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Image Processing based Assessment of Blast Performance in Opencast Mines – Case Studies

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Abstract. Rock mass can be fractured by the process of blasting in which a known volume of the material is obtained by using a calculated quantity of explosive. Explosive selected for blasting will be depends on the factors like rock mass parameters, blasting economics, and blast design. Assessment of the performance of a given blast is essential in larger economics of mining project. A study was conducted to know the blast performance at two different mines located in Southern Part of India. High speed videography was used to assess the blast performance and wastage of gaseous energy. With increase in stemming height from 1.0m to 3.5m at different mines in earlier research, it was found that there will be decrease in the escape of gas ejection from 7.42m to 3.5m, which was almost half the height of ejection. Analysis made during the research shows that the maximum velocity of rock movement was found to be 8.97m/s in Mine-A and 12.40m/s in Mine-B. To determine the fragment size distribution, Wipfrag was used which gives quick and accurate measurements. Using Image Processing methodology, it was observed that Blast-4 of Mine-A with explosive charge of about 33.36kg/hole produced finer fragmentation compared to Blast-4 in Mine-B with same explosive charge.

Keywords: High speed videography; Rock mass movement; Fragmentation; Wipfrag.

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Introduction

Rock blasting is done to break the rock mass into smaller pieces in mines and quarries. In order to achieve the desired objective to be performed in the field, precise engineering application of blasting operation is required. In civil engineering projects like construction of dams, tunnels or caverns hard rock mass has to be removed, using blasting process (Floyd, 1987; Nabiullah et al., 2002). Blasting process can be finished in few seconds and it is not possible to assess the performance of the blast with naked eye (Bhandari, 1997). To view the blast and analyse the design performance of a blast, high speed video camera is used, which can capture video and can be played back to view in slow motion (Chiappetta and Mammele, 1988).

The paper aims at assessing the blast performance using High Speed Video Camera of AOS Technologies, Switzerland, in two different opencast limestone mines located in Southern India. Studies were carried out at limestone Mine-A of Tamilnadu State and limestone Mine-B of Andhra Pradesh State (Figure 1).

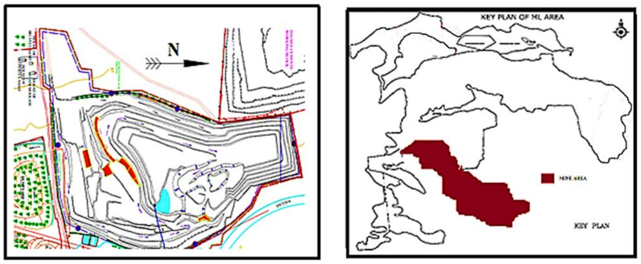


Figure 1a. Mine A

Figure 1b. Mine B

Figure 1. View of limestone mines

Methodology

In total, 22 blasts were carried out in two mines to assess the performance of blasts using image processing technique. High speed video camera was used to record all the blasts (Figure 2). The parameters used in blasting studies are listed in Table 1.

Blastholes were of 115mm diameter in both mines A and B. Depth of blastholes was varying from 5m to 10m in Mine-A, 2m to 9.5m in Mine-B. The fragmentation in blasted muck piles was analysed by Wipfrag software. Slurry explosive available in the form of cartridges was used as primer and column charge in Mine-A, whereas in Mine-B slurry explosive available in the form of cartridges was used as primer and ANFO was used as column charge (CO, 1987).

