The Effectiveness of Pre-Splitting as a Method of Wall Control and Minimize Over-Break in North Mara Gold Mine

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ABSTRACT
This article involves wall control techniques, drilling practices that may lead to over break, causes of over break, and guidelines for presplitting which is the main wall control technique of discussion and possible solutions to the problem. The parameters of drilling and blasting have influence on presplitting outcomes. Those parameters are borehole diameter, explosive strength, powder factor, burden, spacing, stemming length, subgrade drilling depth, boreholes pattern, and the correspondent delay intervals. Presplitting method was used to protect wall from getting damaged due to production blasting operations at north Mara gold mine. Data collection included drilling and charging parameters specifically for presplitting both designed and actual parameters and make comparison to recognize causes of over break associated with presplitting. It has been found that the poor collaring error, uncharged pre-split boreholes and uneven staff off distance from pit wall were the main cause of underperforming pre-split in Gokona pit (North Mara) as a method of wall control. None of the pre-split borehole was drilled in the exact position as planned. Some of the boreholes were not charged for unknown reasons. Comparing actual drilled meters against planned meters to be drilled, only less than 69% was achieved. Therefore, lack of adhering of planned measurement is the main cause of unsuccessful of presplitting as a method of wall control.

Keywords: Blast hole, presplit, drilling, explosive
1.0 INTRODUCTION
Pre-Splitting is a method of blasting in which a planner crack is propagated by blasting to determine the final shape of the rock face before holes are drilled for the final blast pattern (Oxford University Press, 2020). Final slope of the pit alters the cost effectiveness of most open pit mines; steep stable pit walls can be achieved by wall control techniques which include cushion blasting, pre-splitting and post splitting and line drilling. But with each of these techniques, the combined cost of drilling and blasting is relatively high. Careful blast design is the key to ensuring clean, safe pit walls at minimum cost. The blast design needs to consider the rock conditions in the area, the likelihood amount of back break from the blast and design location of the final pit limit.

1.1 Improved Production Blasts
February (2008) careful designed a production blast which is a potentially low-cost method of forming stable pit walls. The designer of these production blasts must carefully consider the effect of geology on blast results. Rock structure and strength, effective burden relief, and the correct location of blast holes are the most important factors. Medium to high rock strength with close jointing is a sign that stable walls may be produced from modified production blasts. Low strength, highly jointed rock types tend to over break excessively. Frequent over break greater than burden distances indicates that even careful production blasts are unlikely to produce clean, stable pit walls (Lewandowski, Luan-Mai & Danell 1996).

1.2 Geology
Rock properties have the greater influence on the effect of blasting on pit walls. Extensive over-break occurs where explosion gases can get into, wedge open and extend closely spaced fissures in rock. Over-break is generally greater where fissures are closely spaced. Tight or in-filled fissures can cause less over break than open fissures. In closely jointed rock, the width of the over break zone is generally consistent and increases from bench floor to bench top level (February 2008).

1.3 Burden Relief
Effective relief of the burden during the blast is the most important factor which affects the result of final wall blast. Increased burden relief reduces the amount of back break produced by a production blast and also makes the amount of back break more predictable. Blasting to a clean, free face, minimising the number of rows in the blast, and providing long delay times between rows of blast holes, are three reliable methods of increasing relief and controlling back-break. Reducing the burden on blast holes, while maintaining a higher powder factor, can also improve burden relief by more effectively throwing the rock away from the pit wall.

Angled blast holes along the crest of the bench may be needed to eliminate excessive toe burden as this is one of the major sources of poor relief during blasting. The row of blast holes nearest pit limit generally need to be angled. Vertical blast holes drilled near pit limit may penetrate the final wall and cause considerable wall damage and instability. Delay timing between rows should allow sufficient time for the burden of each blast hole to detach itself completely from the rock mass before subsequent blasthole fire. When a back row blasthole fires, it will then be able to heave its burden forward easily, causing little over break.
timing should also be chosen to reduce the number of blast holes firing at any one time and minimise the energy transmitted into the final wall.

