

Design of blast pattern with perimeter controls for use in poor ground conditions

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Abstract

This study contains research information on how to counter adverse results (over break, dilution and reduced safety) when conducting blasting operations using Mimosa mine in Zvishavane as a case study. Two perimeter blasting techniques were incorporated into the original blasting pattern used at the mine in order to analyse their effect on blasting operations as compared to the original pattern. To achieve this, a trial blast of each blasting pattern was carried out and the resulting mining heights, dilution and number of bolts replaced to improve safety were recorded and analysed.

These results indicated that using perimeter blasting as a method of controlling a blast was capable of minimizing or possibly eliminating some of the negative effects of blasting in poor ground conditions. Further analysis was carried out between the two perimeter blasting techniques and it was concluded that smooth wall blasting was the best method to use in blasting in poor ground conditions. This was as a result of its low drilling times as well as cheaper drilling cost as compared to line drilling.

Keywords: Perimeter Blasting, Controlled Blasting, Line Drilling, Ground Control.

Introduction

Blasting is the cheapest and most efficient means of fragmenting rock, but it comes with its fair share of complications mainly those related to safety^{2,7,15}. This is mainly due to high stress levels exerted on the ground during blasting⁵. If blasting operations are not controlled, mining activities face higher risks of violent failures which pose a threat to human life. It is said that 67% of fatalities and 30% of accidents on a mine are related to rock falls caused by poor blasting techniques⁴.

The mining industry has evolved over the years, shifting from production-based operations to more sustainable ones which also include health and safety¹⁶. These changes have resulted in the development of better blast techniques that minimize the occurrence of unstable ground conditions^{10,11}.

These techniques range from the designing of better blasting patterns, designs of new blasting cuts, perimeter blasting and

a careful consideration of the explosives to be used while carrying out blasting operations^{1,17,18}.

However, the current trend shows that most mines over the world are leaning towards perimeter blasting as a prime method of controlled blasting to maximize safety in their operations⁶. Research also shows that accidents from ground falls in most mines could be improved by the use of effective controlled blasting techniques. Several large mines in Latin America and Russia have adapted controlled blasting techniques and have deduced that the use of controlled blasting techniques improved safety. This innovation on a global base has seen the shift of some mineral resources into mineral reserves^{9,12-14}.

Over the past few years Mimosa mine, Zimbabwe's third largest platinum producer has experienced significant ground deterioration which has resulted in the mine moving from operations in grounds of Ground Control Districts (GCD) classes A and B to having majority of the operations in class E which is a weaker and less competent rock. Due to this change, the mine has had to take extra measures to ensure that the operations underground continue in a safe manner. These measures included extra support to minimize fall of ground, the change from ANFO to emulsion to try and minimize the damage done to the hanging walls and side walls during blasting and using controlled blasting techniques like smooth blasting to get stable walls. Despite all these efforts, fall of ground remains a big challenge with 4 out of 6 accidents recorded at the mine being attributed to fall of ground. In addition to safety concerns, fall of ground leads to increased dilution.

With the undesired effects of poor blasting in mining operations such as unwanted dilution, reduced safety, increased chances of fall of ground and the possibilities of poor extraction ratio due to safety concerns, the research attempts to identify the possible causes and solutions to these ground conditions taking into consideration previous research on similar cases and the ground type at Mimosa mine. Multiple experimental blast patterns were designed and used. The results were analysed to derive a safe mining method which the mine can use. Each method incorporated a method of controlled blasting technique with respect to Mimosa ground conditions.

Description of Mimosa Mine: Mimosa Mine is situated 32 km west of Zvishavane town in the Midlands Province of Zimbabwe on the eastern edge of the Wedza Geological

Complex located in the southern part of the Great Dyke. Fig. 1 shows the location of the mine.

The Great Dyke as shown in fig. 2 is a layered complex with an elongation of mafic to ultra-mafic layered intrusions in the NNE-SSW direction across Zimbabwe. The Wedza complex (on which the mine sits) is a narrow basin about 60 km long, up to 6 km wide. There are two major stratigraphic portions along the Great Dyke, the overlying mafic sequence and the lower ultra-mafic sequence. The mafic sequence comprises of the norites and gabbro's and the ultra-mafic sequence is made up of cyclic units of harzburgites, serpentinites, chromitites and pyroxenites³. There are six cyclic ore bands units named P1 to P6 going downwards and it is within the uppermost P1 that the Mimosa ore body is found. Within the P1 band, there are two rock formations the websterite and the bronzitite succession. Within the contact zone of these two rock formations, a three-meter-thick platinum bearing reef is found.

The platinum bearing reef does not have any distinguishable colour or texture, hence it is not easily identifiable. However, the peak platinum values are identified using the Main Sulphide Zone (MSZ). The MSZ can be characterized as a region of very high concentration of nickel sulphides and just below it is where the platinum peak values are found, hence it is used as a marker to the platinum reef.

In addition to visible sulphides, the reef is also identified by the gradual change in texture and colour from the Websterite (hanging wall) to bro (foot wall). Websterite is an acicular textured greenish augite rock whereas the bronzitite succession is defined by a complete progression from a basal chromite layer, through dunite, harzburgite and olivine⁸.

