Journal of Mines, Metals and Fuels, 70(9) : 499-507; 2022. DOI: 10.18311/jmmf/2022/32100

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: www.informaticsjournals.com/index.php/jmmf

V-Type Firing Pattern in Blasting: Evidence to Substantiate the Improved Fragmentation

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Abstract

Firing sequence of blastholes in blasting is an inherent part of the blast design for various reasons that range from the spatial requirements to the control of throw during blasting in surface mines. Despite several such patterns in vogue, role of firing sequences in defining the size of fragmented block sizes is not properly understood. The V-type firing pattern is believed to improve blast fragmentation because of the collision of moving fragments during the blasting process, thus resulting in further breakage. There are practically negligible studies that substantiate this assertion. The role of V-type firing pattern has been explored in this paper with simple logic and some field data. It is observed that the V-type firing pattern produces better fragmentation and controls the throw during blasting. A comparison with diagonal firing pattern, in controlled experiments, makes it evident that V-type firing pattern can be used to advantage for fragmentation improvement.

Keywords: *Blasting, Diagonal Firing Pattern, Fragmentation, Throw, V-Firing Pattern*

Symbols and Abbreviations

H_b is bench height (m), B is burden (m), Be is effective burden (m), S is spacing (m), Se is effective spacing (m), Mb is ratio of Se to Be, M_d is ratio of S to B, l_s is stemming length (m), k_{50} is mean fragment size (m), d is blasthole diameter(mm), q is specific charge (kg/m3), Qis the explosive charge per hole (kg), FP is firing pattern, q is specific charge.

1.0 Introduction

The aim of blasting in mining to ease the excavation operation with obtain maximum yield of desire fragmentation and minimize the adverse impact of blasting such as blast induced ground vibration, fly rock and noise. To obtain the desire blast results, various blast design variables and factors viz. burden, spacing, stemming length, type of explosive, powder factor, stiffness ratio, firing pattern etc. are optimized as per requirement.

The firing pattern provide a systematic generation of free face to each blast hole which provide a reflection surface for shock wave, which is necessary for fragmenting the rock mass. this help to get desire rock fragmentation and throw of muck pile without change in any other blast variables and factors. Proper sequencing of inter hole and inter row delay timing is another important contributor in firing pattern towards good blast results. The systematic

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release of energy associated with proper burden is crucial in maintaining the continuous momentum for inter row displacement. Inadequate delay in a multirow blast results in poor breakage from the back rows which result in coarse fragment size, large collar boulders, tight muckpile and also back breaks /over breaks (Choudhary, 2013).

A continuous blast fragmentation analysis plays a vital role to evaluate the effect of blast design and more so of firing pattern on rock fragmentation. If blast fragmentation is not of required size, it can increase production cost and delay in quarry progress due to unnecessary secondary blasting that is a safety concern, or require use of rock breakers to reduce the size of boulders that is costly. To reduce the production cost, blast design should be revisited to match the cost of the Mine Mill Fragmentation System (MMFS) that includes unit operations like drilling, blasting, loading, hauling or conveying and crushing of primary or secondary nature (Hustrulid, 1999). The drilling and blasting cost in open pit mine represent 15-20% of the total mining cost (Afeni, 2009; Da Gama & Jimeno, 1993; Shim *et al.,* 2009). The cost of the blasting unit operation has inverse relationship with the cost of the loading, hauling and crushing(Mackenzie, 1966). This requires determination of an optimum fragment size range so that thecost of MMFS is optimized. However, increasing the cost of the blasting unit may not always be in favors of the system, if the same does not reduce the cost of the other unit operations. There are methods like blast design evaluation that leads to change in main blast design variables like burden, spacing and stemming distance, hence, improved fragmentation and better system performance. Similar method involves change in firing sequence that can be taken into advantage for improving fragmentation (Chouhan & Raina, 2015a)

Different type of firing patterns e.g., row to row, diagonal, V-type are used in bench blasting. Each firing pattern has its own application and advantages (Jimeno *et al*., 1997; Konya & Walter, 1991) there have been numerous technical contributions which have brought a better understanding of rock fragmentation with explosives, an improvement in drilling equipment and a noticeable evolution in the development of new explosives and blasting accessories. The Geomining Technological Institute of Spain (ITCE. This paper focuses on the use of V-pattern of firing wherein studies have been conducted to document the improvement in the blast fragmentation taking advantage of inter-fragment collision during heaving of the blast muck.