Stemming columns in the back row of blastholes must be long enough to prevent cratering. Cratering from this row of blastholes will weaken the term and lead to crest loss. Large craters are usually formed where the stemming length is less than about 60% of the effective burden distance. However, excessive stemming in this row of blast holes may cause the collar rock in front of the final limit to hang up, and result in a safety hazard (Hartman & Britton 1992; Lewandowski et al., 1996; February 2008).

2.0 MATERIALS AND METHODS

2.1 Blast Hole Location
The location of the back row of blastholes is critical to the location of the final pit limit. The back row of blast holes needs to be drilled in front of the final pit limit to allow for back break behind the blast holes, and the correct location depends mainly on previous experience in the pit and trial and error, particularly if the amount of back break is variable. If the stand-off distance between the back row and the pit limit is too small, there will be too much over break into the final face. If the stand-off distance is too large, digging back to the design final face will be difficult, expensive and may need a bulldozer. Sub drilling needs to be carefully controlled when nearing pit limits to ensure stability of berms below current bench. Any sub drilling into a berm will reduce the rock strength and usually in the result of the edge of the berm (Lyall & Calder 1992).

2.2 Effects of Poor Drilling and Blasting Practices

2.2.1 Distance between Holes
Singh, Roy & Paswan, 2014; Uysal & Cavus 2013 highlight that the drill pattern is a critical part of blast design and is related to borehole diameter, explosives energy, bench geometry and rock properties. Drilling that does not adhere to the design has negative consequences to the blast result. Where holes are drilled too close together, rock fragmentation will tend to be over-fine. This may not suite the requirement for the sales of the product and therefore results in lost revenue (example, fines in coal). There is also a loss in profit because of the higher drill and blast cost associated with holes that are drilled closer together than the design calls for. Explosives in nearby unfired holes may become damaged and not detonate properly or it may detonate sympathetically. In either case poor fragmentation results can be expected, especially in the toe region of a blast. The most common error in drilling is boreholes being drilled too far apart or missing holes. Where holes are too far apart, the following problems occur: The explosive energy will be below design levels. Coarser fragmentation will result and high floors will result. This can slow down loading rates and increase loading and crushing costs dramatically. Harder rock is less tolerant of holes being drilled too far apart, and fragmentation will be severely affected.
2.2.2 Collaring
Collaring errors are the results of the drill operator drilling in the wrong place. This can be caused by: poor marking out of borehole positions, Markers being moved through traffic on the blast or the trailing cables of a drill, Poor attention from drill operator and Failure of drill GPS-based positioning systems (Singh et al., 2014).

2.2.3 Angle Errors
There are two types of angle errors that can occur: The hole deflects off line. This is more common in smaller diameter holes that much pull-down force or by dipping rock strata of variable strength. Borehole deflection can be limited, but requires an experienced driller. The drill rig is set up with the boom at a different angle to the desired borehole angle. This is a control problem that can be made worse by inadequate or un-calibrated level checking devices on the drill rig (February 2008).

2.2.4 Hole Depth
Short holes or holes that are too deep are both undesirable. Short holes will always result in high floors or capping being left behind. The explosion pressure at the bottom of a blasthole is much lower than it is at the sides of a hole. Unless the rock is very soft and layered, you cannot expect a hole to fragment downwards below the borehole bottom. Holes drilled deeper than their design depth cause damage to the rock below. If the rock is soft, such as coal, the coal will be pulverized and will most probably be removed by the dragline. Coal losses are a problem with over drilling. Damage to the rock below causes drilling problems in that layer. The drilling problems that are most common are collar blockages and lost holes caused by loose material falling into the hole.

2.2.5 Hole Positioning
The incorrect positioning of holes in a blast has a similar impact on borehole quality as does over-drilled holes from the previous bench. For safety purposes, holes on following benches are normally laid out so that they are positioned between the sockets of the preceding holes. The aim is to avoid drilling into potential misfires. Often holes end up being drilled into badly damaged rock from previous sub-drill damage. This results in collars that collapse very easily and thus present a high risk of borehole blockage due to material falling into the holes (Hartman & Britton 1992).

