FIRING PATTERNS AND ITS EFFECT ON MUCKPILE SHAPE PARAMETERS AND FRAGMENTATION IN QUARRY BLASTS

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Abstract

Proper use of firing pattern vis-à-vis the blast requirements can provide optimal blast performance in terms of fragmentation, throw, wall control etc. This is largely attributed to the importance of firing burden in any blast round. By changing the firing patterns the firing burden, and, thereby the ratio of spacing to burden is also subject to change. Proper initiation timing is as important for fragmentation as the burden, spacing, sub drilling, stemming etc. Simultaneous initiation leads to the problems, such as, coarser fragmentation, blasting of a large number of holes at a given time which leads to the other problems. The present research study which was conducted in three limestone quarries where major problems such as of improper fragmentation, poor wall control, and poor heave characteristics of the muckpile were observed. Designed firing pattern was not able to provide the requisite fragmentation, and, even the throw. Modifications in firing pattern were implemented to obtain the required blast results.

Keywords: *Firing pattern, fragmentation, progressive relief, throw, drop, muckpile*

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1. INTRODUCTION

Rock fragmentation assessment plays a key role in the evaluation of efficiency and productivity of quarry blasting. Hence, regular assessment of rock fragmentation is needed to control it. If rock fragmentation is not controlled, it can increase production cost and delay the quarrying process due to unnecessary secondary blasting or crushing. Therefore, blasting design should take into account the findings of rock fragmentation assessment to cut down the mining cost and shorten the work time. Drilling and blasting cost in open pit mines represent 15-20% of the total mining cost [1,2,3]. Apart from the direct costs, blasting efficiency also influences down the line mining costs.

Firing pattern that provides a pathway for the detonation wave of initiation for the explosive charged in the holes. In any blasting programme, the foremost requirement is sequential generation of free face with the blast progression. The free face is known to provide a reflection surface for the shock wave, which is necessary for fragmenting the rock mass [4,5,6,7]. Without free face, the results of blast rounds could be extremely poor. Towards this end, the firing pattern decides the movement and direction of rock by creating free face for subsequent blast holes and rows [8,9,10]. Various firing patterns such as row to row, diagonal, V-type and skewed V-type are used in mines for detonation of explosive. Proper selection of pattern for a blast round can provide optimal blast performance in terms of fragmentation, throw and wall control etc. This is largely attributed to the importance of firing burden in any blast round. By changing the firing pattern, firing burden, and thereby the ratio of spacing to burden is also changes [11].

Proper sequencing of inter hole and inter row delay timing is another important contributor in firing pattern towards good blast results. The systematic release of energy associated with proper burden is crucial in maintaining the continuous momentum for inter row displacements [12]. Inadequate delay in a multirow blast results in poor breakage from the back rows which results in coarse fragment size, large collar boulders, tight muckpile and also back breaks /over breaks [13]. Furthermore, it was suggested that any change in spacing and/or burden must be accompanied by changes in delay timing. Proper timing exerts a control on the number of rows and thus on the number of holes to be blasted in a pattern. Larger blasts with more number of firing rows give fragmentation problems, especially in the back rows ([14]. This was due to provision of improper relief to the blasting rows. Extensive work had been reported by Smith [8], Hagan [9] , Rai et al. [15], and Rai and Choudhary [16] on different types of firing pattern such as row to row, diagonal, and V-type. Each firing pattern has its own application.

Blast result affects the productivity of the loading equipment, not only because of the size distribution of the material, but also because of its swelling and geometric profile of the muckpile. When rope type hydraulic shovels are used, the height of the bench will be the deciding factor for efficiency of the machines and the blasts should be designed so as to provide adequate fragmentation and a muckpile that is not too extended with few low productivity zones. If the front end loaders are used, the tendency will be towards a type of blasting that produces maximum displacement and swelling of the rock, high fragmentation and reduced height of the muckpile. But in case of shovel in use it requires proper height of muck to handle it.

Muckpile shape parameters are throw, drop and lateral spreading (Fig.1). Throw is the horizontal distance up which center of gravity of blasted muck lies, drop of muckpile is the vertically lowering of the blasted muck and lateral spreading is the horizontal distance up to the blasted muck lies. Throw, drop and lateral spreading of the muckpile are essential parameters for effective pay loader operation and looseness of the blasted muck. Greater throw and drop spreads the muckpile laterally, which largely facilitates the digging of the muck by the pay loaders [15, 17].

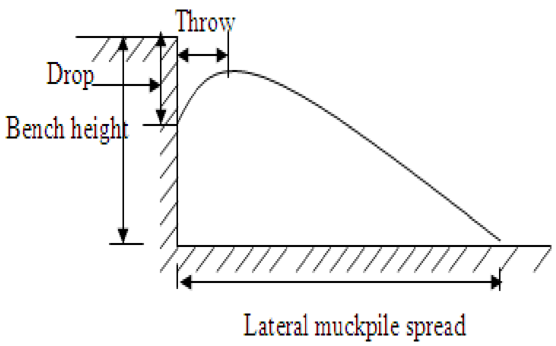
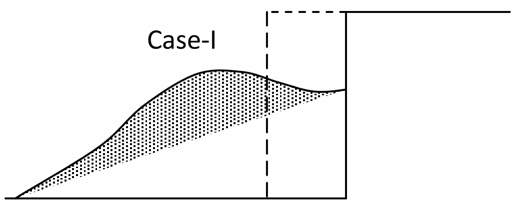
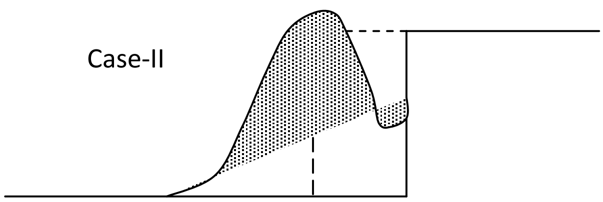


Fig.1: Muckpile shape parameters

The muckpile shape is shown in the Fig. 2 with different cases. Case-I shows large clean up area, low productivity with rope shovel, high productivity with wheel loader and very safe for equipment operation. Case –II shows minimal clean up area, high productivity with rope shovel, and low productivity with wheel loader and dangerous for equipment operation. Case-III shows low clean up area, acceptable productivity and safe for equipment operation.





