FINAL WALL STABILITY IN METAL OPEN PIT MINES USING PRESPLIT BLASTING

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ABSTRACT

Implementing stable final pit walls in open pit mines during the open pit design phase and mine exploitation has become one of the most important concerns of mining engineers in recent years. Failure of mine walls can potentially cause loss of life, roads blocks, and damage to mining machinery, temporarily or permanently halt production at the face and in the worst case scenario, close the mine. Thus, the role of creating stable mine walls is crucial to safety and general operations of mines and any effort to optimize this process has great economic value for mine operators. This paper aims to illustrate the technical aspects of use of the successful presplit blasting method in metal open pit mines. It also shows that using this approach not only increases safety in mines through wall stabilization, but also will boost economic profits by savings in stripping ratio. In this regard, appropriate practical concepts for designing the drilling and blasting patterns and the role of selecting the correct drilling rigs are elaborated in detail through conducting a case study in Chador Malu iron ore mine in Iran.

KEYWORDS

Stability, Final wall, Presplit, Drilling, Blasting, Open pit

INTRODUCTION

Estimating the safe wall angles of mines is necessary to calculate ore-to-waste ratios during the feasibility studies for designing an open pit mine. During the feasibility studies, a great deal of effort is devoted to defining a reliable method to stabilize the final wall, in order to proceed with deep mining operations. Wall stability accidents in open pit mines are one of the leading causes of fatalities in mining operations. Unanticipated failure of mine walls can create hazardous conditions that may endanger lives, destroy mining machinery, block roads, halt mine production and more severely, result in the full closure of the mine. Thus, the slope stability study is one of the most important parameters for safety and economic factors of open pit mines. Slope failures are affected by factors such as slope geometry, rock mechanic characteristics, geological structure, lithology, ground water, mining method and dynamic forces.

Blasting is the main factor governing the optimum achievable bench face angles. From a safety perspective, due to the effect of blasting operations, shear stresses are momentarily increased, resulting in the dynamic acceleration of material, and consequently increasing slope failure in mines. Improperly designed blasting can potentially have significant effects on bench stability. Alongside blast damage that reduces the bench face angle, vibrations from blasting can potentially cause slope failure. Due to the vast quantity of explosives used in open pit mines every day, blasting damage can extend tens of meters into the rock mass behind the pit wall. The rock fracture and joint opening can be damaged by penetration of gas from the blast holes (and subsequent rise in pressure) for considerable distances from the pit wall.

Several techniques can be used to improve wall stability in open pit mines, such as changing the mining sequence rate or mining methods, dewatering methods, mechanical supports for rock reinforcement including anchors, rock bolts, wire mesh and controlled blasting. Among the methods stated, controlled blasting is the most pragmatic and effective approach for tackling this issue in metal open pit mines, due to the nature of resources that basically have a hard formation.

CONTROLLED BLASTING TECHNIQUES

When an explosive is detonated, it produces seismic waves of high intensity. If the energy content of blasting is high enough, it can impose damage to mine walls. The amount of damage to rock walls mainly depends on the magnitude and frequency of blast vibrations. Due to the role of limiting overbreak and damage to rock walls at the perimeter of blasting holes in pit stability, reducing these undesirable effects is crucial. Controlled blasting techniques are used to efficiently distribute explosive charges in a rock mass, thereby minimizing the fracturing of rock beyond the crestline of the highwall or designed boundary of main excavation areas.

Several controlled blasting techniques have been developed during past years and some are now commonly applied in mines. These are basically methods applied to control backbreak while blasting in vicinity of the final pit wall. Control of the amount of explosive detonated per delay, sequence of firing and drilling pattern are methods used to reduce blast damage to bench wall in metal open pit mines. In general, all controlled blasting techniques involve drilling small diameter blasting holes along the final excavation boundary of the mine and charging with lower explosive materials than in the main holes and firing them in a sequential timescale. Even though it is more costly to implement these methods, benefits such as mine safety, wall stability, reducing dilution and saving stripping ratio justify the efforts and associated costs of applying them in open pit mines. The common controlled blasting techniques are line, smooth, cushion and presplit blasting. The latter technique has become the most widely used in metal open pit mines, due to good results and its operational nature in hard rock formation.