2.2.6 Hole Diameter and its Influence on Energy
A blast borehole diameter is usually not the same as the diameter applied in the blast design. This is because of two factors:

a) Bit wear in hard rock will result in holes with smaller diameters than expected.
b) Soft rock or partially damaged rock will result in a hole that is slightly bigger than the expected diameter.

Drill steel slap (most common on poorly balanced drill steel in rotary drills) will cause the borehole diameter to be larger than design. Borehole diameters that are smaller than expected lead to explosive energy starvation at the borehole bottoms and a risk of over-charging with related fly rock and air blast.
Borehole diameters that are larger than expected lead to excessive energy and rock damage and a risk of under-filling. An under-filled blast hole will normally lead to large boulders forming at the top of a blast. The energy impacts are significant on borehole diameter variations that are quite common in the pit.

2.3 Wall Control Techniques
Line drilling, Cushion (buffer) blasting, post splitting (contour trim blasting) and pre-splitting are the four common blasting techniques used to produce final pit walls. Post-split and pre-split blasts are often used alone to produce stable walls. Cushion blasting is frequently overlooked when designing final-wall blasts, but can be the most adaptable and useful method of the four techniques.

2.3.1 Presplitting
Pre-splitting requires a row of closely spaced blast holes drilled along the design excavation limit, charged very lightly, and detonated simultaneously before the blast holes in front of them. Pre-splitting gives more spectacular results than post splitting, but is generally costlier. It rarely gives impressive results in fissured rocks, and if overcharging occurs, pre-splitting can be detrimental, as large volumes of rock may move as the explosion gases are vented along fissures.

Firing of the pre-split charges splits the rock along the design perimeter of an excavation, producing an internal surface to which the later firing blast holes can break. The pre-split plane acts as a pressure release vent for the explosion gases from the charges in the back of blast holes in front of the pre-split. It also partially reflects the blast-generated strain waves and so reduces strains in the wall. The results are relatively undisturbed face with minimum shattering, rock movement and over-break. If the pre-split blast holes are too close together or overcharged, they themselves will produce over-break. Pre-split blasthole diameter is usually in the range 76mm-102mm. In large open pits, blasthole diameter up to 250mm are now being used. For example, in North Mara the borehole diameter for pre-split is 127mm.

Pre-splitting may cause higher vibration levels than production blasts. The relatively high confinement of pre-split charges may cause vibration levels per kilogram of explosive to be considerably higher than those for production blasts. Both the pre-split and the subsequent adjacent blast should be designed to conform to the vibration limit established for the site. When a pre-split charge fires, small cracks are produced around the blast-hole. These cracks are very short until the arrival of the stress wave from an adjacent pre-split blast hole. The tangential stress wave preferentially extends the radial cracks which are growing in the plane of the pre-split blast holes. Gas flow from the blast hole accelerates the growth of cracks in the plane of presplit, while growth of cracks not in the plane of the presplit soon stops.

2.3.1.1 Purpose of Presplitting
The main aims of pre-splitting are: to eliminates or minimizes back break, safety of people working around high walls, maintain integrity of final high walls, benches and overall pit
slope angles, maintain front row burden controls (casting), acts as a dewatering mechanism on the bench and aids in reducing vibrations against high walls.

2.3.1.2 Drilling Presplit Blast holes
As blasthole diameter increases, the spacing between presplit blastholes normally increases. Note that borehole depth will also have a marked effect on presplit quality. Holes too deep may cause over break, but short holes will give insufficient cracking. This could require extra toe holes for excavation and the careful splitting would be lost.

