Journal of Mining and Environment (JME) Vol. 16, No. 1, 2025, 97-110

Shahrood University of Technology

Journal of Mining and Environment (JME)

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

Iranian Society of Mining Engineering (IRSME)

An Investigation of the Cumulative Impact of Decking Length and Firing Pattern on Blasting Results

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Article Info

Received 20 May 2024

Received in Revised form 28 June 2024

Accepted 21 July 2024

Published online 21 July 2024

DOI: 10.22044/jme.2024.14555.2743

Keywords

Fragmentation

PPV

Decking Length

Firing Patterns

Abstract

To conducting efficient blasting operations, one needs to analyze the bench geology, structural and dimensional parameters to obtain the required optimum fragmentation with minimum amount of ground vibration. Joints presence causes difficulty during drilling and subsequent rock breakage mechanism. An idea on joints density will give an idea on deciding with column charging in-terms of decking-stemming and firing patterns. The goal of the research is to develop a hybrid algorithm model to predict joints width and joint angle. In order to achieve the task, advanced softwares, machine learning models and a field data tests were used in this study.

1. Introduction

Use of chemical energy of explosives for the breakage of rock is far more economical compared to all other forms of mechanical application of energy. The total energy of the explosive if not well spent on the fragmentation or the required throw of the material will turn into adverse aspect of ground vibration, fly rock, and noise. Fragmentation desired can vary on the size and type of equipment used for handling the material at the face location and in the downward process until its final destination. Some movement of material called blasted muck profile, from its location is desired so that loading equipment can efficiently load the material. Thus, for the purposes of desired fragmentation, muck profile or throw of material to the desired location of the energy is derived from the chemical in the explosive. Abundant precautions will be taken to see that energy is not wasted away, by properly locating the boreholes with respect to the cracks and weak spots in the rock, sufficiently spaced away from the free faces so that burden is neither less or more, than optimum, commensurate with the strength of rock in question to be broken.

Decking length and its position plays a crucial role in designing and execution of the blast [1]. The process of "decking" involves separating other explosive charges into sections by stemming in the blasthole [2]. While decking may not produce the greatest outcomes when blast holes are short and explosive consumption is low, deck charging will produce the best cost-effectiveness relationships when they are long and high [3,18]. Increasing decking length not only delivers optimal blast

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effects, but it also optimizes cost economics by reducing explosive charge [4,5]. Decking greatly ensures better dissemination of explosive energy along the length of the hole, resulting in better fragmentation [6]. By keeping the deck length in the blasts between 0.60 and 0.80 m, efficacious breakage was achieved while also eliminating the possibility of sympathetic detonation. It was discovered that keeping the decking length at an optimized length of 0.70 m resulted in a lower ground vibration level (PPV) of 1.22 mm/s [7-11]. Similarly, decking minimizes charge weight per delay while also preventing a corresponding reduction in vibration amplitude [12-15]. In the present trials, however, all blasts were executed with conventional solid decking with drill cuttings, with the intention to reduce peak particle velocity along with optimum fragmentation.

Blast pattern has effects on the results of fragmentation and ground vibration [16-19]. The effects are mainly as firing pattern becomes important in determining the resultant burden and spacing, effect secondary crushing once there is movement from the in-situ condition. Therefore, other conditions being the same, V pattern was observed to have generated finer fragmentation [20-22].

With an increase in the compressive strength of the rock mass, MFS and PPV augment in size and intensity [23, 24]. Rocks with good compressive strength can be broken and fragmented economically because the maximum amount of explosive energy can be retained in the rock mass. The higher rock compressive strength is useful not to absorb seismic wave and transmits further. Consequently, reduced attenuation in the wave transmission through the rock results in higher PPV [25].

2. Methods and Materials

2.1. Field Data Collection

Data was collected from opencast mine I, Ramagundam region III area, SCCL, Telangana, India. The mine used to be underground, but it was converted to opencast. The study overburden benches (OB) were 12 meters high. The sandstone and alluvium soil that composed the rock strata is highly brittle. Sandstone was 2.3 g/cc in terms of density.

2.2. Rock Core sample Collection & UCS Testing

For the re-configuration of the new blast design, an AMIL single core barrel machine was used to collect rock core samples shown in figures 1-3.

Figure 1. Coring Machine

Figure 2. Generator

Figure 3 (a&b). Core Sample & Core Barrel Bo with samples

Figure 1 shows the AMIL S7802 single core machine that was used to collect core samples on site. The machine operated at 600 rpm with diamond core bit of NX size (54mm). The total weight of the device, including the bit, is 28 kg, and it runs on 230 v and 10.5 amps. The coring machine was powered by a TMTL, echicher engine 70 KVA generator, as shown in Figure 2. To avoid levelling and vibration problems, a bench is dozed in the target area before the unit is assembled. For easy core collection, the core barrel was greased on the inside, three bolts were tightened to the surface, and one bolt penertared into the earth was anchored for stability.

When coring, extra caution was taken to avoid uneven surfaces, which can lead to core breakage and lodging. Continuous water supply is provided for easy penetration into rock strata, and manual anti-clockwise shaft rotation is strictly avoided, as this breaks the core sample. Rock samples were developed from among cores not effected by in-situ stresses and presence of rock mass discontinuities, but obtained a 11cm long core, as indicated by the Indian Society of Rock Mechanics (ISRM). Core sample and barrel box were shown in figure 3(a&b).

A total of 40 core samples were obtained from four benches, samples taken on the surface and in the cross section between the crest and toe at 10m intervals on each bench. All core samples were carefully stored in a 2ft core barrel case, protected from wet and moisture, and kept dry.

The collected 40 rock specimens were sized with a rock cutting machine and both surface ends were ground to eliminate unevenness during the experiment, prepared specimens and UCS procedure was shown in figure 4(a,b&c). According to ISRM standards, all samples have an L/D ratio of 2 and a sample length of 10-12cm.

The rock specimen was put on the compression machine's bottom plate, and the upper plate was moved lower to make contact with the specimen. Both the ring and dial gauge pre-set to zero. By maintaining axial strain at a rate of 2 to 12% each minute and accordingly every thirty seconds up to a strain of 6%, the compression load is applied. I kept track of the dial gauge reading and the proving ring reading at 6 and 12 percent every 60 seconds. The test procedure and axial load were continued until an axial strain of 20% was obtained or failure surfaces were clearly evident.