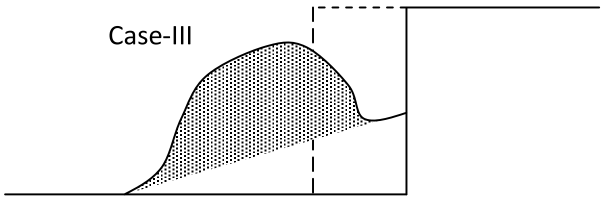


Fig. 2: Profile of the muckpile after blasting [18]

Cunningham [19] analyzed the effect of particle size on product value and production rate. He found that large rocks, and the role of fines in cementing the muckpile, are crucial to the rate of loading. Thote and Singh [20] reported that the muckpile shape and fragment size can be correlated. They found that if the benches are relatively low and shovel is used for digging, the muckpile should not be scattered to ensure a high fill factor. It was observed that in case of coarser fragmentation, muckpile profile was of dome shape and in case of finer fragmentation muckpile profile was spread over large area [21]. This may be due to the inertia and interlocking effect of the coarse fragments.

2. OBJECTIVE

The main objective of research study was to investigate the influence of various firing pattern on fragmentation and muckpile shape so that the blasted muck could be easily loaded by the excavator.

3. RESEARCH METHODOLOGY

In order to fulfill the research objective many full scale blasts were conducted in the two different quarries by varying firing pattern under the similar strata (same bench) and explosive (Ammonium Nitrate Fuel Oil (plant mixed) with shock tube initiation system, density being 0.8 g/cc and the VOD was 3700 m/s.) conditions. The following parameters of the blast were closely monitored and recorded in the field on day-to-day basis.

Muckpile shape parameters: During the fieldwork, throw, drop and lateral spreading of muck for each blast was measured immediately after the blast using tape measurements by taking the offset measurements on blasted muckpile.

Pay loader Cycle time: The cycle time of the pay loaders excavating the muckpile was categorically recorded throughout the excavation history such that realistic cycle time data could be taken as an index to the blast performance. Precise stopwatch was for this purpose. Several researchers [22,23,24] have indicated the relationship between diggability of loading machines with respect to degree of fragmentation in the muckpile.

Fragmentation assessment: Digital image analysis technique was used in the present study by the capturing of scaled digital images of the blasted muck pile to quantify the fragment size and its distribution. In order to cover the entire muck pile, the images were captured at a period interval of 1-hour throughout the excavation history of the muck pile, giving due cognizance to the recommendations made by several researchers [25,26]. The captured images were analyzed by Fragalyst™, a commercial, state-of-art image analysis software (Fig. 3).

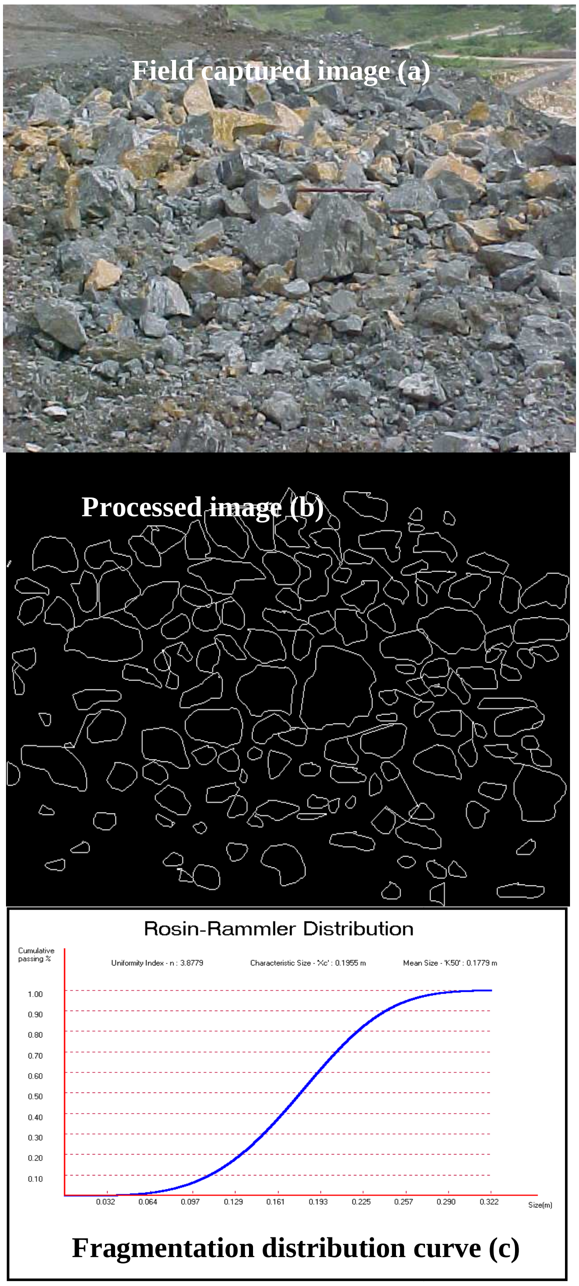


Figure 3: Image analysis for quantification of fragmentation

4. FIELD STUDY

To accomplish these objectives field studies and field data acquisition was conducted at two different limestone quarries. These quarries are owned by two different companies. Quarry-A is situated in Philippines and belongs to the Lafarge cement company, Quarry-B belongs to Ambuja cement, Rajasthan, India. The quarries chosen for the purpose of study were productive quarries of limestone which produce limestone for big cement producing companies. It was stipulated to improve the efficacy of drilling and blasting operations for enhancing the fragmentation which, in turn, affects the downstream operations.

Quarry-A: The annual production of Quarry was over 3 million tonne of limestone. The geology of the deposit was quite difficult owing to frequent shaly and clayey intrusions. The limestone beds, separated at 2-3m interval, were dipping at an inclination of 30 to 40 degree towards the pit. The compressive strength of limestone was about 40 MPa. The specific gravity of limestone was 2.4. The section of mines comprised of seven benches (as shown in Fig. 4) being 7-9m high. Adequate consideration was given to physico-mechanical properties and the geology of the limestone while designing the blast rounds. The designed firing pattern along with the delay sequence is illustrated in Fig. 5 & 6. The explosive used in all the blasts was Ammonium Nitrate Fuel Oil (plant mixed) with shock tube initiation system. The density being 0.8 g/cc and the VOD was 3700 m/s. All the blast rounds were drilled on staggered drilling pattern with ANFO as explosive and sensitized emulsion as primer. The blasts were initiated by shock tube system with delay sequencing of 17ms, 25ms and 42ms. The loading operation was performed by the Front end loader (FEL), Shovel and Backhoe. The blasted muck was loaded on 35 and 50 tonne rear dump trucks. Figure 7 shows the longitudinal section of the blast hole. The section of blast holes for 6.5m bench shows that the length of hole was 7.5 m including 1m of sub-grade drilling.