Table 1. Summary of blasts studied

Limestone Mine-A

Specifications	Blast Number				
	1	*2*	*3*	*4*	*5*
Bench height (m)	5.0	6.0	7.0	7.5	10.0
Burden (m)	2.5	2.5	2.5	2.5	2.5
Spacing (m)	3.0	3.0	3.0	3.0	3.0
No. of blastholes	13	24	23	18	20
Explosive/ hole (kg)	19.25	25.02	29.37	33.36	40.03
Total exp. charge (kg)	250.20	600.48	675.54	600.48	800.64
Stemming (m)	1.5	1.4	1.5	1.4	1.0

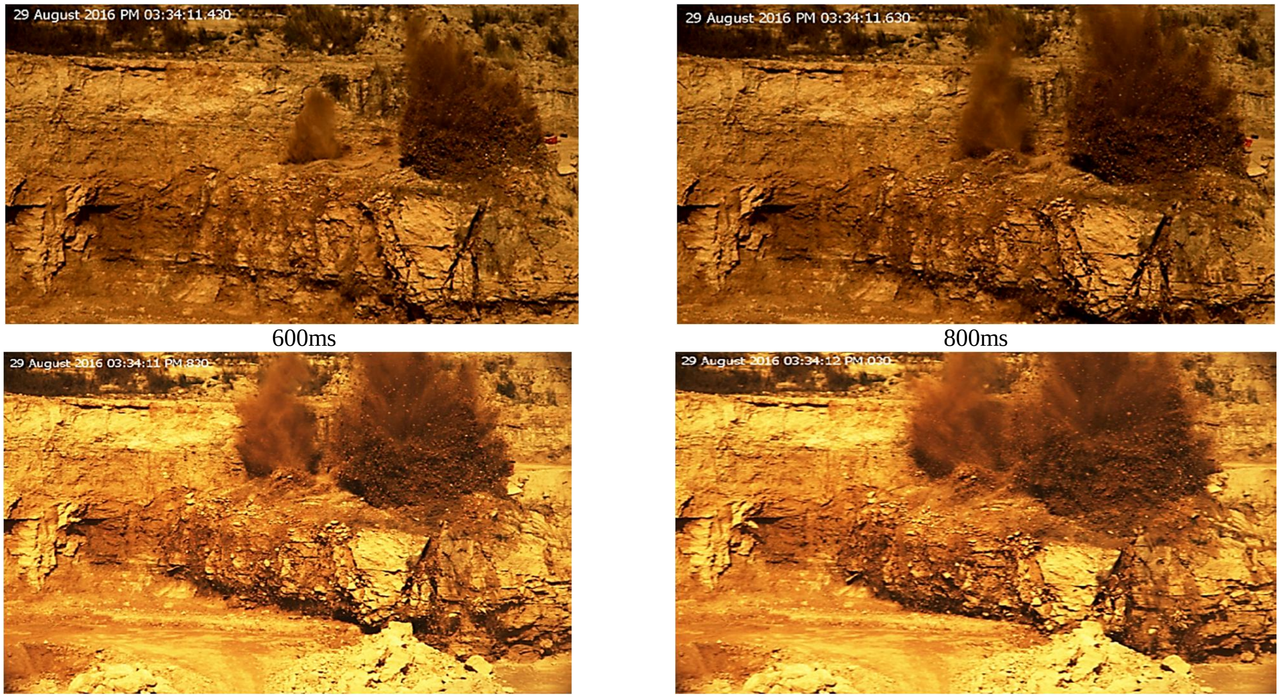
Limestone Mine-B

Specifications	Blast Number				
	1	*2*	*3*	*4*	*5*
Bench height (m)	2.0	3.5	5.0	8.0	9.5
Burden (m)	2.0	2.0	3.0	2.5	3.0
Spacing (m)	3.0	3.0	5.0	5.0	6.0
No. of blastholes	17	12	10	27	15
Explosive/ hole (kg)	03.82	07.00	09.40	33.33	48.21
Total exp. charge (kg)	65.00	85.00	94.00	900.00	723.00
Stemming (m)	1.6	2.7	3.5	3.5	3.7

Image Processing Analysis obtained from the high speed videography of 1000 frames per second capacity was used to understand the dynamics involved in the blasts, which in turn reduce the costly trials that are necessary for optimizing the blast design. High speed video camera provides results on the spot and recorded video can be played using imaging studio (Chiappetta and Mammele, 1987; Sastry et al., 2015a).