PRESPLIT BLASTING

Presplit blasting is an effective technique for stabilizing the final wall in open pit metal mines. This technique is based on the phenomenon that the detonation shock wave is stopped and reflected at any free face. In presplit blasting, an intentional fracture is created at the excavation line prior to the detonation of the main fragmentation load, in order to reflect the shock wave. In this method, a curtain of fracture is created by firing the lightly charged holes before the main or primary production blast holes. These holes are drilled in a row along the final excavation boundary. The lightly fired blast forms a fracture zone between the holes, which ultimately results in the creation of a curtain of fracture. This curtain causes a discontinuity for the subsequent main primary blast. The curtain acts as a pressure release vent for the explosion gases of the charges fired in back of the presplit row, as well as limiting the passage of the shock waves produced across it. For this type of blasting, three different kinds of blasting holes – production, buffer and presplit holes – need to be drilled. The presplit holes are a single row of boreholes that have been drilled along a desired final wall or excavation line with low density charges. The row of holes ahead of the presplit line or the back row of the main production holes (the buffer row) must also be carefully designed with respect to standoff distance from the presplit row.

Presplit hole pattern design

Many formulas and methods for calculating geometric parameters, such as burden, spacing and other parameters, have been developed since the early 1970s. Unlike the drilling and blasting mine plans, the pattern of a presplit blasting is usually dominated by the capabilities of the drilling rig used at open pit mines. As a general rule, large metal open pit mines tend to use rotary drilling rigs to drill production holes and a smaller hydraulic drill (down the hole, DTH) for presplit holes. Successful presplit blasting depends on the accuracy of the design of the drilling pattern.

Presplit holes design

Presplit spacing is one of the most important factors, which is mainly dominated by rock characteristics, such as size of the operation and the height of the bench in a given open pit mine. It is very important to determine the appropriate spacing between the holes and the amount of charge for specific mine rock type. As a general guide for the presplit holes, spacing can be 8–12 times of the hole diameter or about 1/3 to < 1/2 of the normal spacing used in production blast holes. It also can be determined by using the following equation (Rajmeny et al., 2006):

$$\frac{S \leq 2r_b \times 2.54 \times (p_b + T)}{T} \tag{1}$$

where S = Spacing between two presplit holes (in cm); r_b = Borehole radius in cm; P_b = Borehole pressure in MPa; and T = Tensile strength of rock MPa. In equation (1), borehole detonation pressure can be calculated by:

$$P_b = 1.69 \times 10^{-3} Y_e (VOD)^2 (\frac{r_e}{r_b})^{2.6} \tag{2}$$

where P_b = Borehole pressure in psi; Y_e = Specific gravity of explosives; VOD = Detonation velocity of explosive charge ft/s; r_e = Radius of explosive charge in inches; and r_b = Radius of borehole in inches.

Borehole detonation pressure (P_a) for the fully charge can be calculated by:

$$P_d = \frac{1}{2} \times Y_e (VOD)^2 \times 10^6 \tag{3}$$

where P_d = Detonation pressure in MPa; Y_e = Density of explosive in kg/m^3; and VOD = Velocity of detonation in m/s.

A lower value of the borehole pressure (40–60%) to the dynamic compressive strength of the rock is required to obtain optimum results in presplitting. Thus, the required borehole pressure should be in the range of 32 (40% of 80 MPa) to 92.4 (60% of 154 MPa) MPa for a rock dynamic compressive strength of 80–154 MPa (the dynamic compressive strength is generally double or more its static value) (Rajmeny et al., 2006).

Buffer holes design

Normally the spacing and burden of about 2/3 of production holes are used in the buffer row; though if presplit and buffer rows are of the same diameter, then the burden in front of the presplit row to buffer row should be 1.5 times the presplit spacing holes. Moreover, in case of different diameters, the diameter of buffer holes can be set to 12–15 times of presplit holes' diameter.

$$\varphi_{buffer} = 12 - 15 \times \varphi presplit \tag{4}$$

As a general rule, when the diameters of production and buffer holes are the same, then the burden and spacing of the buffer row should be 70–80% of the production blast holes.