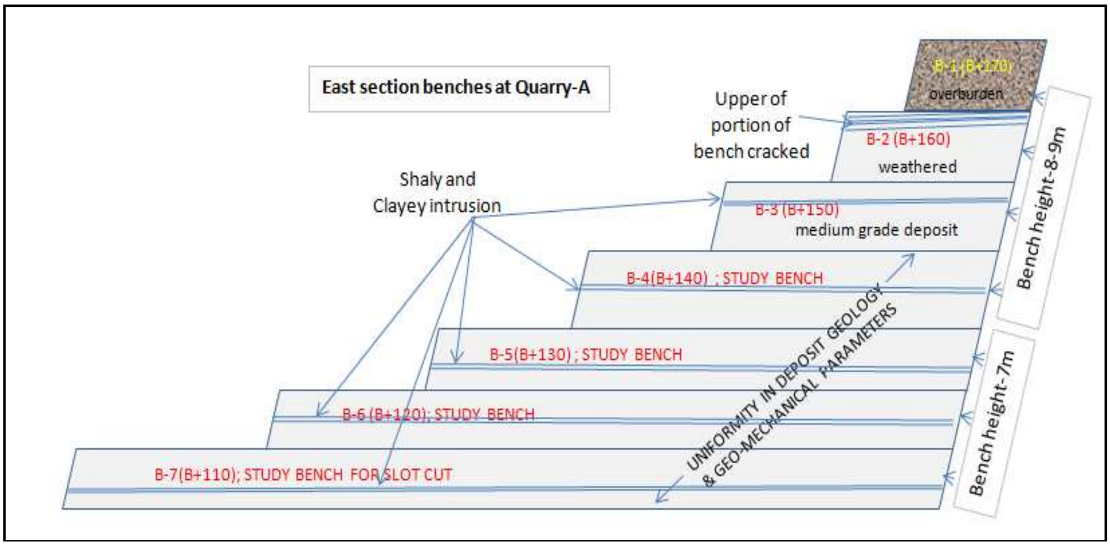


Fig. 4: Benches at quarry-A

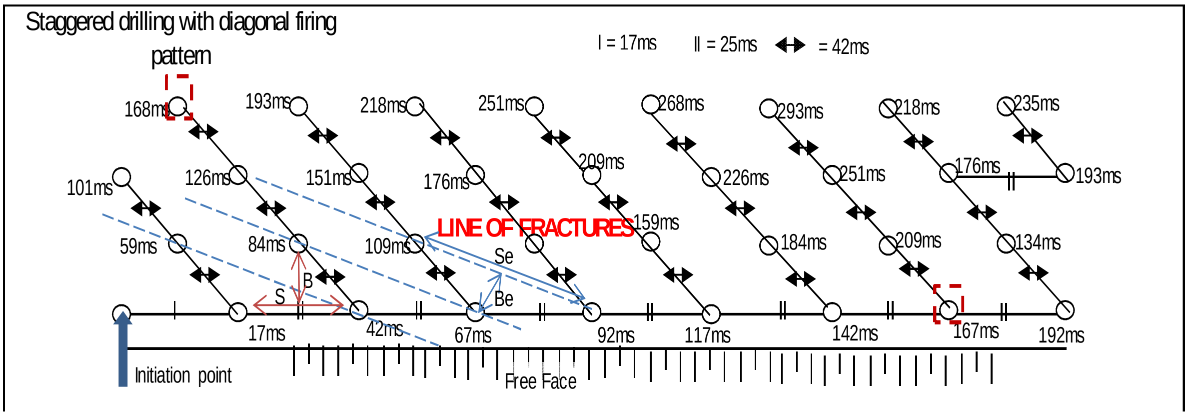


Fig. 5: Staggered drilling with diagonal firing pattern (Blast AB-4)

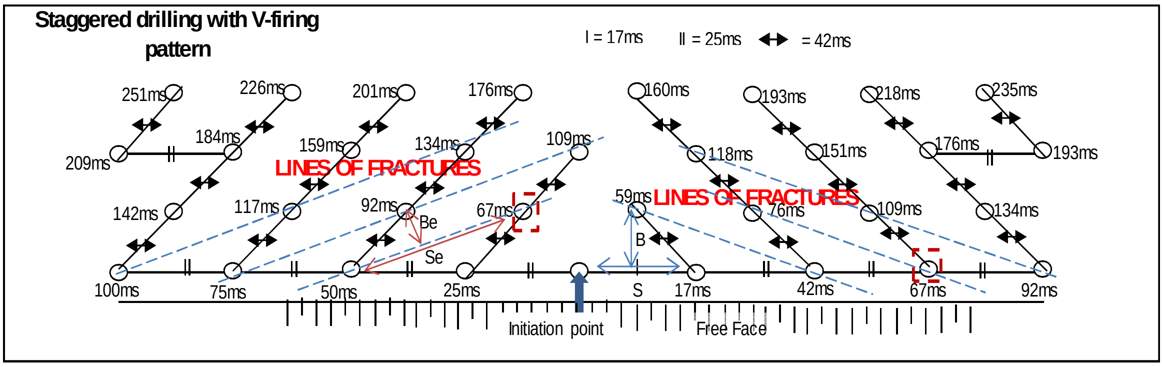


Fig. 6: Staggered drilling with V-firing pattern (Blast AB-12)