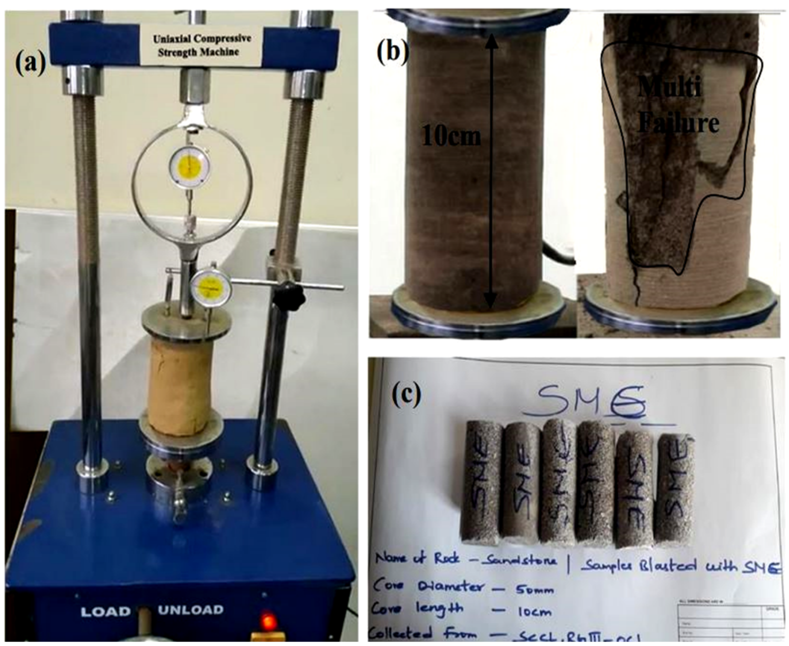


Figure 4 (a, b&c). Uniaxial compressive strength testing procedure, specimen failure and samples.

2.3. Blast Modeling

2.3.1. Blast Design

All blasts are designed in blast design software, using the RENISHAW 3D laser technique, transforms views into multi-dimensional visualization to bring a real approach to blast as shown in figure 5 with early warning as per simulation. The compressive strength of the rock was taken into consideration when designing the blasts. Every blast is primarily aimed at multi-decking, firing pattern and partial change in Se/Be ratio as per the geo-spatial requirement of blasts. A 12m bench with SME explosive, alternative decking 0.5m, 2.5m, and 1m fired with V pattern.

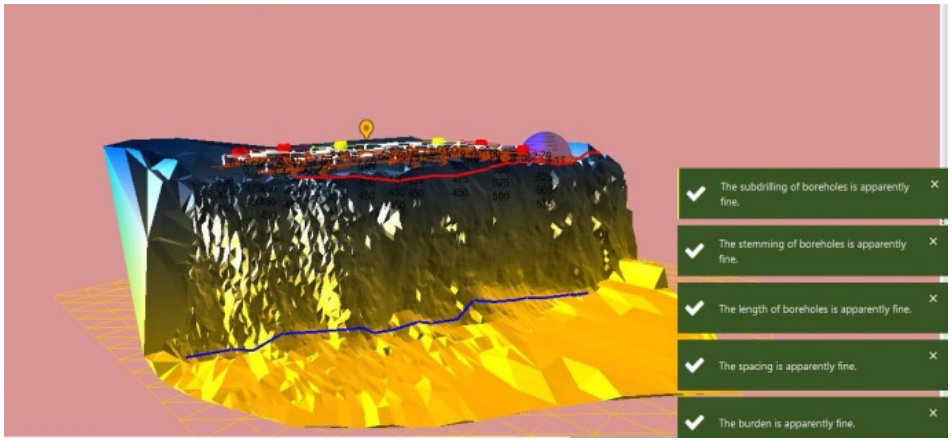


Figure 5. Blast design in O-PITBLAST

Considering the rock conditions and economic viability, the practice of decking is selected to mitigate unwanted induced ground vibrations and to minimize financial uncertainties. Decking involves placing a layer of inert material between explosive charges to absorb energy and control the propagation of shock waves. In this case, a decking strategy of 2 meters between the bottom 2.5 meters and the upper 2.5 meters of the blast is implemented. This decking approach offers several advantages. Firstly, it facilitates maximum utilization of explosives by optimizing their distribution within the rock mass. Secondly, it promotes more efficient breakage patterns, leading to enhanced fragmentation and easier handling of the blasted material during excavation. Figures 6 and 7 provide a visual representation of the bench wire mesh model and the process of implementing decking between charge initiation points.

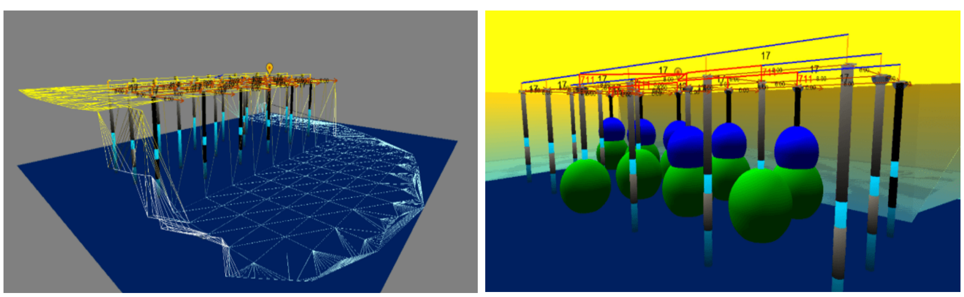


Figure 6 & Figure 7. 12 m wire mesh bench and charge initiation with decking

The heat maps depicted in Figures 8 and 9 highlight the burden distribution and explosive distribution for the designed blasting pattern.

The UI has the ability to examine subtleties like a connection defect, overcharge, burden distribution, hole inclination, stemming, deck misplacement, and structural issues in the area of the blast, as illustrated in figure 10.