Hole charge distribution

Charge density will vary depending on the rock characteristics and spacing determined for the presplit holes. Nevertheless, powder factors will normally range from 1.6–4.8 kg/m^3, whilst the detonating cord is sometimes used as the primary charge in presplit holes or in conjunction with a small primer. This decoupled charge reduces the amount of explosive energy that is transferred to the rock mass. The first requirement for presplit line loading is an adequate decoupling in presplit holes to eliminate crushing. Using the airspace around a charge is the best way of achieving this goal. Presplit holes must be large enough to allow decoupling charging. Therefore, the ratio of the charge diameter to hole is about 0.3–0.4, which reduces the risk of excessive back hole shattering. Usually presplit holes are not stemmed, but if air blast is a problem in the mine, then stemming may be used by a section of plastic for blocking above the hole. The gases freely expand up the borehole, exert the desired pressure on the walls of the blast hole for the short time necessary to form the presplit, and then expand into the air.

As for the other drilling pattern designs in mines, generally the charge calculation for presplit holes is based on the surface area. The specific charge recommended for presplit holes is 0.35–0.5 kg/m^2, and generally the charge factor in the buffer hole is about 75% of a production hole at mines. In Canadian mines, a charge distribution of 1 kg/m of the hole length in 110 mm diameter holes is a common practice for presplit holes. Furthermore, the charge density has to be reduced to 5–15% of the charge in production holes. General guidelines are offered by Gustafsson (1981) and DuPont Hand Book (1977). The Imperial Chemical Industries manual, which recommends the charge loads and blast hole pattern for presplitting, is shown at Table 1 (Rajmeny et al., 2006).

Table 1 – Hole diameter versus cartridge diameter and presplit space (Rajmeny et al., 2006)

Hole diameter (mm)	Charge mass/m of blast hole (kg)	Cartridge diameter (mm)	Presplit space (m)
89	0.65	23	1.0
102	1.0	29	1.4
115	1.0	29	1.4
152	1.8	45	1.8

As a rule of thumb, for designing the appropriate pattern in presplit blasting, as well as the other drilling and blasting approaches, it is necessary to conduct trial blasts at the mine field with the given rock characteristics, hole diameter and the explosive type. However, blasting commencement can also be done with the stated guidelines described in Table 1.

Shooting the presplit line

In order to make a free face to reflect the shock wave resulting from blasting in production holes, the presplit row must be fired at least 50 ms before the main production blast. As a rule, if the presplit holes are to be detonated with production blast holes, generally 200–350 ms of delaying interval between presplit holes and the nearest production row or buffer row is recommended (Rajmeny et al., 2006). A delay may need to be set into the presplit line periodically to avoid possible disruption of nearby buffer holes from detonating presplit holes. Nonetheless, as many holes as possible should be shot instantaneously, taking into account the lead time and any vibration control requirements, because this yields a better defined presplit.

To achieve optimum presplit results, zero detonation delay (simultaneous blasting) should be used between presplit holes. However, if the numbers of holes in the presplit row are more than the usual pattern, blasting may be done in separate groups with minimum delay in sequence.

EVALUATION OF PRESPLIT BLASTING

Developing an effective presplit design that can vary by rock type and competence even within a single blast, requires adjusting the initial design as blast results indicate. The factors that cause a poor result in presplit blasting include hole misalignment, improper hole spacing, hole burden (too high or too low), and decoupling ratio (too high or too low). The results of presplit blasting cannot be assessed until the excavation has been removed from the presplit line at the bench. After crushed rocks are removed from the bench mine, the following items should be surveyed so that adjustments to drilling and blasting pattern can be made as necessary:

- smoothness of presplit surface at final pit wall;
- percentage of half-casts visible remained from the presplit holes on final pit wall (Figure 1);
- occurrence of crest failures; and
- outcrop of failures.

Figure 1 – Half-casts visible remained after blasting of presplit holes

Table 2 describes the damage that arises from improper presplit design, the source of this damage and the rectifications made to prevent these errors.

