PERIMETER CONTROL AT ORAPA DIAMOND MINE

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ABSTRACT: Effective perimeter control during drilling and blasting is critical not only to blasting results but also to the overall stability of the pit over its entire life span. A pit where perimeter control is not given enough attention when conducting drilling and blasting operations, often experiences over-break or back break beyond final pit wall limits, and therefore has a relatively high probability of failure. Such a pit also becomes unsafe, sometimes not easily accessible, has increased loading costs due to production of oversize, longer cycle times and often problems are encountered when blasting subsequent benches. All these are undesirable consequences, which have negative cost implications. Specialised blasting techniques such as trim blasting and pre-splitting have over the years proved to be effective perimeter control measures. However, the success of these techniques is directly attributable to the time and effort given to the processes. This paper presents results of a project undertaken to monitor, review and optimize the trim blasting and pre-splitting processes at Orapa Diamond Mine in Botswana. The project was specifically incepted to improve the final wall conditions, which continued to deteriorate due to persistent over-break during blasting. The paper also analyses the results obtained against a benchmark of results taken prior to project implementation. Specific blast design parameters which are critical to blasting results were identified as problem areas after auditing of the pre-implementation drilling and blasting practices. These include drill-hole depth, spacing, splitting factor for pre-splits and timing of trim blasts. The impact of different rock types on the results was also studied, and recommendations were made at different phases of the project and results obtained after implementation analysed until optimum results were achieved.

Key Words: Pre-split; Trim-blast; High Wall; Stability; Design; Blasting

1 INTRODUCTION

Even though some specialized blasting techniques were used before at Orapa Mine to protect the pit perimeter, the mine continued to experience persistent over break during blasting which often resulted in poor final wall conditions. On top of that, the pit experienced a serious high wall failure (collapse) in the eastern quadrant towards the end of 2005 (See figures 1). So, with the overall pit wall situation continuing to deteriorate with every blast, it became imperative to monitor the pre-splitting and trim blasting processes. The pre-implementation drilling and blasting practices were monitored and audited to identify problem areas, which contributed to poor blasting results. The specific areas include the following:

- Drill Site preparation
- Drilling accuracy and Charging practices
- Explosives and blast timing practices
- Rock mass geology

Figure 1: Orapa Mine high wall failure

2 BACKGROUND INFORMATION

Orapa Diamond Mine is located in north-central Botswana, some 240 km west of the northern city of Francistown. Established in 1971, the mine is the oldest Debswana running operation. The geology consists of AK1 Kimberlite which forms a single surface of expression of 118 ha. The Kimberlite intruded Achaean granite-gneiss and a variety of rocks from the Karoo Supergroup approximately 93 million years ago. Geological information has shown that the pipe consists of two individual intrusions (which are clearly different in geology) that coalesce near the surface namely the northern and southern lobes. Rocks from all three facies, viz. crater, diatreme and hypabyssal have been identified at Orapa.

The Uniaxial Compressive Strengths (UCS) of the common rock types at Orapa pit are shown in tables 1 and 2 below:

ROCK TYPE	**UCS**				
	CODE	COUNT	MIN MPa	MAX MPa	AVRG MPa
A3T	31	15	8	60	33
A1MS	32	7	16	31	21
A1MN	10	11	10	38	24
TKBS	61	8	36	52	44
TKBN	66	5	45	50	48
BAS	70	1	179	179	179

Table 1: Internal Rocks

ROCK TYPE	UCS				
	CODE	**COUNT**	**MIN MPa**	**MAX MPa**	**AVRG MPa**
BAS	**110**	**9**	**35**	**137**	**33**
SST	**120**	**5**	**14**	**34**	**6**
LSST	**130**	**5**	**27**	**55**	**9**
MST	**140**	**3**	**40**	**53**	**6**
LSST	**150**	**2**	**51**	**65**	**7**
CMST	**160**	**2**	**22**	**24**	**1**
GG	**170**	**2**	**163**	**180**	**9**