2.0 Types of Firing Patterns and their Effect on Fragmentation

In opencast blasting different type of firing patterns viz. line pattern, diagonal pattern, V-type pattern used to get desire rock fragmentation as explained further.

2.1 Line Pattern

In this type of firing pattern, holes in the same row of a blast are fired simultaneously or continue to detonate in succession of previous hole in a row. Successive row holes will also fire in the same manner as depicted by Figure 1 and Figure 2. Burden and spacing during blasting which is known as *Be* and *Se* respectively, change from drill burden *(B)* and spacing *(S)* depending upon type of firing pattern deployed. Since this pattern follows a row-to-row firing sequence, the ratio of *Se/Be* or M_b is same as drill *S/B* or M_d i.e., $M_b = M_d$. *Here,* $M_b = Se/Be$, $M_d = S/B$, *S = Drill Spacing, B = Drill Burden, Se = Effective spacing during blasting, Be = Effective burden during blasting*

Figure 1 indicates that there is no benefit from such firing pattern in blasting as no dynamic changes are witnessed in design variables during the blast. Besides this, if the blastholes in the same row are blasted simultaneously, the blast induced ground vibration is very high (Choudhary & Arora, 2018) since the maximum charge per delay in such case equals the maximum charge per round. Such vibrations can result in increased probability of slope failure (Hagan, 1979) away from the possibilities of damage to nearby structures and human response (Raina *et al.,* 2004). Another disadvantage of this firing pattern is that if any of the holes in the same row misfiresthe successive rows get fired and later it is very difficult to assess and deal with misfire holes as these are covered by muck of the blast. Such firing patterns have thus become obsolete for the opencast blasting.

However, such situation can be eliminated by the firing sequence shown in Figure 2. However, in this pattern also, the blasted rock fragments will travel in the same direction with negligible possibility of inter collision of rock fragments for further fragmentation. For such firing pattern $M_b = M_d$.

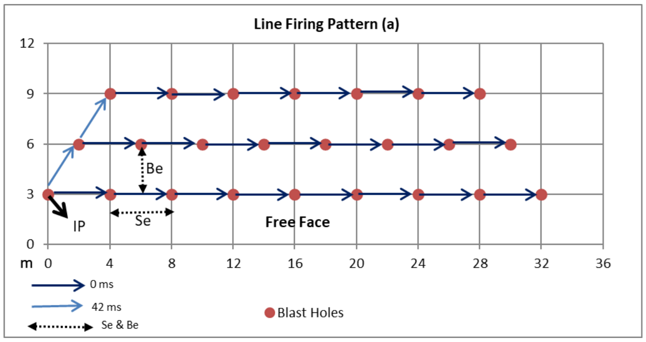


Figure 1. Staggered drilling with line firing pattern (a).

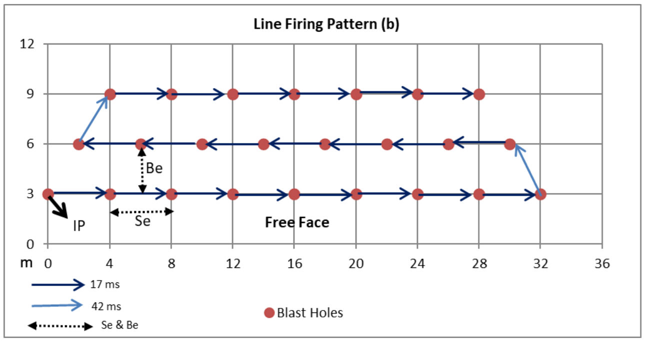


Figure 2. Staggered drilling with line firing pattern (b).

