Shahrood University of Technology

Journal of Mining and Environment (JME)

Journal homepage: www.jme.shahroodut.ac.ir

Iranian Society of Mining Engineering (IRSME)

Improving Open-Pit Mining Efficiency: Economic and Operational Benefits of the Power Deck Method-A Case Study

Hadi Fattahi*, Mohammad Amirabadi Farahani, and Hossein Ghaedi

Faculty of Earth Sciences Engineering, Arak University of Technology, Arak, Iran

Article Info

Received 17 August 2024

Received in Revised form 18 March 2025

Accepted 6 April 2025

Published online 6 April 2025

DOI: 10.22044/jme.2025.14952.2849

Keywords

Drilling and blasting optimization

Power Deck method

Open-pit mining

Specific charge reduction

Rock fragmentation

Abstract

This study introduces an innovative application of the Power Deck method to optimize drilling and blasting operations in open-pit mining, with a focus on the Nizar cement factory in Qom, Iran. Unlike traditional blasting techniques, this method strategically utilizes a controlled air gap at the end of each blast hole to enhance explosive energy distribution, thereby reducing excessive drilling and minimizing explosive consumption. Through five blast phases, optimal hole diameters (76 mm and 90 mm) were implemented while maintaining a standardized 1-meter air gap, eliminating the need for additional drilling tests. The findings demonstrate a significant improvement in blasting efficiency, leading to a 12.5% reduction in specific charge and a 9% decrease in specific drilling compared to conventional methods. Post-blast fragmentation analysis, validated using the F50 index from Split-Desktop software, confirmed particle sizes ranging from 10 to 32 cm, aligning with predictions from the Kaz-Ram, Kaznetsov, and Swedifo models. Furthermore, the adoption of the Power Deck method resulted in a 1,448-ton increase in processed material over two months, minimizing crusher downtime due to oversized fragments. This study provides a novel, cost-effective approach to improving rock fragmentation, reducing blasting-related inefficiencies, and enhancing the overall economic performance of open-pit mining operations.

1. Introduction

The utilization of traditional blasting methods is a common approach for large-scale production in underground and surface mining, such as in open-pit lime mines. Therefore, optimizing blasting patterns is a critical and practical strategy for cutting costs and increasing profitability in mining operations. Typically, the main objective of drilling and blasting in both surface and underground mining is to achieve proper rock fragmentation [1-3]. Indeed, employing drilling and blasting methods in surface mines serves as the initial step to crush rock and produce crushed rock for the primary feed input for processing plants. As such, rock crushing caused by blasting has a significant impact on the mine's overall economy. Effective blasting leads to improvements in rock drilling, loading, transportation after blasting, and post-extraction operations. A well-planned rock crushing stage provides materials with suitable granularity, benefiting the loading, transportation, and processing stages. Therefore, the precise design of the drilling and blasting pattern and accurate forecasting of the rock crushing rate to optimize the mine-to-processing-plant relationship can be seen as the initial step in optimizing production operations. Designing an optimal drilling and blasting pattern not only minimizes drilling and blasting costs but also increases the efficiency of later production stages and enhances safety from blasting, thus raising the value and production of minerals. Developing a systematic method to optimize drilling and blasting processes to achieve ideal crushing, simplify transportation, and provide appropriate dimensions for rock crushers is of utmost importance and should be

Corresponding author: h.fattahi@arakut.ac.ir (H. Fattahi)

implemented in practice. Research has shown that optimal blasting patterns, in addition to the aforementioned benefits, have a considerable impact on ground shaking, air blasts, rock throw, and excessive failure [4-10]. Studies suggest that only 20-40% of the blast energy is used to crush and move rock mass [11], while the rest manifests as destructive phenomena such as blast vibration, backbreak, air blasts, fly rock, noise, and more [12].

To achieve these goals, it is important to identify factors affecting drilling and blasting. In order to conduct a successful explosion, one must first identify the factors influencing drilling and blasting operations and then design an optimal blast pattern based on these factors. Most surface mines face the aforementioned challenges with explosions, and over 80% of the energy from explosions is wasted on undesirable phenomena. To address such issues, it is essential to take steps that can prevent many unwanted incidents [13-16].

Minimizing undesirable crushing, which is primarily the main goal of blasting operations, is necessary. Additionally, production blasting costs should be managed to ensure the feasibility of drilling and blasting operations. In all projects, controllable parameters such as burden, spacing, bench height, stemming, hole diameter, hole number, amount of explosives, specific gravity, specific charge, and specific drilling are optimized to achieve the goals outlined above.

Given the high sensitivity and importance of managing explosions in surface mines, a method called the Power deck has been developed and tested to reduce overbreak, lessen seismic events caused by explosions, optimize crushing at the bottom of benches, and decrease specific charge costs. The basis of this method lies in the air gap at the end of the hole and the predetermined stemming that exists between the air and the explosive material at the bottom of the hole. This method generates pressure equal to 2 to 7 times the pressure exerted by normal charges on the base of benches, preventing the formation of toes. The primary benefit of applying the Power deck method is the reduction in drilling requirements and explosives consumption [17].

According to Chiappetta's research, using a tool called Super Plug at the end of the hole allows for the creation of an air column (as shown in Figure 1). This tool, widely used in the United States, enhances rock fragmentation by improving energy distribution, reduces ground vibrations, and lowers explosive consumption compared to conventional methods [18].

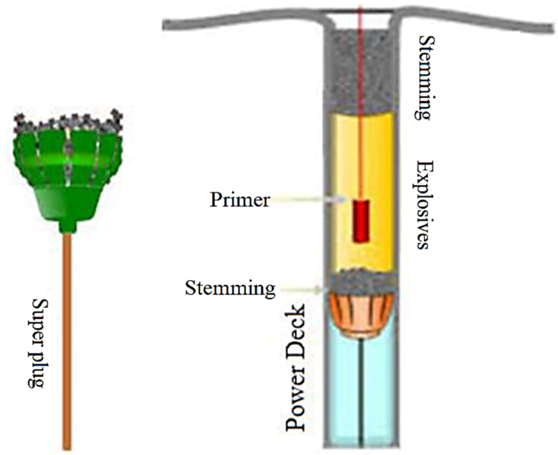


Figure 1. Using the Power Deck method to charge the hole [18]

2. Literature Review

Research on the application of new and innovative methods such as Airdeck and Power deck has been conducted to reduce undesirable phenomena and improve drilling and blasting patterns. For instance, Tannant, Peterson [19] applied the Power deck method for blasting in the Ekati diamond mine. Their study showed that utilizing an air gap at the bottom of shock-resistant holes led to controlled blasting and significant reductions in blasting costs. Correa [20] implemented the Power deck method to reduce over-drilling in the Escondida porphyry copper mine in Chile. His research resulted in a 10% decrease in additional drilling, reduced explosives consumption, and economic savings.

Floyd [21] studied the optimization of the Power deck method in a Northern Nevada gold mine. His findings revealed reductions in charge length by 2.6 meters, extra drilling by 1.2 meters, and overall costs compared to traditional methods. Chiapetta, Wyciskalla [22] closely examined the results of explosions using the Power deck method. They employed tools such as cameras, conventional and laser mapping systems, and image analysis software to assess the amount and quality of mineral crushing. Their study found that using the Power deck method decreases P20 and P80 by 21-24%, and vibration intensity by 32%. They also observed minimal changes in bench floors when using the Power deck method.

Moser, Vargek [23] utilized the air gap method at the bottom of holes in 20 surface mine explosions in Austria. Instead of using horizontal and inclined holes, they applied the Airdeck method to eliminate toe issues and minimize additional drilling. Consequently, over-drilling was significantly reduced. Sazid, Singh [24] outlined the use of Airdeck and Power deck techniques. Through numerical modeling, they emphasized the benefits of these methods and demonstrated a reduction in undesirable destructive phenomena.

Kabwe [25] concluded that employing a Power deck for rock mass blasting does not adversely affect rock fragmentation size or displacement compared to conventional methods, and it can cut overall blasting costs. Saharan, Sazid, Singh [26] utilized the Airdeck method as part of stemming placement, reducing rock throw from explosions while maintaining optimal crushing. Zhang, Wang, Yu [27] employed deck charging in an open-pit mine to mitigate blast-related complaints from nearby residents. They stated that using this approach is financially viable.