Figure 2. High speed video camera of 1000fps capacity

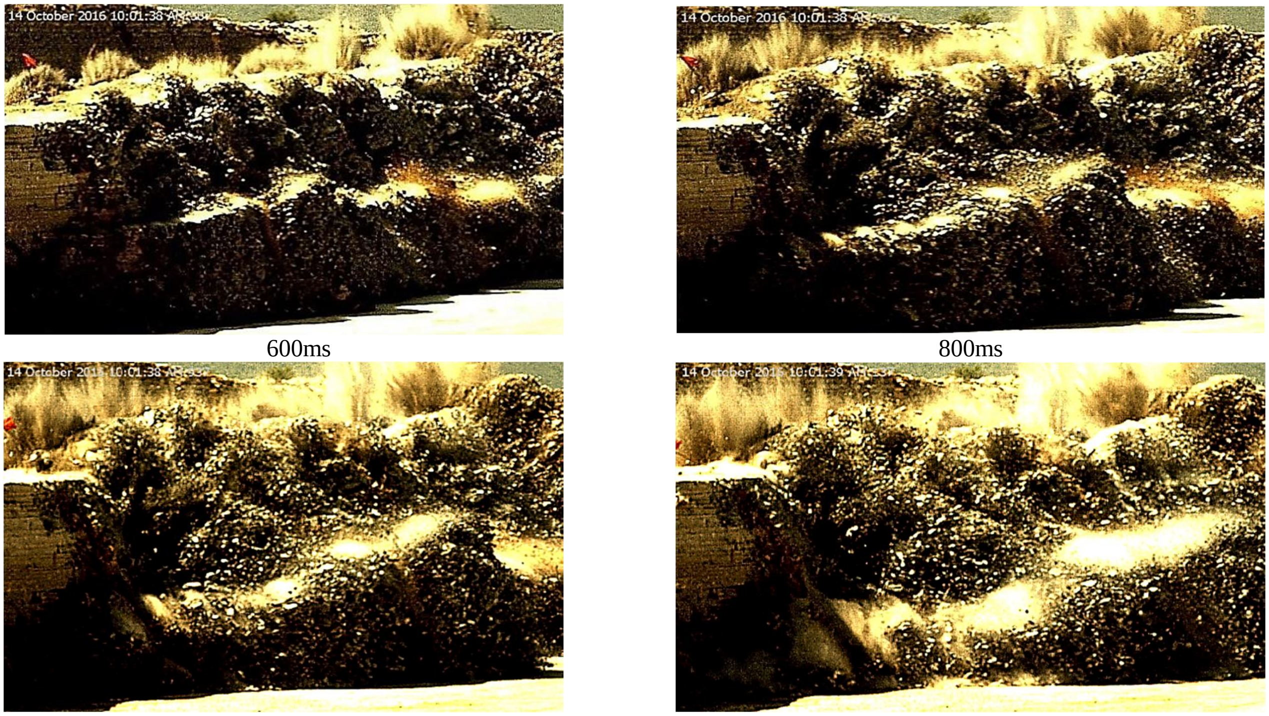
Pro-analyst provides a series of video processing and motion analysis that can be applied to any video or image sequence which will allow users to measure the displacement and velocity of moving fragments (Sastry et al., 2014). It is also used to track particles and know the ejection of gas energy from stemming zone of blasthole (Sastry et al., 2015b). Sequence of blasts with specific time intervals from the time of initiation in Mine-A and Mine-B was observed using high speed video camera and further image processing analysis was carried out using the recorded video (Figures 3 and 4).



600ms 800ms

1000ms 1200ms

Figure 3. Typical blasting sequence in Mine-A



600ms 800ms

1000ms 1200ms

Figure 4. Typical blasting sequence in Mine-B

Fragmentation resulting from blasts was assessed by taking photos of muck pile generated from blasts. After each blast, photos were taken covering various layers of entire muck pile during the process of shovelling at regular intervals. Photos were collected and the process was continued till the entire muck pile got excavated. Wipfrag based image processing analysis was carried out to investigate the fragmentation. Wipfrag uses the technique of analysis of digital image processing of blasted rock to predict the grain size distribution in a muck pile. Scale device was used to view the reference of each sizing zone as a calibrator (Jha, 2013). Muck pile of a blast was photographed and image is then transferred to Wipfrag system. Muck pile generated from different production scale blasts are shown in Figure 5.