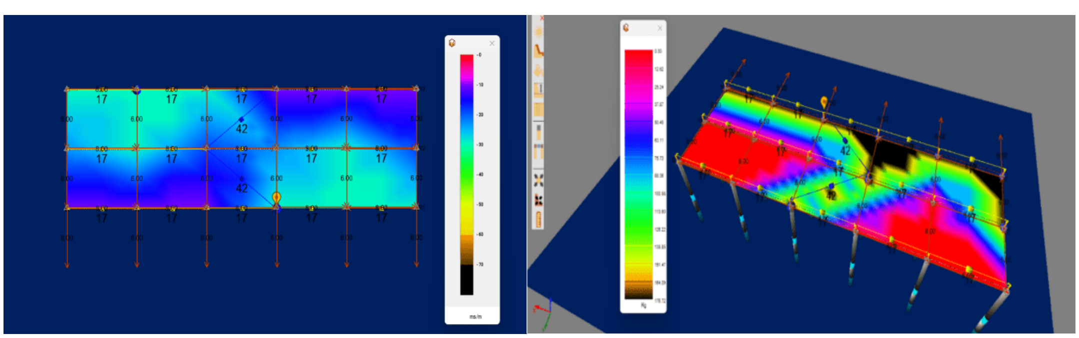


Figure 8 & Figure 9. Burden and explosive distribution with respect to free face

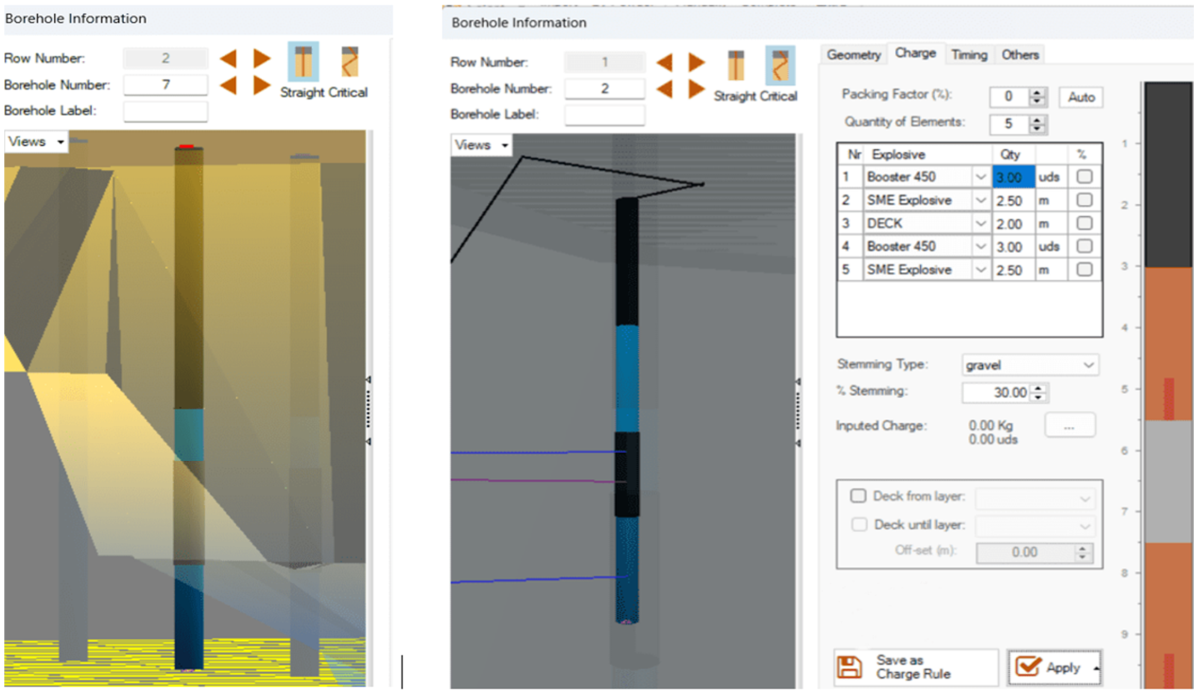


Figure 10. Blast hole charging

2.3.2. Blast Prediction

Blast fragmentation predicted for all blasts with the new set of blast parameters. The blast geometry changed with respective fragmentation sizes predicted by the software. The Kuznetsov concept was used to forecast fragmentation. It gives fragmentation sizes in four categories, X20, X50, X80 and X90 as shown in figure 11.

As shown in Fig. 12, the PPV trends relative to scaled distances were displayed. The maximum charge per delay, measured distances, and monitored vibration data such PPV and peak vector sums of transverse-longitudinal-vector directions, as well as peak vector sums, were used to create the trends. The least-squares approach in logarithmic mode was employed for the regression model. Regression was used to determine the best fit for the blast vibration estimation, with confidence levels of 50% and 95%. PPV values for every blast predicted with the new atteniation law generated by O-PITBLAST.

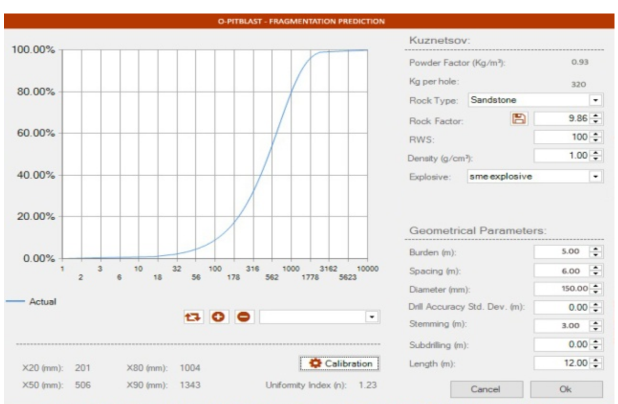


Figure 11. Fragmentation Prediction

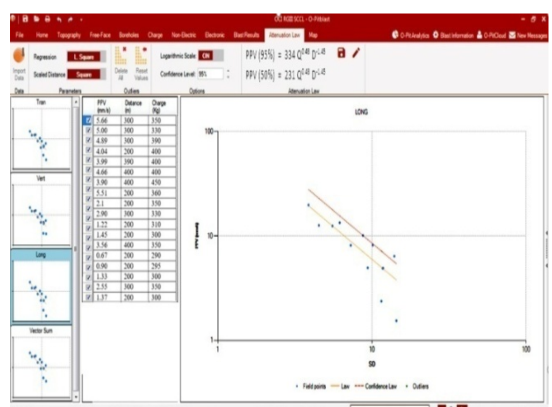


Figure 12. PPV prediction with attenuation law

3. Blast Experimentation

The three OB benches with bench heights of 12m each were selected for the investigation. The mine has been operated underground in the past, therefore there is a significant risk of upsetting strata and generating fractures.

The designed burden and spacing values in O-PITBLAST are shown in Table 1 along with the accurately predicted outcomes. The drilled holes are depicted in figure 13, and the drill bit diameter was selected as 150mm, which was adequate for the bench height, burden, and spacing.