Amiri [28] investigated the geometric effect of hole design on the air gap in the Chah Gaz iron mine in Iran. His study found that the presence of air gaps leads to better crushing and cost reductions in mine blasting operations. Zarei, Shahabi, Hadei, Louei [29] applied the Power deck method for surface lead and zinc mine blasting in Angoran. The results showed improved rock fragmentation and uniformity, reduced bench throw and toes, minimized fly rocks, and enhanced rock pile displacement. The Power deck method significantly reduced explosion costs compared to traditional methods.

Yin, Wang, Wang, Dang, Li [30] discovered that placing the air deck in the middle of a blast hole improved efficiency and increased the time for breaking rock by balancing gas pressure along the hole. Bakhshandeh Amnieh, Aref Mand, Porghasemi Saghand [31] assessed backbreak control and improvements in technical and economic parameters of Mishadwan iron ore mine using the Power deck method. They observed reductions in backbreak by 16.4% and 55% in iron ore mass and rock tailings, respectively. Furthermore, there were reductions of 28.5% in specific charge and 9% in specific drilling compared to conventional methods. Zuo, Yang, Gong, Ma, Wang [32] studied the blast-induced fracture characteristics of iron ore samples using a deck charging approach. They concluded that selecting an optimal range for the decoupling coefficient is necessary to avoid excessive fragmentation and the formation of undesirable transgranular fractures at crack surfaces. Large decoupling coefficients contribute to the latter, while small coefficients lead to the former. Roy, Sawmliana, Singh [33] noted that air-decking extends the effective charge length while maintaining a consistent total amount of explosives. This is accomplished by creating air spaces between explosive charges using prefabricated wooden spacers or specially designed gas bags. Therefore, utilizing Power deck techniques can substantially improve blasting efficiency and reduce costs by minimizing sub-drilling and specific charges. Rezaei, Monjezi, Matinpoor, Bolbanabad, Habibi [34] conducted a study integrating classification and regression tree analysis (CART) with principal component analysis (PCA) to simulate and predict fly rock occurrences during blasting operations at the Sangan iron ore mine. Through CART modeling, 21 essential guidelines for blast pattern design were proposed. Additionally, sensitivity analysis was performed to assess the influence of input variables on fly rock prediction, revealing that the specific load (P) had the highest impact, while distance (S) had the lowest. The study's findings contributed to a significant reduction in both vertical and horizontal fly rock incidents at the Sangan iron ore mine. Rad, Hasanipanah, Rezaei, Eghlim [35] examined the application of least squares support vector machines (LS-SVM) and support vector regression (SVR) in estimating fly rock generated by explosions at the Gole Gohar iron mine in Iran. The results indicated that LS-SVM outperformed SVR in terms of accuracy. Furthermore, sensitivity analysis demonstrated that the powder coefficient and rock density were the most influential parameters affecting fly rock in this case study. Monjezi, Rezaei, Yazdian [36] employed predictive models based on fuzzy set theory and multivariate regression to forecast fracturing at the Gol Gohar iron mine in Iran. The findings revealed that the fuzzy model significantly outperformed the regression model. Sensitivity analysis of the fuzzy model indicated that stem length, hole depth, load, and hole spacing were the most critical factors influencing the backswing phenomenon. The implementation of this model in the Gol Gohar iron mine notably reduced backswing and enhanced blasting efficiency.

Despite numerous studies on Power Deck and Airdecking, a comprehensive investigation into the impact of their placement on rock fragmentation and blasting performance remains lacking. Therefore, it is essential to evaluate the feasibility of utilizing Power Deck in blasting operations to determine its optimal positioning within a blast hole, minimizing blasting disturbances and improving fragmentation. Moreover, a review of existing research suggests that a predictive and optimization model for blasting in cement mines has not yet been developed.

A detailed review of prior research highlights the necessity of an optimization model for blasting in cement rock mines utilizing the Power Deck method. Such an optimization model aims to mitigate issues such as fly rock, blasting costs, rock fragmentation, rock throwing, and ground vibrations. Consequently, the present study focuses on predicting fragmentation resulting from Power Deck blasting, optimizing specific costs and drilling parameters, and assessing blasting operation expenses. Additionally, it evaluates rock fragmentation prediction models before and after blasting and compares rock crusher tonnage over two consecutive months to analyze the impact of the Power Deck method on rock crushing at the Nizar Limestone site in Qom, Iran.

3. Summary of Methods and Models Used in This Research

3.1. Power Deck Method

One of the main challenges in mining is controlling production costs. In recent years, major mining companies have continuously sought to minimize their production costs by optimizing their operations and adopting new technologies. Blast drilling operations are among the primary and critical stages in the mining and extraction process, accounting for approximately 40% of production costs. Therefore, proper implementation and optimization of drilling and blasting significantly impact extraction operations and subsequent mining stages, leading to substantial reductions in mining costs. In general, there has been a focus on downstream processes following explosions, with limited emphasis on the effects of blasting on overall mining operations. Blasting directly influences transportation costs, bench stability, and crushing operations. Given the potential for energy reduction in downstream processes through well-designed and managed blasts, the relationship between blasting and crushing operations is crucial. Optimized blasting can significantly improve tailings management, mill production, and the smoothness and stability of the mine wall. Maximizing the energy from explosions enables more efficient rock crushing. Additionally, the proper distribution of wave energy within the explosive block increases the number of microcracks formed in the rock, enhancing rock crushing operations.

Recently, the Power deck method has gained the attention of many mining companies for its ability to reduce drilling and explosive material requirements while optimizing the use of explosive energy. This method involves placing an air column at the end of the blast hole, resulting in reduced explosive costs, improved crushing, decreased backbreak, minimized air vibration, and better control of bench walls and the mine [37]. The design of drilling and blasting patterns in open-pit mines, as well as the charging of holes with explosives, significantly influences the performance of rock mass blasting operations. Generally, holes can be filled in two ways: full charging with stemming and partial filling with stemming and an air column. In the first approach, the hole is entirely filled with stemming at the end to seal it. This method transfers rock impact wave energy, causing numerous cracks around the hole and rock mass movement due to its intensity. However, this high-intensity explosion can lead to excessive rock crushing and waste of explosive material, known as energy loss.

In the second method, incorporating an air column reduces the intensity of the explosive energy and achieves a more controlled shredding effect. The significant aspect of this approach is that the changes in explosion energy intensity stem from the rapid influx of explosion gases, which compresses the air and transfers energy. Additionally, placing the air column at the bottom of the blast holes directs shock wave oscillations toward the blast hole, reflecting from the stemming and hole bottom to form microcracks in the designed block. Figure 2 illustrates the explosion formation mechanism using the Power deck method [20,38].

In the Power deck method, additional drilling is eliminated entirely, resulting in no excess drilling and aligning the step floor with the level of the hole floor. This method involves placing an air column, typically one meter high, at the bottom of the hole. The height of this air column is determined based on geological parameters, rock type, and the design of explosion patterns. Ultimately, the cost of explosive consumption and specific charge in the Power deck method are lower because it requires less explosive material compared to traditional methods [38].