Material and Methods

Original blast design: The original blast pattern being used at mimosa mine consists of a nine-hole burn cut, 3m long blast holes with a diameter of 38 mm on normal holes and 46 mm for the cut air holes.

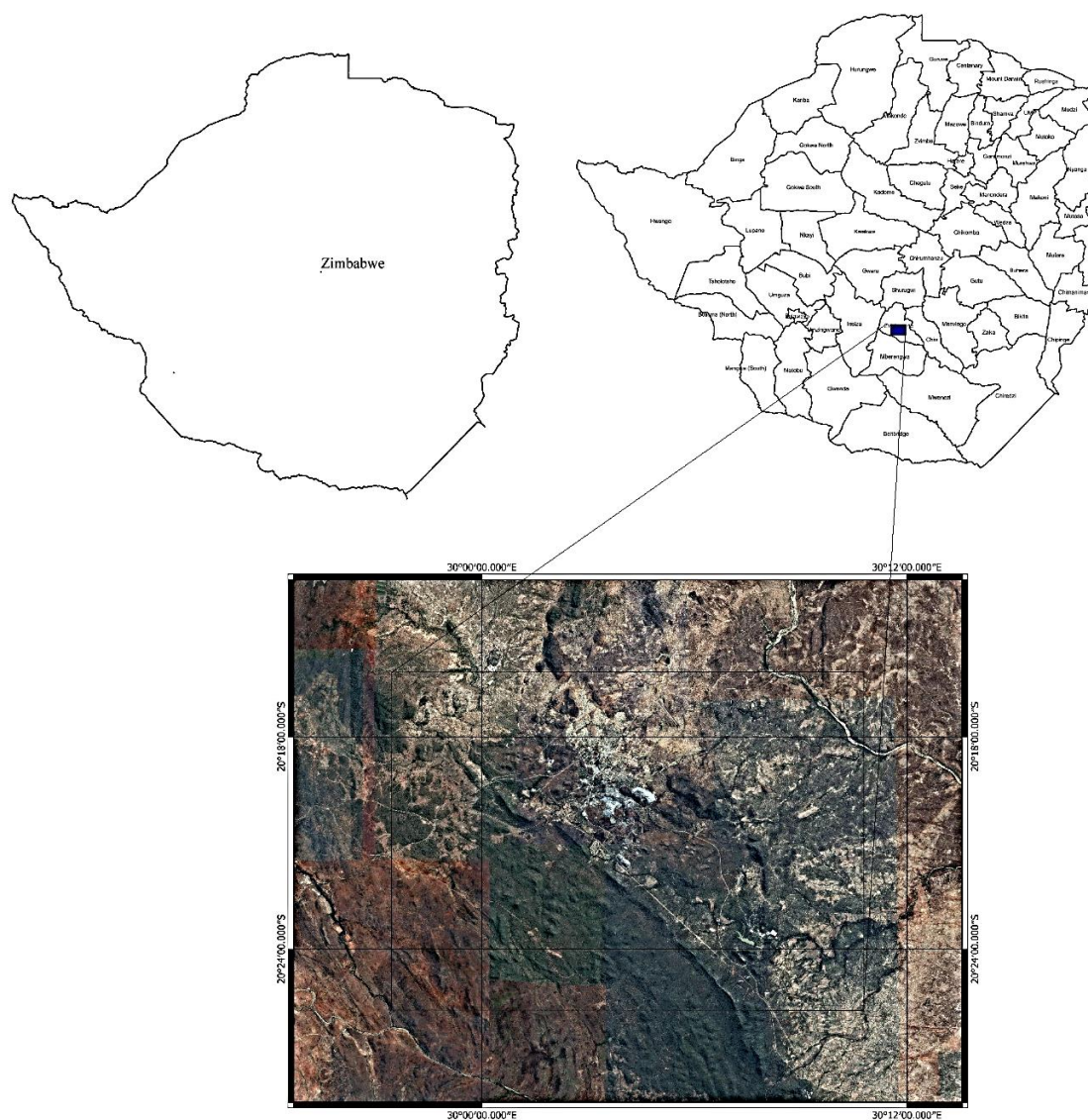


Fig. 1: Location of Mimosa Mine

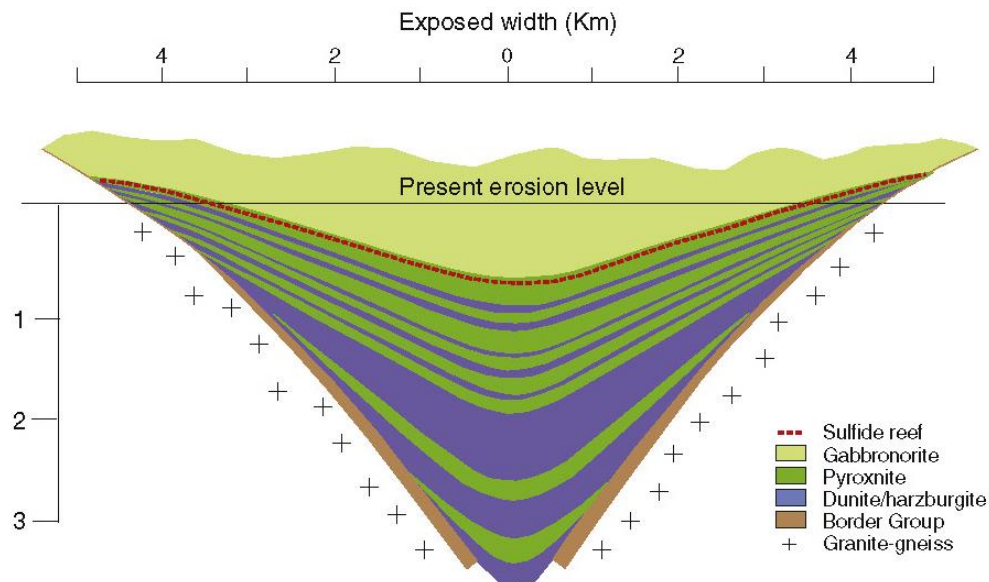


Fig. 2: The cross section of the great dyke

Designing of blast patterns that include perimeter blasting techniques: The original blast design explained above was altered by the controlled blasting techniques.

Designing smooth wall perimeter holes: Smooth wall blast perimeter holes were designed using equations 1 and 2. These holes then substituted the top row holes of the original blast pattern.

$$\text{Spacing} = 20 \times \text{hole diameter} \quad (1)$$

$$\text{Burden} = 1.25 \times \text{spacing} \quad (2)$$

The perimeter holes were charged with an emulsion xxxx calculated using equation 3:

$$\text{Powder Factor} = \frac{\text{Amount of blasted material in tonnes}}{\text{amount of explosives used to blast the material in Kg}} \quad (3)$$

Designing line drilling perimeter holes: Equations 4 and 5 were used to calculate the spacing between the holes in the pattern when using line drilling.

$$\text{Spacing} = 0.75 \times \text{spacing of main production blast} \quad (4)$$

$$\text{Burden} = 0.5 \times \text{burden of main production blast} \quad (5)$$

Determination of impacts of different controlled blasting methods in poor ground conditions: A comparison between the two controlled blasting techniques was carried out and the best method was recommended for use in bad ground conditions.

Using the normal blast patterns: Face profiles (heights) of the sections that were blasted before the implementation of controlled blasting were measured using a distometer. An average of 5 points in every gully was used as the height of that profile and the data are recorded. This was done for 3

blasts and the results of each blast were recorded. The tonnes blasted for all three blasts were calculated in order to determine the level of dilution.

The mass of blasted material in tonnes is calculated using equation 6:

$$\begin{aligned} &\text{Length of gully} \times \text{drilled width} \\ &\quad \times \text{height} \left(\begin{array}{l} \text{distance between} \\ \text{hangingwall and footwall} \end{array} \right) \quad (6) \\ &\quad \times \text{density of rock} \end{aligned}$$

Dilution was calculated using equation 7:

$$\text{Dilution} = \frac{\text{waste tonnes}}{\text{ore tonnes} + \text{waste tonnes}} \quad (7)$$

