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Comparative Analysis of the Conventional Blasting Technique to the Double Saver Plugs Technique Based on Pit Floor Conditions and Cost Evaluation

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Abstract

This study evaluates the performance of double saver plug blasting relative to the conventional blasting method at the Huni Pit Cutback of Abosso Goldfields Ghana Limited, Damang mine with emphasis on cost efficiency and pit floor quality. The motivation for the study stems from operational challenges associated with conventional blasting, including high explosive consumption, hard digging, uneven fragmentation, and poor pit floor conditions. A comparative case-study approach was adopted using operational data collected between May and November 2022. Three conventional blasts and three double saver plug blasts were analysed. Cost analysis was performed using Microsoft Excel based on drilling geometry, explosive consumption, and saver plug costs, while pit floor analysis was conducted using Geovia Surpac 2021 from post-mining survey pick-ups and Digital Terrain Models. The results indicate that the double saver plug method reduced the explosive column from 7.0 m to 5.5 m and lowered the powder factor from 0.61 to 0.47 kg/m^3. Across the three blasts analysed, total blasting cost decreased from US$44,683.481 for the conventional method to US$37,780.451 for the double saver plug method, representing a saving of US$6903.030. On average, this corresponds to a saving of US$20.667 per hole and approximately US$2300.919 per day, with a projected annual saving of US$773,108.784 under similar operating conditions. Pit floor analysis further showed that both methods achieved acceptable floor conditions within the mine's tolerance of ±0.3 m; however, the double saver plug method performed better, with 98% of the floor area rated as good compared with 95% for the conventional method. Overall, the findings demonstrate that double saver plug blasting offers a more cost-effective alternative to conventional blasting while also improving pit floor quality. The study therefore recommends the continued application of saver plugs, subject to proper installation and supervision, and further investigation into their effects on fragmentation and environmental performance.

Keywords

Saver Plugs, Conventional Blasting Techniques, Pit Floor Analysis, Explosives, Open Pit Mining

1. Introduction

Most economic mineral deposits occur within massive hard rocks which require ground fragmentation for easy materials handling (Balasubramanian, 2014). Ground fragmentation is the process whereby hard rock masses are broken into fragments to free and separate the valuable minerals for transportation and further processing (Cunningham, 2006). The various ground fragmentation methods include Drilling and Blasting, Cutting, Hydraulic mining, Flame jet burners and Splitters. Amongst the various ground fragmentation methods, Drilling and Blasting happen to be the most common, most economical and efficient ground technique which has direct impact on downstream mining operations (Saharan & Mitri, 2008; Raman Sundar et al., 2013). Drilling is the first stage of the drill-and-blast cycle, involving the creation of holes in the rock mass according to predetermined design parameters (Mohanty, 1990). The quality of drilling, including hole deviation, spacing, burden, and depth, significantly affects explosive distribution, fragmentation, vibration control and the overall efficiency of mining operations. Saharan and Mitri (2008) defined Blasting as a technique that employs explosives to generate high-pressure shock waves and expanding gases, to fracture and displace rock into fragments suitable for easy materials handling and mineral processing. It is also defined as the breaking and displacement of rock through the detonation of explosives placed in drilled holes to facilitate the efficient excavation, loading and transportation of rock in mining operations (Darling, 2011).

The unit operation of blasting involves charging of blast holes with explosives and firing using a suitable detonator. As a primary method of rock breakage in hard rock mining, blasting has a significant influence on fragmentation efficiency, diggability, pit floor quality, slope stability and the overall cost-effectiveness of mining operations (Darling, 2011). A good blasting operation is likely to result in the desired fragmentation sizes, promote easy digging, produce a good pit floor condition, ensure pit wall/slope stability, reduced flyrocks, ground vibration, air overpressure. Moreover, a good blasting operation has the tendency of reducing cost, optimising operations and subsequently the reduced blasting outcomes help the mine in getting a good social licence with the surrounding communities. A poor blasting operation on the other hand is likely to result in poor fragmentation sizes, uneven pit floors, poor diggability, unstable pit slopes, massive ground vibrations and flyrocks. This could subsequently lead to increased cost in the downstream operations, such as materials handling and mineral processing. In addition, a mine undertaking poor blasting operations is likely to have a poor social licence with the surrounding communities. As such, blasting operations are exercises that do not only impact on the safety and economy of the mining operations but also have the tendency to dictate the very existence of the mining operations within the communities. The aims of mining operations therefore are to employ the optimal blasting techniques with better blasting outcomes, minimal cost and eventually produce minimal impacts on the surrounding communities.