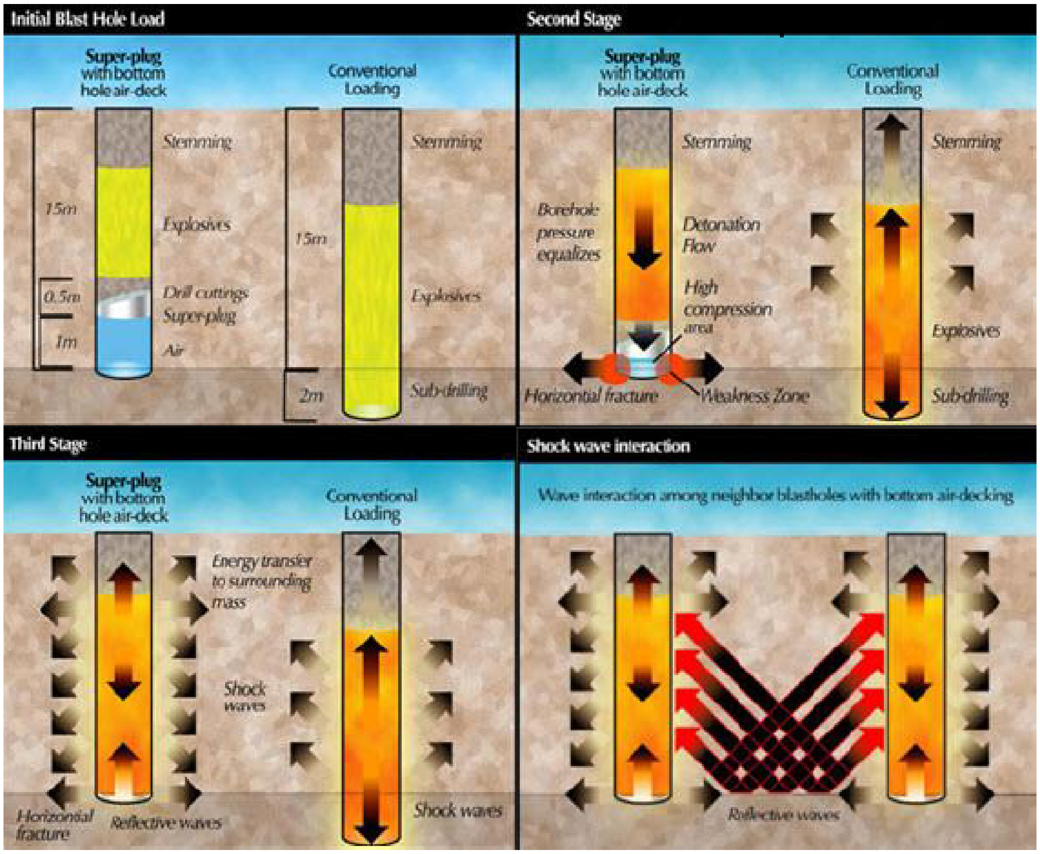


Figure 2. The explosion formation mechanism using the Power deck method [37]

3.2. Analyzing Rock Fragmentation Using Various Models

The size and dimensions of rock fragments produced in open-pit mines are influenced by the type and size of mining equipment, as well as loading and unloading processes during extraction and the crushers available in the mine. Consequently, assessing the level of fragmentation and the size of pieces resulting from blasting can aid in reducing costs and improving efficiency. This section explores methods for evaluating rock fragmentation.

3.2.1. Kaznetsov model

In 1973, Kaznetsov introduced an equation, referred to as Equation 1, to predict rock fragment sizes resulting from explosions. This equation employs TNT as the explosive and takes into account various parameters such as the type of explosive used, joint characteristics, rock type, and burden [39].

$$X^{-} = A \times \left[\frac{V}{Q_{TNT}} \right]^{0.8} \times Q_{TNT}^{0.167} \tag{1}$$

where X (cm) represents the average dimensions of crushed rock, A is the rock factor, Q (kg) weight of explosives inside the hole, and V denotes the mass volume of crushed rock. Table 1 displays the rock factors for various types of rocks according to the Kaznetsov model

Table 1. Factors for Different Types of Rocks [39]

State of the Rock Mass	Proto-Diakonov Coefficient	Rock Factor
Very Soft Rock	3-5	3
Soft Rock	5-8	5
Medium Rock	8-10	7
Hard and Jointed Rock	10-14	10
Hard and Homogeneous Rock	14-16	13

3.2.2. Kaz-Ram model

In 1983, Cunningham introduced a model designed to evaluate the dimensions of rocks resulting from blasting operations in mines. This model, which builds on the experimental equations related to the Kaznetsov model and the Rosin-Rammler distribution, is formulated to determine the average dimensions of rock fragments produced by blasting [40]. Consequently, it is referred to as the Kaz-Ram model, represented by Equation 2.

$$X^{-} = A \times \left[\frac{v}{Q}\right]^{0.8} \times Q^{0.167} \times \left(\frac{115}{E}\right)^{0.633} \qquad (2)$$

In this equation:

- X (cm) is the average dimension of fragments resulting from the explosion.
- A is the explosiveness index.
- V (cm^3) is the volume of broken rocks.
- E is the relative weight power of explosives, which is 100 for ANFO.
- Q (kg) is the amount of explosives required per hole.

Table 2 lists the rock factor for various rock masses according to this model.

Table 2. Rock Factors for Different Rock Masses [40]

State of the Rock Mass	Proto-Diakonov Coefficient	Rock Factor
Very Soft Rock	3-5	3
Soft Rock	5-8	5
Medium Rock	8-10	7
Hard and Jointed Rock	10-14	10
Hard and Homogeneous Rock	14-16	13

Following this, the researcher Rosin-Rammler introduced an exponential function to estimate the dimensions of the rock fragments resulting from blasting, as represented in Equation 3 [40].

$$R(X) = 1 - e^{-(\frac{x}{x_c})^n} \qquad (3)$$

where: R(X)% is the cumulative percentage of materials passing through the sieve of dimensions x, X (cm) is the size of the hole, x_c is the opening of the hole through which 63.9% of the fragments pass, and n (%) is an index that depends on various blasting parameters such as hole diameter, burden, and row distance between holes.

If the numerical value of *R(X)* is set to 0.5 in Equation 3, the following relation is obtained [40]:

$$x_c = \frac{X^{-}}{(0.693)^{\frac{1}{n}}} \qquad (4)$$

On the other hand, Cunningham also proposed the following relationship to calculate the index *n*:

$$n = \left(2.2 - 14\frac{B}{D}\right)\left(\sqrt{1 + \frac{\frac{S}{B}}{B}}\right)^{0.5} \times \left(1 - \frac{W}{B}\right) \times \left(0.1 + \frac{Abs(l_b - l_c)}{l}\right)^{0.1} \times \frac{l}{H} \times p \qquad (5)$$

In the above equation:

- D is the hole diameter (m)
- L is the total length of charging (m)
- L_c is the length of charging between the holes (m)
- L_b is the lower charging length (m)
- H is the stair height (m)
- W is the hole deviation (m)
- S is the distance of the hole in a row (m)
- B is the burden (m)
- P is the arrangement factor of the hole.

3.2.3. Modified Kaz-Ram Model

Recognizing the significant influence of rock mass parameters on material fragmentation after blasting, Cunningham modified his initial model and presented it in the form of the following equation [40].

$$X^{-} = 0.06BI \times \left[\frac{v}{Q}\right] \times Q^{0.167} \times \left(\frac{115}{E}\right)^{0.633} \quad (6)$$

In this equation:

- X (cm) is the average dimension of fragments resulting from the explosion
- A is the explosiveness index
- V (cm^3) is the volume of broken rocks
- Q (Kg) is the amount of explosives required in each hole
- E is the relative weight power of explosives, which is 100 for ANFO
- n is an index that depends on various blasting parameters such as hole diameter, burden, and row distance between holes

According to Equation 6, the Blasting Index (BI) is defined as an explosiveness index, introduced by Lilly in 1992, to evaluate the result of the explosion, as given in Equation 7:

$$BI=RMD+JP_s+JP_0+RDI+HF \quad (7)$$

In this equation:

- RMD is the Rock Mass Description index
- JP_s is the Joint Distance Factor
- JP_0 is the Joint Direction Factor
- RDI is the Rock Density Index
- HF is the Hardness Factor on the Mohs scale

Table 3 provides the values for the effective parameters used in calculating the BI.

Table 3. Effective parameter values in BI [40]

Geomechanical parameters	Score
Rock mass description index	RMD
Crispy and very crispy	10
Block rock	20
Mass rock	50
Distance two discontinuity surface	JP_s
Less than 0.1 m or closed	10
Between 0.1-1.0 meters or medium	20
Greater than 1 meter	50
Direction of discontinuity	JP_0
Horizontally	10
Discontinuity slopes outward	20
Discontinuity extension perpendicular to the free surface	30
slope of the discontinuity towards the interior of the domain	40
Specific Weight	25-50
Hardness factor	HF
Young modulus less than 50 GPa	1/3 Young modulus

3.2.4. The Swedenfo Model

Larson's equation 8 suggests that step height and hole blockage have no impact. However, in 1993, Ku and Rusten introduced the following equation [41], incorporating these parameters:

$$d_{50} = C_d \times \left[1 + 4.67 \times \left(\frac{T}{L}\right)^{2.5} \times e^{0.29 \ln B^2 \sqrt{\frac{S}{1.2s}} - 1.18 \ln\left(\frac{q}{c}\right)^{-0.82}}\right] \quad (8)$$

In this equation: C represents the rock constant, q (kg/m^3) signifies specific charge, B (m) denotes burden, T (m) stands for obstruction length, S (m) indicates hole row spacing, and C_d represents the explosion capability constant.