The number of roof bolts for support that were marked for replacement after all the 3 blasts, were counted and the cost of replacement was calculated.

Blasting using smooth wall blasting: A pattern that included smooth wall was used on 3 trial blasts as done with the normal blasting pattern. The results were recorded which included the face profile heights achieved by each trial. The top row was charged with 3.5 kg of emulsion.

Blasting using line drilling: The third option was blasting trials using line drilling. Closely spaced perimeter holes were drilled as a substitute of the top row from the original blast pattern.

Three trial blasts were carried out and the same parameters were either measured or calculated and recorded.

Time required to drill a face of blasting patterns: For each method, the total time the time it took to mark and drill a face to completion with the exclusion of down times was

recorded using a stopwatch. An average of the 3 trials was taken to be the time it took to drill a face using each particular method.

Cost benefit analysis: To conduct a cost benefit analysis, the total cost of the drilling operations and explosives cost of each method were analysed to determine the cheapest method.

Assessment of drilling cost associated with each method: Data was collected from the mine planning offices showing the cost per meter of drilling of various drilling components (drill rods, couplings, bits, reamer bits, pilot adapters etc.). The total cost was then multiplied by the total meters drilled for each method. The total meters drilled were calculated by multiplying 3 m (expected length of holes) by total holes drilled. The results were recorded and analysed.

Charging cost associated with each method: Total purchasing cost of emulsion and ez-stoppers, booster cartridges, trunk-liner and safe start and connecting wires used in each method was calculated and recorded.

Results and Discussion

Designed blast patterns: Figure 3 is a pattern that is being used at mimosa mine; it consists of a nine-hole burn cut, 3 m long blast holes of a diameter of 38 mm on normal holes and 46 mm for the cut air holes.

Blast pattern including smooth wall blasting: Fig. 4 is a blast pattern that was designed using equations 1,2 and 3 when smooth wall blasting was done at the perimeter of the blast design. It includes a nine-hole burn cut as well as holes of 3 m in length and diameters of 38 mm. From equation 1, the perimeter blast holes are to be charged with 2.7 kg of emulsion.

