MH3 pit.

Table 5. Explosive characteristics used in the mine

Designation	**ANFO**
Density (g/cm3)	0.8
Detonation velocity m/s	3200
Critical detonation diameter (mm)	50-55
Resistance to water	Poor
Domain of application	medium and soft rock

The approximate results of the loading density calculation for a variety of borehole diameters (see Table 6):

Table 6. Loading density as a function of diameter.

D (mm)	102	150	251	311
ƒ (Kg/m)	2.83	6.13	17.16	26.34

It is clear that increasing the diameter maximizes the vibrations responsible for fresh fractures [18].

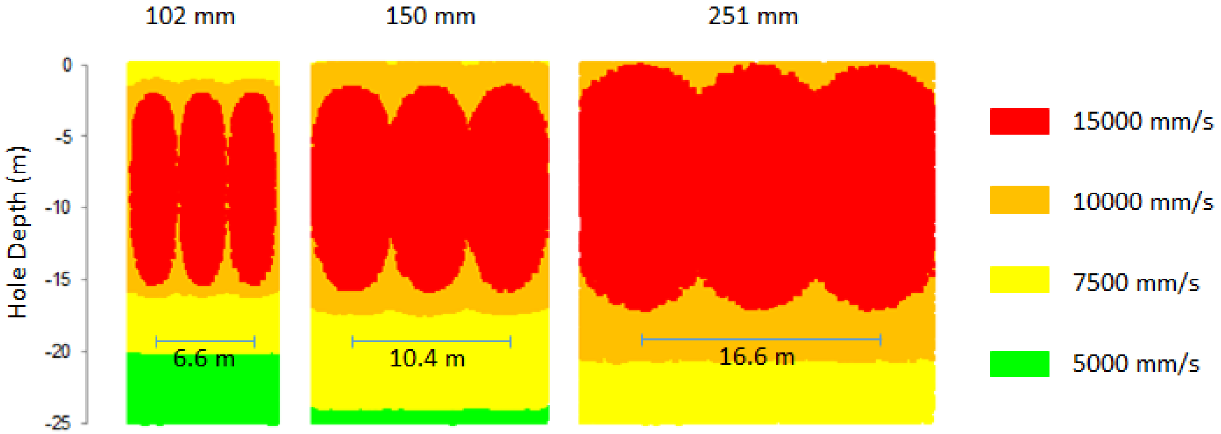


Figure 15. Heat maps showing vibration intensity around blast holes of 102, 150, and 251 mm diameter