Conventional blasting technique involves the filling of the blast holes with explosives to the required column and stemming with inert materials afterwards to produce an effective blast (Atta, 2019). This type of blasting technique happens to be the most commonly used technique in mining operations. However, there have been discoveries of problems associated with the use of this technique. Amongst such problems include the long explosive columns and higher densities of the explosives. Moreover, the energy from the detonators when blasting is initiated is opposed by the explosives due to it higher mass and density (Eshun & Dzigbordi, 2016). In addition, the longer the explosive columns translate to higher quantity of explosives, thus leading to a higher cost of explosives (Eshun & Dzigbordi, 2016). Also, groundwater condition massively influences the conventional blasting as the explosives at the bottom of the holes get into contact with groundwater and consequently reduce the explosive energy. In addressing these setbacks in blasting, several modifications have been made to the conventional blasting technique with the aim of improving blasting efficiency, reducing explosives consumption, minimising the environmental impacts, enhancing fragmentation and reducing the mining cost. These modifications primarily involve changes to blast hole charging, initiation systems, blast geometry, and explosive confinement. Amongst such modifications is the use of saver plugs as a specialised blasting technique (Oduro et al., 2016). This is a relatively new technique which has been commercially adopted by a limited number of mining operations.

The double saver plug blasting technique is an air-decking method in which two saver plugs are installed within the charging zone of a blast hole to create air gaps that replace part of the explosive column (Antwi, 2020). Unlike conventional blasting, where the blast hole is filled with explosives to the required column before stemming, the saver plugs create voids that alter the propagation of the shock waves during detonation (Atta, 2019). When the explosives are initiated, the shock wave follows the path of least resistance into the air deck beneath the saver plug, where it is reflected and amplified at the bottom of the hole. This is followed by a high-pressure gas front that extends microfractures within the rock, thereby improving fragmentation while using less explosive. The focused downward energy also enhances breakage at the toe and produces a more even pit floor. Gold Fields Ghana Limited adopted the double saver plug technique in 2019, in collaboration with AECI Mining Explosives (formerly AEL Mining Services), to address operational challenges associated with conventional blasting, including hard digging, uneven fragmentation, persistent toes, excessive explosive consumption, and irregular pit floors. In addition to improving blast performance, the technique reduced blasting costs by replacing a portion of the explosive column with air decks, minimized environmental impacts such as ground vibration, flyrocks, and noxious gases, and provided a more efficient and cost-effective blasting system.

Whereas the efficiency of blasting techniques such as stemming plugs, blast plugs and air decking have been well studied and reported in literature, there is yet to be a study which reports on the efficiency of the saver plugs blasting technique (Sazid & Singh, 2013; Gomes-Sebastiao & de Graaf, 2017; Yang et al., 2018; Bhaskar et al., 2019; Rehman et al., 2021; Zhang et al., 2021). Moreover, there is yet to be a study which compares the efficiency of the conventional blasting technique to the double saver plugs technique (a modification of the saver plugs technique) based on pit floor analysis and cost analysis. Most studies have based their comparative analysis of the blasting performance of various blasting techniques on fragmentation sizes, cost, ground vibration and flyrocks (Eshun et al., 2016; Agyei & Owusu-Tweneboah, 2019; Agyei & Dadzie 2022). There is limited literature on pit floor analysis as a parameter for the measurement of blasting efficiency (Eshun et al., 2016; Agyei & Owusu-Tweneboah, 2019; Agyei & Dadzie, 2022). This study therefore seeks to address 2 notable gaps in literature, that is the comparative analysis of the double saver plugs technique to the conventional blasting technique and also the use of pit floor analysis as a blasting efficiency parameter.

1.1. Conventional Blasting Technique at the Damang Mine

At the Damang mine, conventional blasting is achieved by filling the blastholes with explosives (charge and detonator) to the required column and stemming with rock chippings in order to produce an effective blast. After, detonation is initiated, thus causing the chemical energy of the explosive to be released, and the compact explosive turning into a glowing gas with enormous pressure. To break up a large body of hard rock, charges are placed in a series of holes drilled so that as holes closest to the exposed surface are fired. The blasts create new exposed faces at the appropriate distances from the next set of holes in which charge firing is slightly delayed. Holes are fired in a predetermined order, within a millisecond. The mine also employs conventional blasting in the production blasting.

The process of drilling is carried out by compressed air powered drill machines. All holes are drilled based on specified blast design which includes hole depth of 9 m plus a subdrill of 1 m, 115 mm hole diameter, spacing and burden of 3.8 m × 3.8 m respectively and hole angle with respect to the batter face angle. The drilled holes are loaded with emulsion at an explosive column of 7 m. The holes are then filled and covered with the stemming materials to confine gases to enhanced fragmentation and to reduce the fly rocks. The hole diameters applied are 115 mm. **Figure 1** shows how blast hole is charged using the conventional blasting technique. **Figure 2** shows the applications of the conventional blasting technique at the Damang mine.