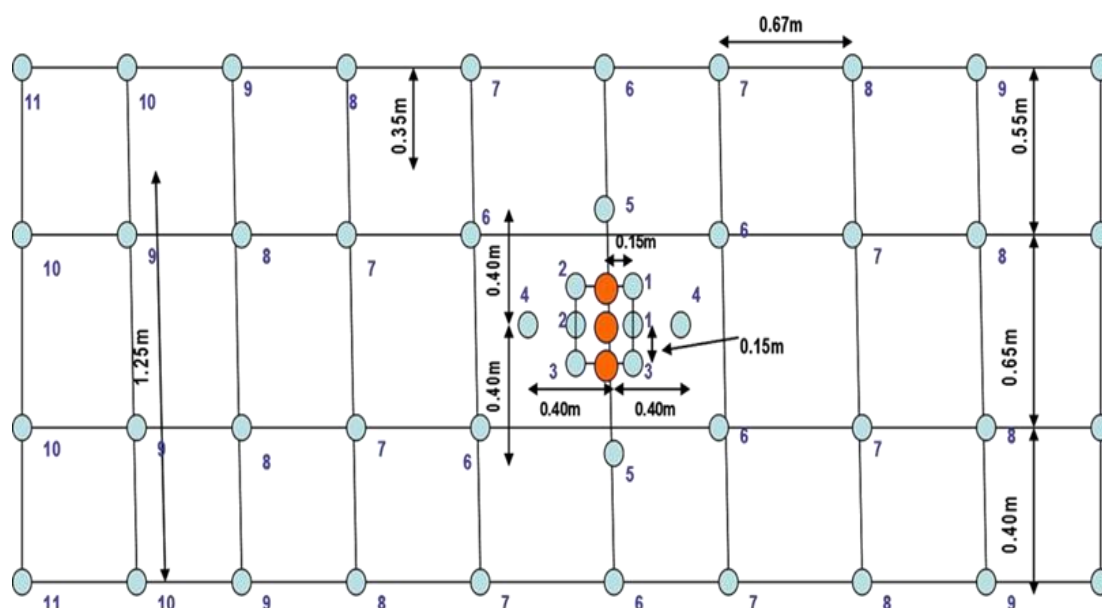


Fig. 3: Normal blast pattern used at Mimosa Mine

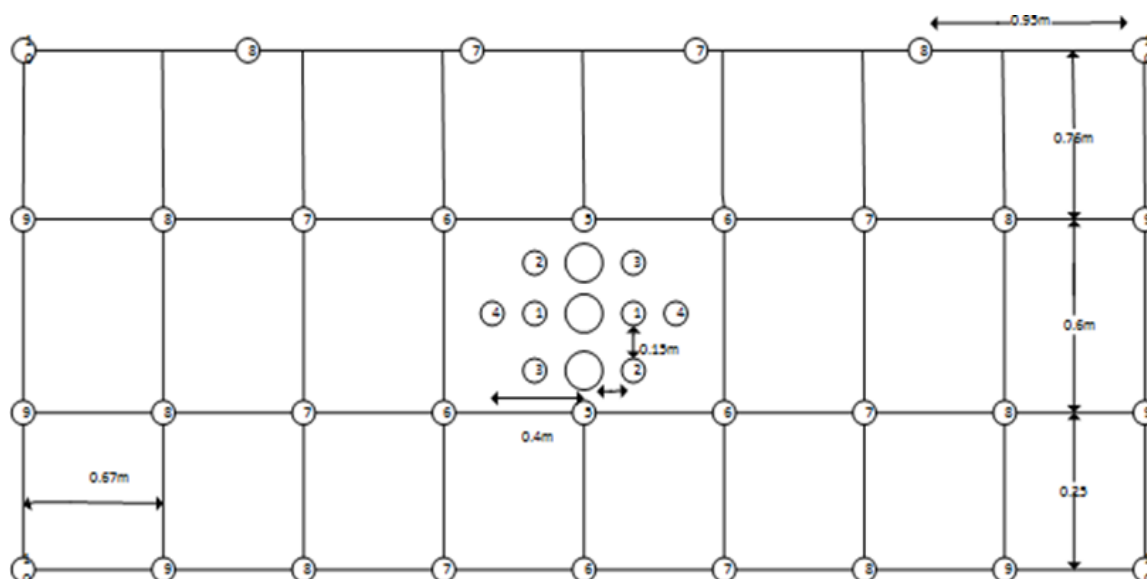


Fig. 4: Blast pattern designed with smooth wall perimeter holes

Blast pattern including line drilling: Fig. 5 is the pattern that was obtained using equation 4 and 5 when line drilling parameters were incorporated into the blast pattern. The first row of holes along the perimeter are 0.3 m from the rest of the production holes (the perimeter holes). All the charged holes have a diameter of 38 mm, the line drilling holes also have a diameter of 38mm (the perimeter holes in this pattern are not charged) and the air holes have a diameter of 46mm.

Evaluation of blast patterns: Three trial blasts were conducted using each method and the results were recorded and analyzed with the aim of deducing the optimum blasting pattern.

Trial blast without any controlled blasting techniques: The results obtained from blasting operations were conducted without the use of controlled blasting. Table 1

shows the heights that were recorded on each face profile after each of the 3 blasts.

The results in table 1 show that the average heights of each profiles are 2.84m, 2.72m and 2.81m, hence it can be assumed that all blast operations that take place in face profiles 1,2 and 3 within GCD E will have an average excess of 0.84m, 0.72m and 0.81 m respectively more than the budgeted 2 m.