Mine-A

Mine-B

Figure 5. Typical muck pile obtained from the blasts

Results and Discussion

To track down the rock movement of bench face and find out the escape of gaseous energy, Pro-analyst was used (Ash, 1973). Research study based on image processing analysis revealed that the bench height of 10m in Mine-A resulted in gas ejection of 7.42m, whereas the bench height of 7.5m in the same mine resulted in gas ejection of 8.73m. Thus, it may be interpreted that wastage of gas energy was less in taller benches. Figure 6 shows typical case analysis in Mine-A, and Figure 7 for Mine-B.

Comparison of gas ejection from Mine-A and Mine-B using image processing results revealed that gas ejection was found to be more in Mine-A. This may be due to lesser stemming height in Mine-A when compared to Mine-B. Stemming height of 1.0m in Mine-A resulted in gas ejection of 7.42m, whereas stemming height of 3.5m in Mine-B which resulted in gas ejection of 3.82m, which was almost half the height in Mine-B.

Height of bench

Escape of gas energy

Tracking of burden rock mass

Displacement of rock mass

Figure 6. Analysis of a blast in Mine-A

Height of bench

Escape of gas energy

Tracking of burden rock mass

Displacement of rock mass

Figure 7. Analysis of a blast in Mine-B

Velocity of burden rock was varying from 6.58m/s to 8.97m/s in Mine-A and 8.34m/s to 12.4m/s in Mine-B. Burden rock movement was found to be greater in both mines by increasing the bench height to burden (BH/B) ratio. Velocity of 6.58m/s resulted with charge factor of 0.28kg/m^3 and velocity of 8.97m/s resulted with charge factor of 0.41kg/m^3 in Mine-A. In Mine-B, a velocity of 8.34m/s resulted with charge factor of 0.18kg/m^3 and 12.4m/s with charge factor of 0.25kg/m^3. Thus in both mines A and B, the velocity of burden rock was found to increase with an increment in charge factor. Comparative results of rock mass velocity with BH/B ratio are précised in Table 2 and Table 3.

Table 2. Comparison of Velocity of rock movement with BH/B ratio

Limestone Mine-A

Parameters	Blast number				
	1	2	3	4	5
Time (s)	1.2	1.1	0.9	0.8	0.8
Velocity (m/s)	6.58	7.68	7.95	8.29	8.97
BH/B ratio	2.0	2.4	2.8	3.0	4.0

Limestone Mine-B

Parameters	Blast number				
	1	2	3	4	5
Time (s)	0.9	0.8	0.8	0.7	0.7
Velocity (m/s)	8.34	9.26	8.76	9.57	12.4
BH/B ratio	1.0	1.75	1.67	3.2	3.16

Table 3. Comparison of Velocity of rock movement with charge factor

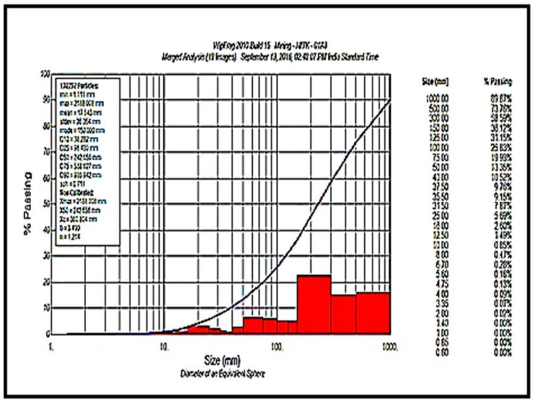
Limestone Mine-A

Parameters	Blast number				
	1	2	3	4	5
Volume (m^3)	900	1620	1800	1500	1950
Velocity (m/s)	6.58	7.68	7.95	8.29	8.97
Charge factor (kg/m^3)	0.28	0.37	0.38	0.40	0.41