Table 2 – Evaluation of presplit blasting results

Type of damage	Origin	Correction
Backbreak around presplit holes cause no half-casts visible in fracture line	Shortage of burden or spacing in presplit line or excessive charging in buffer or presplit holes	Modify burden, spacing and hole charge density
Backbreak visible just around the presplit hole area	Detonation pressure in presplit holes exceeded rock compression strength	Modify hole charge density and charging method
Backbreak visible just between the presplit hole area	Shortage of buffer row spacing	Increase spacing in buffer row and decrease charging density in buffer holes
Roughness and irregularity of final wall behind presplit surface	Excessive spacing or shortage of burden in presplit row	Decrease spacing and hole charge density in presplit row
Shortage of rock breaking in final wall	Excessive burden between presplit and buffer rows	Decrease burden between presplit and buffer rows
Excessive joints and cracks at final wall crest	High weathering and poor condition of final wall rock	Use guide holes between presplit holes or drilling presplit holes with retract bit for fracture control

Crack formation sometimes deviates from the direction between the drilled presplit holes and instead follows the natural cleavage direction of the rock. This may result in a concave or convex shape due to improper spacing. To counteract such tendencies, holes should be drilled at closer or farther distance so that force crack formation follows the row of the holes. Figure 2 shows the irregularity in presplit row fracture due to improper spacing.

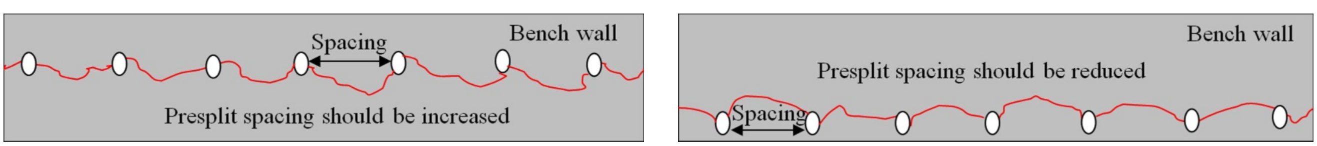

Figure 2 – Irregular fracture due to improper spacing in presplit holes

TECHNICAL ASPECTS OF PRESLPIT DRILLING

The effectiveness of the presplit technique is extremely contingent upon maintaining a good drill alignment. Drilling straight holes is the most important factor to obtain the desired result; thus, deviation should be avoided as much as possible. The magnitude of in-hole deviation is exponential to the hole depth. Better selection of drilling methods and drilling rigs will help minimize hole deviation. Selecting the best drilling method for drilling presplit holes is also crucial. Conventional drilling methods in metal open pit mines are rotary, DTH and COPROD, all of which result in less deviation than the top hammer drilling method. Nevertheless, as the rotary drilling rigs have a heavy mast and presplit drilling needs to drill holes at a specific angle, inclinational drilling is made difficult by rotary drilling rigs. Therefore, the best methods for this purpose are DTH and COPROD systems. Figure 3 shows drilling deviations result from different drilling methods in open pit mines.

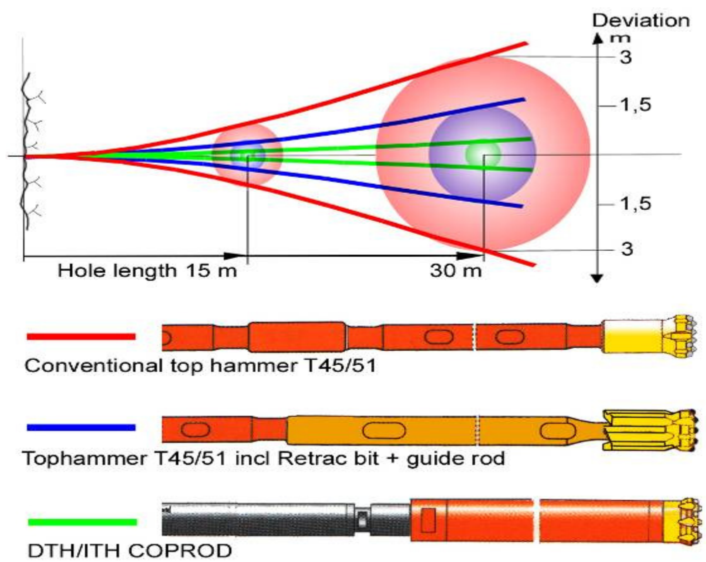

Figure 3 – Drilling deviations result from different drilling methods (Atlas Copco Handbook, 2006)

In addition, precision in collaring and hole alignment can be achieved with appropriate surveying and marking of the drill pattern grid, coupled with a drill angle indicator mounted on the feed and a hole depth instrument. Studies on hole deviation in open pit mines show that common sources of misalignments in presplit drilling consist of the following.