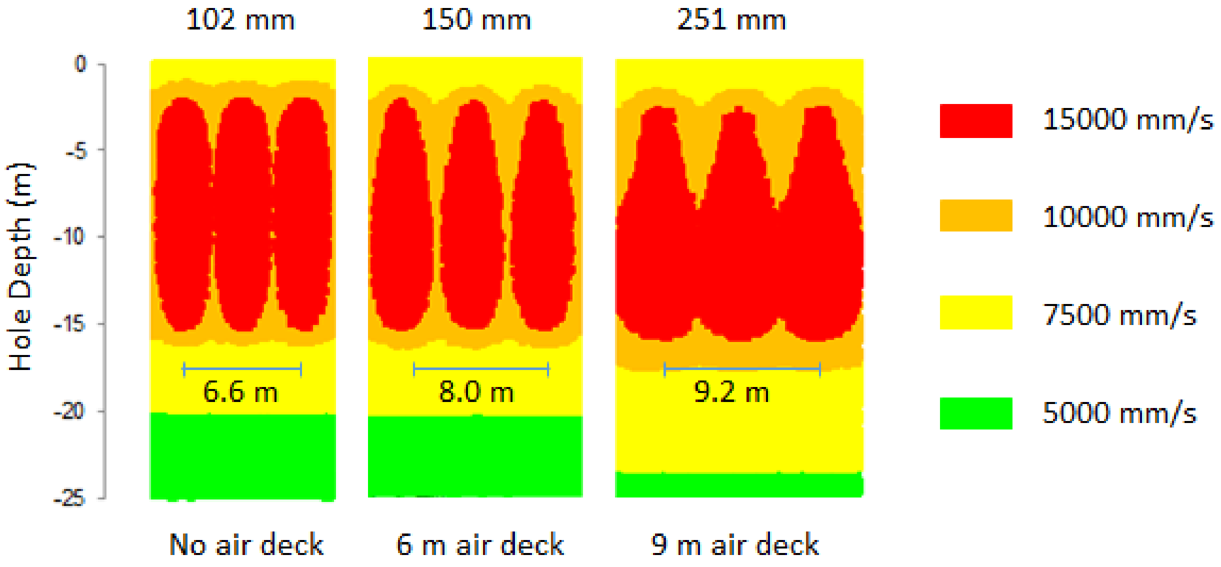


Figure 16. The use of air decks in blast holes diameter

Figure 15 presents arguments on the importance of reducing the diameter of the hole to properly minimize the vibration intensity and control the shock energy sent to the rock mass.

6. Blasting Optimization

At this stage, the mine of M'HAOUDATT can no longer support the voluminous blasts which damage the walls of the pit.

In order to control this point, we have started tests to optimize the blasting in two steps:

- Reduce the tonnage of explosives
- Reduce the diameter of the holes

6.1. Reduce the Tonnage of Explosives

The first idea that a geotechnical engineer may propose is to reduce the quantity of explosives used in the holes. A proposal to separate the charge by empty air deck was adopted (discontinuous charge) instead of confining the charge to the bottom of the hole. Simulations show the efficiency of the experiment (Figure 16) [19].