Table 2 shows the number of tonnes blasted and the percentage dilution that was obtained after each three blasts using the blasting method shown in figure 2 currently being used at the mine. It can be shown that the dilution incurred deviated from the budgeted dilution in all 3 blasts. Therefore, an average of 23% deviation from the budgeted 20% dilution is to be expected when the normal blasting pattern is being used.

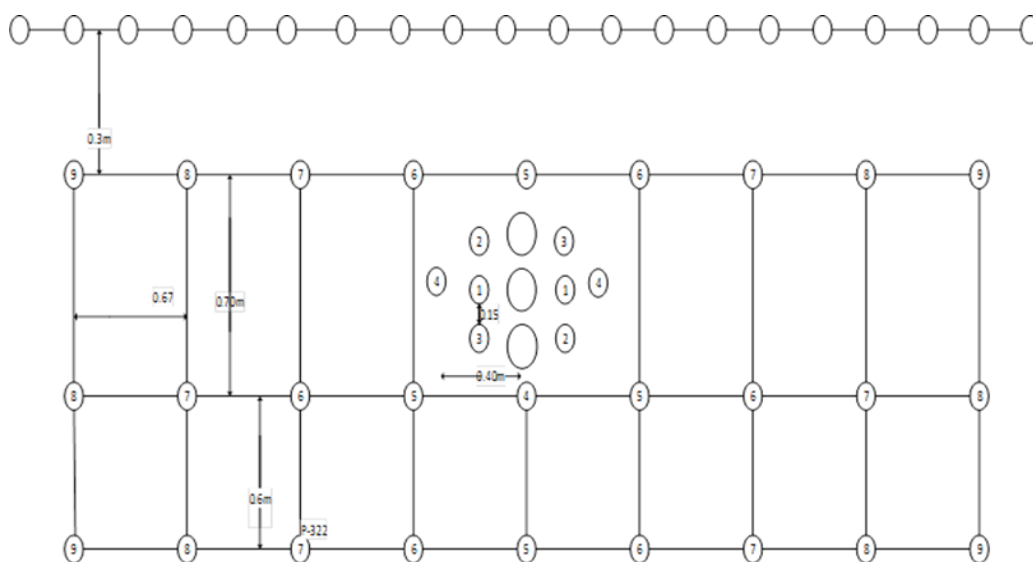


Fig. 5: Blast pattern designed with smooth wall perimeter holes

Table 1

The face profile heights measured after each blast and an average for each blast

Blast Height	No. 1 (m)	No. 2 (m)	No. 3 (m)
Height 1	2.70	2.80	2.70
Height 2	3.10	2.70	2.90
Height 3	2.80	2.80	2.90
Height 4	2.90	2.60	2.85
Height 5	2.70	2.70	2.70
Total	14.20	13.60	14.05
Average	2.84	2.72	2.81
Budgeted	2.00	2.00	2.00

Table 2

Tonnes blasted in relation to dilution using the blast pattern being used at Mimosa

Blast No.	Tonnes blasted	Dilution Incurred (%)	Planned Dilution (%)	Increase in dilution (%)
1	167.47	43.66	20.00	23.66
2	160.39	41.17	20.00	21.17
3	165.70	43.60	20.00	23.60

Table 3 shows the number of bolts that are replaced after each blast using the current blasting pattern due to protrusion. The average cost of replacement of bolts is approximately \$40.38 per blast.

Trial blast conducted using smooth wall blasting: The following results (Table 4) were obtained from blasting operations that were conducted using smooth blasting techniques. The results in table 4 show the heights that were recorded on each face profile after each of the 3 trial blasts using smooth wall blasting.

Table 5 shows the total tonnes blasted and the percentage dilution that was attained after each trial blast using the smooth wall blasting method shown in figure 3. It can be shown that the dilution incurred deviated from the budgeted 20% dilution in all 3 blasts. Therefore, an average of 5.63 deviation from the budgeted dilution is to be expected when the smooth blasting pattern is being used.

Table 6 shows the number of roof bolts that were replaced after each trial blast due to protrusion and the total cost of replacement. The average cost of replacement of roof bolts is about \$20.16 per blast.

Trial blast results using line drilling: The results in table 7 were obtained from blasting operations using line drilling as a form of controlled blasting. The results in the table 7 show the heights that were recorded on each face profile after each of the 3 trial blasts using line drilling.

As shown in the table the average heights of face profiles no.1, no. 2 and no. 3 were 1.79m, 1.70 and 1.69m respectively, hence it can be assumed that all blast operations that take place in GCD E using this method, will have lower mining heights than the budgeted 2m. However, the distribution of the height classes from 1.58 to 1.89 shows some inconsistencies that might be occurring during the blasting operations.