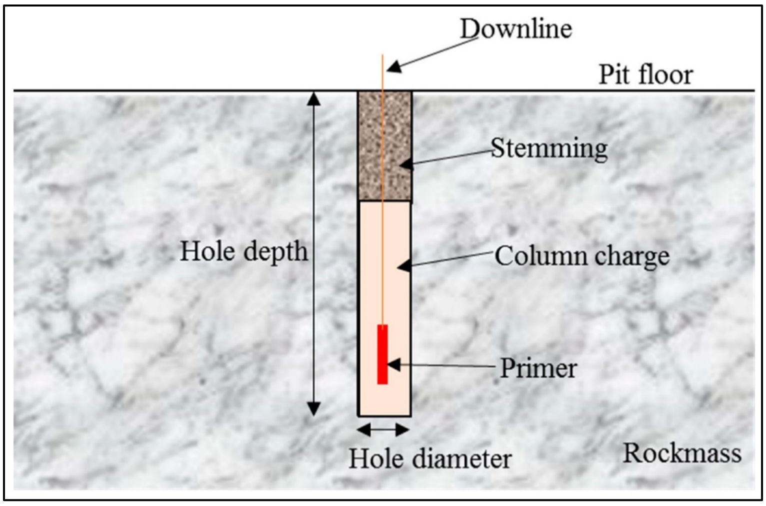

Figure 1. Blast hole charging using the conventional blasting technique (Antwi, 2020).

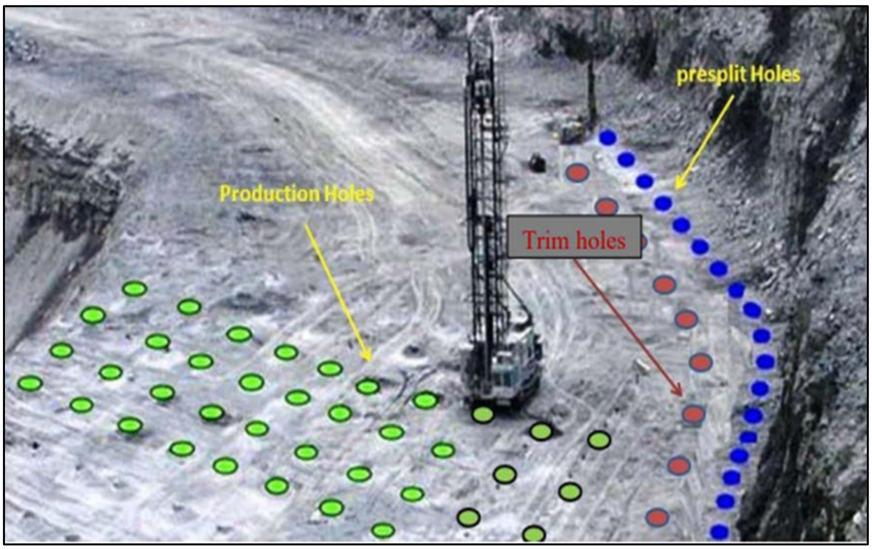

Figure 2. Applications of the conventional blasting at Damang Mine (Antwi, 2020).

1.2. Double Save Plugs Technique

At the Damang mine, the double saver plugs technique is employed where 2 saver plugs are placed at the bottom of the blasthole, thus reducing the charge column and eventually translating to a reduced amount of explosives. The saver plugs are used to create a bottom deck which result in reductions in flyrock, vibration, drilling costs, and the volume of explosives used. It creates a void at the bottom of the blast hole that when the hole is initiated, a pressure pulse will be directed into the void beneath the saver plugs followed by the high pressure gas front. The high pressure is sufficient to increase fragmentation. Despite the reduction in explosives consumption, fragmentation consequently improves as a result. This is because, the saver plugs are designed such that the blast energy is focused downwards upon detonation of explosives (Antwi, 2020). Hence, much energy is generated downwards to cause higher fragmentation. **Figure 3** shows the samples of saver plugs used at the Damang mine.

In order to ascertain the most efficient blasting technique, the Damang mine employed both the conventional blasting technique and the double saver plugs technique within the same pit over a period. Then during such period, a comparative analysis will be conducted to ascertain the best technique amongst the 2 techniques.

Figure 3. Samples of saver plugs used at the Damang Mine.

2. Materials and Methods Used

The methodological framework for this study comprised of 3 main stages: data collection, pit floor analysis and cost analysis. There were both primary and secondary data used for this study. Primary data consisted of the spatial coordinates of blast holes and post-blast pit floor surfaces acquired using the Trimble Real-Time Kinematic (RTK) Global Positioning System (GPS) receiver. Secondary data were obtained from the mine's drilling and blasting database and included blast design parameters, the number of drilled blast holes, explosive loading records, unit costs of explosives, and saver plug procurement costs. Surpac Version 2021 mining software was used for the pit floor modelling and analysis and Microsoft Excel for cost computations and statistical data processing. The purposive sampling technique was used in selecting the 3 blasts for the various techniques to ensure that the blasts are within the same pit with the same number of holes with the same elevations.