4. Case study

4.1. Location

According to Figure 3, the lime and marl mines of Nizar Cement Company are situated in Qom province, Iran, 46 km along the old Qom-Isfahan road. The area experiences a mild mountainous climate, with summer temperatures ranging from 35 to 50 degrees Celsius and winter temperatures dropping to -5 degrees Celsius. Annual rainfall is approximately 25 mm, occurring mostly as rain, with occasional snow in the mountain passes. Given these climatic conditions, mining activities can proceed year-round. The region's gentle topography provides ideal conditions for implementing the mining plan, and there is no significant vegetation that would impede mining operations.

Figure 3. Access routes to Nizar cement lime mines in Qom, Iran

4.2. Mining method

Given the substantial volume and shape of the mineral deposits, which are positioned on ground with varying slopes, the optimal extraction method for the Limestone and marl mines is an open stepped approach. The construction steps in this mine are approximately 10 meters high, based on regional topography, the experience from similar mines (Kurdistan cement and Kashan), and the machinery capacity. The benches in the open-pit mine have a face angle of 85°, meaning that the vertical walls of each step are inclined at 85 degrees relative to the horizontal plane.

The width of the Benches depends on the topography: gentler slopes allow for wider steps, while steeper slopes require a minimum width of 15 meters to accommodate machinery. The overall slope of the mines is set at 60° due to the strength of the Limestone and comparisons with similar mines. General information for the Nizar cement mine in Qom is presented in Table 4.

Table 4. General Information of Nizar Cement Mine in Qom, Iran

Title	Value
Specific weight of Limestone	2.68 Ton/M³
Width of the main and internal mine ways (ramps)	At least 14 m
Slope of the main and internal mine ways (ramps)	Maximum 10%
Extraction drop	0.05
Dilution	0
Production schedule	1,170,000 tons of Limestone per year
Production schedule (including 5% waste)	1,230,000 tons of Limestone per year

Extraction is performed in two stages. The first stage involves constructing ramps and stairs from the mine floor level (1330) to the highest level. During this stage, the lime required by the factory is sourced from the ramp and stair construction sites. In the second stage, after completing the ramps and stairs, extraction begins from the highest step and continues until the final boundary, gradually shaping the mine to its final form.

4.3. Drilling and Blasting Situation

Optimizing drilling and blasting methods is crucial in open pit mining. Given the variability of these parameters across different mines due to structural conditions and production requirements, designing a fixed, universally applicable pattern is challenging. However, it is possible to develop a model close to ideal conditions based on theoretical foundations and work factors. Tables 5 and 6 outline the drilling and blasting parameters for the Nizar Cement mines in Qom, Iran. The operations involve drilling holes with diameters of 76 mm and 90 mm. Each blast consists of 250 to 300 holes, and the mine produces 5,000 tons of material daily. The explosives used include Emulite and ANFO, applied with delayed detonators.

Table 5. Table 5. Drilling and Blasting Parameters (76 mm Hole Diameter)

Title	Value	Unit	Considerations
Hole diameter	3	inch	76 mm
Hole length (including additional drilling)	11	m	1m additional drilling
Drilling network dimensions	2.6 × 2.4	m	-
Distance between holes in each row	2.6	m	Spacing
Row distance	2.4	m	Burden
Initial expenditure as primer (Emulite)	2	Kg	-
Type of delayed electric detonator in each hole	2	N	1.2 or 1.1000 S
Stemming height	2	m	0.7 to 1.3 hole length

Table 6. Drilling and Blasting Parameters (90 mm Hole Diameter)

Title	Value	Unit	Considerations
Hole diameter	3.6	inch	90 mm
Hole length (including additional drilling)	11	m	1m additional drilling
Drilling network dimensions	3.1 × 2.8	m	-
Distance between holes in each row	3.1	m	Spacing
Row distance	2.8	m	Burden
Initial expenditure as primer (Emulite)	1	Kg	-
Type of delayed electric detonator in each hole	1	N	1.2 or 1.1000 S
Stemming height	2	m	0.7 to 1.3 hole length

5. Power Deck Method Design in Nizar Cement Mine, Qom, Iran

Based on the blasting activities conducted in the mine and the characteristics of the existing rock, the following design has been adopted for implementing the power deck method:

- Air gap free of explosive material at the end of the hole: 1 meter
- Stemming applied to a 15 cm cap

Table 7 outlines the explosion parameters using the power deck method in the Nizar Cement mine in Qom, Iran.

Table 7. Explosion Parameters Using Power Deck Method

Title	Value	Unit	Considerations
Hole diameter	3.6	inch	90 mm
Hole length	10	m	-
Air distance at the end of the hole	1	m	-
Drilling network dimensions	3 × 3	m	-
Distance between holes in each row	3	m	Spacing
Row distance	3	m	Burden
Type of delayed electric detonator in each hole	1	N	1.2 or 1.1000 S
Stemming height	2	m	0.7 to 1.3 hole length

For the power deck method implementation, the distance between the hole and the burden is set at 3 meters. Additionally, the optimal length of the hole for this method is 1 meter, and the stemming height is 2 meters. Consequently, 7 meters of the hole with a 90 mm diameter will be filled with explosive material.

6. Results of the Blasting Operations after Implementing the Power Deck Method

Figure 4 illustrates the five stages of blasting conducted in the Nizar mine in Qom, Iran using the power deck method.

The specifications of these explosions are detailed in Table 8. The air gap created by the plastic pipe at the end of each hole was 1 meter. The average charge length in each hole was 7 meters, with the blasting occurring at the 1420-step level.

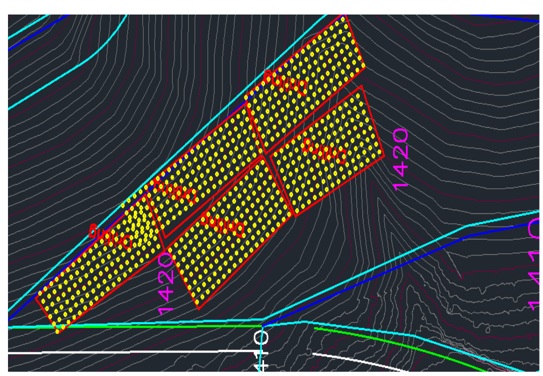


Figure 4. Five Stages of Blasting Using the Power Deck Method

Table 8. Blasting Specifications Using the Power Deck Method

Explosion Number	Burden (m)	Hole Diameter (mm)	Average Hole Depth (m)	Additional Drilling (m)	Stemming Height (m)	Charge Length (m)	Air Distance (m)
1	3 × 3	90	10	0	2	7	1
2	3 × 3	90	10	0	2	7	1
3	3 × 3	90	10	0	2	7	1
4	3 × 3	90	10	0	2	7	1
5	3 × 3	90	10	0	2	7	1

6.1. Evaluation of Post-Blast Stair Toe Formation after Implementing the Power Deck Method

Investigations into non-power deck method blasting revealed that an additional 1 meter of drilling was often added to prevent the creation of a toe after the explosion. However, with the power deck method, this additional drilling is either minimized or eliminated. This approach effectively prevents toe formation, assuming minimal human error and proper adherence to the air distance specifications. In the Nizar cement mine in Qom, Iran, it has been observed that maintaining the specified air gap results in no toe formation post-explosion. Figure 5 clearly shows the absence of any toe at the base of the stairs after the blasting using the power deck method.

Figure 5. Post-Blast Condition Using the Power Deck Method in Nizar Mine, Qom, Iran

6.2. Evaluation of Specific Charge after Implementing the Power Deck Method

Calculations were performed to determine the specific charge for both standard and power deck methods across five stages. Table 9 presents a comparison of the specific charge for both methods.

Table 9. Comparison of Specific Charge Results in Normal and Power Deck Blasting Methods

Explosion Number	Specific Charge with the Usual Method (Kg/ton)	Specific Charge with the Power Deck Method (Kg/ton)	Specific Charge Reduction Percentage
Step 1	0.231	0.202	0.125
Step 2	0.228	0.2	0.125
Step 3	0.233	0.204	0.125
Step 4	0.24	0.21	0.125
Step 5	0.239	0.209	0.125

6.3. Evaluation of Specific Drilling after Implementing the Power Deck Method

Given the high costs associated with each meter of drilling at the Qom Nizar cement mine, Table 10 presents a comparison of specific drilling metrics for both the conventional and power deck methods.