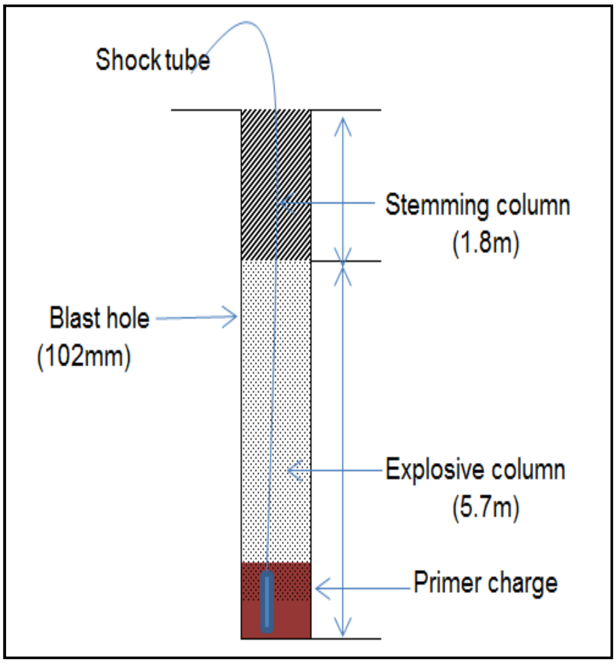


Fig. 7: Longitudinal section of the blast hole

Quarry-B: The mine was producing 2.4Mt of limestone annually from its three different working sections Hill-1, Hill-2 and Hill-3. Each section was having 3-4 production benches. The study was conducted at Hill-3 benches (Fig. 8) because of absence of any significant anomalies in these benches. Upper bench was weathered and low grade limestone hence, the excavated material was dumped in the waste stock yard. The compressive strength of limestone was about 145 MPa. The specific gravity of limestone was 2.7. The designed firing pattern along with the delay sequence is illustrated in Fig. 9 & 10. The explosive used in all the blasts was Ammonium Nitrate Fuel Oil (plant mixed) with shock tube initiation system. The density being 0.8 g/cc and the VOD was 3700 m/s. All the blast rounds were drilled on staggered drilling pattern with ANFO as explosive and sensitized emulsion as primer. The blasts were initiated by shock tube system with delay sequencing of 17ms, 25ms and 42ms. Figure 11 shows the longitudinal section of the blast hole with and without decking. The section of blast holes for 7m bench shows that the length of hole was 8 m including 1m of sub-grade drilling.

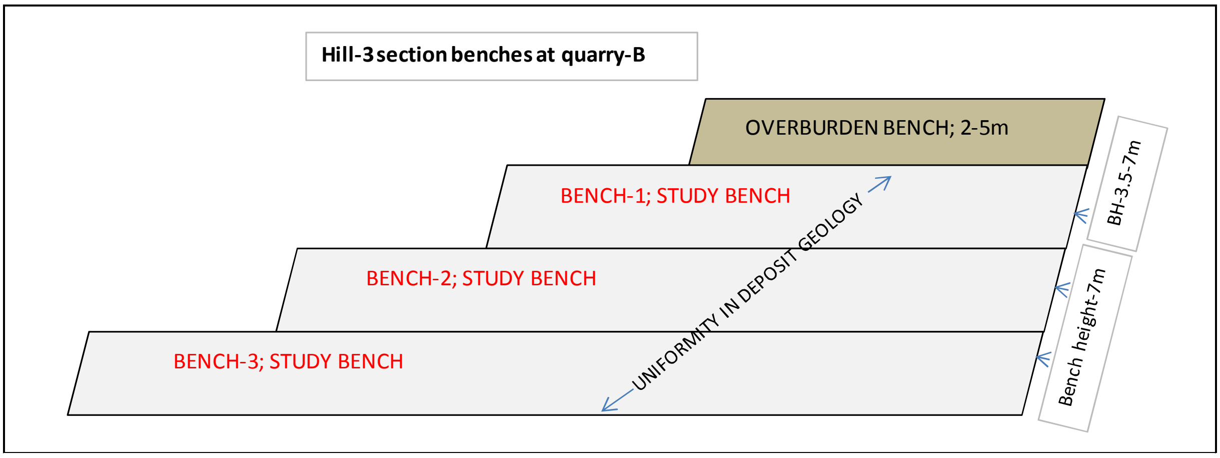


Fig.8: Hill-3 section benches at Quarry -B

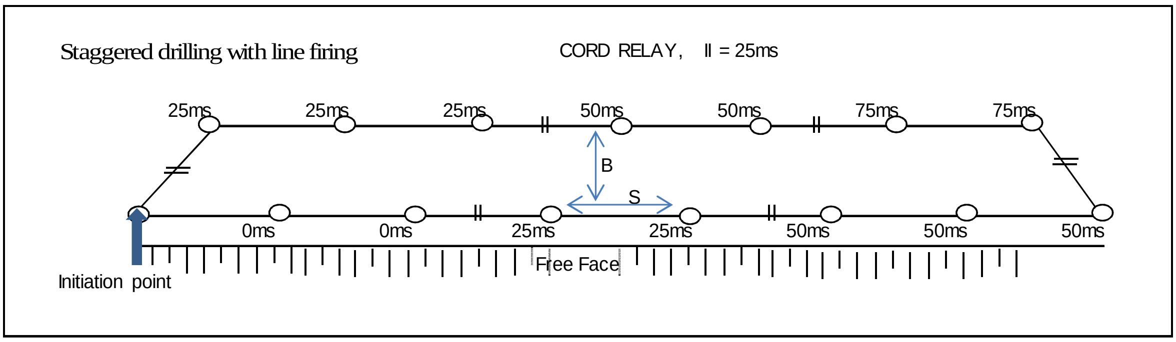


Fig. 9: Staggered drilling with line firing pattern (Blast BB-4)

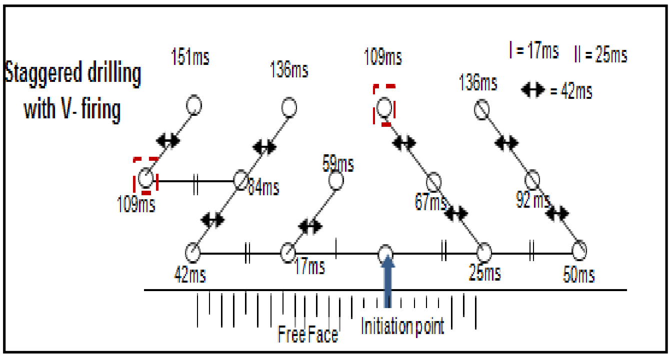


Fig. 10: Staggered drilling with V type firing pattern (Blast BB-7)