2.1. Study Area

Abosso Goldfields Limited (AGL), Damang mine is located in the South-Western part of Ghana about 300 km by road from Accra, the capital town of Ghana. The mine is positioned at Latitude 5˚11'N and Longitude 1˚57'W. The mine is located 30 km North of the town of Tarkwa. The Damang concession covers a total area of 23,666 ha.

The mine experiences a tropical climate with an average annual rainfall of 2030 mm. The area is characterised by two distinct rainy seasons from March to July and September to November. Temperatures are high throughout the year and range from 23˚C to 28˚C. Although there may be minor disruptions to operations during the wet season, there is no operating or long-term constraint on production due to climate (Mireku-Gyimah & Gyebuni, 2019). The vegetation in the area is a mixture of tropical rain forest and semi-deciduous forest. Due to subsidence farming by the local population, the area has undergone massive deforestation and has altered the vegetation in the environments of the mine to secondary forest, shrub and cleared land. For this reason, there is no primary forest on the concession. The principal crops which cause this alteration include cocoa, yam, coffee, plantain, etc. (Antwi, 2020).

The mineral orebodies of Damang are found within the Tarkwaian sediments, which constitute a significant part of the stratigraphy of the Ashanti belt in southwest Ghana. The Ashanti belt is a structure broadly synclinal that strikes to the north-east, consisting of sediments of the lower Proterozoic and underlying volcanics and metavolcanics and metasediments of the Birimian system. The Tarkwaian unconformably overlies the Birimian and is characterised by lower intensity metamorphism and the predominance of coarse-grained, immature sedimentary units (Antwi, 2020). The Damang Gold Mine exploits both the oxide and the fresh hydrothermal mineralisation beyond all paleoplacer mineralisation. The hydrothermal mineralisation is found in the Tarkwaian sediments and is the only deposit of its kind located on the eastern side of the Ashanti belt in the south-west of Ghana (Antwi, 2020).

The Damang mine employs the Open pit mining method for mining both the oxide and hard rock materials. The mining cycle involves drilling, blasting, loading and hauling. The mine employs the conventional shovel-truck system in the load and haul operations. The mining schedule is set up to blast 9 m and 6 m benches and excavate in 3 m flitches. Contractor equipment availability, drilling and blasting procedures, and spatial compliance to design and adhere to geotechnical standards are all important considerations in the mine. Road construction and maintenance, bench preparation, dust suppression, and erosion control are all supported by ancillary equipment such as bulldozers, graders, water trucks, service vehicles, and wheel loaders. Damang has a progressive reclamation strategy in which inactive regions are selected for rehabilitation by contouring and topsoil placement, seeding, planting, and fertilizing (Anon, 2018).

2.2. Data Collection

The data collection period for this study spans from May, 2022 to November, 2022 at Abosso Goldfields Limited. Both primary and secondary data were obtained in the study. Primary data consisted of the spatial coordinates of blast holes and post-blast pit floor surfaces acquired using the Trimble R10 RTK GPS. Secondary data were obtained from the mine's Drilling and Blasting database and included blast design parameters (burden, spacing, bench height, hole depth, stemming length, and explosive column length), the number of drilled blast holes, explosive loading records, unit costs of explosives, and saver plug procurement costs. During the data collection stage, the number of drilled blast holes and their associated geometric design parameters were compiled for each blast event. The surveyed blast-hole data were used to determine the total number of holes per blast, which formed the basis for estimating explosive consumption and overall blasting costs. Table 1 shows the blast geometric parameters used for the conventional blasting technique and the double saver plugs technique at the Huni pit cutback. Table 2 shows the explosives parameters used for the conventional blasting technique and the double saver plugs technique at the Huni pit cutback.

Table 1. Blast geometric parameters used at Huni pit cutback.

Parameters	Unit	Conventional Blasting Technique	Double Saver Plugs Technique
Hole Depth	m	10	10
Hole Diameter	mm	115	115
Burden	m	3.8	3.8
Spacing	m	3.8	3.8
Bench Height	m	9	9
Sub-drill	m	1	1
Stemming Height	m	3.0	3.0
Specific Gravity of Rock		2.78	2.78
Drill Pattern		Staggered	Staggered
Unit Cost of Saver Plug	$	N/A	4
Unit Cost of S110 Explosives	$	1.6	1.6

Table 2. Explosive parameters used at Huni pit cutback.

Charging Parameters	Units	Conventional Blasting Technique	Double Saver Plugs Technique
Explosive Density	g/cc	1.15	1.15
Explosive Column	m	7	5.5
Powder Factor	kg/m^3	0.61	0.47
Length of Double Saver Plug	m	N/A	1.5 (0.75 each)
Composition of Explosives		S110	S110

2.3. Data Analysis

The study conducted 2 forms of analysis, that is the pit floor analysis and the cost analysis. Cost analysis was performed using Microsoft Excel by comparing the total blasting costs of the conventional and double saver plug blasting methods, considering explosive consumption and saver plug costs.