Table 10. Comparison of Specific Drilling Results in Normal and Power Deck Blasting Methods

Explosion Number	Specific drilling with conventional method (m/ton)	Specific drilling with power deck method (m/ton)	Specific drilling reduction percentage
Step 1	0.0558	0.0507	9
Step 2	0.0551	0.0501	9
Step 3	0.0563	0.0512	9
Step 4	0.0579	0.0526	9
Step 5	0.0577	0.0525	9

6.4. Evaluation of Hole Productivity after Implementing the Power Deck Method

Hole productivity is calculated as the volume of rock obtained from blasting relative to the depth of the hole:

$$\text{Hole productivity} = \frac{B \times H \times S}{\text{depth of hole}}$$

If the depth of the hole decreases, the productivity parameter of the hole will increase. Therefore, by reducing or eliminating over-drilling, hole productivity can be enhanced. Table 11 presents the results of hole productivity for blasting using both the power deck and conventional methods.

Table 11. Comparison of Hole Productivity Results in Normal and Power Deck Blasting Methods

Explosion Number	Efficiency of the hole with conventional method	Efficiency of the hole with power deck method	Increase in productivity
Step 1	9	8.1	0.09
Step 2	9	8.1	0.09
Step 3	9	8.1	0.09
Step 4	9	8.1	0.09
Step 5	9	8.1	0.09

6.5. Evaluation of Fragment Size Distribution after Implementing the Power Deck Method

The size of the fragments resulting from the explosion is a critical parameter in evaluating the effectiveness of the blast. If the fragment sizes are not optimal, loading operations in the mine can encounter issues. Additionally, the mine's rock crusher can only handle fragments up to a certain size. To assess the fragmentation caused by the power deck method, Split Desktop software [42] was utilized. Table 12 shows the size distribution of crushed rock particles after blasting using the power deck method.

The results indicate that the F80 (the particle size below which 80% of the material falls) obtained from numerical image analysis varies between 17 and 43 cm. The granulation diagram obtained is presented in Figure 6.

Table 12. Size of Crushed Rock Particles After Blasting

Index	Particle Size (cm)				
	Step 1	Step 2	Step 3	Step 4	Step 5
F_{10}	7.65	2.04	1.15	3.9	2.06
F_{20}	11.5	4.05	10.13	18.44	16.05
F_{30}	14.17	6.04	12.68	22.93	20.08
F_{40}	16.48	8.1	14.8	26.69	23.49
F_{50}	18.66	10.04	16.83	30.26	26.79
F_{60}	20.95	12.04	18.97	33.97	30.3
F_{70}	23.44	14.48	21.38	38.11	34.42
F_{80}	26.33	17.83	24.37	43.31	39.43
F_{90}	30.1	22.74	29.32	51.51	47.58

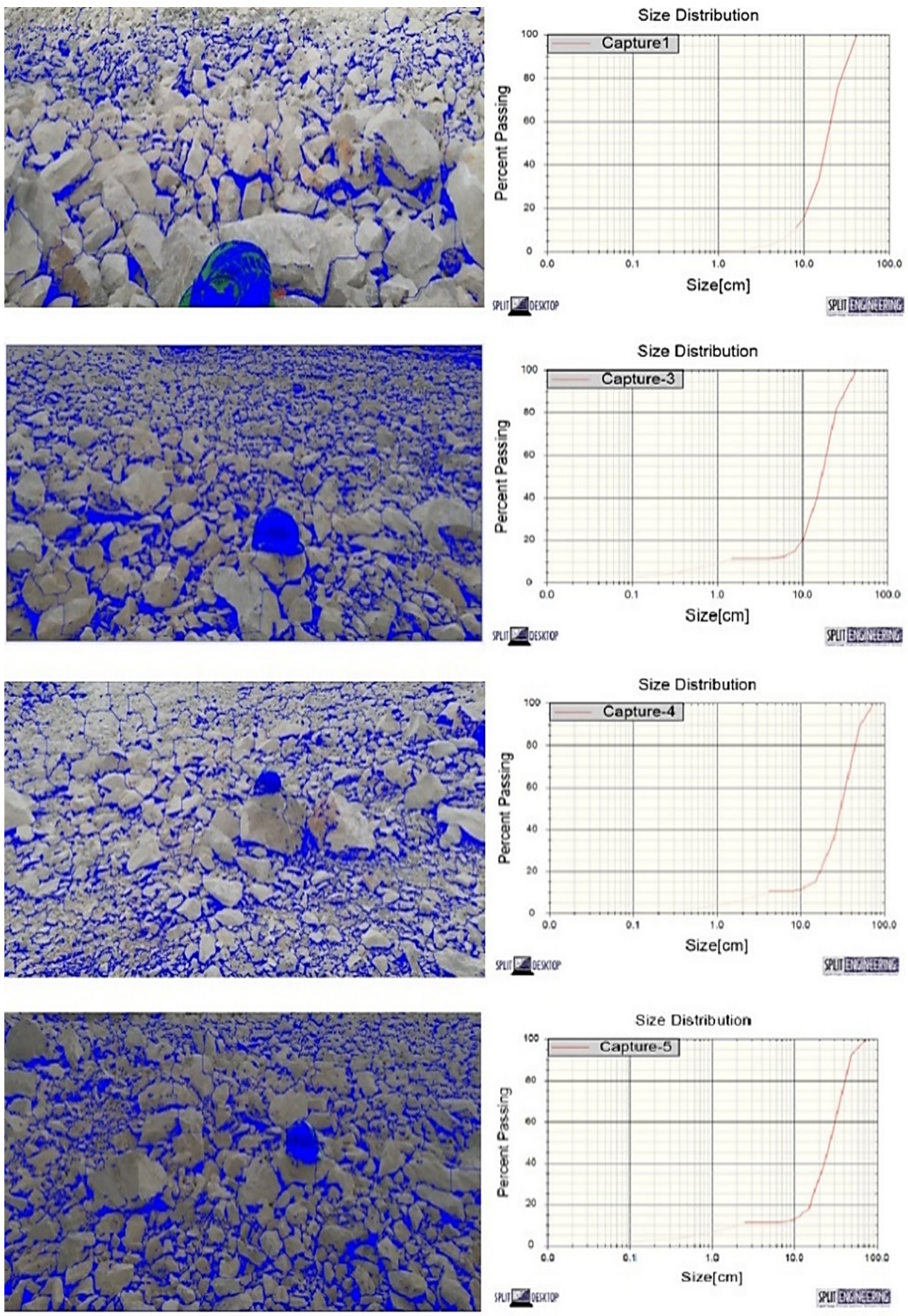


Figure 6. Example of Rock Crushing Analysis and Granulation Distribution After Blasting in Split Softwar

Using rock crushing forecasting models, the distribution of rock fragment sizes was further analyzed. The parameters for the Kaz-Ram modified, Kaznetsov, and Swedifo models are presented in Tables 13, 14, and 15, respectively.

Table 13. Parameters Used in the Modified Kaz-Ram Model

Parameter	Value
60	V
31.5	Q
100	E
146	BI

Table 14. Parameters Used in the Kaznetsov Model

Parameter	Value
V	60
A	10
Q	36.64

Table 15. Parameters Used in the Swedifo Model

Parameter	Value
C_b	0.55
T	2
L	10
S	3
B	9
Q	0.479
C	0.35

According to the results from the Split software, the particle sizes from the explosion ranged from 10 to 30 cm for the median value (50% passing). Additionally, the particle size predictions using the modified Kaznetsov, Swedifo, and Kaz-Ram methods were 27 cm, 29 cm, and 32 cm, respectively. The pre-explosion and post-explosion analyses provided similar predictions for the particle sizes resulting from the blasts.

6.6. Evaluation of Rock Crusher Performance after Implementing the Power Deck Method

The size of the rock fragments resulting from the explosion is critical; fragments larger than the crusher's opening can lead to increased costs due to the need for re-crushing. Additionally, oversized fragments can cause loading and transportation issues for mining equipment. At the Nizar mine in Qom, a hammer rock crusher is utilized to crush large rocks and process minerals. This crusher, specifically designed for rocks larger than 80 cm, is fixed and located at the top of the production line. The crushing process is executed by hammers rotating and striking the rocks against an anvil, resulting in particle collisions and further fragmentation. The crusher at the Nizar mine has a capacity of 800 tons per hour and processes incoming rocks larger than 80 cm to output fragments of 80 cm or less.