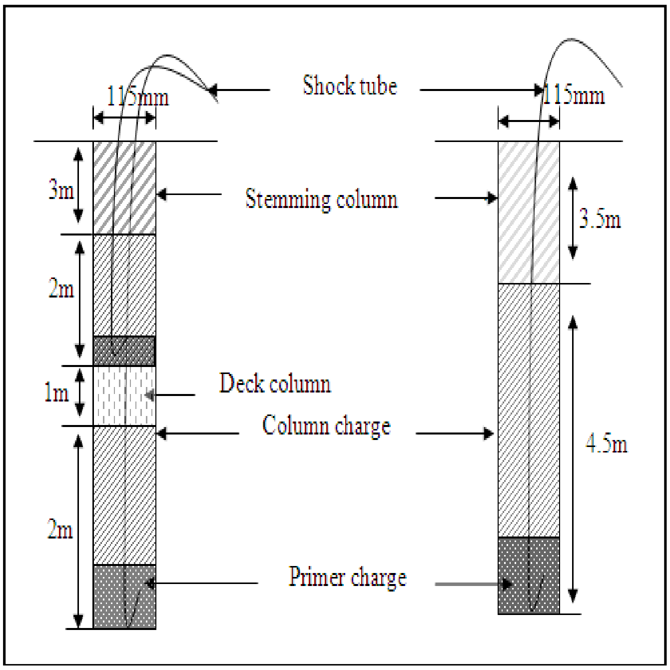


Fig. 11: Longitudinal section of the blast hole (with and without decking)

5. FIELD OBSERVATION, RESULT AND DISCUSSION

5.1 Firing patterns investigations and results at Quarry-A

In this quarry all the blasts were drilled on staggered drilling pattern. The blast holes were bottom initiated with shock tube system. A representative blast hole section with bottom initiation system and a representative staggered drilling with Diagonal and V-type firing pattern with designated inter-row delay timing for one of the blasts for instance, is illustrated in Fig. 5, 6 and 7. Blasts AB-1 to AB-6 was fired on diagonal firing pattern and blasts AB-7 to AB-12 were fired on V-type of firing pattern. The complete fragment size distribution revealing the K20, K50, K80 and K100 for all the blasts AB-1 to AB-12 are given in the fragmentation distribution curves Fig. 21 and 22. The results are tabulated in table 1 and 2.

Table 1: Details of base line data observation for diagonal firing pattern in Quarry-A

Parameters	Blast Number					
	AB-1	AB-2	AB-3	AB-4	AB-5	AB-6
Burden (m)	2.8	2.8	2.8	2.8	3	3
Spacing (m)	3.2	3.2	3.6	3.6	4	4
Depth of holes (m)	6.5	6.5	6.5	6.5	6.5	6.5
No. of holes	49	63	74	34	24	74
No. rows	4	6	7	4	4	4
Total Explosive (kg)	1472	2125	1838	902	723	2021

Firing pattern	Diagonal	Diagonal	Diagonal	Diagonal	Diagonal	Diagonal
Delay	17/25/42	17/25/42	17/25/42	17/25/42	17/25/42	17/25/42
Throw (m)	8	10.5	8	12	12	6
Cycle time (sec)	28.12	49.23	50.19	29.22	28.16	28.76
Total limestone transported (t)	6134	10625	10200	4526	3805	13475
PF (kg/t)	0.24	0.20	0.18	0.20	0.19	0.15
Uniformity index, n	2.44	3.06	3.77	3.31	3.60	3.21
Characteristic size, xc	0.34	0.29	0.37	0.25	0.31	0.42
K20 (m)	0.21	0.18	0.26	0.15	0.21	0.26
MFS, K50 (m)	0.29	0.25	0.35	0.22	0.28	0.37
K80 (m)	0.38	0.33	0.43	0.29	0.34	0.47
K100 (m)	0.49	0.49	0.63	0.41	0.47	0.69

Table 2: Details of experimental blasts conducted on V- firing pattern in Quarry-A

Parameters	Blast Number					
	AB-7	AB-8	AB-9	AB-10	AB-11	AB-12
Burden (m)	2.8	2.8	2.8	2.8	3	3
Spacing (m)	3.2	3.2	3.6	3.6	4	4
Depth of holes (m)	6.5	6.5	9	6.5	9	9
No. of holes	69	30	65	47	36	34
No. rows	5	4	3	3	4	3
Total Explosive (kg)	2250	909	1749	1504	1210	1122
Firing pattern	V	V	V	V	V	V
Delay	17/25/42	17/25/42	17/25/42	17/25/42	17/25/42	17/25/42
Throw (m)	13	10	5	10.15	13.25	9
Cycle time (sec)	29.14	29	29.58	48.7	47	48
Total limestone transported (t)	9000	4132	12493	8847	6368	6234
PF (kg/t)	0.25	0.22	0.15	0.17	0.19	0.18
Uniformity index, n	3.05	3.91	3.12	3.05	3.14	3.14
Characteristic size, xc	0.24	0.13	0.34	0.21	0.15	0.34
K20 (m)	0.15	0.10	0.19	0.14	0.11	0.21
MFS, K50 (m)	0.21	0.12	0.28	0.19	0.14	0.30
K80 (m)	0.27	0.14	0.35	0.25	0.18	0.38
K100 (m)	0.41	0.20	0.46	0.36	0.26	0.45

From the tables 1 it is quite evident that the blasts AB-1 to AB-6 were fired on diagonal firing. Fragmentation in terms of MFS (0.27-0.37m) is satisfactory but the maximum fragment size (K100) (0.41-0.69m) is larger. The K100 value is larger than the optimum fragment size (OFS) (0.22-0.35m). It means fragment size distribution is non-uniform. Oversize fragments were observed (Fig. 12) inside the muck during excavation which increased the average cycle time of the front end loader and backhoe. The muckpile parameters were poor so dozer was deployed to assist the front end loader during separation of collar generated boulders, spreading the muck.

From the table 2 it is evident that the blasts AB-7 to AB-8 were fired on V firing pattern to see its effects on fragmentation results. On perusal of the fragmentation results it reveals considerable improvement in MFS (0. 12-0.30m) and K100 (0.20- 0.46). The improvement in MFS and K100 size (Fig. 14 & Fig. 15) helped in improving the excavation process which resulted less cycle time of loaders and excavators. The throw was almost identical (8-12m) with the diagonal firing but muckpile shape in terms of throw, drop and lateral spreading (Fig.14 &16) was much different than diagonal firing (Fig. 13). These improvements clearly indicate the improvement in the fragmentation within the muckpile. The excavator cycle time also reduced. A little different muckpile profile observed in blast AB-7 (Fig. 16) due to more number of rows.