2.3.1.3 Presplit Depth
Presplit effectiveness depends greatly on good blasthole alignment. Deviation usually limits the length of 76mm and 89mm diameter blastholes to about 15mm. A major advantage of large diameter blasthole is that deviation is reduced and presplit blasts of greater depth can be fired. A single presplit blast may be fired for a number of benches. Where short benches are used (less than 6m), presplit may be drilled 15-20m deep to form a presplit for 3 benches. A single blast over 3 benches is cheaper, and leaves a cleaner and safer final wall.

2.3.1.4 Charging Presplit Blast holes
In average rock conditions, the charge load required for effective presplitting increases with the blastholediameter. Optimum charge varies considerably with rock properties. Very weak or closely fissured rock need reduced charge load and blast hole spacing. Massive rock with high dynamic tensile breaking strain could require a higher charge load. In unconsolidated ground, the charge weight per linear meter in the upper portion of blasthole may have to be reduced by 50% or so if over-break at the crest of the final is to be minimised.

Continuous charges of power shear are available on reels to speed the charging of presplit blastholes. Continuous charges ensure energy is distributed evenly along the blasthole. Energy concentration of continuous charges can be varied by taping two or more continuous charges together, or by changing the stemming length or uncharged collar length of the blasthole. Changing the blasthole diameter will also vary the effective energy concentration. Presplit blastholes should generally be charged to within about 8 blasthole diameters (d) of the collar. In closely fissured rock, the uncharged collar may need to be as long as 15d (Hartman & Britton 1992; Singh et al., 2014).

2.3.1.5 Water-filled Pre-split Holes
Lewandowski et al., 1996; Uysal & Cavus 2013 describe water as incompressible fluid, so the explosive energy from decoupled charges is more effectively transmitted and driven into the surrounding rock. Existing joints will be wedged open by powerful hydraulic force of the water. In solid, massive rocks, not many new cracks will be formed, so a good presplit can be expected. Highly jointed rock will be damaged and loosened more than an equivalent dry hole presplit.
2.3.1.6 Stemming Presplit Holes
Presplit blast holes should not be stemmed unless there is a need to control airblast. Leaving the collar of presplit blast holes un-stemmed allows the explosion to jet into the atmosphere very rapidly. This ensure that the explosion won’t hit the side walls of blasthole. Un-stemmed presplit blast holes reduce damage to the crest of the final berms and lower probability of crest loss. The spacing of stemmed presplit blastholes can be increased, because the confined explosion gases help the propagation of the presplit. Unfortunately, stemming also increases damage to the crest final berms Uysal & Cavus 2013; Lyall & Calder 1992.

2.3.1.7 Firing Presplit Blast
Uysal & Cavus 2013; Oageng et al., 2008 indicate that presplit charges must be initiated simultaneously by joining all down lines from presplit blastholes to a detonating cord trunk line. Where ground vibrations are likely to cause over-break or disturb residents, delays should be used to fire groups of blast holes. The number of blastholes in each group should be sufficient to archive a satisfactory splitting action while not exceeding the maximum charge weight that can be fired per delay. If detonating cord trunklines cannot be used, each downline can be initiated at the collar of the blasthole by short delay detonator (preferably zero delay). Presplit blastholes should be fired in the same blast as the adjacent final wall blast if the total burden distance is smaller than about 150 times the diameter of the presplit blastholes. If the burden on the presplit blast is less than this, ground movement from the presplit could cause cracking of the rock. The broken ground would cause drilling, charging, charging or cut-off problems.

Best presplit results are generally obtained when presplit blasts are fired separately, and ahead of the adjacent final-slopes blast. Separate firing is possible if the total burden distance is very large or when blasting in the solid. The burden on the presplit blastholes needs to be sufficient to prevent movement of entire block of rock in front of the presplit. When blasting in the solid, the effective burden on the presplit is not meaningful and can be regarded as infinite.

2.3.1.8 Protecting the Presplit Face
Presplit faces will be damaged if production blastholes are drilled too close. On the other hand, if stand-off distance between the presplit and the blastholes in front of them is successive, the broken rock will be left on the presplit face. Optimum stand-off distance can
be determined only by trials and is usually 40-70% of the burden distance of the back-row production (or cushion) blastholes.