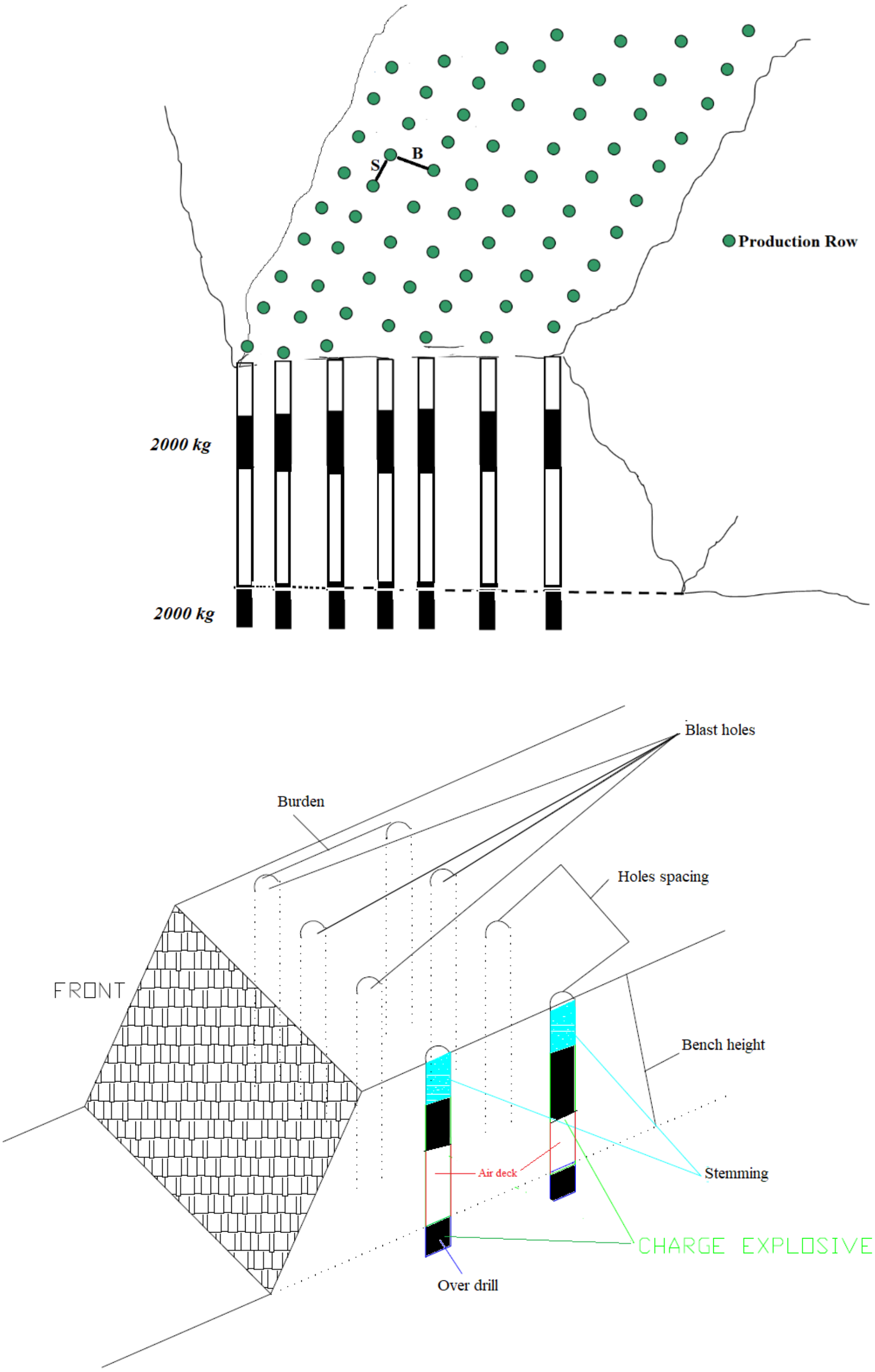


Figure 17. Proposed pit slop blasting design

Figure 17 shows the pattern of the blast holes on the platform.

6.2. Reduce Hole Diameter

The absence of secondary drilling machines requires drilling the pit walls with large diameter holes for stripping purposes. With this diameter, it is difficult to control the radial shear of the surrounding rock.

We have thought of a practice that will allow the hole diameter to be reduced