The pit floor analysis was conducted using Surpac Version 2021 by generating 3-dimensional surface models from the RTK GPS survey data and comparing the resulting post-blast pit floor profiles to evaluate floor evenness and blasting performance under the two blasting techniques. Survey pick-ups were done at the blast areas after mining. The survey data was then processed using the Digital Terrain Model (DTM) created using Geovia Surpac 2021 software and saved. After that, contours of 0.1 m intervals were created, and the results reclassified based on the pit floor analysis requirements. At the Damang mine, the requirement for pit floor analysis was in the range of ±0.3 m. After the modelling was done to obtain the high, good and low pit floors, the Microsoft excel was used employed in the rating of the floors. A total of 3-blasts within the Huni pit were used for the pit floor analysis for both the conventional blasting technique and the double saver plugs technique. The floor analysis was done for all the 3 blasts in each case because all the blasts were within the same reduced level in each case.

The procedure for pit floor analysis using the Surpac software was:

1) Create boundary of the blast from the survey data (as-built or as-mined);

2) Use the boundary string to cut the area of interest from the survey data and save both the boundary and the floor area file separately;

3) Create Digital Terrain Model (DTM) using the floor file and save;

4) Use the saved Digital Terrain Model (DTM) file to create contours of 0.1 m interval and save;

5) Use 'file tools' on the Surpac toolbars to classify the contour file by string numbers;

6) After the classification, digitize the respective boundaries of the strings showing high, good and low areas;

7) Use the segment properties to determine the areas of the respective boundaries; and

8) Finally, use the Microsoft excel to do the rating of the floors.

3. Results and Discussions

3.1. Pit Floor Analysis for Conventional Method

Results for the conventional blasting technique for the 3 blasts were combined because all the shots were adjoining shots and were on the same reduced level. Thus the floor analysis was combined also since all the shots occurred on the same reduced level. There was a comparison of the resultant floor with the ±0.3 m standard floor ranges. The reduced floor for which the blast was taken was 900 m, indicating that the 3 m flitch taken will lead the reduced level to 903 m with the allowable ±0.3 m floor ranges. For the rating of the quality of the floor, reduced levels (z) beyond 903.3 m were classified as High (indicating higher exceedance from the standard). The reduced floor between the 903.3 m to 902.7 m were classified as Good (indicating a good blast falling with the planned ±0.3 m floor ranges). The reduced floor that was below 902.7 m was classified as Low (indicating below the planned ±0.3 m floor ranges). Results for the conventional blasting technique indicated that out of the 1256.6 m^2 total area blasted, 65.2 m^2 representing 5% of the pit floor was within the High range, 1191.4 m^2 representing 95% of the pit floor was Good and none of the pit floor was below the required range of ±0.3 m. Figure 4 shows the results for the floor analysis. Table 3 shows the results for the pit floor analysis for the conventional blasting technique at Huni pit cutback.

Table 3. Pit floor analysis for conventional method at Huni pit cutback.

912_903_Blast (Conventional Method) Pit Floor Analysis			
Range	Floor Area (m^2)	Percentage (%)	Rating
Z > 903.3	65.2	5%	High
902.7 ≤ Z ≤ 903.3	1191.4	95%	Good
Z < 902.7	0.0	0%	Low
Total	1256.6	100%	

Note: Where Z represents the reduced level.

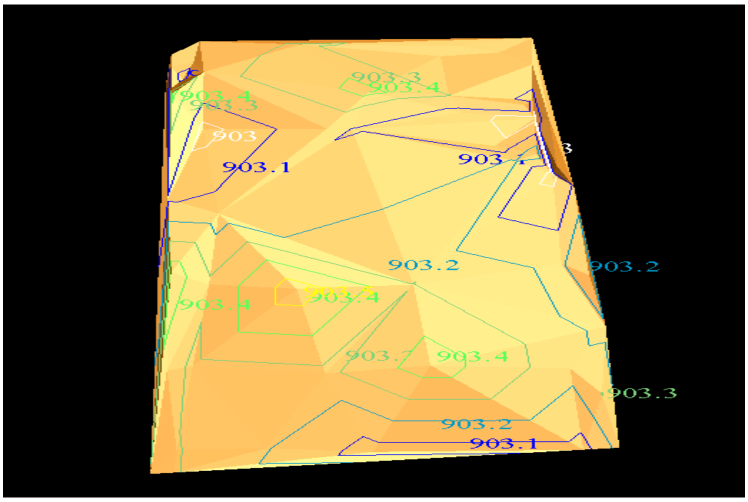

Figure 4. Digital terrain model and contour for conventional blasting technique.