2.2 Diagonal Pattern

The diagonal pattern also has two variants i.e.,

1. Diagonal Firing Pattern (RHS)
2. Diagonal Firing Pattern (LHS)

2.2.1 Diagonal Firing Pattern (RHS)

In this type of firing pattern (Figure 3), delays connected to rows represent a line which is leaning towards Right Hand Side (RHS). In this type of firing pattern M_b is calculated by

$$Mb = \frac{(B^2 + 0.25S^2)}{BXS}\ Equation\ 1$$

and $M_b < M_d$

From Figure 3 and Equation 1, one can observe that blasting burden i.e., *Be* is greater than the drill burden *(B)* and hence this condition results in coarser fragmentation. However, such patterns can be used in case of soft formations to improve the explosive costs and also case where coarse and uniform fragmentation is required.

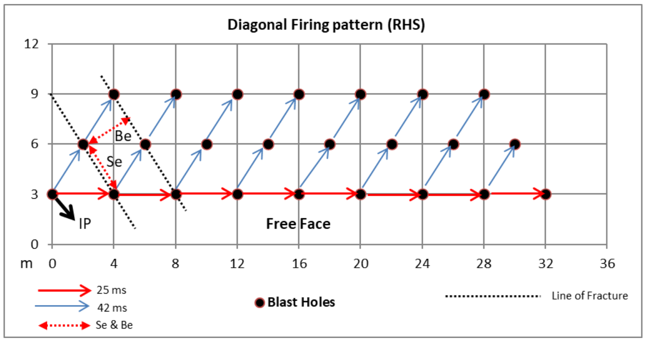


Figure 3. Staggered drilling with diagonal firing pattern (RHS).

2.2.2 Diagonal Firing Pattern (LHS)

In this type of firing pattern (Figure 4), delays connected to rows represent a line which is leaning towards Left Hand Side (LHS). In this type of firing pattern, the M_b is calculated by Equation 2.

$$Mb = \frac{(B^2 + 2.25S^2)}{BXS}\ Equation\ 2$$

and $M_b > M_d$

Figure 4 and Equation 2 reveal that blasting burden i.e., *Be* is lesser than the drilled burden *(B)*. In such case smaller fragmentation can be achieved provided the spacing of the blastholes is not too high.

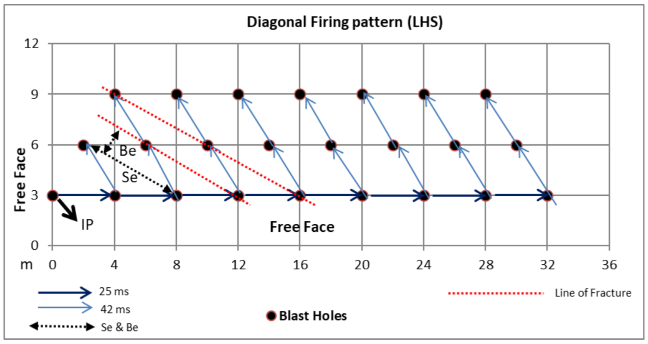


Figure 4. Staggered drilling with diagonal firing pattern (LHS).

Since in these pattern, the blasted rock fragments also travel in a same direction as in line pattern, result of which there is little possibility of inter collision of rock fragments which leads to no further fragmentation.