To this end it must be understood that the firing pattern affects the spacing to burden ratio. By changing the firing patterns the effective spacing to burden ratio (Se/Be) increases in comparison to the drilled spacing to burden ratio. The increased spacing and reduced burden at the time of blasthole initiation, results in increased in-flight collisions of broken rock during its movement hence, improved the fragmentation results.

Fig.12: Large boulder generation in the muck profile (Diagonal firing)

Fig.13: Excessive congestion of the blasted muck along the back rows (Diagonal firing)

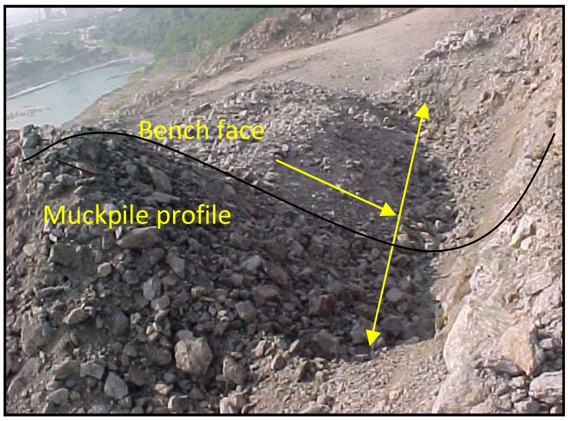


Fig. 14 (a): Good fragmentation within the muckpile with excellent displacement & good wall (V-firing)

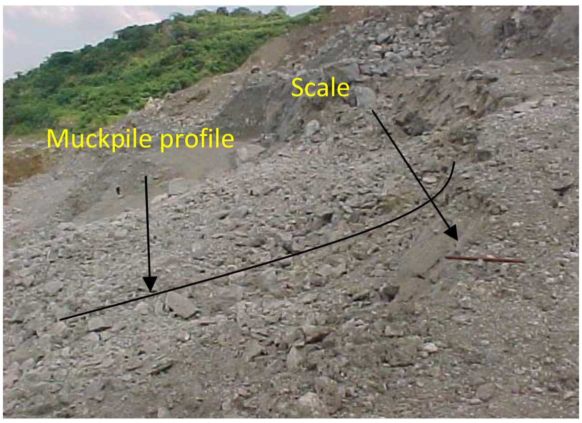


Fig. 14 (b): Good fragmentation within the muckpile with excellent displacement & good wall (V-firing)

Fig.15: Efficient loading by the excavator on evenly fragmented muck (V-firing)

Fig.16: Well displaced muckpile (V-firing)

5.2 Firing patterns investigations and results (Quarry-B)

In this quarry all the blasts were drilled on staggered drilling pattern. The blast holes were bottom initiated with shock tube system. Blasts BB-1 to BB-6 were fired on line firing pattern and blasts BB-7 to BB-12 were fired on v-type of firing pattern, one of the blasts for instance, is illustrated in Fig. 9, 10 and 11. The complete fragment size distribution revealing the K20, K50, K80 and K100 for all the blasts BB-1 to BB-12 are represented in the fragmentation distribution curves (Fig.23 and 24). The results are tabulated in table 3 and 4.

Table 3: Details of experimental blasts conducted on L- firing pattern in Quarry-B

Parameters	Blast Number					
	BB-1	BB-2	BB-3	BB-4	BB-5	BB-6
Burden (m)	2.5	2.5	3	3	3.5	3.5
Spacing (m)	3	3	3.5	3.5	4.5	4.5
Depth of holes (m)	8	8	8	8	8	8
No. of holes	9	27	19	15	10	15
No. of rows	2	4	3	2	2	2
Explosive Quantity(kg)	332	891	610	495	380	570
Firing pattern	L	L	L	L	L	L
Delay	17/25/42	17/25/42	17/25/42	17/25/42	17/25/42	17/25/42
Throw (m)	4.5	2	2	0.5	5	2
Cycle time (sec)	27	23	27	30	32	32
Total limestone transported (t)	1250	3675	3712	2950	2780	4320

PF (kg/t)	0.27	0.24	0.16	0.17	0.14	0.13
Uniformity index, n	2.37	3.00	3.20	3.06	4.09	2.13
Characteristic size, xc	0.39	0.26	0.22	0.32	0.57	0.49
K20 (m)	0.20	0.19	0.14	0.19	0.36	0.24
MFS, K50 (m)	0.33	0.25	0.20	0.28	0.52	0.41
K80 (m)	0.44	0.35	0.25	0.35	0.63	0.61
K100 (m)	0.77	0.49	0.37	0.53	0.82	0.99

Table 4: Details of experimental blasts conducted on V- firing pattern in Quarry-B

Parameters	Blast Number					
	BB-7	BB-8	BB-9	BB-10	BB-11	BB-12
Burden (m)	2.5	2.5	3	3	3.5	3.5
Spacing (m)	3	3	3.5	3.5	4.5	4.5
Depth of holes (m)	8	8	8	8	8	8
No. of holes	14	6	32	21	10	13
No. of rows	3	2	3	4	2	2
Explosive Quantity(kg)	425	206	1060	698	325	420
Firing pattern	V	V	V	V	V	V
Delay	17/25/42	17/25/42	17/25/42	17/25/42	17/25/42	17/25/42
Throw (m)	2	3	2	1	2.5	2
Cycle time (sec)	23	19	20	20	18	18
Total limestone transported (t)	1940	814	4200	4115	2950	3800
PF (kg/t)	0.22	0.25	0.20	0.17	0.11	0.11
Uniformity index, n	3.22	2.81	2.98	3.17	2.33	2.60
Characteristic size, xc	0.30	0.27	0.13	0.18	0.25	0.23
K20 (m)	0.19	0.16	0.09	0.11	0.12	0.13
MFS, K50 (m)	0.27	0.23	0.12	0.16	0.21	0.20
K80 (m)	0.34	0.32	0.15	0.21	0.28	0.28
K100 (m)	0.49	0.48	0.22	0.29	0.51	0.43

From the table 3 it is evident that the blasts fired on line firing pattern generated large boulder count and increased the cycle time of excavator considerably. Some large sized fragments were observed in the blasted muck (Fig. 17 and 18). The K100 value (0.37-0.99m) is larger than the optimum fragment size (OFS) (0.20-0.27m). It was difficult to load by excavator which was having bucket size of 2.4m3.