![Figure 2: Shows pre-split boreholes and adjacent uneven pit wall](image)

**2.3.1.9 Advanced Presplit**
With careful planning, it is possible to give maximum protection to final wall berms and crests by extending the presplit beyond the current bench height, into the floor of the next bench. The technique requires that no final limit blastholes are collared or stemmed in the vicinity of the newly forming crest or berm edge. Figure 3 illustrate the unnecessary cost incurred if pre-split results become poor. The excavator is used to scale the wall to remove any loose rocks and straightening the wall of the pit.

![Figure 3: Excavator scaling the wall](image)

### 3.0 DATA ANALYSIS AND DISCUSSION
Total designed meters to be drilled was 295.9m
Actual drilled was 203.2m

\[
\text{Portion archived} = \frac{\text{actual drilled units}}{\text{designed units}} = \frac{203.2}{295.9} \times 100\% = 68.67\%
\]

As shown on Figure 6 standoff distance varies from 4m to 6m, also observed on Figure 4 only 68.67% were achieved. Likewise, for charging only the same percentage were achieved...
hence poor charging and the pre-split won’t work effectively. If under-break occurs excavators were used to scale the wall to reach intended position.

Total designed units to be drilled = 1192,
Actual Drilled units=955.5,
Charged units=365.5

Since diameter of presplit holes was 127mm, the volume of drilled holes would be

\[ V = \pi r^2 h, \text{ where } r = 63.5 \text{mm, } h = 955.5 \text{mm, hence} \]

\[ V = 3.14 \times (0.0635)^2 \times (0.9555) \]

\[ V = 0.012 \]

Therefore, volume of drilled holes that were ought to be charged=0.012m\(^3\)

Amount of explosives were= 3.14 \times (0.0635)^2 \times (0.3655)

\[ = 0.0046 \]

\textbf{Charged volume}= 0.0046m\(^3\)

Archived charging was\[ \frac{365.5}{1192} \times 100\% \]

\[ = 30.66\%, \]

Drilled units \[ \frac{955.5}{1192} \times 100\% \]

\[ = 80.15\% \]

The amount of meters charged as seen from calculation was minimal as compared to units that were intended to be charged and contribute to unevenness distribution of explosives energy.

\[ \text{Figure 4: Difference between designed borehole depth and actual drilled borehole depth} \]
As shown in Figure 5, some holes were not drilled at all such as borehole number 5 and 8 and others were drilled partially according to design, for example hole 3 and hole 7. As holes are not drilled according to design, also charging according to plan become a problem, therefore holes were little charged or not charged at all. Finally, the effect of pre-split was not met hence either over break at some areas or under-break. Short holes will always result in high floors or capping being left behind. The explosion pressure at the bottom of a blasthole is much lower than it is at the sides of a hole. Unless the rock is very soft and layered, it is not expected a hole to fragment downwards below the borehole bottom. Blastholes that are drilled deeper than their design depth cause damage to the rock below. Damage to the rock below causes drilling problems in that layer. The drilling problems that are most common are collar blockages and lost holes caused by loose material falling into the hole.

3.1 Charging Approximations
There was no any design that showed amount of explosive to be used per unit borehole length. So, blasters tend to approximate the stemming length according to their experience. The charging was done by approximating the stemming length according to hardness of rocks at that particular area. Approximation mostly didn’t give spectacular results. Therefore, pre-split results to over break or under break as shown in Figure 5.

Figure 5: Designed borehole depth and actual borehole depth against charged length of borehole
Collaring error and standoff distance; collaring errors were the result of the drill operator drilling in the wrong place. Surveyors transfer designed patterns into actual ground, sometime operators of drill rig failed to drill at exact position since the position indicated to be drilled was very close to the wall and hence the rig can’t drill there, or just laziness of an operator to position the drill rig at intended position. This leads to unevenness spacing between pre-split holes which were required to be 1.2m. The stand-off distance allows for back break effect to take place without affecting the final wall limit. If the standoff distance was too small like 4m, the back-break effect might reach the wall depending on rock strength, but if the standoff distance was too small as 6m, there slight chances that any back-break effect from either trim shot or production blasting to reach the wall as shown in Figure 6 and Figure 7.