This rock crusher has two secondary and main hubs, handling approximately 6500 tons of rock per day. According to the size distribution charts from Split software, the load sizes sent to the rock crusher (d80) after the first, second, third, fourth, and fifth explosions were analyzed. Based on the dimensions of the crusher's output and the sizes of the fragments post-explosion, it can be concluded that the power deck drilling and blasting pattern used at the Nizar mine in Qom is effective. This method has reduced potential costs related to rock crushing, explosives, and drilling. Figure 8 shows a view of the rock crusher used in Qom Nizar mine.

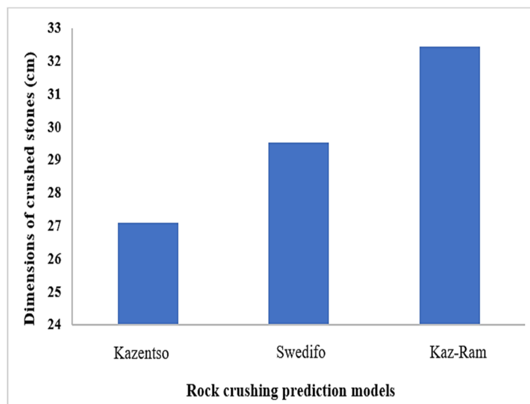
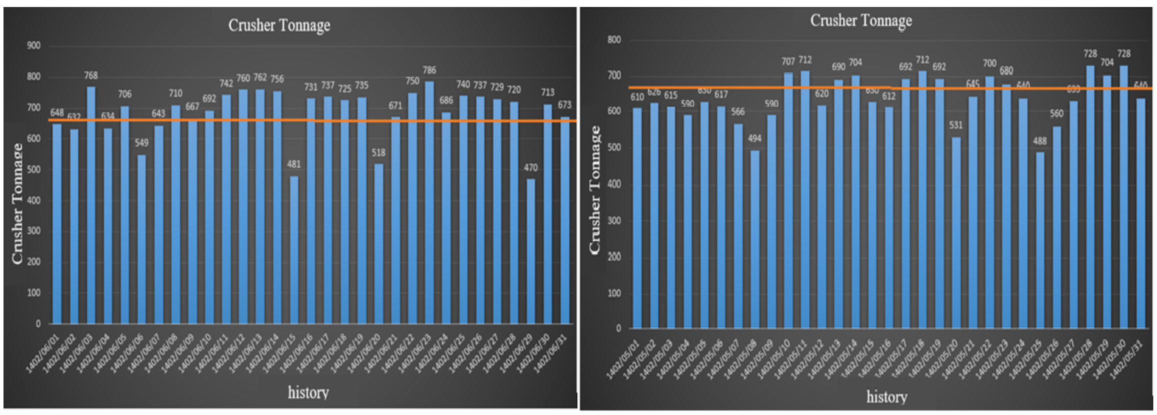


Fig 7. Examination of Rock Crushing Prediction Models

Figure 9 shows the crushing of rock by a hammer crusher during a month using conventional blasting and power deck methods.

In the Qom Nizar mine, the maximum daily crushing capacity is 680 tons. A comparison of the two graphs in Figure 9 indicates that in September, the use of the power deck method resulted in an increase in crusher throughput by 1448 tons compared to the previous month. By employing the power deck method, the mine has optimized its blasting efficiency, resulting in better fragmentation that aligns with the crusher's capacity. This improvement has led to significant cost savings and enhanced operational efficiency. The power deck method has demonstrated its effectiveness in reducing the need for secondary crushing, minimizing the handling and transportation challenges, and ultimately improving the overall productivity of the mining operation.

Figure 8. A View of the Rock Crusher Used in Qom Nizar Mine, Iran



(a) (b)

Figure 9. The Tonnage of Rock Crusher in a Month According to Explosions Carried Out With: a) Powerdeck method, b) without Powerdeck method

6.7. Evaluation of Economic Efficiency after Implementing the Power Deck Method

As demonstrated in previous sections, the use of the power deck method reduces the amount of explosive charge required in each hole. If the cost savings from reducing the charge are coupled with a decrease in drilling expenses, this method proves to be economically advantageous. The cost of Anfo and Emmolite is 25,000 and 85,000,000 rials per kilogram, respectively. The cost of drilling a hole per meter is 30,000,000 rials for a 76 mm diameter hole and 60,000,000 rials for a 90 mm diameter hole. Tables 16 and 17 present the cost savings achieved at each stage of the explosions.

Table 16. Economic Efficiency Calculations for Explosions with 76 mm Diameter Holes

xplosion Stages	Explosive Substance (Million Rials)	Drilling (Million Rials)	Total (Million Rials)
Step 1	12240000000	12000000000	24240000000
Step 2	4896000000	14400000000	19296000000
Step 3	7956000000	12600000000	20556000000
Step 4	20808000000	10800000000	31608000000
Step 5	16524000000	11400000000	27924000000
Cumulative	62424000000	61200000000	-

Table 17. Economic Efficiency Calculations for Explosions with 90 mm Diameter Holes

Explosion Stages	Explosive Substance (Million Rials)	Drilling (Million Rials)	Total (Million Rials)
Step 1	17100000000	12000000000	29100000000
Step 2	6840000000	14400000000	21240000000
Step 3	11115000000	12600000000	23715000000
Step 4	29070000000	10800000000	39870000000
Step 5	23085000000	11400000000	34485000000
Cumulative	87210000000	61200000000	-

By comparing the cost savings across these stages, it is evident that the power deck method results in significant economic benefits. The reduction in explosive material usage and drilling requirements translates into substantial cost savings. These savings are especially notable when considering the cumulative costs, indicating that the power deck method enhances overall economic efficiency in mining operations. Implementing the power deck method in the Nizar mine in Qom has demonstrated its potential to lower operational costs by optimizing the drilling and blasting process. This approach not only reduces the amount of explosives and drilling needed but also minimizes the expenses associated with rock crushing and transportation, leading to a more cost-effective and efficient mining operation.

7. Limitations and Future Work

This study primarily focuses on optimizing drilling and blasting patterns in the Nizar Cement Factory open-pit mine in Qom, Iran, using the Power Deck method to reduce operational inefficiencies and minimize negative impacts. However, several limitations must be acknowledged. One key limitation is the inherent uncertainty in geological parameters, which can significantly affect drilling and blasting outcomes. Since rock mass characteristics vary across different locations, the optimization performed in this study is site-specific and may not be directly applicable to other mining conditions. For this reason, separate optimization must be conducted for each region to account for local geological variations. With advancements in technology, soft computing techniques such as machine learning and intelligent algorithms offer promising solutions for optimizing drilling and blasting patterns. Unlike traditional approaches, these methods can process complex geotechnical data efficiently, providing faster, cost-effective, and more accurate predictions. Future studies should explore the suitability of various soft computing algorithms for predicting and optimizing blasting parameters in different mining environments. To further enhance the efficiency of the Power Deck method, a hybrid approach integrating soft computing with traditional techniques—such as experimental, analytical, and numerical methods—should be investigated. This comparative approach would enable cross-validation of results, ensuring that intelligent algorithms provide reliable predictions confirmed by direct field applications. Such an integrated methodology can lead to a more comprehensive understanding of blasting efficiency, improving both economic and operational outcomes. By combining AI-driven predictive modeling with real-world geotechnical validation, future research can advance the effectiveness of the Power Deck method and develop a more generalized framework for optimizing drilling and blasting operations across diverse mining conditions.

8. Discussion

This study highlights the significant potential of the Power Deck method as an innovative approach for optimizing drilling and blasting operations in open-pit mining. Traditional blasting techniques often result in inefficient fragmentation, excessive drilling, high explosive consumption, and undesirable environmental impacts, such as excessive ground vibrations, fly rock, and rock throw. The findings confirm that the Power Deck method provides a practical, efficient, and cost-effective alternative, enhancing fragmentation quality while reducing operational costs.