From the table 2 it is evident that the blasts BB-7 to BB-8 were fired on V firing pattern to see its effects on fragmentation results. On perusal of the fragmentation results it reveals considerable improvement in MFS (0. 12-0.27m) and K100 (0.22- 0.51). The improvement in MFS and K100 size (Fig. 19 & Fig. 20) helped in improving the excavation process which resulted less cycle time (18-23 sec) of loaders and excavators. The muckpile shape in terms of throw, drop and lateral spreading (Fig.18 &20) was much different than line firing (Fig. 17). These improvements clearly indicate the improvement in the fragmentation within the muckpile.

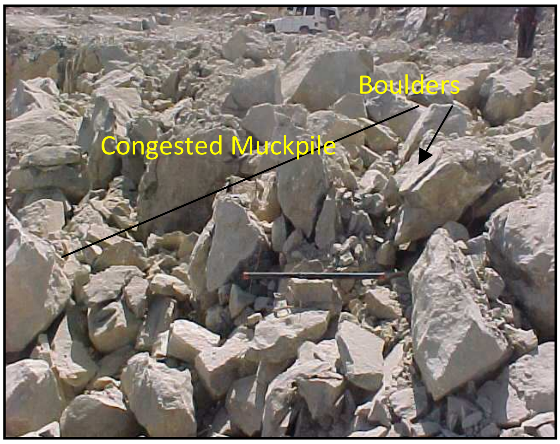


Fig.17: Large boulder generation at the collar region (in line firing)

Fig.18: Large boulders at muckpile slope (in line firing)

Fig. 19: Good fragmentation in loose muckpile (V- firing)

Fig.20: Well displaced muckpile showing proper throw (V-firing)

Significant reduction in the boulder count, clearly indicate the improvement in the fragmentation within the muckpile. In the line firing, all the drill holes in a row are initiated simultaneously and the consecutive rows are delayed as per the prescribed delay sequence. This type of firing causes the burden rock to shear between the boreholes (along spacing) and arrests the full development of crack network around the blasthole. As told that the firing pattern affects the spacing to burden ratio. By changing the firing patterns the effective spacing to burden ratio (Se/Be) increases in comparison to the drilled spacing to burden ratio. The increased spacing and reduced burden at the time of blasthole initiation, results in increased in-flight collisions of broken rock during its movement hence, improved the fragmentation results.

5.3 Relationship between fragment size and cumulative passing

Curves for fragment size vs cumulative passing for each blast round is obtained after processing of field captured photographs using Fragalyst™ software. From the distribution curve, fragment size of K20, K50, K80 and K100 are taken for analysis. These curves were manually plotted on one sheet (Fig.21 to 24) in order to compare the fragment size distribution results.

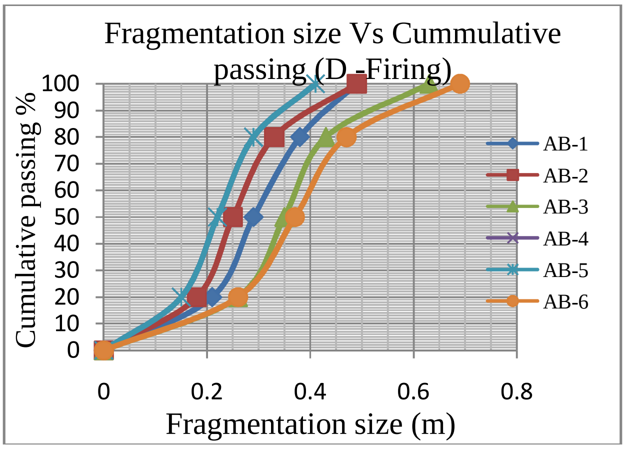


Fig.21: Composite fragment size distribution curve for blast AB-1to AB-6 in Quarry-A

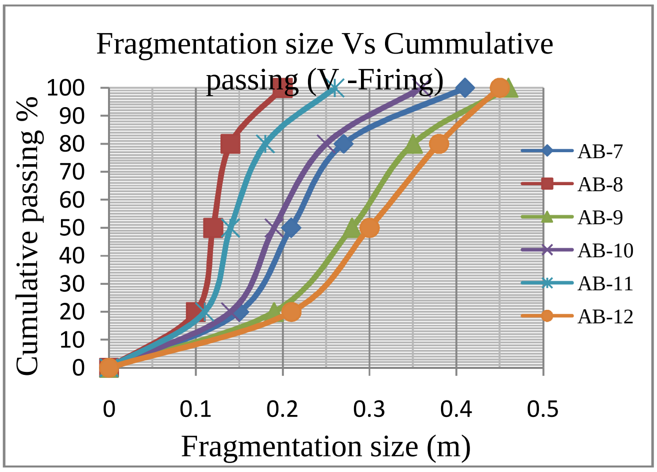


Fig.22: Composite fragment size distribution curve for blast AB-7 to AB-12 in Quarry-A

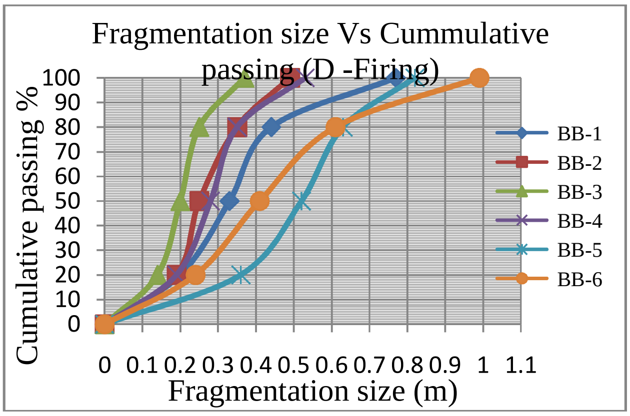


Fig.23: Composite fragment size distribution curve for blast BB-1 to BB-6 in Quarry-B