Also collaring error lead to change in standoff distance from the wall, hence affects performance of explosives, which later brings about poor pre-splitting. If the standoff distance is too large, digging back to the design final face will be difficult, expensive and may need a bulldozer or excavator as shown in Figure 3.
It was experienced in some positions in the pit that location of holes had to be approximated due to failure of Global Positioning System (GPS) to communicate with four satellites required. This occurs especially at areas very close to walls at level 1210 at Gokona pit in north Mara. As seen in Figure 8 there was deviation in every hole, this means there was no even a single hole that was drilled in correct position.

The standoff distance varies due to poor marking of holes position or negligence of operator to drill in correct position, and hence distance between final wall and presplit line affects effectiveness of presplitting. Therefore, sufficient distance should be left to account for any back effect due to trim shot or production blasting. Spacing between presplit holes should be maintained at 1.2 m from each other. Refer Figure 8.
3.2 Spacing between Holes
The required distance between holes according to design was 1.2m. At Gokona pit, distance between presplit holes was varying. Since each hole was charged, and spacing between them was uneven, it contributes to uneven distribution of explosive energy. Some areas will break well and form a natural line that will stop or deviate any back effect from trim or production blasting reaching the final wall, some holes will be very close to each other which lead to high energy and hence it weakens rocks around the holes which will enable any back effect to reach the final wall very easily.

The distance between pre-split holes was not constant causing other holes to be very close to each other and causes over-break. Spacing depends mostly on correct positioning of holes. Due to poor performance of GPS and surveyors due to work pressure, spacing becomes uneven hence poor distribution of explosives energy. Also, inappropriate positioning of drill rig contributes to uneven spacing.

3.3 Water-filled Presplit Holes
Water is incompressible, so the explosive energy from decoupled charges is more effectively transmitted and driven into the surrounding rock. Existing joints will be wedged open by powerful hydraulic force of the water. In solid, massive rocks, not many new cracks will be formed, so a good presplit can be expected. Highly jointed rock will be damaged and loosened more than an equivalent dry hole presplit. Also, water causes collapse of holes since it drives the aggregates back to the drilled holes. In this sense it reduces performance of presplit wall control technique.

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion
Ineffective pre-splitting had been largely caused by poor drilling and charging practices. Holes were under drilled or over drilled and hence poor presplitting. Collaring error also was a big challenge. Holes were not drilled at designed positions due to several reasons such as ignorance/negligence of operator, and surveyor or inefficiency of equipment used such as drill rig and GPS and hence incorrect positioning of holes. Water in holes was the other challenge towards achieving efficient presplitting. Water drives in the aggregates due to drilling and causes blockage or collapse of holes due to erosion. And holes mostly collapse when they are drilled and left for some time without being charged and blasted.

4.2 Recommendations
Pre-split should be designed as other patterns and stop using approximations. The design should be adhered to recognize the amount of explosives to be charged or length of hole to be charged instead of current means of just approximating from experience. Approximations become associated with a lot of errors like over-charging or undercharging which results to poor presplitting. Quality control and quality assurance should be done also to pre-split holes. Re-drilling of short holes or collapsed holes should be conducted at north Mara, so that
whatever holes length that can be charged were charged by adhering to the designed distance of 10-12m. Standoff distance should be constant to maintain equal distribution of explosive energy. The drill rig operators should work hard to maximize accuracy in terms of drilling at correct position. The use of plastic pipes to avoid fall of loose materials back into drilled holes. The pipes will stop any material that will fall back into the drilled holes. Also, it will help the drilled hole not to collapse easily as shown in Figure 9.

![Figure 9: Pipe inserted in a presplit hole to avoid collapse of hole](image-url)
5.0 REFERENCES

February, AO 2008. Safe and efficient blasting in open cut mines.