- Collaring deviations can be caused by the topography of the drill site, poor drill positioning and the inability of the drilling rig to hold the boom and feed in a rigid position due to worn out pins and bushings.
- Deviations or inaccuracies in setting the feed on which a drilling rig is mounted in a planned direction can be caused by drilling rig instability, lack of precision in positioning equipment, misaligning the feed beam, topography at the collaring point, and structural geology.
- In-hole deviation may result from the hole design (inclination, diameter, length), equipment (bit, rod, stabilizer, coupling) and rock properties (structure, hardness, foliation). The drill hole tends to deviate to a direction perpendicular to the jointing and the more structured, foliated and faulted rock. This is apparent in Figure 4.
- An inexperienced drilling rig operator can set the drilling parameters incorrectly (bit thrust, percussion, rotation, flushing velocity).

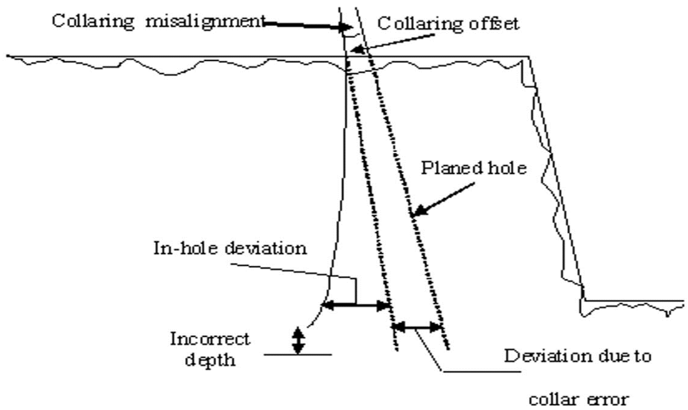

Figure 4 – Schematic showing sources of hole drilling deviations on mine bench

CHADOR MALU IRON MINE SITE PROFILE

Chador Malu iron ore mine, located in 180 km northeast of Yazd province in central Iran is the biggest iron concentrate producer in the Middle East, with 400 million tons of ore reserve. Reconnaissance for the Chador Malu deposit was first done in 1921 and more detailed work was carried out in the beginning of 1960s. Finally, detailed exploration began in 1975 and ended in 1978. Complementary studies and operations for exploitation and acquiring plant equipment were carried out from 1981–1996, and the plant was formally inaugurated in 1997. Petrography studies on the mine rocks show that major rocks in Chador Malu mine area are metasomatite, albitite, diorite, magnetite and hematite. The iron ore concentrate contains about 68% iron and 0.045% phosphorus. The apatite concentrate contains a minimum of 33% P2O5 with a maximum of 3% iron (EBE, 1991). The iron ore concentrate is used for steel production by the direct reduction process while the apatite concentrate are used for producing phosphoric acid or phosphate fertilizer in petrochemical complexes.

Regarding the equations and practical operations stated in this paper, while considering the available drilling rigs on the mine site, the drilling and blasting patterns have been designed as follows.

Production holes drilling pattern

The Chador Malu iron mine drilling rig fleet comprises DMH, DML, DM45 and more recently two Titon 600 DTH hydraulic drill rigs (used especially for presplit drilling). Two main drill patterns are used, depending on the fracturing and hardness of the rock. For hard rocks, a burden of 6 m with 7 m hole spacing is used and in softer rocks or a more fractured zone, the pattern of 7 × 8 m has been adopted for drilling production holes. ANFO explosives with dynamite primers are used for charging the blasting holes.

In the case of drilling in the final wall of the mine, DMH rotary drilling rigs are used for drilling the production holes with the specific parameters in Table 3.