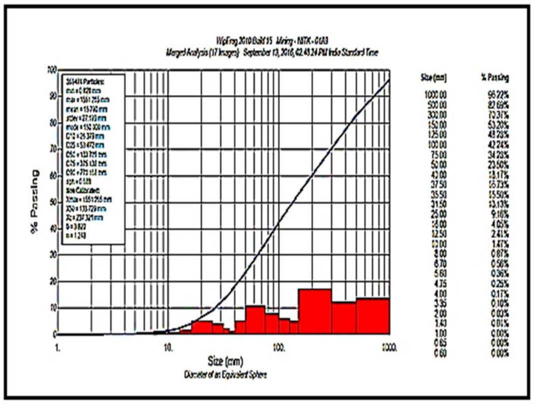
Limestone Mine-B

Parameters	Blast number				
	1	2	3	4	5
Volume (m^3)	360	425	450	3750	2892
Velocity (m/s)	8.34	9.26	8.76	9.57	12.4
Charge factor (kg/m^3)	0.18	0.20	0.21	0.24	0.25

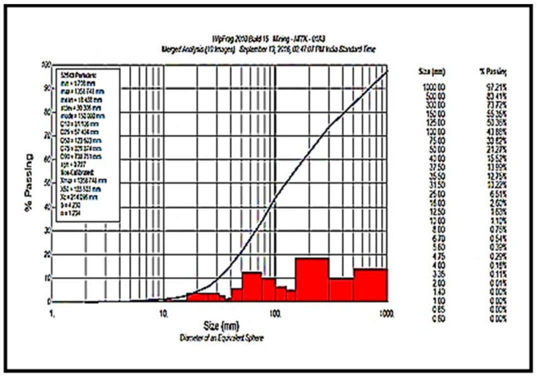
Output of fragmentation analysis obtained from Wipfrag based image processing analysis comprises of cumulative size in both the limestone mines and results are shown in Figures 8 and 9.