2.3 V-Type Firing Pattern

In this type of firing pattern (Figure 5) a central hole in the first row detonates first and the delays are so

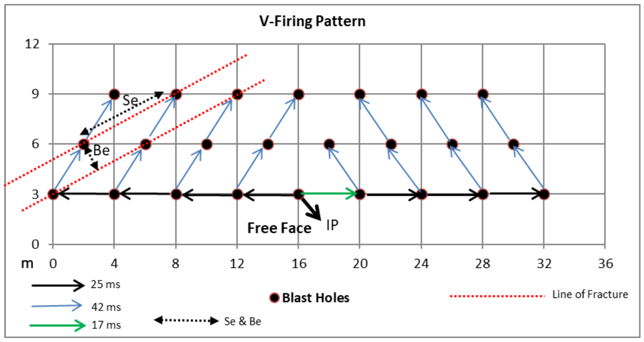


Figure 5. Staggered drilling with V-type firing pattern

connected in rows so that they form two opposite lines of fire, which is resemble a shape of "V". Hence, this pattern is called V-Type firing pattern. Since this pattern provides same line of facture as provided by diagonal firing pattern (LHS), in this type of firing pattern M_b is also calculated by same formula i.e., Equation 2.

It also reveals that burden during blasting i.e., *Be* is decreases to drill burden *(B)*, with a potential to produce smaller fragment sizes of rocks. Since in this pattern, the blasted rock fragments from opposite lines of holes travel in opposite directions, the inter collision of rock fragments happens (Chouhan & Raina, 2015a) that leads to further fragmentation.

In line with the above, this study has been attempted to compare the diagonal pattern (LHS) Figure 4 and V-type pattern Figure 5 on their impact on fragmentation through empirical methods. In such cases, it is essential to define the geometric aspects of the blast design.

3.0 Blast Mechanism

It is known that explosive in a blast hole detonate rapidly and convert into gases of huge volume having high pressure and high temperature. This rapid change in volume from solid to gas generated a detonation pressure all around the blast hole. The pressure wave travels all around the blast hole and is transmits through the rockmass. When this pressure wave (compressive wave) reaches to the free face, it returns back and resulting in tensile stresses. These continuous interceptions waves working on the rock in opposite direction (Duvall & Atchison, 1957) fragments the rock. Since, the tensile strength of the rock is nearly 10 times lower than the compressive strength of the rock (Dey & Sen, 2003) and when the force applied by the tensile wave is higher than the tensile strength of the rock, the rock breaks.

3.1 Effect of the Ratio of Effective Spacing to Effective Burden on Fragmentation - Diagonal vs. V-Type

Burden and spacing are two important aspects of blast design in case of bench blasting. A difference in the drilled blast design variables exists owing to the firing patterns as different holes fire at different times.

3.1.1 Diagonal Firing Pattern (LHS)

In case of diagonal firing pattern, the effective or blasting burden and spacing changes with hole-to-hole firing of the blast round. Such condition can be visualized with the help of Figure 6.

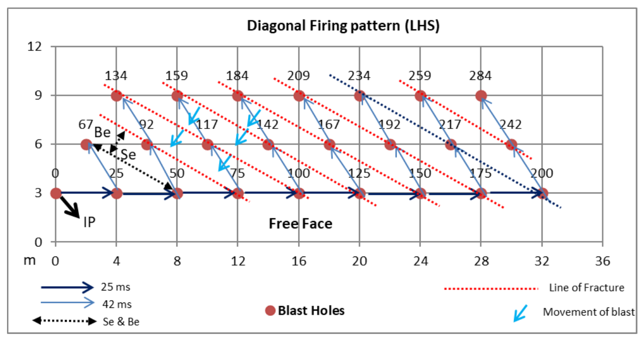


Figure 6. Staggered drilling with diagonal firing pattern (LHS) with direction of movement of blast.

Figure 6 represents a diagonal firing pattern in which dotted lines in black color denote the actual fracture lines while dotted lines in red are effective spacing (Se) and the blue lines the effective burden (Be). The ratio of Se/Be given by Equation 1 mentioned earlier. The only advantage with this firing pattern is that it reduces the effective burden that can result in improved fragmentation.