Table 3
Number of support bolts replaced after each blast

Trial blast	Number of replaced bolts	Total cost of bolt replacement (\$)
1	7	60.48
2	3	25.92
3	4	34.56
Total	14	120.96

Table 4
Face profile heights measured after each blast and an average for each blast using smooth wall blasting

Blast Height	No. 1	No. 2	No. 3
Height 1 (m)	2.17	2.50	2.05
Height 2 (m)	2.08	2.23	2.10
Height 3 (m)	1.98	2.02	2.21
Height 4 (m)	2.42	2.33	2.10
Height 5 (m)	2.17	2.13	2.05
Total (m)	10.82	11.21	10.51
Average (m)	2.16	2.24	2.10
Budgeted (m)	2.00	2.00	2.00

Table 5
Tonnes blasted in relation to dilution

Trial blast	Tonnes blasted	Budgeted Dilution (%)	Dilution Incurred (%)	Increase in dilution (%)
1	127.37	20.00	25.93	5.93
2	132.09	20.00	28.57	8.57
3	123.83	20.00	23.97	3.97

Table 6
Number of support bolts replaced after each blast

Trial blast	Number of replaced bolts	Total cost of bolt replacement (\$)
1	2	17.28
2	4	34.56
3	1	8.64
Total	7	60.48

Table 7
Face profile heights measured after each blast and an average for each blast with line drilling

Trial blast	No. 1	No. 2	No. 3
Height 1 (m)	1.75	1.68	1.77
Height 2 (m)	1.89	1.73	1.63
Height 3 (m)	1.77	1.67	1.58
Height 4 (m)	1.73	1.68	1.71
Height 5 (m)	1.80	1.74	1.75
Total (m)	8.94	8.50	8.44
Average (m)	1.79	1.70	1.69
Budgeted (m)	2.00	2.00	2.00

Table 8
Tonnes blasted in relation to dilution

Trial blast	Tonnes blasted	Budgeted Dilution (%)	Dilution (%)	Change in dilution (%)
1	105.55	20.00	10.61	-9.39
2	100.25	20.00	5.89	-14.11
3	99.65	20.00	5.32	-14.68

Table 9
Number of support bolts replaced after each blast

Trial blast	Number of replaced bolts	Total cost of bolt replacement (\$)
1	0	0
2	0	0
3	2	17.28
Total	2	17.28

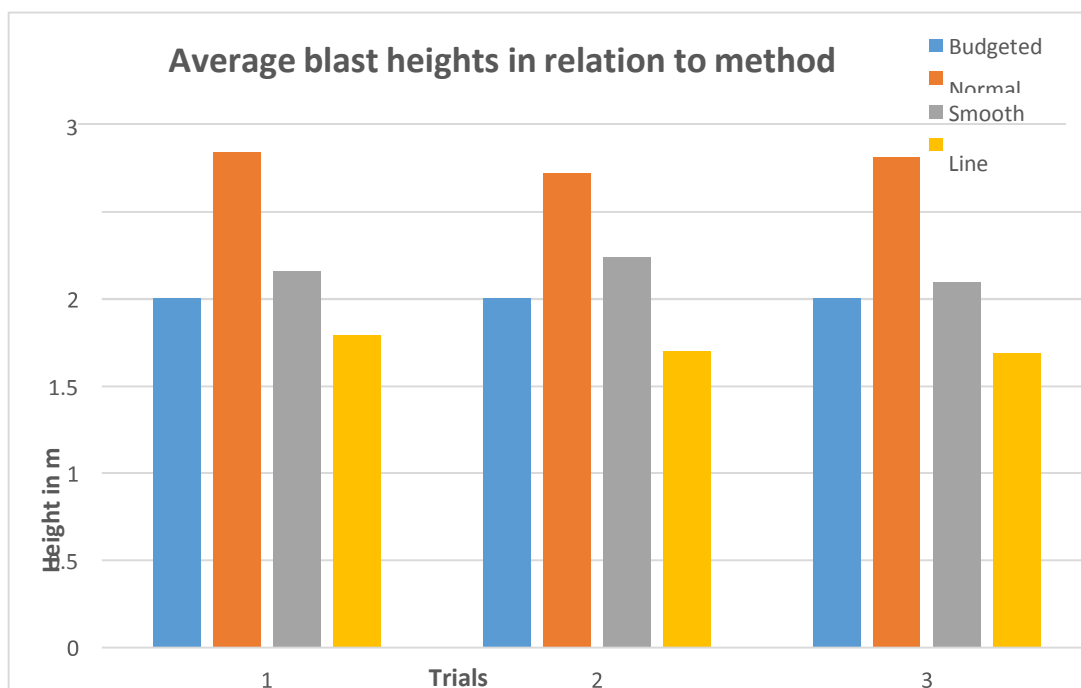


Fig. 6: Blast heights in 3 different trials using different blasting technique

Table 8 shows negative changes in dilution levels from the budgeted ones. It shows that line drilling is better in reducing dilution as the small dilution levels prove that the design results fell within the budgeted dilution ranges resulting in low dilution of the ore during extraction. Table 9 shows that

2 bolts were replaced in the 3 trial blasts when smooth wall blasting was implemented. The average cost of replacement of bolts is approximately \$5.76 per blast. This is within the budget and it reduces chances of increase in operational cost.

Evaluations of blast patterns: The results in figure 6 show that the line drilling technique provides the lowest mining heights in all three blasts and these were lower than the budgeted height; smooth wall blasting techniques give heights that are slightly above the budgeted value and finally blasting without a controlled blasting technique gives mining heights that exceed the budgeted value. Based on this table, the smooth wall blasting technique proves to be the best method of controlled blasting due to the fact that it produces heights closer to budget but will not interfere with mining equipment as a result of low mining heights.