3.2. Pit Floor Analysis for the Double Saver Plug Technique

Results for the double saver plugs blasting technique for the 3 blasts were combined because all the shots were adjoining shots and were on the same reduced level. Thus the floor analysis was combined also since all the shots occurred on the same reduced level. There was a comparison of the resultant floor with the ±0.3 m standard floor ranges. Results for the double saver plugs blasting technique indicated that out of the 1252.7 m^2 total area blasted, 29.9 m^2 representing 2% of the pit floor was within the High range, 1222.8 m² representing 98% of the pit floor was Good and none of the pit floor was below the required range of ±0.3 m. Figure 5 shows the results for the floor analysis. Table 4 shows the results for the pit floor analysis for the double saver plugs blasting technique at Huni pit cutback.

Table 4. Pit floor analysis for double saver plug technique at Huni pit cutback.

912_903_Blast (Double Saver Plug Method) Pit Floor Analysis			
Range	Floor Area (m²)	Percentage (%)	Rating
Z > 903.3	29.9	2%	High
902.7 ≤ Z ≤ 903.3	1222.8	98%	Good
Z < 902.7	0.0	0%	Low
Total	1252.7		

Note: Where Z represents the reduced level.

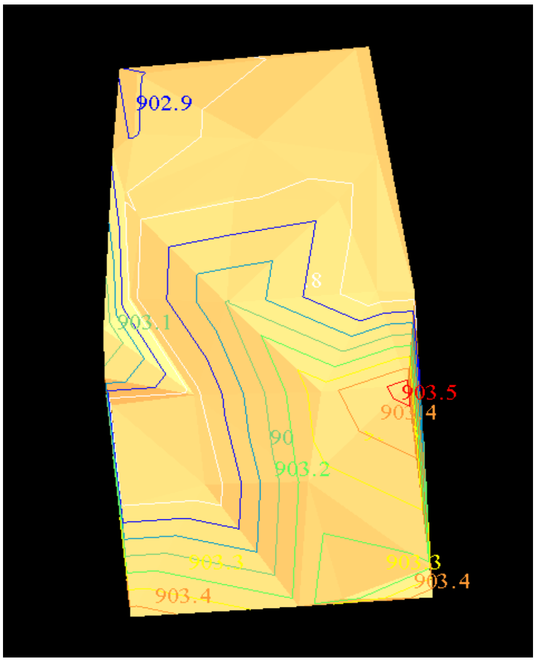

Figure 5. Digital terrain model and contour for double saver plug technique.

3.3. Comparative Analysis of the Pit Floor of the Conventional Blasting Technique and the Saver Plugs Technique

Results for the pit floor analysis for the conventional blasting technique and the double saver plugs technique indicated that the double saver plugs technique outperformed the conventional blasting technique. Whereas about 98% of the floor using the double saver plugs technique was Good, 95% of the floor using the conventional blasting technique was Good. The floor that was High beyond the 903.3 elevation was about 2% in the case of the double saver plugs technique whereas that of the conventional blasting technique was 5%. In all, none of the techniques gave resulted in a Low outcome, that is elevations below 902.7 m. Therefore, it can be seen that both techniques resulted in good floor conditions but the double saver plug technique gives a better floor condition than the conventional blasting technique.

3.4. Cost Analysis of Conventional and Double Saver Plug Blasting Method

The cost analysis was aimed at evaluating the cost of each blast based on the techniques and also to evaluate the cost-effective technique amongst the 2 techniques. The analysis was done on 3 sets of blast each for the conventional and saver plug blasting techniques having the same number of holes. The parameters used for the blasts have been outlined below:

1) Blast Pattern = 3.8 m × 3.8 m;
2) Density of Explosives = 1.15 g/cc (or 1150 kg/m^3);
3) Explosive Column (conventional method) = 7 m;
4) Explosive Column (double saver plug ie. two saver plugs in a hole) = 5.5 m;
5) Depth of hole = 9 m + 1 m (subdrill);
6) Diameter of hole = 115 mm or 0.115 m;
7) Stemming Height = 3 m;
8) Total length of saver plug = 1.5 m (0.75 m each);
9) Unit Cost of Saver Plug = **$** 4.00;
10) Density (explosive) = mass (explosive) / volume (explosive);
11) Determining volume of explosive per 1 m drill hole depth;
12) Volume (Explosive) = $\pi r^2 h$, since drill hole is cylindrical in shape;
13) Volume (Explosive) = $\pi (0.115/2)^2 \times 1 = 0.01038689071$ m^3;
14) Therefore, the volume of explosives per 1 m drill hole depth of 115 mm (0.115 m) hole diameter is 0.01038689071 m^3;
15) Determining mass of explosives;
16) Mass (Explosives) = Density (Explosives) × Volume (Explosives);
17) Mass (Explosives) = 1150 kg/m^3 × 0.01038689071 m^3 = 11.9449 kg; and
18) Mass of explosives per 1 m drill hole depth is 11.9449 kg.