3.1.2 V-Type Firing Pattern

The V-type firing pattern is on similar lines of fracture with that of the diagonal pattern, but has two such limbs of diagonal firing pattern which are at an angle to each other as described in Figure 7. The geometry of the pattern can thus be used to calculate the blasting burden and spacing. There are several other variations of this

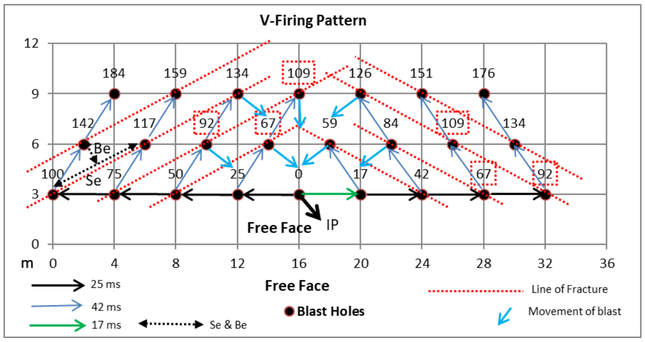


Figure 7. Staggered drilling with V-type firing pattern with direction of movement of blast.

pattern viz. extended V-Pattern and U Pattern wherein the limbs of the firing sequence get extended or modified due to connections. However, such patterns are beyond the scope of this paper.

Figure 7 shows that same line of fracture is achieved as that of the diagonal firing pattern during blasting and hence, as a result *Se/Be* ratio will also be same as achieved with diagonal pattern. However, the movement of each limb is towards each other and hence there are high probabilities of collision during the flight of the fragments.

Many of authors (Choudhary, 2013) advocate that the V-type firing pattern gives smaller fragmentation size compare to diagonal firing pattern due to increase in effective spacing *(Se)* to effective burden *(Be)* ratio (M_b) i.e., increase in effective spacing *(Se)* and decrease in effective burden *(Be)*. Although, the *Mb* shows similar values in both the cases of diagonal and V-Type pattern, the later practically represents a case of two blasts moving towards each other with ample chances of fragment collisions.

3.2 Effect of the Firing Pattern on Free Face Availability of the Blast Face on Fragmentation - Diagonal Vs. V-Type

Considering the case of a bench with two free faces, then in case of the diagonal firing pattern (Figure 6) the pattern generates two free faces for each blast hole and good fragmentation is achieved. However, if blast face is having only one free face, then V-firing pattern (Figure 7) helps to create two free faces for each of the blast hole for achieving good fragmentation, possibly because in this type of firing pattern blast is initiated at the middle of the face and splits into two faces which provide further free face for each row and holes (Chouhan& Raina, 2015a). The opposite lines of blast holes collide with each other and induces further rock fragmentation. Accordingly, the effect of V-type firing pattern on fragmentation is evaluated in this paper.

4.0 Area of the Study

The study was conducted in a limestone mine in India. The deposit belongs to a hilly terrain of Precambrian age of Delhi Super Group. The annual production of mines was 6 MTPA. Compressive strength of limestone varies from 80 to 110 MPa. The mine uses a blast hole diameter of 115 mm. ANFO was used as explosive having density 800 kg/m^3 and average VoD measured was 3700 m/s. The blasts were initiated by shock tube system with delay sequencing of 17ms, 25ms and 42ms. with staggered hole pattern was used for drill pattern. The loading operation was performed by front end loader, shovel and backhoe. The blast muck was transported by 55 MT rear dump trucks. Figure 8 depicts the longitudinal section of a typical blast hole used by the mines.

In order to achieve the objectives of this study, blast trials were conducted in the mines by deploying diagonal and V-type firing patterns. Other variables of the blast