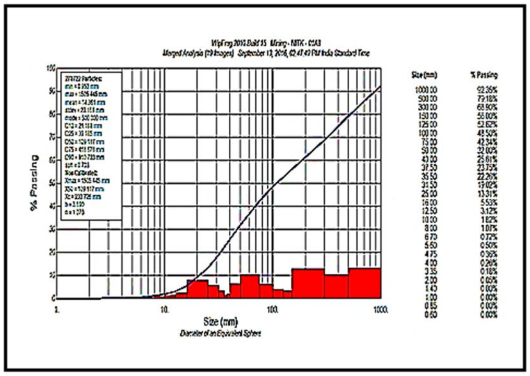
a Blast-1



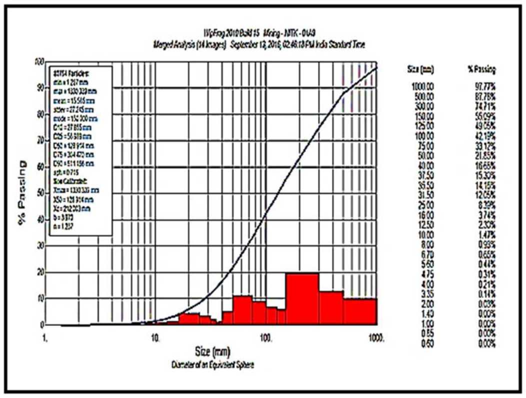
b Blast-2



c Blast-3

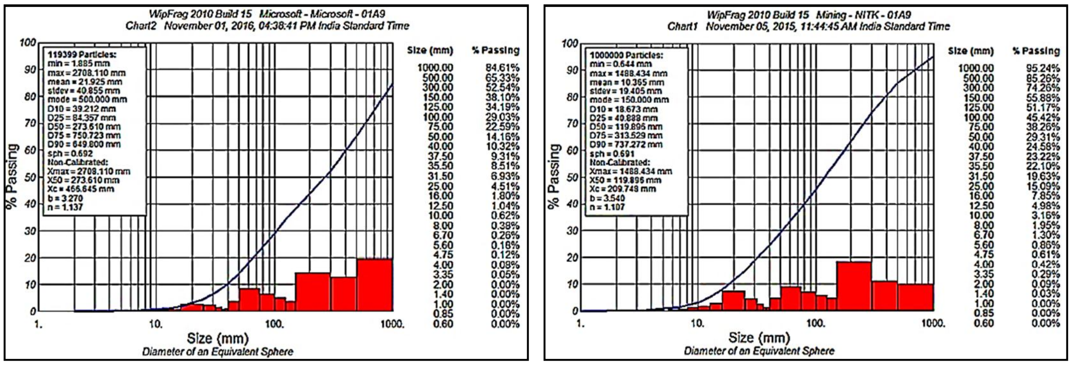


d Blast-4



e Blast-5

Figure 8. Fragmentation analysis of different blasts at Mine-A



```
119399 Particles:
min = 1.885 mm
max = 2708.110 mm
mean = 21.925 mm
stdev = 40.855 mm
mode = 500.000 mm
D10 = 39.212 mm
D25 = 84.357 mm
D50 = 273.610 mm
D75 = 750.723 mm
D90 = 649.800 mm
sph = 0.692
Non-Calibrated:
Xmax = 2708.110 mm
X50 = 273.610 mm
Xc = 466.645 mm
b = 3.270
n = 1.137
```

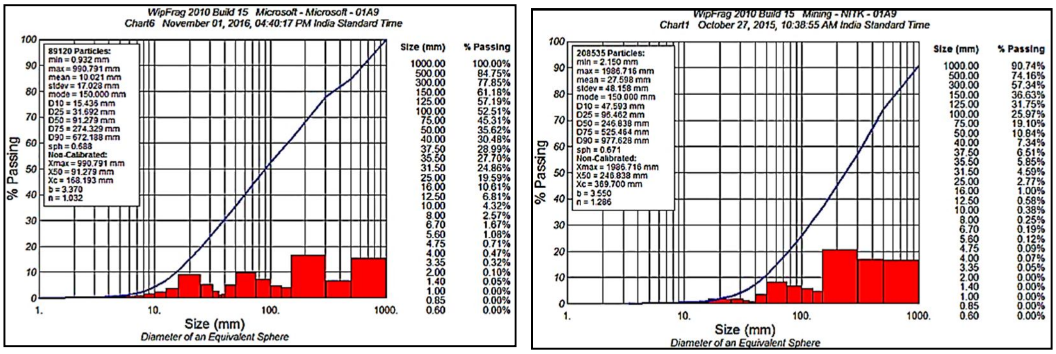
Size (mm)	% Passing
1000.00	84.61%
500.00	65.33%
300.00	52.54%
150.00	38.10%
125.00	34.19%
100.00	29.03%
75.00	22.59%
50.00	14.16%
40.00	10.32%
37.50	9.31%
35.50	8.51%
31.50	6.93%
25.00	4.51%
16.00	1.80%
12.50	1.04%
10.00	0.62%
8.00	0.38%
6.70	0.26%
5.60	0.18%
4.75	0.12%
4.00	0.08%
3.35	0.05%
2.00	0.00%
1.40	0.00%
1.00	0.00%
0.85	0.00%
0.60	0.00%

a Blast-1

```
1000000 Particles:
min = 0.644 mm
max = 1488.434 mm
mean = 10.365 mm
stdev = 19.405 mm
mode = 150.000 mm
D10 = 18.673 mm
D25 = 40.888 mm
D50 = 119.896 mm
D75 = 313.529 mm
D90 = 737.272 mm
sph = 0.691
Non-Calibrated:
Xmax = 1488.434 mm
X50 = 119.896 mm
Xc = 209.748 mm
b = 3.540
n = 1.107
```