3.5. Cost Analysis for the Conventional Blasting Technique

The conventional blasting technique was used for 3 blasts at different dates having the blast numbers as Shot 912_903 m RL number 7, Shot 912_903 m RL number 18 and Shot 912_903 m RL number 33 respectively. Since the entire hole length is loaded with explosives in the case of the conventional blasting technique, the charge length for each hole was 7 m. The quantity of explosive is determined by multiplying the number of holes by the charge length and the mass of explosives per 1 m length of hole depth. Table 5 shows the cost analysis for the 3 blasts for the conventional blasting technique.

3.6. Cost Analysis for the Double Saver Plugs Blasting Technique

In order to ascertain the cost analysis for the double saver plugs technique, a total of 3 blasts at different dates having the blast numbers as Shot 912_903 m RL numbers 42 and 50, Shot 912_903 m RL number 49 and 50b and Shot 912_903 m RL number 51 respectively were used. In the double saver plugs technique, 2 saver plugs of length 0.75 m each are placed at the bottom of the holes. Thus the length of the hole to be charged will be reduced by 1.5 m, thereby making the charge length 5.5 m. The quantity of explosive is determined by multiplying the number of holes by the charge length and the mass of explosives per 1 m length of hole depth. Table 6 shows the cost analysis for the 3 blasts for the double saver plugs blasting technique.

3.7. Comparative Cost Analysis Conventional Technique and Double Saver Plugs Technique

Table 5. Cost analysis for the 3 blasts for the conventional blasting technique.

Date of Blast	Blast Number	Number of Holes	Charge Length (m)	Mass of Explosives (in kg per 1 m Hole Depth)	Explosives Quantity in kg (Number of holes × Charge length × Mass of Explosives)	Unit Cost of S110 Explosives (in $ per 1 kg)	Total Cost of Explosives ($)
30th May, 2022	Shot 912_903 m RL number 7	114	7	11.9449	9532.03	1.6	15,251.25
18th June, 2022	Shot 912_903 m RL number 18	130	7	11.9449	10,869.86	1.6	17,391.77
23rd August, 2022	Shot 912_903 m RL number 33	90	7	11.9449	7525.29	1.6	12,040.46
Total Costs		**334**					**44,683.48**

Table 6. Cost analysis for the 3 blasts for the double saver plugs blasting technique.

Date of Blast	Blast Number	Number of Holes	Charge Length (m)	Mass of Explosives (in kg per 1 m Hole Depth)	Explosives Quantity in kg (Number of holes × Charge length × Mass of Explosives)	Unit Cost of S110 Explosives (in $ per 1 kg)	Total Cost of Explosives ($)	Cost of Saver Plugs ($4 per plug)	Overall Cost of Blast ($)
20th October, 2022	Shot 912_903 m RL number 42 and 50	114	5.5	11.9449	7489.45	1.6	11,983.12	912	12,895.12
22nd October, 2022	Shot 912_903 m RL number 49 and 50b	130	5.5	11.9449	8540.60	1.6	13,664.97	1040	14,704.97
23rd October, 2022	Shot 912_903 m RL number 51	90	5.5	11.9449	5912.73	1.6	9460.36	720	10,180.36
Total Costs		**334**					**35,108.45**	**2672.00**	**37,780.45**

From Tables 5-7, it was observed that the cost for the respective blasts for the conventional blasting technique was higher than that of the double saver plugs technique. This is because of the reduced explosive columns in the double saver plugs technique. In total, the cost of the 3 blasts for the conventional blasting technique was $44,683.48 for the 334 number of holes whereas the total cost for the 3 blasts for the double saver plugs technique was $37,780.45 for the same number of holes. This shows an amount of $6903.03 difference in the 2 blasting techniques. Table 7 and Figure 6 show the comparative coat analysis for the 2 techniques for the 3 different set of blasts.

Table 7. Comparative cost analysis for the conventional blasting technique and the double saver plugs technique.

Blast	Conventional Blasting Cost ($)	Double Saver Plug Blasting Cost ($)	Revenue Saved from Double Saver Plug Blasting ($)
Blast 1	15,251.248	12,895.124	2356.124
Blast 2	17,391.774	14,704.966	2686.808
Blast 3	12,040.459	10,180.361	1860.098
Total	**44,683.481**	**37,780.451**	**6903.030**

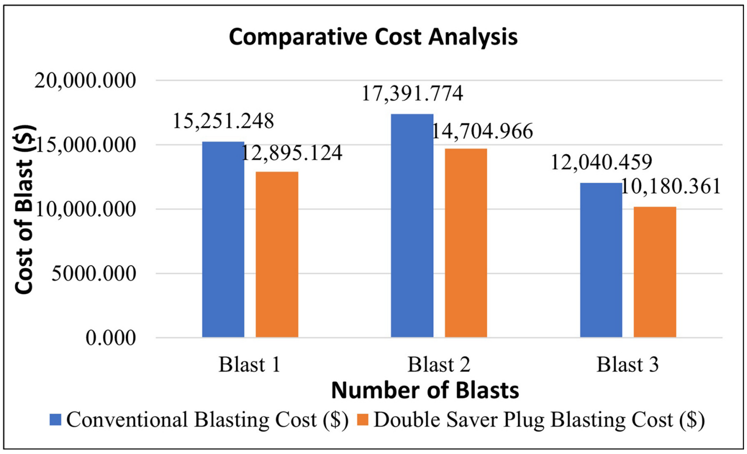

Figure 6. Comparative cost analysis for the conventional blasting technique and the double saver plugs technique.