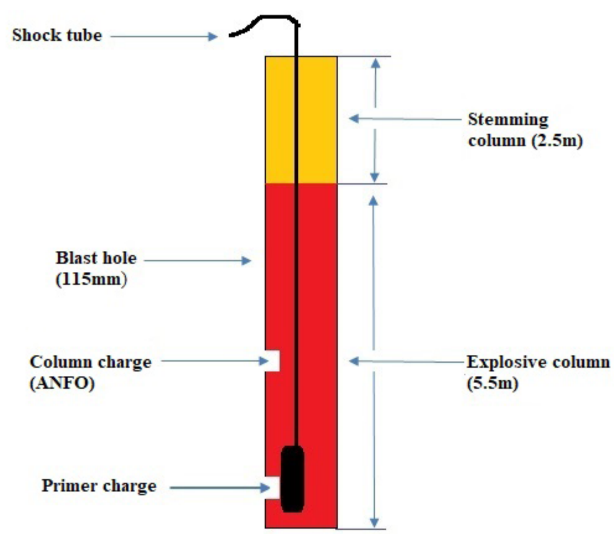
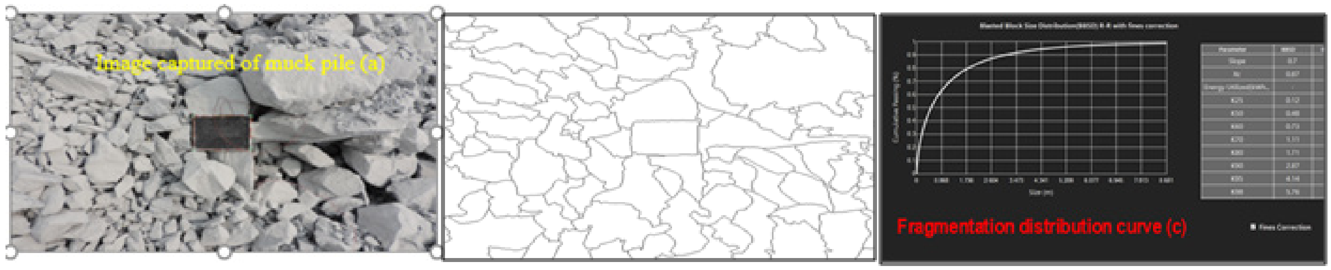


Figure 8. Longitudinal section of the blast hole (not to scale).



(a) (b) (c)

Figure 9 Process of image analysis for quantification of fragmentation **(a)** Original image of fragments with a calibrator **(b)** Network identification by Fragalyst Software, **(c)** Fragment size distribution of the image analyzed.

design were held constant so that the effect of firing patterns on the fragmentation can be compared.

4.1 Fragmentation Assessment

To quantify the rock fragmentation size and its distribution in muck pile, Fragalyst software used. The representative muck pile images were captured at different time interval during excavation of muck pile to cover all size of fragmentation in whole muck pile. The process of fragmentation assessment is depicted by Figure 9.

The process involves taking representative images of the muck generated by a blast and processing these with the help of Fragalyst Software that ultimately results in determination of the mean fragment size (k_{50}) of a blast. Such analysis was performed for all blasts monitored during this study.

5.0 Analysis of the Data Generated

Sixteen full-scale blasts were conducted in the while monitoring of the blast design variables like burden, spacing and stemming, bench height, specific charge, and firing patterns with one free face availability. Summary of the data generated thus is presented in Table 1.
where, D - Diagonal Pattern and V – V-type pattern

Two major outputs viz. throw and fragmentation were evaluated for the said blasts. Since other blast design variables were held constant, the pure effect of change in firing pattern in case of fragmentation can be seen in Figure 10.

The plot of diagonal and V-pattern (Figure 10) shows that there is strong influence of the firing pattern on the fragment size obtained. It is also evident that the fragmentation in case of diagonal patterns is higher (Figure 11) than the those achieved with V-type firing pattern (Figure 12), which supports the hypothesis that there is collisional breakage resulting in further fragmentation. A change of average fragment size from 0.28 m in case of diagonal firing pattern to 0.17 m in case of V-type firing pattern can be seen.

In addition to fragmentation, the throw of the broken rock was also evaluated (Figure 13).

As can be seen from Figure 13, the throw in case of diagonal firing pattern is more than that observed in case of V-type firing pattern and varies over a wide range. The optimum throw of the muck is however obtained in case of V-type firing pattern. A reduction in average throw of 27 m in case of diagonal firing pattern (Figure 14) to 15 m in case of V-type firing pattern has been observed (Figure 15).