Table 2: Country Rocks

3 PRE-IMPLEMENTATION PRACTICES

The perimeter control practices at Orapa prior to project implementation were as follows:

3.1 Pre-splitting

3.1.1 Design parameters

The pre-implementation pre-split design parameters which were common for all the rock types across the pit are shown in Table 3 below:

Hole diameter (mm)	165
Hole length (m)	15
Hole spacing, S (m)	1.3
Hole orientation	Vertical
Explosive	Magnum Buster (50x560
Mass per hole (kg)	5.24
Splitting factor (kg/m^2)	About 0.3
Linear charge, Mh (kg/m)	0.35
Initiation system	Cordtex 10
Delay	Pseudo-Simultaneous

Table 3: Pre-implementation Pre-split Parameters

3.1.2 Charging

Charging of all the pre-split holes was done as shown in Figure 2 below:

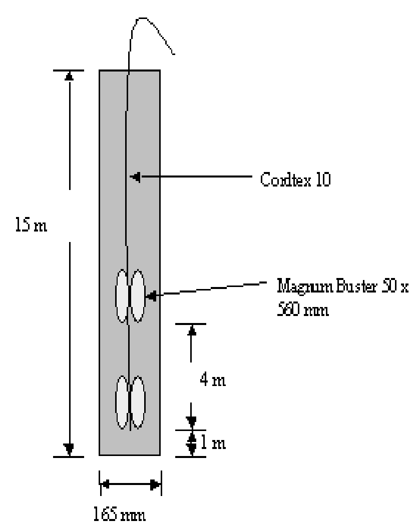

Figure 2: Pre-split charging (Not to scale)

3.2 Trim blasting

Trim blasting practices before the project was implemented at Orapa Mine are summarized in Table 4 below:

Explosive type	**P700B**
Hole Diameter (mm)	**165 and 250**
Burden (m)	**Ranges from 5 - 8 depending the rock type and hole diameter**
Spacing (m)	**Ranges from 6 – 9.5 depending on rock type and hole diameter**
Stemming (m)	**Increasing towards buffer row**
Crest stand-off (m)	**Varies from 2 - 4 with rock type and hole diameter**
Firing sequence	**Oblique**
Maximum number of rows	**Variable**
Charging method	**Reduce charge mass towards the buffer row (pre-split)**

Table 4: Pre-implementation Trim Blast Parameters

3.3 Results from Pre-implementation Practices

Figure 3 below shows part of the results of pre-implementation practices at Orapa Mine. It is evident from the figure that the final wall is badly damaged and irregularly shaped due to some back break.

Figure 3: Pre-implementation Results

4 RECOMMENDED CHANGES

Some recommendations were made following the auditing of the pre-implementation practices. The implementation of these was such that one change at a time was introduced, monitored and then the results analysed. Below are the changes that were made to address the problem:

4.1 Drilling Accuracy

Despite the criticality of drilling accuracy to blasting results, this factor was not given enough attention before this project was implemented specifically in pre-splits. Even though it was apparent that holes were collapsing and being lost during drilling of pre-splits (See figure 4 and 5), there was no actual hole depth monitoring system in place at the time to establish the actual number of holes or meters lost.