Size (mm)	% Passing
1000.00	95.24%
500.00	85.26%
300.00	74.26%
150.00	55.88%
125.00	51.17%
100.00	45.42%
75.00	38.26%
50.00	29.31%
40.00	24.58%
37.50	23.22%
35.50	22.10%
31.50	19.63%
25.00	15.09%
16.00	7.85%
12.50	4.98%
10.00	3.16%
8.00	1.95%
6.70	1.30%
5.60	0.86%
4.75	0.61%
4.00	0.42%
3.35	0.29%
2.00	0.09%
1.40	0.03%
1.00	0.00%
0.85	0.00%
0.60	0.00%

b Blast-2



```
89120 Particles:
min = 0.932 mm
max = 990.791 mm
mean = 10.021 mm
stdev = 17.028 mm
mode = 150.000 mm
D10 = 15.436 mm
D25 = 31.692 mm
D50 = 91.279 mm
D75 = 274.329 mm
D90 = 672.188 mm
sph = 0.688
Non-Calibrated:
Xmax = 990.791 mm
X50 = 91.279 mm
Xc = 168.193 mm
b = 3.370
n = 1.032
```

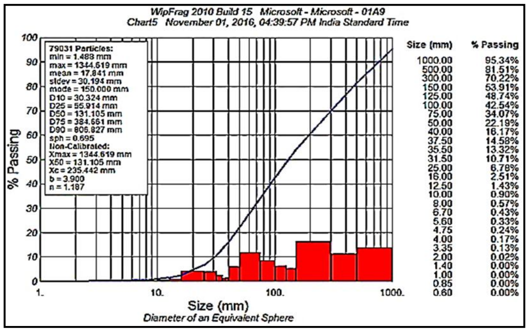
Size (mm)	% Passing
1000.00	100.00%
500.00	84.75%
300.00	77.85%
150.00	61.18%
125.00	57.19%
100.00	52.51%
75.00	45.31%
50.00	35.62%
40.00	30.48%
37.50	28.99%
35.50	27.70%
31.50	24.86%
25.00	19.59%
16.00	10.61%
12.50	6.81%
10.00	4.32%
8.00	2.57%
6.70	1.67%
5.60	1.08%
4.75	0.71%
4.00	0.47%
3.35	0.32%
2.00	0.10%
1.40	0.05%
1.00	0.00%
0.85	0.00%
0.60	0.00%

c Blast-3

```
208535 Particles:
min = 2.150 mm
max = 1986.716 mm
mean = 27.598 mm
stdev = 48.158 mm
mode = 150.000 mm
D10 = 47.593 mm
D25 = 96.462 mm
D50 = 246.838 mm
D75 = 525.464 mm
D90 = 977.628 mm
sph = 0.671
Non-Calibrated:
Xmax = 1986.716 mm
X50 = 246.838 mm
Xc = 369.700 mm
b = 3.550
n = 1.286
```

Size (mm)	% Passing
1000.00	90.74%
500.00	74.16%
300.00	57.34%
150.00	36.63%
125.00	31.75%
100.00	25.97%
75.00	19.10%
50.00	10.84%
40.00	7.34%
37.50	6.51%
35.50	5.85%
31.50	4.59%
25.00	2.77%
16.00	1.00%
12.50	0.58%
10.00	0.38%
8.00	0.25%
6.70	0.19%
5.60	0.12%
4.75	0.09%
4.00	0.07%
3.35	0.05%
2.00	0.00%
1.40	0.00%
1.00	0.00%
0.85	0.00%
0.60	0.00%

d Blast-4



```
79031 Particles:
min = 1.488 mm
max = 1344.619 mm
mean = 17.841 mm
stdev = 30.194 mm
mode = 150.000 mm
D10 = 30.324 mm
D25 = 55.914 mm
D50 = 131.105 mm
D75 = 384.661 mm
D90 = 806.827 mm
sph = 0.695
Non-Calibrated:
Xmax = 1344.619 mm
X50 = 131.105 mm
Xc = 235.442 mm
b = 3.900
n = 1.187
```