after drilling to ensure the distribution of linear loads evenly over the length of the hole.

This practice consists of drilling holes without over-depths and introducing pipes of length 15m and diameter 150 mm (Figure 18).

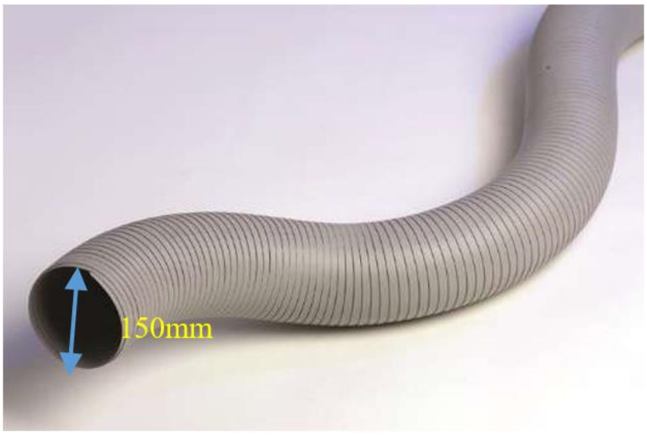


Figure 18. Form of the pipes used

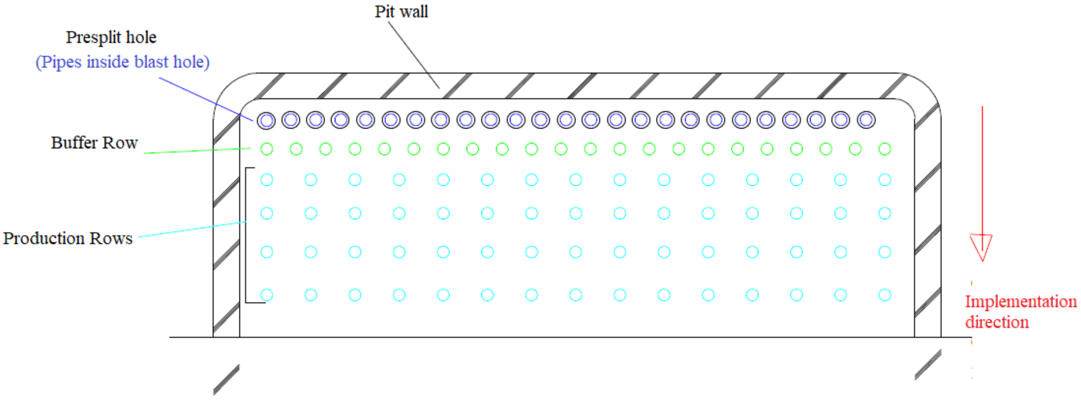


Figure 19. Implementation of the pit blast rows using pipes

The proposed blasting scheme is illustrated in Figure 19.