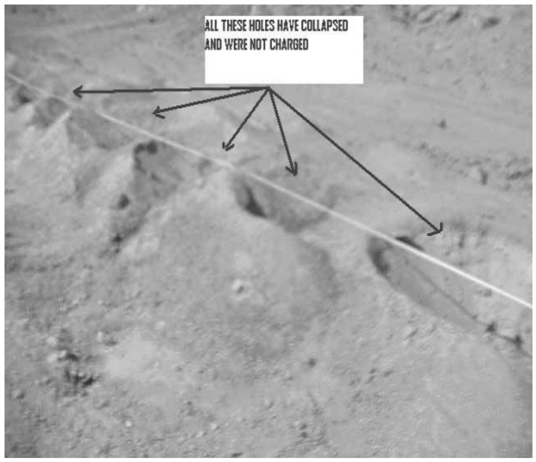

Figure 4: Evidence of hole loss

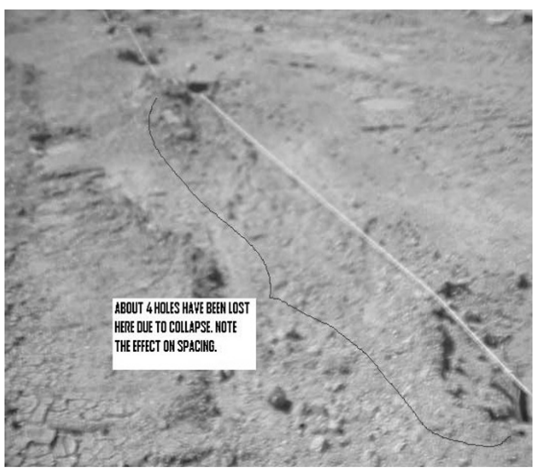

Figure 5: Hole collapse

This was never a problem with trim blasting because there were some drill-hole accuracy control and corrective measures already in place. The actual hole depths were measured before charging and compared to the planned depth after which some re-drilling or backfilling can be done depending on whether the actual depth is less or more than planned, respectively.

As a result, the following recommendations were made to address the drilling problem on pre-splits:

- Pre-split holes should always be measured to confirm the actual depth before charging. Part of the measurements done following this recommendation which confirmed a serious loss of holes and hole depth is shown in figure 6 below:

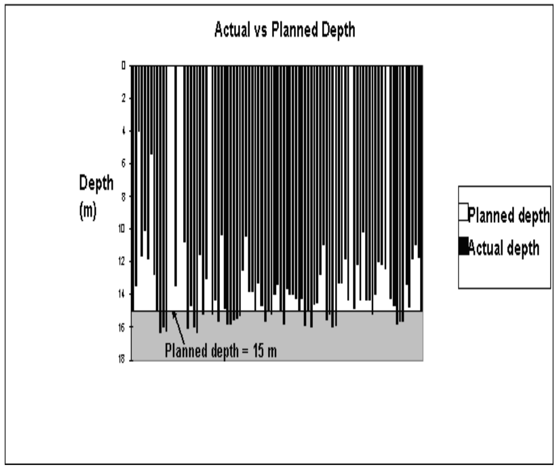

Figure 6: Actual vs. Planned depth (Level 950-935, Block ZAB 38-41)

- More effort should be made to recover blocked holes or holes that have collapsed
- Sufficient drill site preparation should be emphasized and strongly encouraged at all times to reduce the amount of loose material that might fall back into the holes after drilling
- Accurate hole positioning to be done to encourage parallelism
- Where chances of blast hole collapse are high as in wet, muddy conditions, the top of the pre-split holes should be covered immediately after the drilling machine finishes drilling. This was done using gas bags
- Sufficient supervision and active monitoring of the drilling process by the relevant supervisors to promote adherence to standards.

With all the above standards closely observed and adequately emphasized during drilling of pre-split holes, there was a significant improvement on drilling accuracy evidence by the reduced number of holes lost and improvement in hole depth. Part of that is shown in figure 7 below:

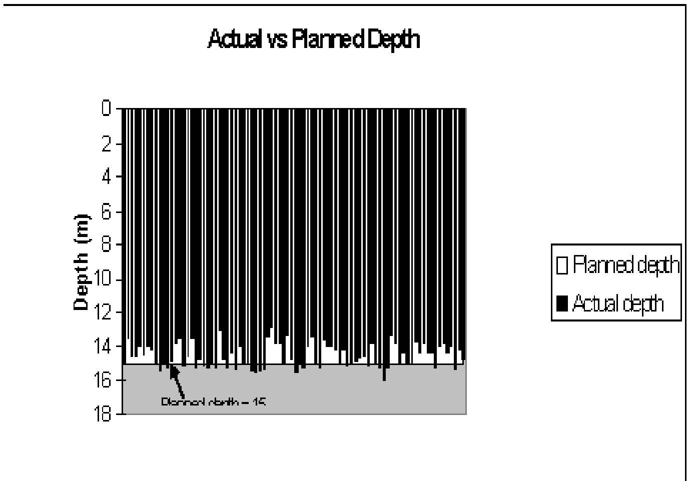

Figure 7: Actual vs. Planned Depth (Level 935-920, Block ZAC 20-25)

4.2 Charging

A recommendation was made to de-couple the cartridges more at a pre-determined spacing when charging pre-splits to promote explosives energy distribution along the blast hole length as shown in figure 8 below:

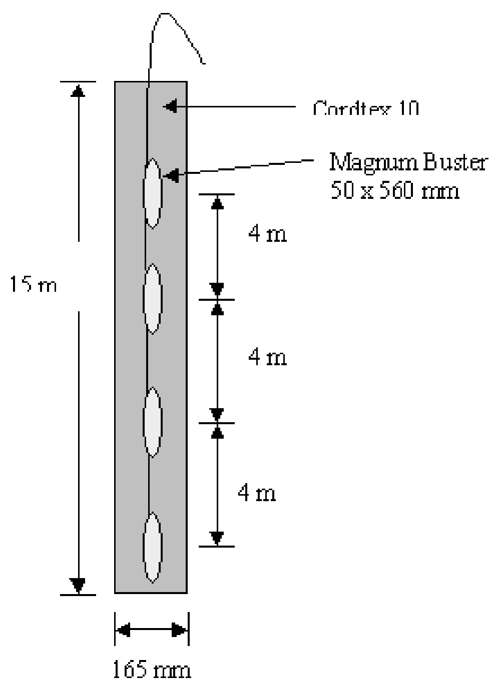

Figure 8: Recommended pre-split charging method (Not to scale)

There was already a good practice in trim blast charging since for each pattern, a charging plan specific to the relevant conditions and parameters was produced with proper control of charge mass towards the buffer row.

4.2.1 Post-implementation Results

Part of the results obtained after implementing a change in charging method in pre-splits while adhering to all significant drilling standards, is shown below (Figure 9):

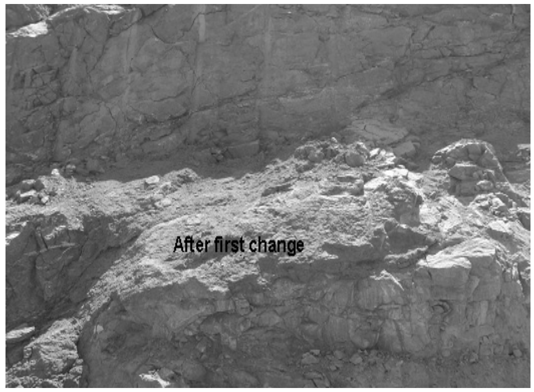

Figure 9: Level 830-815, Block UV 15-17

4.2.2 Analysis

This change brought about a noticeable improvement in final wall conditions especially for soft rocks such as Kimberlite, mudstone, sandstone, etc. However some back damage and freezing against the split was still evident. So a more look into the pre-split design was recommended mostly to establish optimum parameters for hard rocks.

4.3 Pre-Split Design Review

The following design principles (basics) were used to come up with some rock type specific pre-split parameters.