Figure 13. Drone captured drilling picture

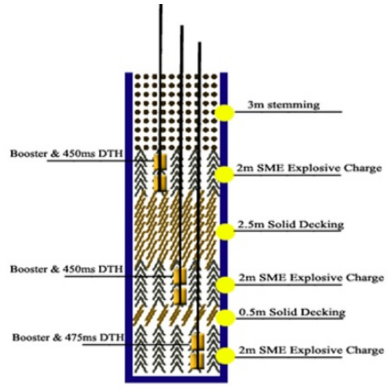


Figure 14. Charging & decking

Triple and double decking have been used, in accordance with the compressive strength of the neighbouring rock as given in table 2. To evaluate the impact of multiple decks and firing patterns on rock fragmentation and ground vibration based on rock compressive strength, a total of 36 blasts were conducted. In three phases, 36 blasts were carried out on three benches. As indicated below, the phases are A, B, and C.

Phase A: Intially, firing pattern is changed, all other blast design parameters remain same.

Phase B : All blast design parameters kept constant and decking length and postion is changed as per rock compressive strength.

Phase C: Decking length and firing patterns were changed together, as well as the consideration of rock compressive strength, while the rest of the parameters remained unchanged.

SME was utilized uniformaly in all blasts. Booster explosive was used along with NONELs. The delay were 475 ms and 450 ms as per the decking pattern. Average explosive used was between 45-55kg. The general configuration of charging shown in figure 14.

4. Blast result Analysis

4.1. Fragmentation Analysis and Ground Vibration Measurement

Photographs perpedicular to the plane of field, known as ortho-photographs, were taken to create 3D fragmentation model based on point cloud data. The model used digital terrain model to enhance visual analysis of fragmentation in each corner in muck pile. The percentages of total rock with specific diameters or less, known as D10, D20...D80, D90 shown in figure 17, whose values generate based automatically on the concepts of KUZ-RAM and SWEBREC algorithms. The AI assigns different colours to different rock fragmentation sizes, as shown in Figure 15. For all blasts fragmentation graphs were taken and the resulting colour plates were produced with the help of AI.

Field-obtained results in terms of rock fragmentation and peak particle velocity are presented as violin graphs in Figures 18 (a & b).

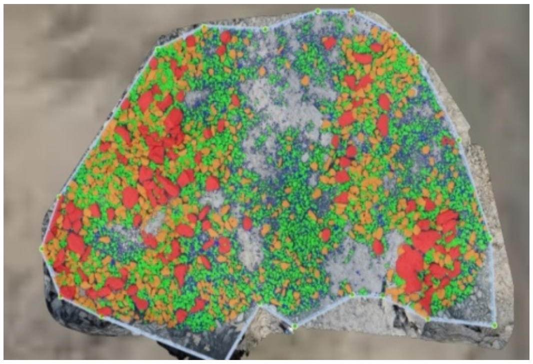


Figure 15. Muckpile delineation

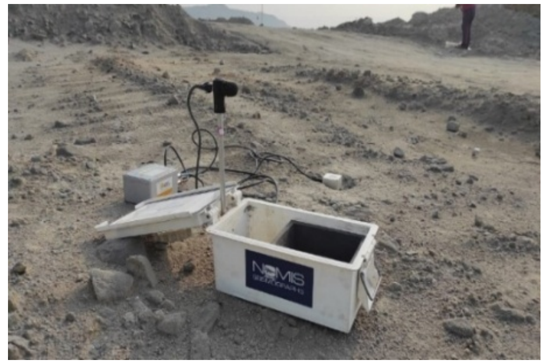


Figure 16. NOMIS sesimpgraph at point

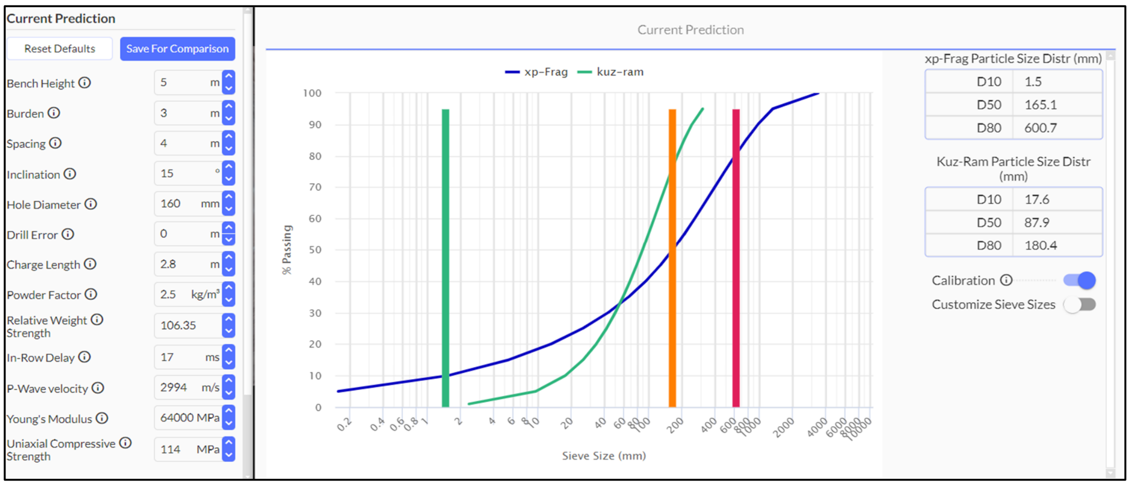
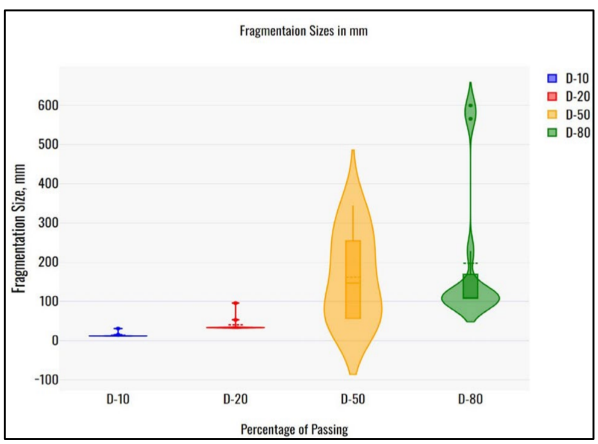
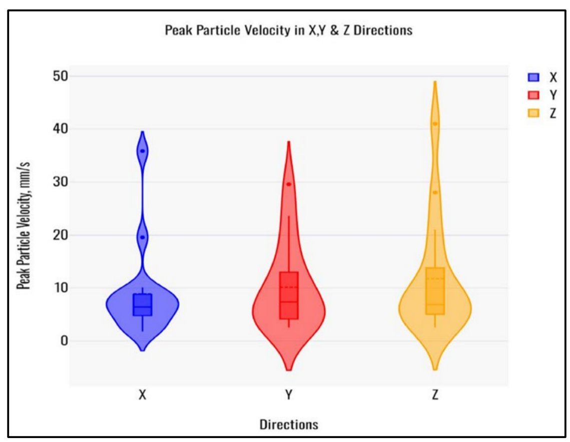