In summary, figures 7 to 9 show the relationship between blasted tonnes of each method and the percentage change in dilution from the budgeted 20%. In general, blasting without any method of perimeter blasting resulted in very high percentages of dilution. The dilution levels in smooth wall blasting were closer to the budgeted values, with the highest figure being 8% in the 3-trial blasts. Finally, line drilling patterns resulted in minimal levels of dilution. Thus, line drilling is preferred as it results in negative dilution which reduces the processing cost.

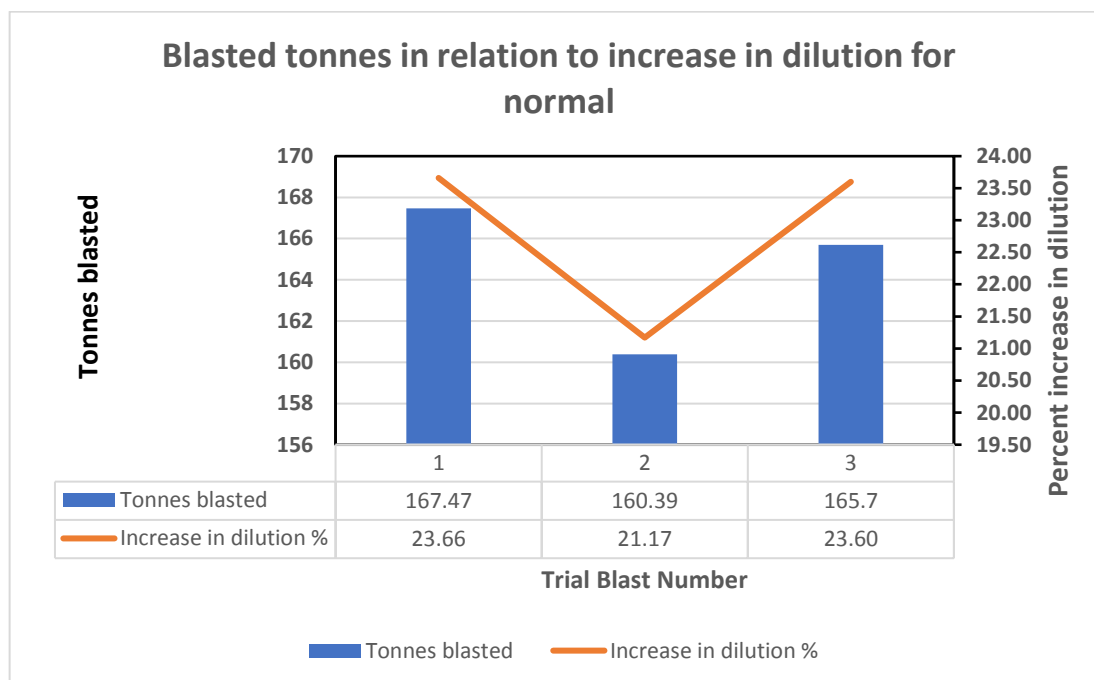


Fig. 7: Relationship between blasted tonnes and percent increase in unbudgeted dilution for normal blasting.

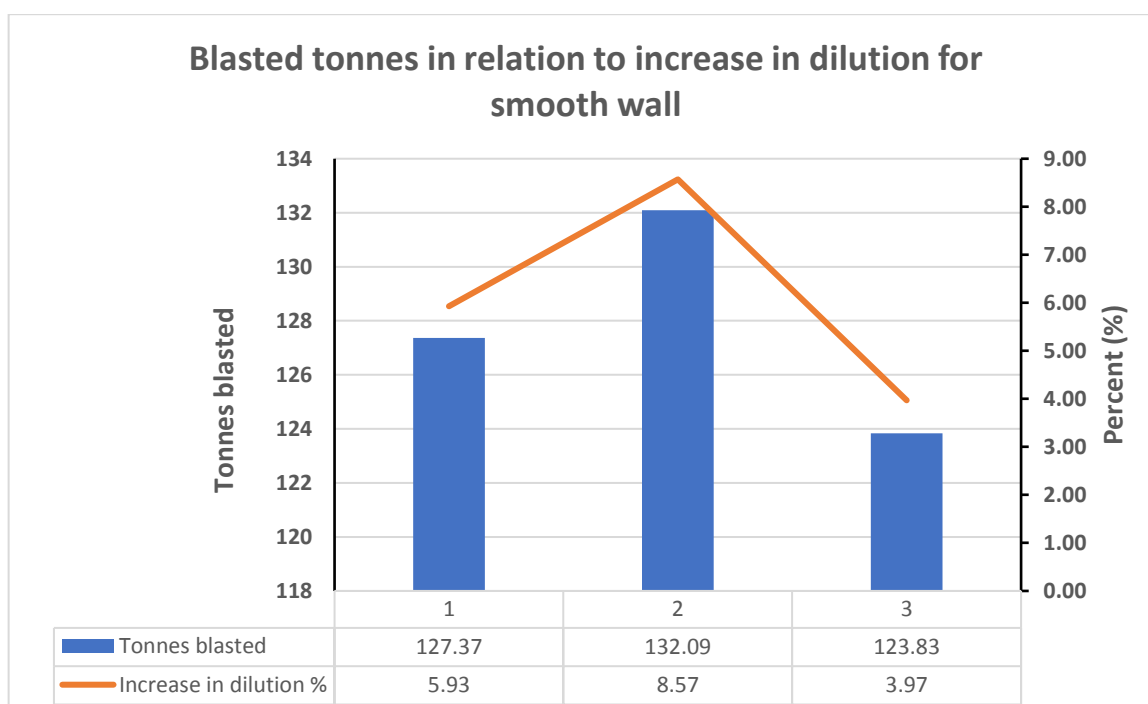


Fig. 8: The relationship between blasted tonnes and % increase in unbudgeted dilution for smooth wall blasting