One important observation is that the throw of the muck is similar in all blasts in case of V-type firing patterns. This points to the fact that the pattern is better suited to the mine in which trial blasts were conducted.

Table 1. Field data of blasts conducted on diagonal firing pattern variables monitored during the trials

Blast No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ave. Burden (m)	2.79	2.8	2.86	2.82	2.85	2.81	2.83	2.82	2.79	2.8	2.85	2.81	2.74	2.73	2.79	2.71
Ave. Spacing (m)	4	4	4	3.95	4	4	3.95	3.96	3.8	3.8	3.41	3.46	3.89	3.82	3.93	3.81
Ave. Stemming (m)	2.5	2.58	2.5	2.52	2.5	2.5	2.5	2.5	2.5	2.5	2.78	2.5	2.5	2.5	2.5	2.5
Ave. Bench Height (m)	8.85	9.97	8.97	8.41	8.35	9.8	9.8	9.85	9.5	9.5	9.34	9.29	9.78	9.5	9.88	9.25
Ave. Specific Charge (Kg/m3)	0.49	0.48	0.49	0.47	0.5	0.52	0.5	0.51	0.53	0.5	0.55	0.56	0.54	0.51	0.57	0.5
Type of firing pattern	D	D	D	D	D	D	D	D	V	V	V	V	V	V	V	V
Delay (ms)	25 42	25 42	25 42	25 42	25 42	25 42	25 42	25 42	17 25 42	17 25 42	17 25 42	17 25 42	17 25 42	17 25 42	17 25 42	17 25 42
Mean fragmentation size (K50)	0.29	0.29	0.27	0.28	0.27	0.27	0.27	0.29	0.15	0.13	0.21	0.21	0.18	0.16	0.16	0.19
Throw (m)	25	25	25	22	30	30	30	28	14	15	15	16	15	12	16	15

Table 2. The general statistics of the variables measured

Statistics	**Avg. Burden (m)**	**Avg. Spacing (m)**	**Avg. Stemming (m)**	**Avg. Bench Height (m)**	**Avg. Specific Charge (kg/m3)**	**Mean fragment size (k50, m)**	**Throw (m)**
Mean	2.80	3.86	2.52	9.38	0.51	0.23	20.81
Standard Error	0.01	0.05	0.02	0.13	0.01	0.01	1.66
Median	2.81	3.94	2.50	9.50	0.51	0.24	19.00
Mode	2.79	4.00	2.50	9.50	0.50	0.27	15.00
Standard Deviation	0.04	0.18	0.07	0.51	0.03	0.06	6.66
Sample Variance	0.00	0.03	0.01	0.26	0.00	0.00	44.30
Kurtosis	0.15	2.43	13.00	-0.05	-0.50	-1.63	-1.74
Skewness	-0.76	-1.75	3.54	-0.90	0.59	-0.31	0.24
Range	0.15	0.59	0.28	1.62	0.10	0.16	18.00
Minimum	2.71	3.41	2.50	8.35	0.47	0.13	12.00
Maximum	2.86	4.00	2.78	9.97	0.57	0.29	30.00
Sum	44.80	61.78	40.38	150.04	8.22	3.62	333.00
Count	16.00	16.00	16.00	16.00	16.00	16.00	16.00

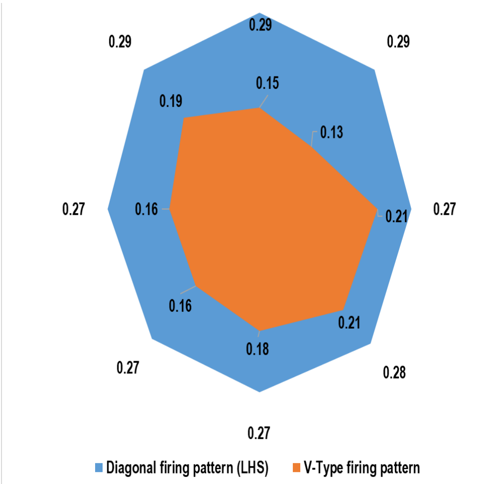


Figure 10. Mean fragmentation size (m) in case of diagonal and V-Type firing patterns.