Figure 17. Fragmentation Graph



(a)



(b)

Figure 18 (a & b). Various particle sizes produced during blasting & PPV generated in X, Y and Z direction

4.2. Ground Vibration Measurement

NOMIS engineering seismograph was used as shown in Fig. 16, for measuring the ground vibration. The transducer, which has sensor, was attached to spikes, and spikes were securely driven into the earth to stay in contact with the crust of the ground. The instrument was placed at a distance of 500m which is measured by the drone. Measurement was done for all 36 blasts. The maximum charge delay was maintained between 280-350 kg per hole. Each blast generates vibration data, which is recorded and archived. The seismograph recorded PPV for the longitudinal

(R), vertical (V), and transverse (T) components, vector sum velocity (VS), during the blasts, as indicated in table 2.

5. Principal Component Analysis

In XLSTAT, the PCA generates a correlation circle, essential for interpreting the data. The analysis divides variables into three categories: positively correlated, negatively correlated, and orthogonally correlated. Positively correlated variables are closely spaced, negatively correlated variables are in opposite quadrants, and orthogonally correlated variables are in adjacent quadrants, indicating no association.

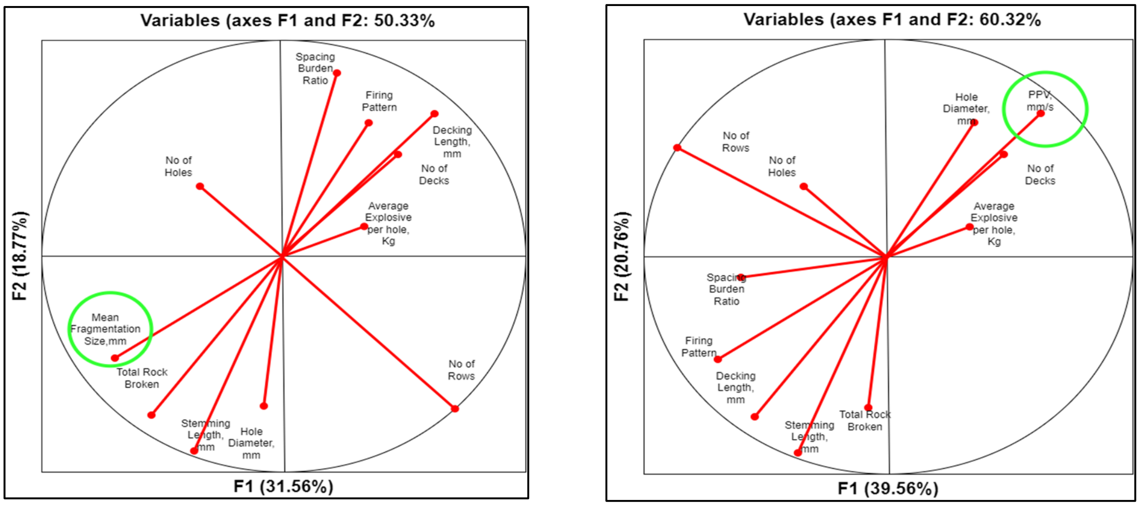


Figure 19. (a) shows that MFS (Mean Fragmentation Size) has a positive relationship with stemming length, hole diameter, and total broken rock, indicating that MFS increases as these parameters increase. Conversely, MFS has a negative relationship with spacing burden ratio, firing pattern, decking length, number of decks, and average explosive quantity, suggesting that a reduction in any of these parameters may lead to an increase in MFS. Additionally, the number of rows and holes does not show any significant relationship with MFS.

Similarly, Figure 19(b) shows that PPV (Peak Particle Velocity) has a positive relationship with hole diameter, number of decks, and average explosive quantity, indicating that PPV increases as these parameters increase. Conversely, PPV has a negative relationship with spacing burden ratio, firing pattern, and decking length, suggesting that a reduction in any of these parameters may lead to an increase in PPV. Additionally, the number of rows and holes does not show any significant relationship with PPV. Figure 19 (c &d) presents UCS & D80 relationship.