One of the major advantages of the Power Deck method is its ability to minimize excessive drilling and optimize explosive energy utilization. By strategically placing a controlled air gap at the base of the blast hole, this technique redistributes explosive energy more efficiently, leading to improved rock breakage and reduced occurrence of oversized fragments. The study demonstrated a 12.5% reduction in specific charge and a 9% reduction in specific drilling, resulting in significant cost savings while maintaining optimal fragmentation quality. These improvements are essential for enhancing mine efficiency, reducing waste, and lowering overall production costs. Additionally, the Power Deck method eliminates toe formation at the bottom of the benches, a common challenge in traditional blasting operations. In conventional methods, over-drilling is often required to prevent toe formation, increasing operational costs and time. The Power Deck method naturally prevents toe formation, reducing the need for excessive drilling while maintaining bench floor stability. This ensures a more uniform bench height, facilitating safer and more efficient loading and hauling operations. Another key advantage observed in this study is the improvement in crusher performance. The application of the Power Deck method resulted in a 1,448-ton increase in material processed by the crusher over two months, demonstrating its ability to reduce crusher downtime due to oversized fragments. Maintaining a consistent feed size is crucial for maximizing the efficiency of downstream processing. By achieving better fragmentation control, this method significantly reduces the energy required for secondary crushing, thereby lowering operational costs and enhancing overall productivity. From an economic standpoint, the findings demonstrate that the Power Deck method is a highly cost-effective solution. Over five blasting stages, the economic evaluation confirms that the Power Deck method significantly improves cost efficiency in open-pit mining operations. The total blasting cost per ton of broken rock decreased from 5.64 million rials (conventional method) to 4.94 million rials (Power Deck method), representing a 12.4% reduction in blasting costs. This cost reduction is attributed to lower explosive consumption and reduced drilling requirements, making the Power Deck method a financially viable alternative for optimizing rock blasting operations. By reducing both drilling and explosive costs while improving fragmentation efficiency, this method presents a strong case for its wider adoption in mining operations.

In addition to economic benefits, the Power Deck method improves safety and reduces environmental impact. Conventional blasting techniques can produce excessive ground vibrations and fly rock, posing risks to both workers and surrounding infrastructure. By controlling the distribution of explosive energy, the Power Deck method reduces these hazards, thereby enhancing mine safety and environmental sustainability.

Furthermore, the study provides a detailed analysis of specific charge and specific drilling in both conventional and Power Deck blasting methods. The results show that the Power Deck method significantly reduces explosive consumption per ton of rock while maintaining optimal fragmentation, leading to improved operational efficiency. The reduced specific drilling values indicate less drilling per unit volume of blasted rock, ultimately lowering fuel consumption, equipment wear, and labor costs.

While this study confirms the effectiveness of the Power Deck method, its success is dependent on site-specific geological and operational conditions. Factors such as rock type, blast hole spacing, and explosive properties influence blasting outcomes. Future research should focus on:

- Adapting the Power Deck method to various geological settings to confirm its effectiveness under different rock mass conditions.
- Optimizing air gap configurations to further improve fragmentation and cost efficiency.
- Integrating artificial intelligence (AI) and machine learning techniques to refine blasting parameters dynamically.

Overall, the findings of this study provide valuable insights for mining engineers, geotechnical professionals, and industry stakeholders, demonstrating that the Power Deck method is a highly efficient, cost-effective, and sustainable approach for improving drilling and blasting operations in open-pit mining. Its application leads to greater operational efficiency, reduced costs, enhanced crusher performance, and improved mine safety, making it a promising alternative to conventional blasting methods.

9. Conclusions

Given the critical importance of optimizing drilling and blasting patterns in open-pit mining, achieving an optimal fragmentation process significantly enhances material handling, crusher efficiency, and overall operational productivity. The Power Deck method offers an effective alternative to traditional blasting approaches by reducing explosive charge consumption and minimizing excessive drilling requirements.

In this study, five blasting stages were analyzed in the Nizar Cement Factory open-pit mine in Qom, Iran, comparing the economic and operational efficiency of the Power Deck method to conventional techniques. The results demonstrated:

- A 12.5% reduction in specific charge and a 9% reduction in specific drilling compared to traditional methods.
- Prevention of toe formation at the base of blast holes due to the 1-meter air gap, leading to a more controlled blasting process.
- Post-blast particle size distribution ranged between 10 and 30 cm, aligning closely with pre-blast fragmentation predictions from the Kaz-Ram, Swedifo, and Kaznetsov models.
- Total cost savings over five blasting stages reached 73000 million Rials for 90 mm holes and 52000 million Rials for 76 mm holes.
- A 9% and 16% reduction in specific drilling costs for 90 mm and 76 mm holes, respectively.

- A 1,448-ton increase in crusher throughput over two months, reducing crusher downtime and enhancing material processing efficiency.

These findings confirm that the Power Deck method is a powerful tool for drilling and blasting optimization in cement mining operations. Compared to conventional methods, it offers significant advantages in cost reduction, fragmentation efficiency, and operational performance, making it a promising technique for future applications in open-pit mining.

Reference

[1]. Cleeton, J. (1997) Air-deck Techniques: Improvements in costs and efficiency linked with the use of gas bags. Quarry Managemente-Institute of Quarrying,

[2]. Guido, A. D., Gianluca, C., Dario, L., & Andrea, A. (2021). Analysis of the improvement of production process in a limestone quarry. *International Multidisciplinary Scientific GeoConference: SGEM*, *21* (1.1), 235-242.

[3]. Akbari, M., Lashkaripour, G., Bafghi, A. Y., & Ghafoori, M. (2015). Blastability evaluation for rock mass fragmentation in Iran central iron ore mines. *International Journal of Mining Science and Technology*, *25* (1), 59-66.

[4]. Lowery, M., Kemeny, J., & Girdner, K. (2001). Advances in blasting practices through the accurate quantification of blast fragmentation. *Mining engineering-new york then littleton colorado-*, *53* (10), 55-61.

[5]. Latham, J.-P., Van Meulen, J., & Dupray, S. (2006). Prediction of fragmentation and yield curves with reference to armourstone production. *Engineering geology*, *87* (1-2), 60-74.

[6]. Adamson, W., Scherpenisse, C., & Diaz, J. (1999). The use of blast monitoring/modelling technology for the optimisation of development blasting. *Proc Explo-99, Kalgoolie, WA*, 35-41.

[7]. Crosby, W., & Bauer, A. (1982). Wall Control Blasting in Open Pits. *Mining Engineering*, *34* (2), 155-158.

[8]. Rezaei, M., Monjezi, M., & Varjani, A. Y. (2011). Development of a fuzzy model to predict flyrock in surface mining. *Safety science*, *49* (2), 298-305.

[9]. Dehghani, H., & Ataee-Pour, M. (2011). Development of a model to predict peak particle velocity in a blasting operation. *International Journal of Rock Mechanics and Mining Sciences*, *48* (1), 51-58.

[10]. Monjezi, M., Rezaei, M., & Varjani, A. Y. (2009). Prediction of rock fragmentation due to blasting in Gol-E-Gohar iron mine using fuzzy logic. *International Journal of Rock Mechanics and Mining Sciences*, *46* (8), 1273-1280.

[11]. Singh, T., & Singh, V. (2005). An intelligent approach to prediction and control ground vibration in mines. *Geotechnical & Geological Engineering*, *23*, 249-262.

[12]. Armaghani, D. J., Mahdiyar, A., Hasanipanah, M., Faradonbeh, R. S., Khandelwal, M., & Amnieh, H. B. (2016). Risk assessment and prediction of flyrock distance by combined multiple regression analysis and Monte Carlo simulation of quarry blasting. *Rock Mechanics and Rock Engineering*, *49*, 3631-3641.

[13]. Khandelwal, M., & Saadat, M. (2015). A dimensional analysis approach to study blast-induced ground vibration. *Rock Mechanics and Rock Engineering*, *48*, 727-735.

[14]. Rezaeineshat, A., Monjezi, M., Mehrdanesh, A., & Khandelwal, M. (2020). Optimization of blasting design in open pit limestone mines with the aim of reducing ground vibration using robust techniques. *Geomechanics and Geophysics for Geo-Energy and Geo-Resources*, *6*, 1-14.

[15]. Tribe, J., Koroznikova, L., Khandelwal, M., & Giri, J. (2021). Evaluation and assessment of blast-induced ground vibrations in an underground gold mine: a case study. *Natural Resources Research*, *30*, 4673-4694.