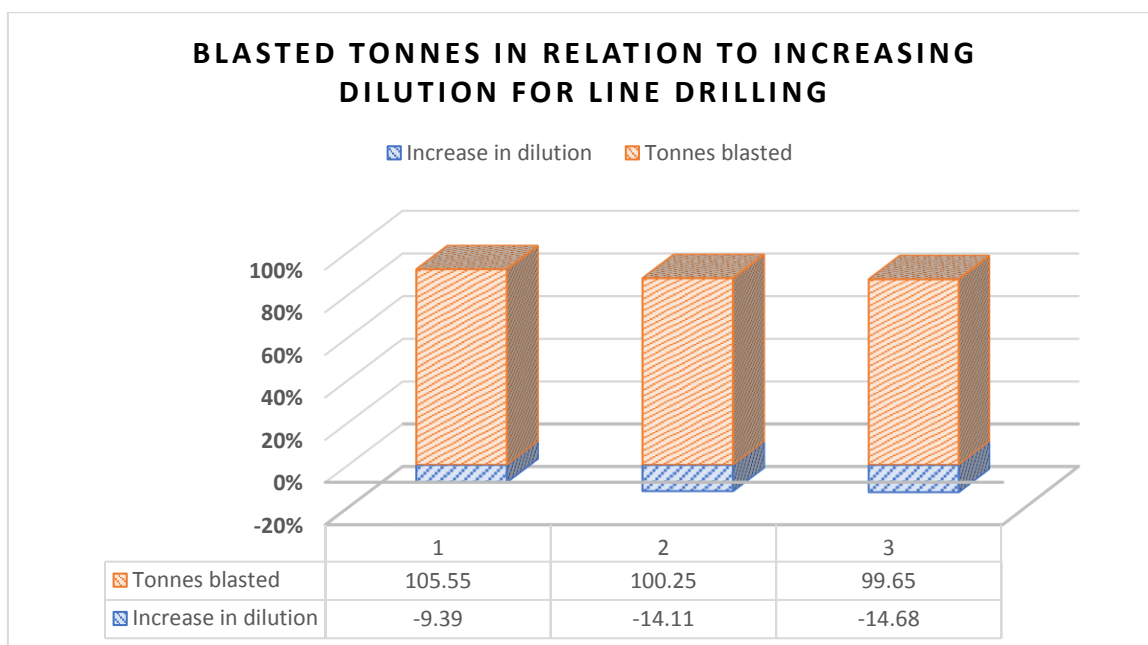


Fig. 9: Relationship between blasted tonnes and percent increase in unbudgeted dilution for line drilling

Table 10
Time used at face with each method

Drilling Face	Normal (minutes)	Smooth wall (minutes)	Line drilling (minutes)
1	105	110	120
2	110	105	150
3	120	110	145
Total	335	325	415
Average	112	108	138

Table 11
Drilling tools costs associated for each blast

Method	Normal	Smooth wall	Line drilling
Total meters drilled	153 m	132 m	174 m
Total drilling cost/m	\$2.46	\$2.46	\$2.46
Total drilling cost	\$376	\$324.72	\$428.04
Total charging cost	\$256	\$227	\$195
Total cost	\$632	\$552	\$623

The results in table 10 show the drilling time taken to drill three faces using each of the blasting techniques and the average time take by each method. Line drilling clearly has the longest drilling time with an average of 138 minutes, the normal drilling technique (without controlled techniques) having an average of 112 minutes and smooth drilling having the lowest average drilling time of 108 mins. With respect to time, the research favors the use of smooth wall blasting.

Cost benefit analysis: Table 11 summarizes the results of the cost benefit analysis that was conducted on each method in terms of drilling equipment and explosives used for each blast. The results in table 11 show that the more meters drilled the more expensive the operations are. In spite of the

high charging cost in smooth wall blasting it has the lowest drilling cost and total cost.

Conclusion

Both line drilling and smooth blasting are better mining techniques but blasting operations are being conducted in poor ground conditions. Smooth blasting proves to be the most effective way to deal with bad ground conditions. Despite line drilling resulting in dilution lower than the budget, having the lowest bolt replacement cost and lowest mining, cost of drilling and time of drilling are too high, hence the smooth blasting technique was preferred. Smooth blasting offered an average dilution of 6.16% more than the planned dilution but 16.7% less than the current dilution, in addition to this low cost of drilling and less drilling time

made the method more effective despite the dilution ratio, the stope height being slightly above the budgeted.

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