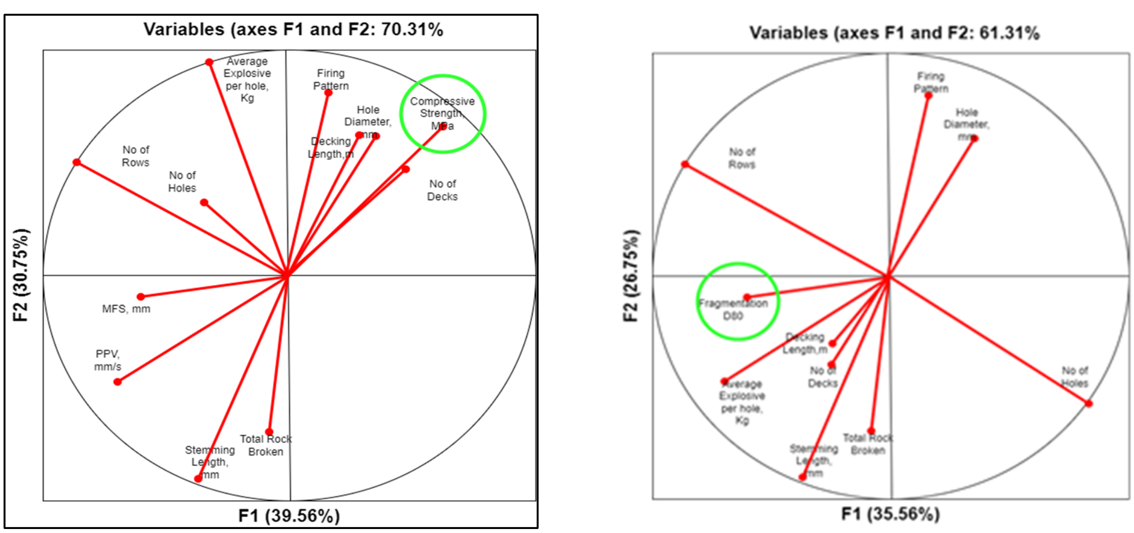


Figure 19 (a, b, c & d): PCA Correlation Circle of MFS, PPV, UCS & D80

Table 1. Blast Design Parameters

S.No	Bench Name	Phases	Blast No	No. rows	No Holes	Hole Diameter,	Average Hole Depth,	Spacing Burden	Front Row Burden, m	No of Decks	Deck Length, m	Stemming Length, m	Average Explosive	Total Explosive, kg	Firing pattern
1	I De-coaled Seam Bench	Phase - A	A1	3	27	150	12	1.3	2.5	3	**1.5**	3	275	7,425	Diagonal
2			A2	5	27	150	12	1.2	2.5	2	**2.5**	3	375	10,125	Diagonal
3			A3	3	27	150	12	1.3	2.5	2	**3.5**	3	300	8,100	Diagonal
4		Phase - B	B1	3	27	150	12	1.3	2.5	3	3	3	310	8,230	**Line**
5			B2	3	27	150	12	1.3	2.5	3	3	3	300	8,100	**V**
6			B3	3	27	150	12	1.3	2.5	3	3	3	300	8,100	**Diagonal**
7		Phase - C	D1	3	27	150	12	1.3	2.5	2	**1.5**	3	190	5,130	**Diagonal**
8			D2	3	27	150	12	1.3	2.5	2	**2.5**	3	290	7,100	**Diagonal**
9			D3	3	27	150	12	1.3	2.5	2	**3.5**	3	220	5,940	**V**
10	3A De-coaled Seam Bench	Phase - A	A4	3	27	150	10.5	1.2	2.5	2	**1.5**	3	210	6,110	V
11			A5	3	27	150	10.5	1.3	2.5	2	**2.5**	3	270	7,290	V
12			A6	3	27	150	10.5	1.3	2.5	2	**3.5**	3	225	4,500	V
13		Phase - B	B4	3	27	150	10.5	1.3	2.5	2	3.1	3	230	6,210	**Line**
14			B5	3	27	150	10.5	1.3	2.5	2	3.1	3	220	5,940	**Diagonal**
15			B6	3	27	150	10.5	1.3	2.5	1	3.1	3	245	6,615	**V**
16		Phase - C	D4	3	28	150	10.5	1.3	2.5	2	**1.5**	3	200	5,400	**Diagonal**
17			D5	3	27	150	10.5	1.3	2.5	2	**2.5**	3	185	4,995	**V**
18			D6	3	27	150	10.5	1.3	2.5	2	**3.5**	3	230	6,210	**V**
19	3A Seam Bench	Phase - A	A7	3	27	150	11	1.3	2.5	3	**1.5**	3	240	6,480	V
20			A8	3	29	150	11	1.3	2.5	3	**2.5**	3	320	9,280	V
21			A9	3	27	150	11	1.4	2.5	2	**3.5**	3	260	7,020	V
22		Phase - B	B7	3	27	150	11	1.2	2.5	2	3	3	250	6,000	**Diagonal**
23			B8	3	28	150	11	1.3	2.5	2	3	3	265	7,420	**Line**
24			B9	3	27	150	11	1.2	2.5	2	3	3	270	7,290	**V**
25		Phase - C	D7	3	27	150	11	1.3	2.5	2	**1.5**	3	195	5,265	**V**
26			D8	3	27	150	11	1.3	2.5	3	**2.5**	3	175	4,725	**V**
27			D9	3	27	150	11	1.3	2.5	2	**3.5**	3	210	5,670	**Diagonal**

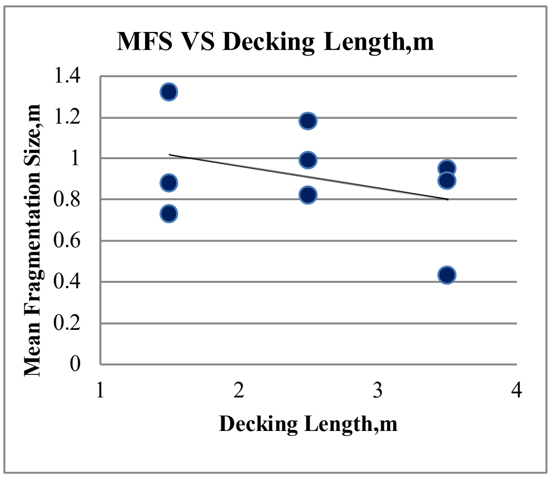
Table 2. Blast Results

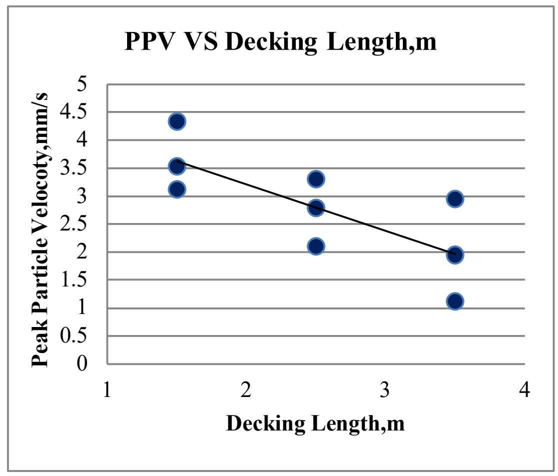
S.No	Blast No	Phases	Fragmentation				Ground Vibration			Rock Compressive Strength, Mpa
			Prediction		Actual		Distance	Prediction	Actual	
	Bench	Phases	K50,mm	K80,mm	K50,mm	K80,mm		PPV,mm/s	PPV,mm/s	
1	I De-coaled Seam Bench	Phase - A	0.67	1.66	0.55	1.59	500	4.91	4.33	62
2			1.4	1.97	1.18	1.69	500	4.26	3.29	64
3			0.91	1.43	1.2	1.56	500	4.78	2.94	62
4		Phase - B	1.2	1.66	1.6	2.49	500	4.02	4.56	59
5			0.89	1.34	0.78	1.16	500	5.90	5.15	57
6			0.55	1.22	0.65	1.42	500	4.22	4.79	61
10		Phase - C	0.44	0.89	0.65	2.08	500	2.11	3.21	63
11			0.38	0.97	0.89	1.13	500	2.95	2.80	67
12			0.31	0.88	1.21	0.94	500	2.04	2.21	63
13	3A De-coaled Seam Bench	Phase - A	0.88	1.66	1.02	1.95	500	3.20	3.52	56
14			1.1	1.97	1.59	2.34	500	3.01	2.78	59
15			0.91	1.43	0.89	1.22	500	3.08	1.94	47
16		Phase - B	1.2	1.66	0.911	1.39	500	3.01	3.96	59
17			0.82	1.44	0.89	1.82	500	3.99	4.51	55
18			0.47	1.11	0.74	1.93	500	2.21	3.55	43
22		Phase - C	0.38	0.75	1.3	0.95	500	2.04	2.55	50
23			0.38	0.89	0.911	1.07	500	1.94	2.03	35
24			0.34	0.79	0.6	0.97	500	2.21	2.85	53
25	3A Seam Bench	Phase - A	0.57	1.83	0.88	1.73	500	3.95	3.11	49
26			0.56	1.39	0.82	1.33	500	3.23	2.09	56
27			0.91	1.43	1.6	2.07	500	3.91	1.11	41