[16]. Wang, W., Bergholm, F., & Stephansson, O. (2020) Image analysis of fragment size and shape. In: Rock Fragmentation by Blasting. CRC Press, pp 233-243

[17]. Mead, D., Moxon, N., Danell, R., & Richardson, S. The use of air-decks in production blasting. In: International symposium on rock fragmentation by blasting, 1993. pp 437-443

[18]. Chiappetta, R., & Mammele, M. E. Analytical high-speed photography to evaluate air decks, stemming retention and gas confinement in presplitting, reclamation and gross motion applications. In: Proc. of the 2 nd Int. Symp. on Rock Fragmentation by Blasting, 1987.

[19]. Tannant, D., & Peterson, J. Evolution of blasting practices at the Ekati Diamond Mine. In: 17th International Mining Congress and Exhibition of Turkey, 2001.

[20]. Correa, C. E. (2003). Use of air-decks to reduce subdrillings in Escondida mine. *Fragblast*, *7* (2), 79-86.

[21]. Floyd, J. (2004). Power deck optimization. *Power Deck Company Blast Dynamics*.

[22]. Chiapetta, R., & Wyciskalla, J. (2004). Bottom-hole and multiple power decks-Independent test results of a new blasting technique. *Quarry Management*, *31* (2), 21-32.

[23]. Moser, P., & Vargek, J. Blasting with air decks in the bottom of blast holes. In: Vienna Conference Proceedings 2007, 2007. pp 205-216

[24]. Sazid, M., & Singh, T. Mechanism of air deck technique in rock blasting-a brief review. In: Fourth Indian Rock Conference, no. May, 2013. pp 29-31

[25]. Kabwe, E. (2017). Improving collar zone fragmentation by top air-deck blasting technique. *Geotechnical and Geological Engineering*, *35*, 157-167.

[26]. Saharan, M. R., Sazid, M., & Singh, T. (2017). Explosive energy utilization enhancement with air-decking and stemming plug,'SPARSH'. *Procedia engineering*, *191*, 1211-1217.

[27]. Zhang, X. J., Wang, X. G., & Yu, Y. L. The application of deck charge technology in Hua Neng open pit Mine. In: E3S Web of Conferences, 2018. EDP Sciences, p 03031

[28]. Amiri, H. (2019). Analysis of hole geometry on air deck in surface blasting (case study:Chah Gaz Iron mine). *Ms thesis, Tarbiat Modares University, Engineering faculty*.

[29]. Zarei, M., Shahabi, R. S., Hadei, M. R., & Louei, M. Y. (2022). The use of air decking techniques for improving surface mine blasting. *Arabian Journal of Geosciences*, *15* (19), 1545.

[30]. Yin, Z., Wang, D., Wang, X., Dang, Z., & Li, W. (2021). Optimization and application of spacing parameter for loosening blasting with 24-m-high bench in barun open-pit mine. *SHOCK and vibration*, 2021, 1-13.

[31]. Bakhshandeh Amnieh, H., Aref Mand, E., & Porghasemi Saghand, M. (2022). Controlling backbreak and improving technical and economic parameters in Mishdovan Iron Ore Mine. *Journal of Mineral Resources Engineering*, *7* (1), 99-111.

[32]. Zuo, J., Yang, R., Gong, M., Ma, X., & Wang, Y. (2022). Fracture characteristics of iron ore under uncoupled blast loading. *International Journal of Mining Science and Technology*, *32* (4), 657-667.

[33]. Roy, P. P., Sawmliana, C., & Singh, R. K. (2023). Optimization of powder factor, fragmentation and oversized boulders through subsystem studies in an opencast coal mine. *International Journal of Mining & Geo-Engineering* (2).

[34]. Rezaei, M., Monjezi, M., Matinpoor, F., Bolbanabad, S. M., & Habibi, H. (2023). Simulation of induced flyrock due to open-pit blasting using the PCA-CART hybrid modeling. *Simulation Modelling Practice and Theory*, *129*, 102844.

[35]. Rad, H. N., Hasanipanah, M., Rezaei, M., & Eghlim, A. L. (2018). Developing a least squares support vector machine for estimating the blast-induced flyrock. *Engineering with Computers*, *34*, 709-717.

[36]. Monjezi, M., Rezaei, M., & Yazdian, A. (2010). Prediction of backbreak in open-pit blasting using fuzzy set theory. *Expert Systems with Applications*, *37* (3), 2637-2643.

[37]. Zhang, Z.-X. (2016) Rock fracture and blasting: theory and applications. Butterworth-Heinemann,

[38]. Chiappetta, R. F. (2004). New blasting technique to eliminate subgrade drilling, improve fragmentation, reduce explosive consumption and lower ground vibrations. *Journal of explosives engineering*, *21* (1), 10-12.

[39]. Kuznetsov, V. (1973). The mean diameter of the fragments formed by blasting rock. *Soviet mining science*, 9, 144-148.

[40]. Cunningham, C. The Kuz-Ram model for prediction of fragmentation from blasting. In: Proc. first int. symp. on rock fragmentation by blasting, 1983. pp 439-453

[41]. Kim, K. (2006) Blasting design using fracture toughness and image analysis of the bench face and muckpile. Virginia Tech.

[42]. Potts, G., & Ouchterlony, F. (2005) The capacity of image analysis to measurefragmentation, an evaluation using Split Desktop®. Swedish Blasting Research Centre; Luleå tekniska universitet.

بهبود کارایی استخراج معادن روباز: مزایای اقتصادی و عملیاتی روش پاور دک – مطالعه موردی

هادی فتاحی*، محمد امیرآبادی فراهانی و حسین قائدی

گروه مهندسی ژئومکانیک، دانشکده مهندسی علوم زمین، دانشگاه صنعتی اراک، ایران

ارسال ۲۰۲۴/۰۸/۱۷، پذیرش ۲۰۲۵/۰۴/۰۶

* نویسنده مسئول مکاتبات: h.fattahi@arakut.ac.ir

چکیده:

این مطالعه کاربرد نوآورانه‌ای از روش پاوردک را برای بهینه‌سازی عملیات حفاری و آتشکاری در معادن روباز، با تمرکز بر کارخانه سیمان نیزار در قم، ایران، معرفی می‌کند. برخلاف تکنیک‌های سنتی آتشکاری، این روش به‌طور استراتژیک از یک فضای هوای کنترل‌شده در انتهای هر چال انفجاری برای افزایش توزیع انرژی انفجاری استفاده می‌کند، در نتیجه حفاری بیش از حد را کاهش داده و مصرف مواد منفجره را به حداقل می‌رساند. در طی پنج مرحله آتشکاری، قطرهای بهینه چال (۷۶ میلی‌متر و ۹۰ میلی‌متر) با حفظ یک فضای هوای استاندارد ۱ متری به کار گرفته شد و نیاز به آزمایش‌های حفاری اضافی را از بین برد. یافته‌ها نشان‌دهنده بهبود قابل توجهی در بازدهی آتشکاری است که منجر به کاهش ۱۲/۵ درصدی بار ویژه و کاهش ۹ درصدی حفاری ویژه در مقایسه با روش‌های معمول می‌شود. تجزیه و تحلیل قطعه‌بندی پس از انفجار، که با استفاده از شاخص F50 از نرم‌افزار Split-Desktop اعتبارسنجی شد، اندازه‌های ذرات را در محدوده ۱۰ تا ۳۲ سانتی‌متر تأیید کرد که با پیش‌بینی‌های مدل‌های Kaz-Ram، Kaznetsov و Swedifo مطابقت دارد. علاوه بر این، اتخاذ روش پاوردک منجر به افزایش ۱۴۴۸ تنی مواد فرآوری شده در طی دو ماه شد و زمان خرابی سنگ‌شکن را به دلیل قطعات بزرگ به حداقل رساند. این مطالعه یک رویکرد نوآورانه و مقرون‌به‌صرفه برای بهبود قطعه‌بندی سنگ، کاهش ناکارآمدی‌های مرتبط با آتشکاری و افزایش عملکرد اقتصادی کلی عملیات معدن روباز ارائه می‌دهد.

کلمات کلیدی: بهینه‌سازی حفاری و آتشکاری، روش پاوردک، استخراج معادن روباز، خردایش سنگ، بازدهی سنگ‌شکن