7. Results and Discussions

The tests are executed on an independent front of the MH3 pit for safety reasons.

We drilled a platform 300m long and 460m wide, the row on the pit wall is divided according to the nature of the tests as cited Figure 20A:

- Test 1 on 150m of the row: optimization of the tonnage of the explosive in the holes (Figure 20B).
- Test 2 on the remaining 150m: installation of the pipes in the blasting holes (Figure 20B).

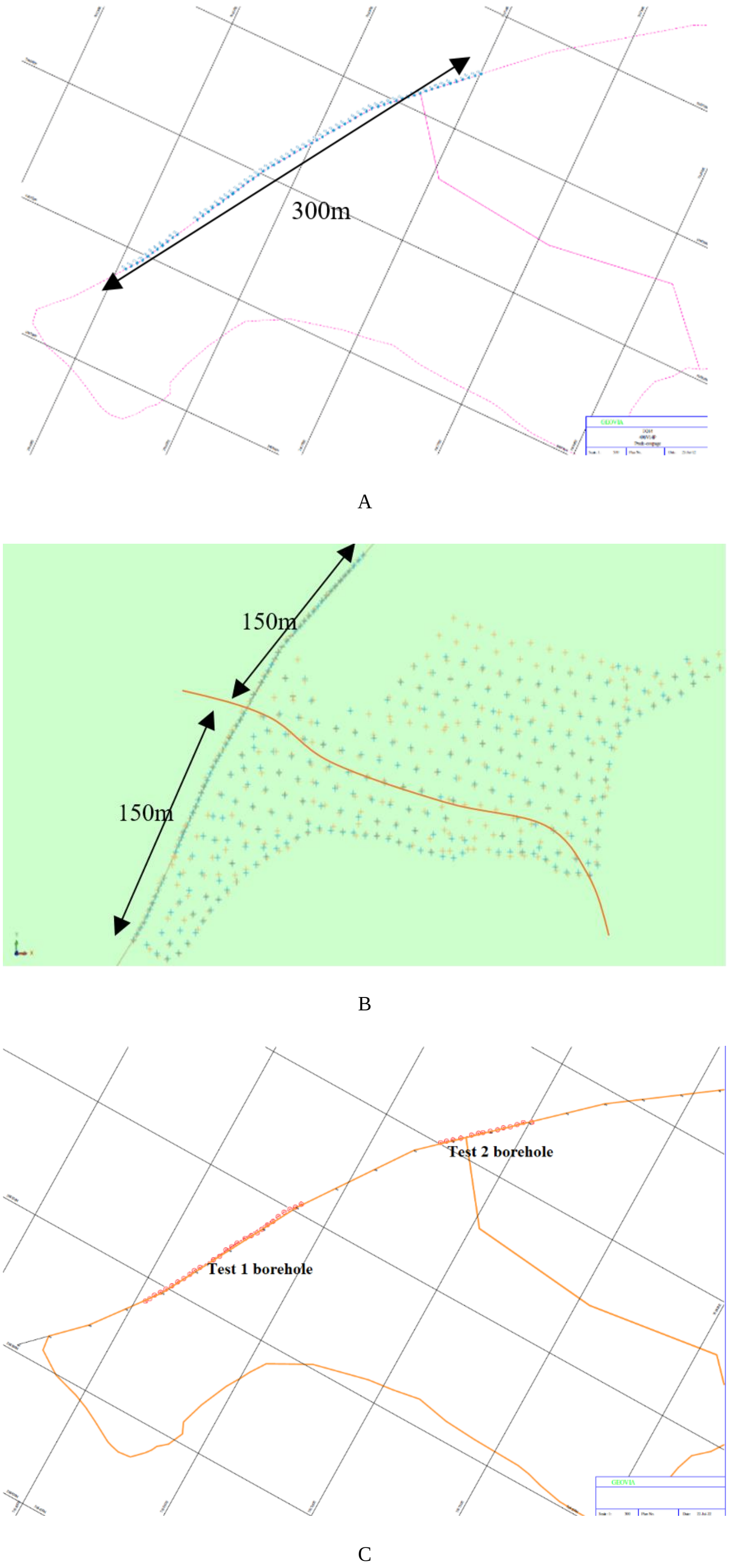


Figure 20. Drilled row scheme on the pit wall side: (A) platform 300m long, (B) divided platform according to the tests, (C) Test boreholes

The purpose of this design is to distribute explosive energy in such a way that certain fragmentation and muck pile displacement will be achieved.

Blast holes must be arranged in the desired manner with the correct depth, the right quantity of explosives placed into the holes and the appropriate initiating technique used to effect the detonation.

Factors that inform the design of a blast include the rock structure, porosity, rock density, bench geometry, explosive characteristics, charge distribution, arrangement of delays used and method of initiation. These factors are generally in two groups; controllable and uncontrollable.

The modulus of elasticity is the ratio of stress to strain in simple compression or tension. If a body is compressed equally from all directions, its original volume will be decreased. Weathered and fractured rocks have a low modulus of elasticity while rocks with a higher modulus of elasticity are stronger [20].

Blast damage can be grouped as fabric due to fracturing, structural damage exploiting discontinuities and shears, and lithological damage causing parting between two different rock units or lithological boundaries between similar rock types.

To control over-break, the creation of loose rocks, and produce a competent final wall, these blasting tests have been initiated as wall control blasting techniques.

These techniques are adopted to control the extent to which rocks are broken; thus, it ensures that rocks are not broken beyond the excavation limit, and to protect personnel and equipment from back break and loose rock falls [21].

The second implantation is considered a presplitting line with the combination of blast holes and pipes, the concept is that radial cracks from lightly shot boreholes either join an adjacent borehole or other radial cracks from an adjacent hole to form a plane of broken rock between the boreholes. This is a technique for protecting the final wall from being damaged by production blasting.

Upon detonation of the charged boreholes, the rock is cracked smoothly along the plane coincident with the axes of the holes. The method reduces drilling costs to a minimum and provides improved results over the previous presplitting and other known methods [22].

Figure 21 shows the progress of the tests on the drilled platform.

After the blasting and loading of the waste rock piles, a topographic survey for the test line is requested to rule on the reliability of the method performed as indicated in Figure 22.