6. Discussions

6.1. Relation between decking length – MFS & PPV (Phase I):

In Phase I, three Decking lengths of 1.5m, 2.5m, and 3.5m were used to reduce explosive quantity where it was not necessary owing to the less rock compressive strength present in the bench section. The decking length was selected based on the compressive strength of each site rock to explore the impact on mean fragmentation size and peak particle velocity. The decking incremental chosen on the basis of column rock compressive strength. Because the rock strength is decreased owing to pre-existing discontinuities, less explosive is enough to shatter the rock with proper placement. Minimum MFS produced over three investigative benches with 1.5m deck length is 0.73m, 2.5M decking length is 0.82m and 3.5m decking length is 0.43m as shown in figures 13 (a). Consequently, PPV with the effective closure of cracks by the stemming was reduced. From the above graph it can be observed that the PPV is showing decreasing trend and produced 1.11 mm/s with the increase of decking length with 3.5m of boreholes due to effective blinding of the joints and transmission affected by the pre-existing joints as shown in figure 13(b).



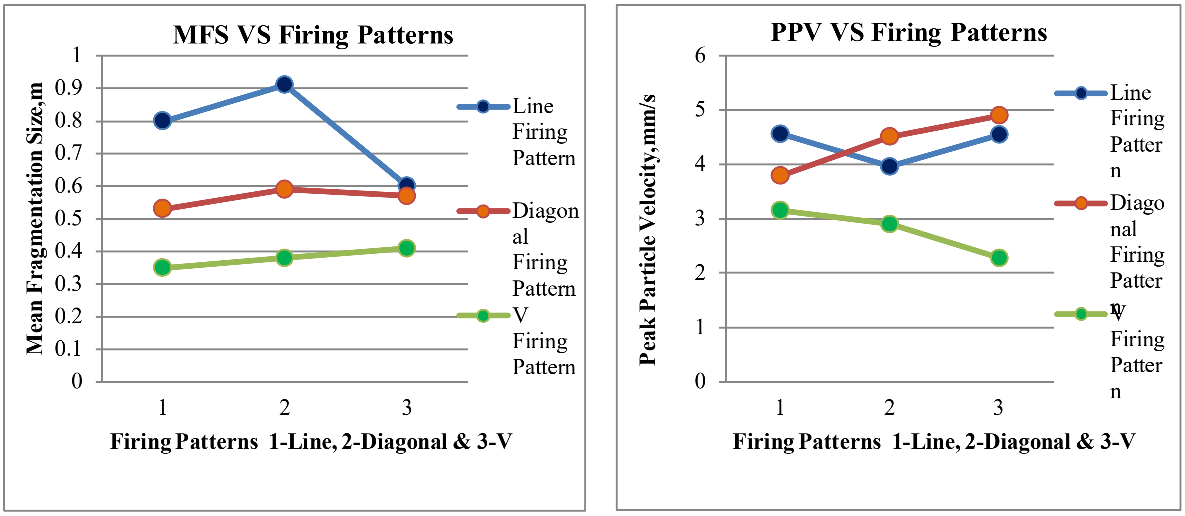


(a) **(b)**

Figure 13(a&b). Relation between decking length – MFS & PPV

6.2. Relation between Firing Patterns – MFS & PPV (Phase II)

In Phase II, it is observed that in all three firing patterns, V produced good fragmentation sizes are hovering between 0.35 to 0.41m, perpendicular firing initiation with V pattern made reduction in hole burdens and increased spacing at the time of hole initiation and in-flight collision of broken rock during its movement, the lowest MFS 0.41mm can be seen in figure 14(a). In case of PPV, safe PPV produced in between 2.28 to 3.1mm/s in different monitoring distances with V firing pattern due to cancellation of the wave patterns generated by simultaneous holes on both the arms of the V as compared to diagonal or line firing patterns, except few blasts PPV little higher due to presence of only one joint set causing no attenuation rather rock absorption. The lowest PPV recorded was 2.28mm/s as shown in figure 14(b).

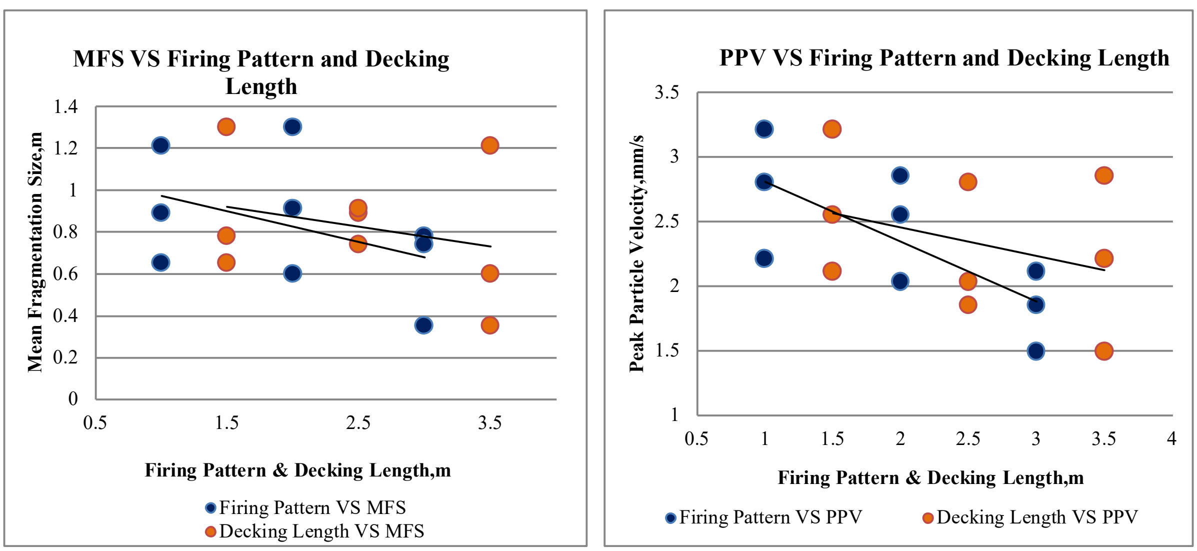


(a) (b)

Figure 14(a&b). Relation between firing pattern – MFS & PPV

6.3. Relation between Combination of Firing Patterns & Decking Lengths – MFS & PPV (Phase III)

The combination of decking length and firing pattern was explored sequentially in Phase III. Since both are required to alter to meet blast configuration as per rock compressive strength. The decking lengths of 1.5 m, 2.5 m, and 3.5 m, as well as the firing patterns diagonal and V were repeated since they produced better blasting results in its individual phases.