Size (mm)	% Passing
1000.00	95.34%
500.00	81.51%
300.00	70.22%
150.00	53.91%
125.00	48.74%
100.00	42.54%
75.00	34.07%
50.00	22.19%
40.00	16.17%
37.50	14.58%
35.50	13.32%
31.50	10.71%
25.00	6.78%
16.00	2.51%
12.50	1.43%
10.00	0.90%
8.00	0.57%
6.70	0.43%
5.60	0.33%
4.75	0.24%
4.00	0.17%
3.35	0.13%
2.00	0.02%
1.40	0.00%
1.00	0.00%
0.85	0.00%
0.60	0.00%

e Blast-5

Figure 9. Fragmentation analysis of different blasts at Mine-B

Image processing based fragmentation analysis revealed major insights that may not be observed by naked eye. In Mine-A, Blast-4 with explosive charge of about 33.36kg/hole produced coarser fragmentation compared to Blast-5 with explosive charge of about 40.03kg/hole. In Mine-B, Blast-4 with explosive charge of about 33.33kg/hole produced coarser fragmentation compared to Blast-5 with explosive charge of about 48.21kg/hole. Similarly, in mine-A Blast-4 with explosive charge of about 33.36kg/hole produced finer fragmentation compared to Blast-4 in mine-B with explosive charge of about 33.33kg/hole. Fragmentation results of Mine-A and Mine-B are formulated in Tables 4 and 5.

Table 4. Fragmentation values obtained from blasts in Mine-A

Blast Number	Number of Holes	Percentage Passing				
		1000 (mm)	500 (mm)	300 (mm)	150 (mm)	100 (mm)
1	13	89.87	73.76	58.59	36.12	25.83
2	24	96.22	82.69	70.37	53.20	42.24
3	23	97.21	83.41	73.72	55.35	43.88
4	18	92.35	79.18	68.90	56.00	52.62
5	20	97.77	87.78	74.71	55.09	42.19

Table 5. Fragmentation values obtained from blasts in Mine-B

Blast Number	Number of Holes	Percentage Passing				
		1000(mm)	500(mm)	300(mm)	150(mm)	100(mm)
1	17	84.61	65.33	52.54	38.10	29.03
2	12	95.24	85.26	74.26	55.88	45.42
3	10	100.00	84.75	77.85	61.18	52.51
4	27	90.74	74.16	57.34	36.63	25.97
5	15	95.34	81.51	70.22	53.91	42.54

Conclusions

High speed videography is a very good image processing tool for analysing the performance of blast in mines and quarries, in terms of tracking down the burden rock movement, behaviour of bench with different explosive loading and initiation pattern, ejection of stemming from stemming zone, role of structural discontinuities, etc. Similarly, the digital image processing techniques predicted the fragmentation size resulting from blasts quite effectively. Following are the major understandings from the study carried out in two different limestone mines:

- From the image processing analysis carried out, it was observed that bench height of 10m resulted in 7.42m of stemming ejection (on average) and bench height of 7.5m resulted in 8.73m of stemming ejection (on average). Hence, it may be concluded that increase in bench height results in lesser stemming ejection, and better utilisation of explosive energy.
- Results clearly indicating an increase in burden rock movement with upsurge in charge factor. Velocity of 6.58m/s resulted with a charge factor of 0.28kg/m^3, whereas velocity of 8.97m/s resulted with increased charge factor of 0.41kg/m^3. It was observed from the image processing analysis that greater velocity of rock mass movement was resulted with an increase in bench height.
- Bench height to burden (BH/B) ratio of 2.0 was resulted in burden movement / burden rock velocity of 6.58m/s and 2.8 was resulted in burden movement / burden rock velocity of 7.95m/s.
- From the Wipfrag based image processing analysis, there was a clear indication of increased charge factors resulting in enhanced fragmentation.

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