Table 3 – Drilling pattern for production holes at Chador Malu iron ore mine

Hole diameter (mm)	Sub drilling (m)	Burden (m)	Spacing (m)	Charge density (g/cm^3)	Stemming (m)	Explosive	Bottom charge (m)	Hole depth (m)	Bench height (m)	Hole angle (º)
251	2.25	–6	7	1.0	7.25	ANFO	1	17.25	15	90

Buffer holes drilling pattern

The buffer row of 165 mm diameter is drilled 3 m behind the last production row. The holes in the buffer row are drilled at 4 m spacing, while the burden on the buffer row is 3 m. Larger buffer holes cause more cracks since the generated cracks depended on the charge diameter. Therefore, it is better to use smaller diameters for the buffer row. Buffer holes at the final wall in Chador Malu iron mine are drilled using DM45 DTH drilling rigs with the specific parameters (Table 4).

Table 4 – Drilling pattern for buffer holes at Chador Malu iron ore mine

Hole diameter (mm)	Decoupling ratio	Buffer burden (m)	Buffer spacing (m)	Charge density (g/cm^3)	Stemming (m)	Explosive	Hole depth (m)	Hole angle (°)
165	0	3	4	1.0	2	ANFO	6	90

Presplit holes drilling pattern

Chador Malu mine received the final wall boundary and the presplit takes place between the final wall and buffer blast line at the open pit. In this mine, behind the row of production holes, one row of buffer holes followed by the presplit row is designed to control the back break and maintain the final pit wall configuration. The presplit row consists of drilling 114 mm diameter holes at 1.45 m spacing, which are drilled by two DTH drilling rigs (Titan 600) at an angle of 75º. In addition, no sub-drilling is carried out in these holes for backbreak control. The benches are 15 m high and considering a 15º inclination for presplit holes, the hole length will be 15.5 m. This drilling profile can be seen in Figures 5 and 6.