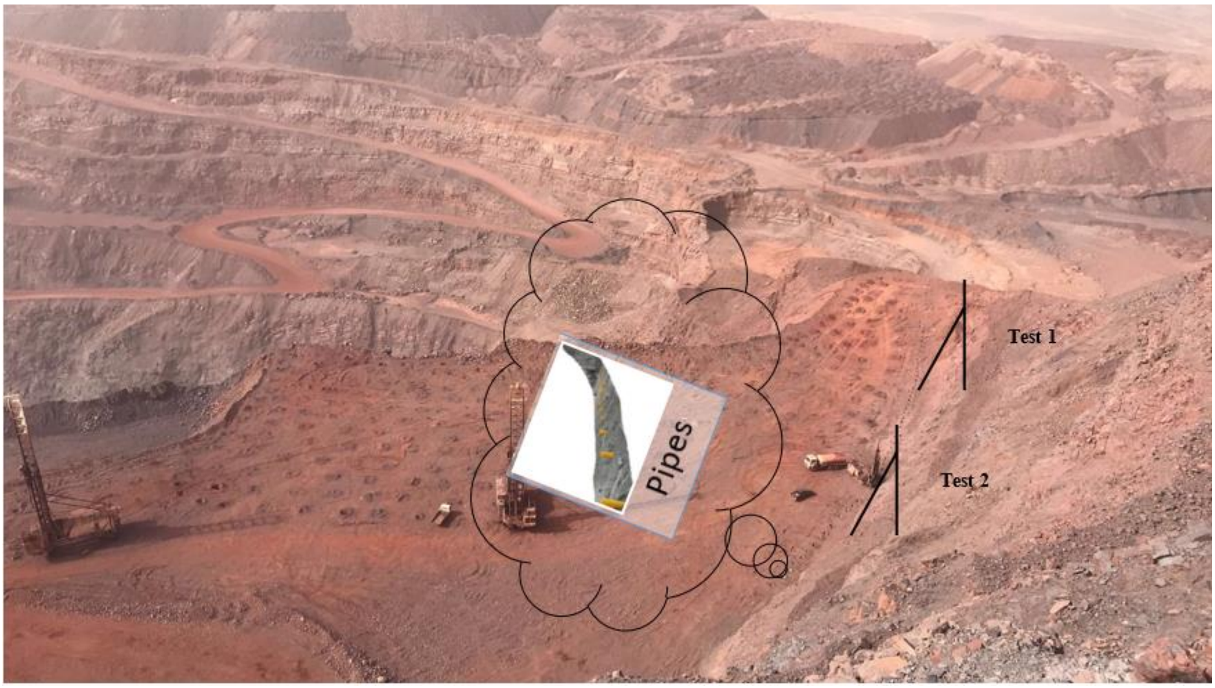


Figure 21. Test Platform before the blasting

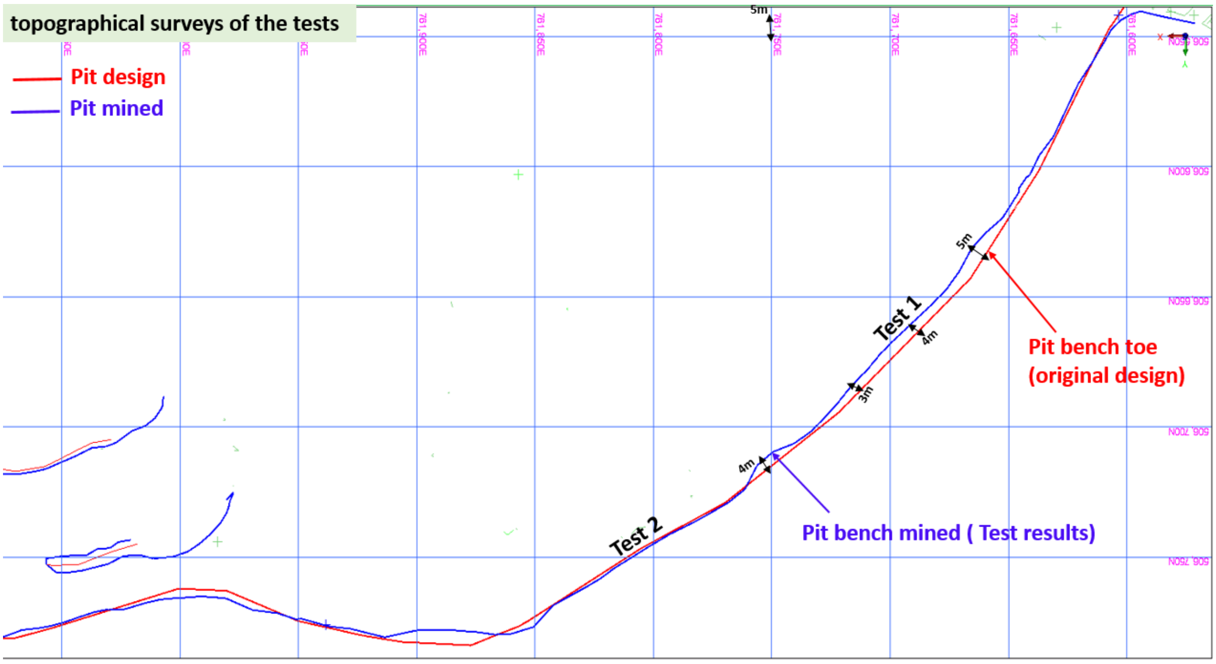


Figure 22. Topographical results of the tests

We had difficulties with the excavation of the bench toe 498 in tes1 (distribution of the explosive tonnage), while the bench toe was well fragmented and liberated in Test2 (use of pipes) as indicated in Figure 20.