It can therefore be deduced that the higher the number of holes blasted the greater the revenue generated by using the saver plug.

Also, Saver plug Assuming,

Average Number of holes = (114 + 130 + 90)/3 = 334/3 = 111.333 per day

The average number of holes blasted per day is 111.333 holes

Amount saved per hole using saver plug = total final amount saved from saver plug/ total number of holes blasted

Amount saved per hole using saver plug = (2356.124 + 2686.808 + 1860.098)/(114 + 130 + 90)

Amount saved per hole using saver plug = 6903.030/334 = 20.667

This implies,

Amount saved by using saver plugs per day = 111.333 × 20.667

Amount saved by using saver plugs per day = $2300.919 per day

If the mine saves $ 2300.919 per day by using saver plugs, then

For 7 days (1 week) assuming blasting occurs every day of the week

$2300.919 × 7 = $16,106.433 per week

For 4 weeks (1 month)

$16,106.433 × 4 = $ 64,425.732 per month

For 12 months (1 year)

$64,425.732 × 12 = $773,108.784 per year

This implies that the Damang mine likely save $ 773,108.784 a year using double saver plugs at a hole diameter of 115 mm based on the observed average number of holes blasted for this study. Table 8 shows assumptions on amount saved by using double saver plug.

Table 8. Assumptions on amount saved by using saver plug.

Assumptions	Amount Saved ($)
Average Holes per day	(114 + 130 + 90)/3 = 111.333 per day
Amount saved per hole	$6903.030/334 = 20.667
Amount saved per day	111.333 × 20.667 = 2300.919
Amount saved per week	2300.919 × 7 = 16,106.433
Amount saved per month	16,106.433 × 4 = 64,425.732
Amount saved per year	64,425.732 × 12 = 773,108.784

4. Conclusions

This study evaluated the performance of the conventional blasting technique and the double saver plugs technique at the Huni Pit Cutback of the Damang Mine using pit floor quality and blasting cost as the principal performance indicators. The results demonstrate that the double saver plugs technique provides a technically and economically superior alternative to the conventional blasting method.

The introduction of two saver plugs reduced the explosive column from 7.0 m to 5.5 m, resulting in a reduction in the powder factor from 0.61 to 0.47 kg/m^3 without compromising blast performance. Pit floor assessment showed that both techniques satisfied the mine's acceptable floor tolerance of ±0.3 m. However, the double saver plugs technique produced a higher proportion of acceptable pit floor, with 98% of the blasted area classified as good compared with 95% for the conventional method, indicating improved toe breakage and floor uniformity.

The economic analysis further demonstrated the advantages of the double saver plugs technique. For the three production blasts analysed, the total blasting cost decreased from US$44,683.481 for the conventional method to US$37,780.451 for the double saver plugs technique, representing a total saving of US$6903.030 or approximately US$20.667 per blast hole. Under similar operating conditions, these savings translate to an estimated daily saving of US$2300.919 and a projected annual saving of approximately US$773,108.784.

Overall, the study demonstrates that the double saver plugs technique is capable of simultaneously improving pit floor quality while significantly reducing explosive consumption and blasting costs. The findings further establish pit floor analysis as a practical performance indicator for evaluating blasting efficiency in addition to the conventional measures of fragmentation, vibration and flyrocks.

5. Recommendations

Based on the findings of this study, it is recommended that the Damang Mine continue the adoption of the double saver plugs technique for production blasting where geological and operational conditions are comparable to those investigated. Proper installation of saver plugs and strict adherence to blast design specifications should be maintained to ensure consistent blasting performance and realization of the anticipated cost savings.

The mine should incorporate routine pit floor analysis into its blast performance evaluation programme, as the results demonstrate that pit floor quality is an effective indicator of blasting efficiency and excavation performance. Integrating pit floor assessment with conventional blast performance indicators will provide a more comprehensive evaluation of blasting outcomes.

Future studies should investigate the influence of the double saver plugs technique on additional blast performance parameters, including rock fragmentation, diggability, equipment productivity, ground vibration, flyrock, air overpressure and downstream processing efficiency. Also subsequent studies should report on the rock types, groundwater conditions, bench geometry, and operating conditions to ensure that the performances are based on the type of blasting technique of the ground conditions as well to evaluate how it is affecting the results. It is also recommended that subsequent studies should also report on the blasted volumes and tonnages and the results per each blast instead of the combined results. Furthermore, research involving different rock mass conditions, bench heights, hole diameters and geological settings is recommended to establish the wider applicability and optimization of the technique across various surface mining operations.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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