4.3.1 Splitting Factor

The splitting factor was determined using the formula:

$$S = \frac{M_h}{P} \text{ metres}$$

Where: **S** is the hole spacing (m)

Mh is the effective charge density (kg/m)

P is the splitting factor – mass of explosives per square meter of area to be pre-split (kg/m^2)

P values for pre-splitting on surface range between 0.3 – 0.6 kg/m^2

4.3.2 Centre-to-Centre Cartridge Spacing (Dc)

The centre-to-centre spacing of cartridges along the cordtex 10 in the hole was calculated using:

$$Dc = L \times \frac{M_c}{M_h}$$

Where: **Dc** is centre-to-centre spacing (m)
L is cartridge length (m)
Mc is mass of explosives per unit length of charge (kg/m)
Mh is mass of explosives required per unit length of hole (kg/m)

Keeping the hole spacing of 1.3m, the hard rock pre-split parameters shown in table 5 below, were recommended:

Table 5: Recommended Hard Rock Parameters

Hole Diameter (mm)	**165**
Hole Length (m)	**15**
Hole spacing (m)	**1.3**
Mass per hole (kg)	**8.7**
Splitting Factor (kg/m^2)	**0.45**
Linear Charge Mh (kg/m)	**0.59**
Centre-to-centre Cartridge spacing (m)	**2.4**

4.3.3 Post Blast Results

Part of the results obtained after implementing hard rock pre-split design parameters is shown in Figure 10 overleaf:

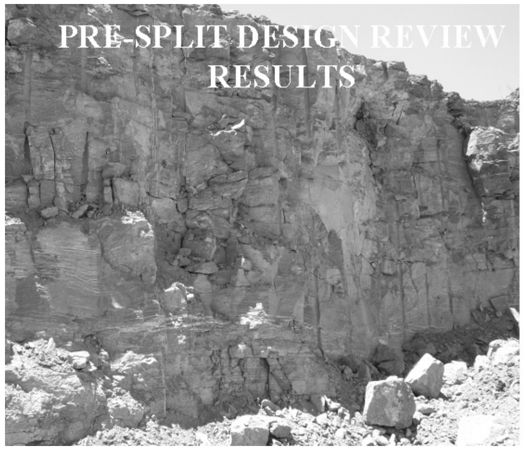

Figure 10: Pre-split design review results (Level 950-935, Block YAA 37-41)

4.3.4 Analysis

Some reasonable improvement on the results (barrels visible) was realized but still not satisfactory as there was significant back break and freezing evident. This prompted a decision to review trim blast design.

4.4 Trim Blast Design Review

With significant over break and freezing still being experienced, a review in trim blast design was done. The review covered the following critical trim blasting areas:

- Size – It was recommended that big (wide) trim blasts be avoided to reduce the amount of explosives energy into the high wall. A maximum of 4 rows for a trim blast was adopted to try to address this.
- Charging – The mine already had a good charge mass control as the mass decreased (longer stemming) towards the buffer row.
- Timing – Taking into consideration the following critical points when timing the blast can lead to effective trim blasting:

  - *Thrust direction (Angle of impact)* – A direct perpendicular angle of impact to the wall, causes some freezing against the split and back break. This is addressed by the use of oblique firing sequence. Evidence of freezing against the walls confirmed that the timing plan, which recommended oblique firing sequence, was not fully implemented on the field.

  - *Burden relief* – The timing used did not give the buffer row holes enough burden relief thereby causing some back break into the high wall. It was then recommended that the inter-row delays between the back and buffer rows be increased to promote enough burden relief and control the rate of impact.

  - *Charge mass per delay* - Keeping the maximum charge mass per delay as minimum as possible helps in reducing the amount of explosives energy going into the high wall in the form of vibrations. This is achieved by employing single hole firing.

- Where pre-split and trim blasts are taken as one blast, the pre-split should be given enough time to develop to its fullest extent. To address this, it was recommended that the pre-split should always go first and then a delay of at least 75 ms be introduced before firing of the trim blast.