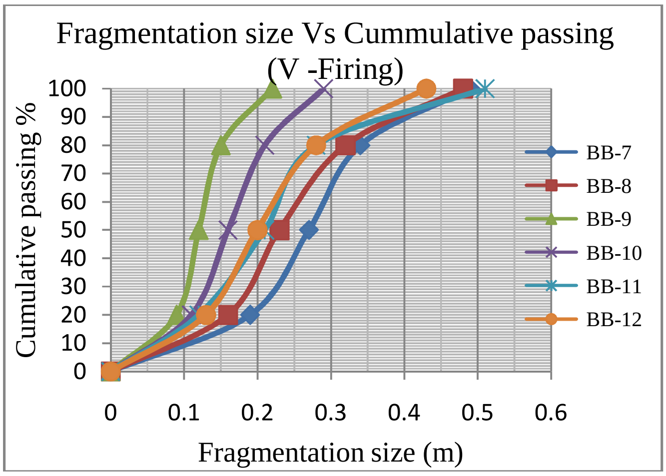
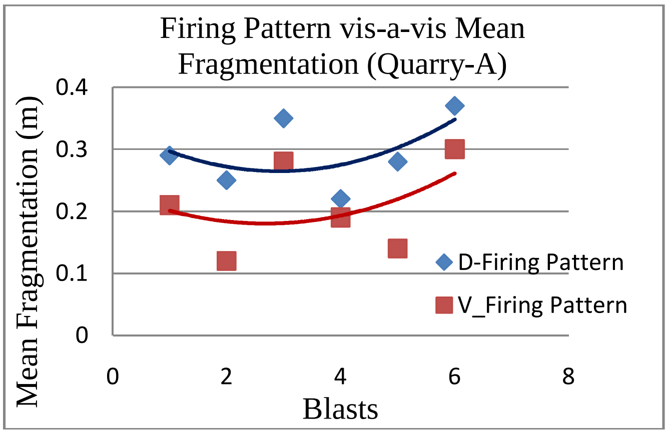


Fig.24: Composite fragment size distribution curve for blast BB-7 to B-12 in Quarry-B

A perusal of figure 21 to 24 clearly appraises the improvement of blast performance. Curves obtained due to diagonal and line firing is flatter in comparison to V firing. Flatness and spread of curve indicates non uniformity of fragmentation, whereas steep and less spread curves reveals uniformity in fragmentation size distribution. Hence, it may be precisely understood that by V firing fragmentation in the muckpile was uniform and good. Additionally, it may be observed from the curves that increased flatness for the line and diagonal firing blasts reveals the spread of maximum fragmentation size beyond the OFS.

5.4 Relationship between Firing Patterns and Mean Fragment Size

The firing patterns vs mean fragments size relationship for analyzed blast round have been deduced from tables 1 to 4. The results are plotted graphically and are shown in Fig. 4.50 to 4.52.



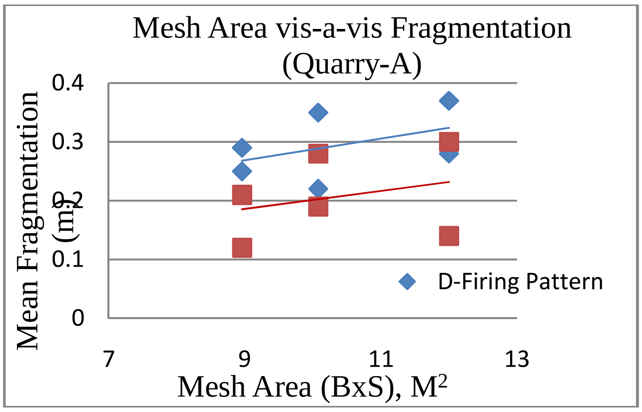


Fig.25: Mean fragment size for Diagonal and V- firing pattern for Quarry-A

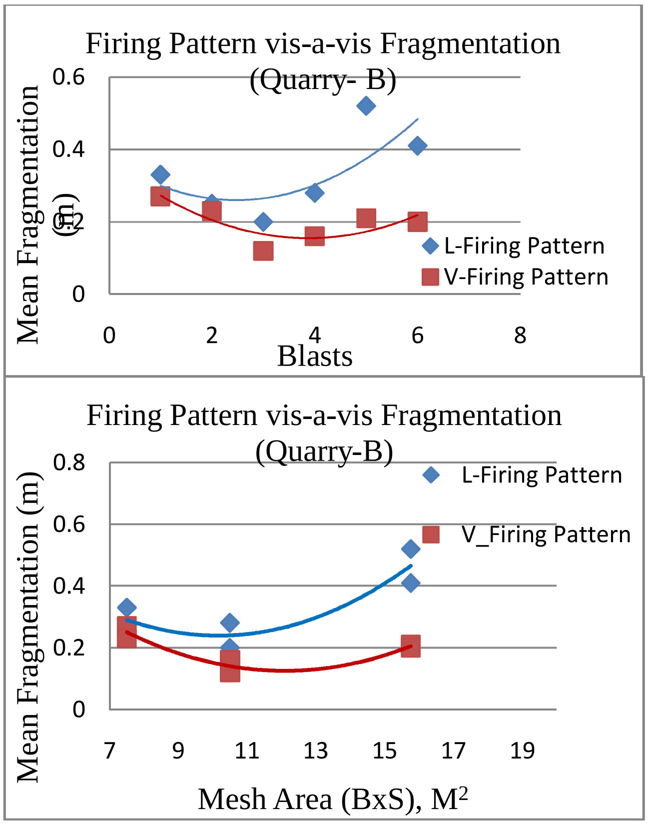


Fig.26: Mean fragment size for L- and V- firing pattern for Quarry-B

It is evident from the figures 25 and 26 that the blast fired with V firing pattern is having lower mean fragment size in comparison to diagonal and line firing pattern. It is also evident from the figure 25 that the fragment sizes increases as the mesh area increases in case of quarry-A but in case of quarry–B it decreases up to mesh area of 13 and then it starts increasing. Optimum mesh area may be obtained considering the OFS for different quarries.

CONCLUSIONS

The following conclusions may be drawn from the present study:

1. The present study clearly reveals the scope and efficiency of state-of –art image analysis technique in conjunction with some important indirect measurement techniques on a comprehensive assessment of fragmentation results.
2. Shift in firing pattern from diagonal/ Line to V-type has been effective in improving the fragmentation and improving the throw, drop and spreading characteristics of the muckpile.
3. Deterioration in muckpile shape parameters naturally implies poor throw and spreading of muck, which entails higher dozing hours especially for front end and more cycle time for other excavators.
4. Mean fragment size (MFS) has been found to be lower in all study blasts with V-firing pattern in comparison to diagonal or in line firing. This may be attributed to the greater inter rock collisions during the burden movement.
5. Concept of optimum mesh area is useful in improving the fragmentation results.
6. To obtain optimum mesh area in the field scale blasts, the approach of implementing systematic incremental mesh areas in conjunction with the thorough documentation of the analysis of results, appears to be fairly reasonable.

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