This can be interpreted by the reason that the air deck in the holes is not able to accommodate the energy of the blast hole, which has led to bad mining results. Also, the wall clean-up of the holes and the existence of joints in the massif influence the blasting operation.

To control the vibration impacts of large diameter hole attenuation waves in the back rows of blast holes, we require the use of low density explosives, decoupled charges (distributed charges in large diameter blast holes), and toe shear (confinement through a reduced base charge).

Figure 19 indicates that the aerodynamic practices to reduce the diameters of pit holes can be very successful, offering the mine operator the ability to drill all holes with the same diameter and type of drill, while reducing the diameter through an auxiliary support to reduce charge distribution to cut the pit wall.

The results of Test 2 are acceptable and their impact on the mining method is minimal, in order to preserve the powder factor and fragmentation objectives.

The utilization of pipes to reduce the hole diameter is considered as ordinary pre-splitting drilling, which acts to filter the vibrations of the subsequent production holes with which any desired blast pressure can be achieved.

It is important to note that the restrictions to limit the impact of the explosion on the pit wall, can have a major impact on the programming and productivity of the excavators.

For two years of operation in the M'HAOUDATT pit, we have noted that safety is menaced by falling blocks, the absence of safety benches and the difficulty of making the pit benches correctly.

These anomalies pushed us to an investigation in the heart of the production chain in order to save the feasibility of the resources as well as the material and human resources of the mine.

In this article we were at the same distance between productivity and safety of the mine.

It was not easy to put the finger on the problem until after several experiments and concentration.

The exhaustive use of explosives in every blasting operation has put us in front of a big question mark about the effect of shock waves on the stability of the pit.

This method is being improved to be compatible to replace the pre-splitting in the mines that do not have small diameter drilling machines. It is always required before the execution of the method:

- Clean the blast platform.
- Blow the holes blast to avoid "over-confinement" and expansion of the charges.
- Use a free face to allow rapid charge movement and minimize retention times for high pressure blast gases.
- Priming sequence to promote rock movement in a direction nearly perpendicular to the pit wall.

The above concepts are intended to reduce the concentration of the linear charge near the pit wall in order to minimize the vibration levels induced in the adjacent faces at the time of blast.

8. Conclusions

The mining method in an open pit is always influenced by the instabilities and damage to the wall caused by uncontrolled large-scale blasting.

The quantity of explosives and the degree of vibration sent to the pit walls generate significant sliding on the pit slopes.

This use is due to the large diameter drilling with a non-respect of the orientations of the discontinuity families on the pit walls.

A particular follow-up of the blasting method in the MH3 pit, allowed us to react in the diameter of the drilling in order to control the shock energy of the blast.

The evaluation of the stability of the fronts recommended us to react on the optimization of the vibrations of the blasting through the reduction of the tonnage planned to fragment the rock mass.

The reduction tests discussed in this article concluded on the importance of cutting the pit fronts by an average opening diameter with a linear charge well distributed on the hole column.

The M'HAOUDATT mine does not have the equipment to drill this type of hole, which leads us to use pipes to reduce the opening of the hole and control the hole charge.

An attenuation method seems to be effective with the smallest anomaly, and it has been observed that the flying rocks ejected from the holes have an almost vertical trajectory and their maximum projection distance does not seem to exceed 50 meters and that the high pressure gases do not penetrate the pit wall.

The foregoing observations and conclusions suggest that the blast damage factor can probably be fairly well estimated from vibration modeling, provided that the expansion and initiation sequence factors are appropriately controlled.

It remains to be noted that continued use of the method requires careful consideration, and the method itself does not always produce the desired results in terms of pit slope stability.

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