The trim blast parameters following the above recommendations are summarized in table 6 below:

Explosive type	P700B
Hole Diameter (mm)	165 and 250
Burden (m)	Ranges from 5 - 8 depending the rock type and hole diameter
Spacing (m)	Ranges from 6 – 9.5 depending on rock type and hole diameter
Stemming (m)	Increasing towards buffer row
Crest stand-off (m)	Varies from 2 - 4 with rock type and hole diameter
Firing sequence	Oblique
Maximum number of rows	Four
Charging method	Reduce towards the buffer row (pre-split)
Timing delays	Increase inter-row delays between back and buffer rows
Timing when trim blast and pre-split shot together	First trim hole at least 75ms after all the pre-split holes have fired

Table 6: Recommended Trim Blast Parameters

This phase coincided with the introduction of Splitex, so tests were also done using the explosive for pre-splitting and comparing the results with that obtained using magnum busters. Two different splitex sizes available for trials at the mine were 25 mm and 32 mm diameter cartridges. The same parameters used for magnum busters were used for splitex.

4.4.1 Post Implementation Results

The following figures 11, 12, 13 and 14 show part of the final results obtained for different explosives following the introduction of changes in trim blast design.

Figure 11: Level 950-935, Basalt Rock (Magnum Busters)

Figure 12: Level 830-815, NPK Kimberlite Rock (Splitex 25 mm Diameter)

Figure 13: Level 950-935, Block AC 27-30 (Basalt, Splitex 32 mm Diameter)

Figure 14: Level 935-920, Block ZAC 20-25 (Basalt, Splitex 32 mm diameter)

4.4.2 Analysis

Good, desirable results were obtained after implementing changes in trim blast timing. The resultant back break is very insignificant and the barrel traces are completely exposed and visible especially on problem, hard rock type of basalt. More importantly, the best results for this exercise were obtained behind the failure area, which to an extent will help stabilize the area. Splitex 32 mm diameter explosive yielded the best results for pre-splitting and still continues to do so.

5. RECOMMENDATIONS

The criticality of perimeter control needs not to be overlooked in every day drilling and blasting operations as it contributes to the final total cost of production. The successful implementation of an optimum blast design for effective perimeter control depends primarily on the following:

- Time and effort given to the process
- Knowledge and understanding of how to undertake the process
- Total commitment to quality. That is, adhering to drilling, charging and timing standards
- Level of dedication by the concerned supervision

The following parameters (Tables 7 and 8 overleaf) have been identified as giving desirable results and hence recommended for different rock types at Orapa pit:

5.1 Pre-splitting

Hole diameter (mm)	**165**
Hole length (m)	**15**
Hole spacing, S (m)	**1.3**
Hole orientation	**Vertical**
Explosive	**Splitex 32 mm diameter**
Mass per hole (kg)	**8.7 (hard rocks) and 5.24 (soft rocks)**
Splitting factor (kg/m^2)	**0.45 (hard rocks) and 0.3 (soft rocks)**
Linear charge, Mh (kg/m)	**0.59 (hard rocks) and 0.35 (soft rocks)**
Initiation system	**Cordtex 10**
Delay	**Pseudo-simultaneous firing**

Table 7: Final Pre-split Parameters

5.2 Trim Blasting

Explosive type	P700B
Hole Diameter (mm)	165 and 250
Burden (m)	Ranges from 5 - 8 depending the rock type and hole diameter
Spacing (m)	Ranges from 6 – 9.5 depending on rock type and hole

	diameter
Stemming (m)	Increasing towards buffer row
Crest stand-off (m)	Varies from 2 - 4 with rock type and hole diameter
Firing sequence	Strictly Oblique
Maximum number of rows	Four
Charging method	Reduce charge mass towards the buffer row (pre-split)
Timing delays	Increase inter-row delays between back and buffer rows (last 2 rows)
Timing when trim blast and pre-split are shot together	First trim hole at least 75ms after all the pre-split holes have fired

Table 8: Final Trim Blast Parameters

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