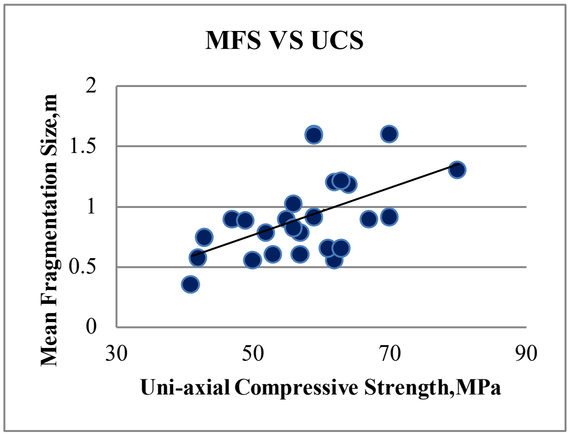


(a) (b)

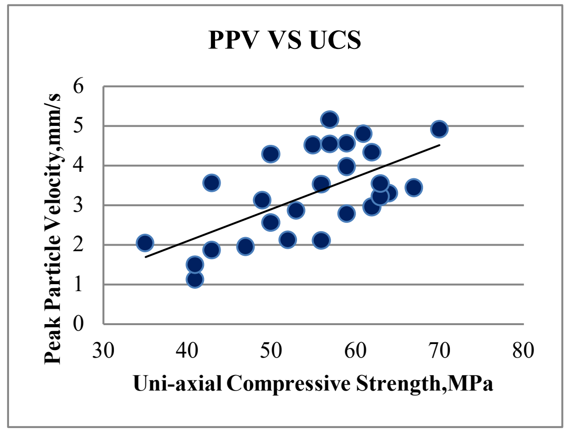
Figure 15 (a&b). Relation between firing pattern & decking length combinations – MFS & PPV

The link between MFS, decking length, and firing pattern is depicted in figure 15(a). As far as feasible, the decking is done to block the primary horizontal seam while adhering to the predicted decking length. When the decking length was 3.5 m, the V firing pattern generated excellent mean fragmentation size 0.35m. This technique lowered explosive amount while increasing explosive intensity in week and less compressive strength rocks ranging 35 to 41Mpa.

The lower PPV indicates the efficacy of concealing the geological discontinuities that may be encountered in the borehole. Decking length 3.5 m indicates a significant decline in PPV of 1.49 mm/s at 500m as shown in figure 15(b) and a maximum of 2.85mm/s at the same distance.



(a)



(b)

Figure 16 (a&b). Relation between UCS – MFS & PPV

MFS increases as the compressive strength of the rock mass increases. When rock strength fluctuated between 35 and 50 MPa, good fragmentation 0.35 to 0.65m was produced, and MFS rose continuously with rock UCS as seen in the figure 16(a). The high uni-axial compressive strength UCS suggests that either the rock components or the cementing substance that binds them are strong. As a result, the PPV is projected to be greater as the rocks are subjected to higher detonating velocities before succumbing to explosive strength. PPV raised with UCS as competent rock creates a path for PPV to migrate to the next layer as shown in figure 16(b). When the rock UCS is 40 and the PPV is 1.11mm/s, the PPV increases. The variable compressive strength of the rock aided in the selection of various blast combinations in all phases.

7. Conclusions

- The drone substantially aided in the capturing blast fragmentation images in uncertain environments, which is difficult to perform conventionally by human. With its satellite-based remote control, determining directions and distances between desired sites becomes simple.
- AI-based softwares excelled to properly predict and analyze rock fragmentation sizes and ground vibration with closer values. The accuracy of the results is discovered to be dependent on the quality and quantity of drone images.
- Principle Component Analysis well assist in understanding the relationship among the dependent and independent variables.
- Satisfactory fragmentation and PPV achieved by combining re-engineered decking length and firing pattern with rock compressive strength consideration rather than considering them separately. Combination of 3.5m decking length and V firing pattern produced good mean fragmentation size and safe PPV i.e., 021mm and 1.11mm/s.
- Rock compressive strength of 40-50 Mpa caused good fragmentation, although PPV increased with increasing rock strength, however the PPV value is relatively low when compared to A, B, and C phases.
- The study concluded that using the Tri-Consideration of decking length, firing pattern, and rock compressive strength, blasting could be done in an effective and safe manner in OB benches.

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بررسی تاثیر تجمعی طول انقطاع و الگوی انفجار بر نتایج انفجار

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ارسال ۲۰۲۴/۰۵/۲۰، پذیرش ۲۰۲۴/۰۷/۲۱

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چکیده:

برای انجام عملیات انفجار کارآمد، نیاز به تجزیه و تحلیل زمین‌شناسی نیمکت، پارامترهای ساختاری و ابعادی برای به دست آوردن تکه تکه شدن بهینه مورد نیاز با حداقل مقدار ارتعاش زمین است. وجود اتصالات باعث ایجاد مشکل در حین حفاری و متعاقب آن مکانیسم شکستن سنگ می‌شود. ایده‌ای در مورد چگالی اتصالات، ایده‌ای در مورد تصمیم گیری در مورد شارژ ستون از نظر طول گل‌گذاری و الگوی انفجار به شما می‌دهد. هدف از این تحقیق توسعه یک مدل الگوریتم ترکیبی برای پیش‌بینی عرض و زاویه اتصال است. به منظور دستیابی به مهم، در این مطالعه از نرم افزارهای پیشرفته، مدل‌های یادگیری ماشین و آزمون داده‌های میدانی استفاده شد.

کلمات کلیدی: خرد شدن، PPV، طول عرشه، الگوهای انفجار.