Figure 12. Good fragmentation in muck pile (V-type firing pattern).

Figure 14. Excess throw of muck pile (diagonal firing pattern, LHS).

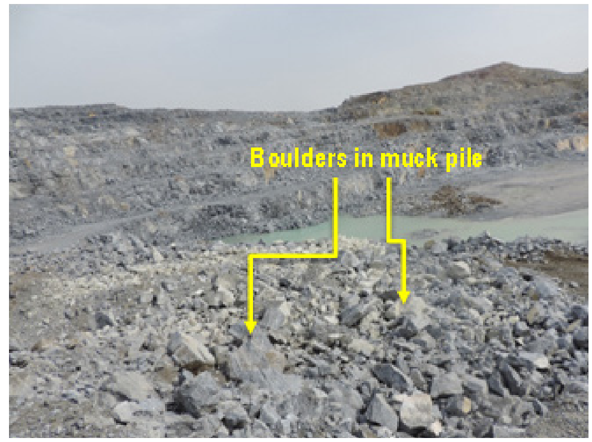


Figure 11. Boulder in muck pile (Diagonal firing pattern, LHS).

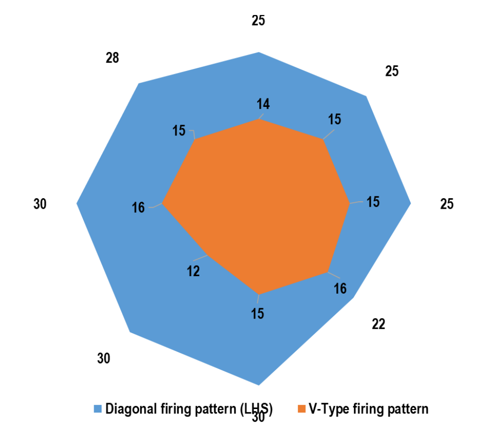


Figure 13. Throw (m) in case of diagonal and V-Type firing patterns.

Figure 15. Optimum throw of muck pile (V-type firing pattern).

6.0 Summary and Conclusions

Blasting produces cracks in rock which can be categorized in two groups, first is visible cracks i.e., major/minor and second is invisible cracks i.e., microcracks. The visible cracks expand by gas pressure generated during blasting and results in fragmentation. However, invisible or internal cracks require additional force to produce further fragmentation. Since in diagonal firing pattern, rock fragmentation moves in a same direction so there are less chances of collision of fragmentation. However, on another hand, V-type firing pattern provides opportunity for collision between opposite line of holes, that helps to provide further fragmentation. In order to satisfy the conditions for further breakage by collision process in case of V-Type pattern several conditions must be met (Chouhan & Raina, 2015b).

Such effect of firing patterns has been evaluated with the help of 16 number of blasts with 8 each with diagonal and V-Type firing pattern in a limestone mine. All other blast design variables were kept constant while varying the firing patterns only. This leads to determination of the pure effect of change in firing pattern on the fragment sizes obtained and the throw of the muck. The data thus acquired showed that there is significant change in fragmentation in case of V-Type firing pattern and counts for 37.66% in comparison with that obtained by deploying the diagonal firing pattern. The throw of the blasts is also controlled in case of V-Type firing pattern with a reduction of 41.70% in comparison with that of the diagonal pattern. This study although limited in cases has demonstrated that the fragmentation is improved in case of the V-Type firing pattern and can be ascribed to the collisional process.

7.0 Acknowledgements

The paper forms a part of the Ph.D. work of the first author. The authors are thankful to their respective employers for their permission to publish the findings. Help of several persons in conducting the study is duly acknowledged.

8.0 Conflict of Interest

The authors declare that there is no conflict of interest to disclose.

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