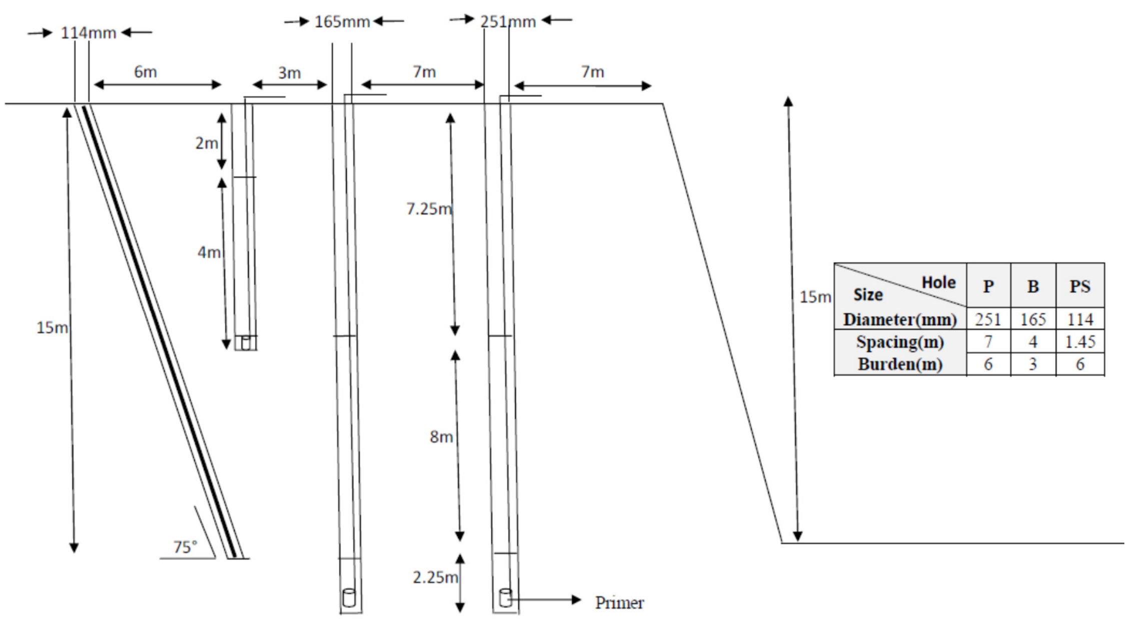

Figure 5 – Schematic of drilling profile in Chador Malu mine

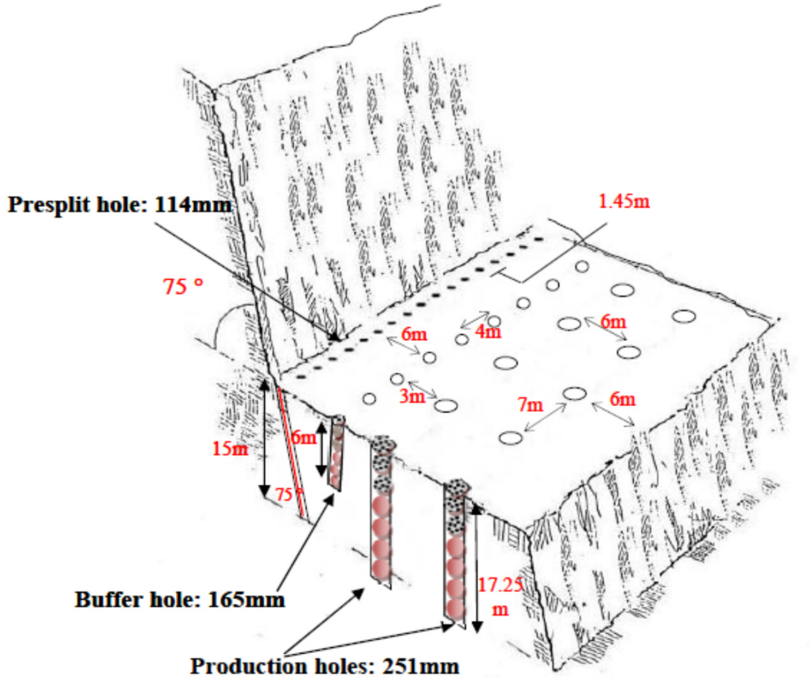

Figure 6 – Schematic showing drilling and blasting design in Chador Malu mine

In order to charge the presplit holes, two types of PVC tubes with 40 and 60 mm diameters are provided. The 60 mm PVC tube is 30 cm long and the 40 mm PVC tube is 1520 cm long. They are used for each hole and charged with Azar powder (a kind of powder explosive with 1.03 g/cm^3 density) in the bottom and the rest of hole, respectively. The powdering dynamite used as a primer and detonation cord (Cordtex) as the firing system. The other parameters are given in Table 5.

Table 5 – Drilling pattern for presplit holes at Chador Malu iron ore mine

Hole diameter (mm)	Charge Decoupling ratio	Cartridge diameter (mm)	Presplit spacing (m)	Charge density (g/cm^3)	Burden (m)	Time delay (ms)	Stemming and Subdrilling (m)	Hole depth (m)	Hole angle (º)
114	0.35	40	1.45	1.03	6	200	0	15.5	75

CONCLUSIONS

Implementing stable final pit walls in open pit mines has become one of the most important concerns of mining engineers during the final years of a mine's life. Failure of mine walls can potentially cause loss of life, road blockage, and damage to mining machinery, temporarily or permanently ceasing production at the face and, in the worst case scenario, closing the mine. Several techniques are used for improving wall stability in open pit mines, among which presplit blasting is the most pragmatic and effective approach for tackling this issue in open pit metal mines. This is due to the nature of resources with hard formations. Results achieved from the half-casts visible remaining from the presplit holes at the final pit wall of Chador Malu iron ore mine were completely satisfactory. Evidence also shows that the orientation of geological structures has great influence on the presplit fracture. As such, surveying structural mapping and joint sets is essential to obtain a suitable final wall in open pit mines. Furthermore, avoiding deviation during presplit holes drilling is of utmost importance in open pit mines due to the depth of presplit holes.

However, it is important to note that the effect of geological phenomena can never be completely eliminated, but certain measures can be taken to ensure desired blasting results. The most important of such measures is using DTH and COPROD drilling systems, both of which result in less deviation than other drilling methods.

Finally, for achieving the appropriate pattern for presplitting, as well as the other drilling and blasting approaches, further trial blasts need to be conducted in the mine with given rock characteristics, hole diameter and explosive type.

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