Assessing the Explosive Energy Utilization in Mine Blasting – Role of High Speed Videography

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Abstract:

Blasting activity involving the utilization of explosive energy is an important operation in mining and civil engineering projects for obtaining fragmentation and displacement of the hard strata. A study was taken up in three different limestone mines to assess the blast performance. Analysis of the blasts was done using High Speed Video Camera for assessing burden rock movement and wastage of gaseous energy. High Speed Videography revealed the release of gaseous energy prematurely through structural discontinuities in the face. Analysis indicated the maximum burden rock movement of about 15.25m/s in Mine - A, 8.265m/s in Mine - B and 8.667m/s in Mine - C. Analysis of funneling effect of gaseous energy (through stemming ejection) revealed higher gas energy release with shorter stemming columns. Blasts in Mine - C having a bench height of about 7m, resulted in 2.36m gas ejection through stemming zone which is 20% higher funneling compared to blasts in Mine - B whose bench height is about 8m with stemming ejection of about 1.96m. When the stemming height in blastholes increased from 2m to 2.75m, there is 2 - 3 times decrease in the escape of gas energy through stemming zone as observed by High Speed Video Camera.

Keywords: *High Speed Videography, Blast Performance, Burden Rock Mass Movement, Funneling, Fragmentation.*

1. Introduction:

Rock blasting is the major task in opencast mines to fragment the strata for achieving required production with desirable fragmentation and with minimum side effects. Many technological developments happened in the recent past for safe and efficient usage of explosives. ANFO based explosives are safer and in the study which was taken up in three limestone mines, ANFO is used as explosive column (Anon, 1987),[1] (Jha, 2013).[2] The effectiveness of ANFO is assessed in the given limestone formations, along with its ability to produce optimum fragmentation, the side effects like ground vibrations, noise, fly rock etc. Trivedi et al. (2014).[3]

The proposed paper aims at assessment of the performance of blasts using High Speed Video Camera in three opencast limestone mines located in Southern India. Studies were conducted in a scientific manner in terms of fragmentation, muck pile disposal, and wastage of explosive energy through ground vibrations and escape of gas energy through stemming zone (Mishra, 2012),[4] Nabiullah et al. (2002).[5] Investigations were carried out in two limestone Mines - A and B belonging to Telangana, while one limestone Mine - C belonging to Andhra Pradesh (Figure 1).

Mine - A

Mine – B

Specifications	Blast Number				
	1	*2*	*3*	*4*	*5*
Bench height (m)	8	9	9	9	9
Burden (m)	3	3	3	3	3
Spacing (m)	6	6	6.3	6	6.3
No of Blastholes	84	53	59	61	68
Explosive/ Hole (kg)	47	54	45	47	49
Total Exp. Charge (kg)	3975	2850	2975	2875	3320
Stemming (m)	2	2.5	2.75	2.5	2.5

Mine - C

Figure 1: View of limestone mines

2. Methodology:

In total, 35 blasts were conducted in all three mines to assess the blast performance. All blasts were recorded by high speed video camera (Figure 2). Various blast parameters used in studies are listed in Table 1. Blastholes were of 115mm diameter. Depth of the blastholes was varying from 8m to 9m in Mine - A, 6m to 8m in Mine - B and 6m to 7m in Mine - C. The fragmentation in blasted muckpiles was analyzed by digital image processing based Wipfrag software.

Specifications	Blast Number						
	1	*2*	*3*	*4*	*5*	*6*	*7*
Bench height (m)	8	7	6	7.5	8	6	7.5
Burden (m)	3	3	3	3	3	3	3
Spacing (m)	6	5.5	5.5	6	6	5.5	5.25
No. of Blastholes	34	30	34	26	34	26	63
Explosive/ Hole (kg)	46	37	31	46	49	34	41
Total Exp. Charge (kg)	1550	1100	1050	1200	1650	875	2574
Stemming (m)	2.5	2.25	2.25	2.5	2.5	2	2

Figure 2: High speed video camera of 1000fps capacity

Table 1: *Summary of blasts studied*
Limestone Mine - A
Limestone Mine - B
Limestone Mine - C

Specifications	Blast Number						
	1	*2*	*3*	*4*	*5*	*6*	*7*
Bench height (m)	7	7	7	7	7	6	7
Burden (m)	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Spacing (m)	6	6	6	6	6	6	6
No. of Blastholes	16	30	24	18	30	20	10
Explosive/ Hole (kg)	39	37.5	35	37	38	25	28
Total Exp. Charge (kg)	625	1125	841	658	1150	492	283
Stemming (m)	2.5	2.5	3	3	2.5	3.5	3.5

The millisecond delay configuration in all blasts was also monitored. High speed video camera used to record the blasts is of S-MOTION model camera. S-MOTION is a compact, portable high speed camera used in industrial research and biochemical analysis. Camera provides results on the spot and recorded video is played using imaging studio software. It is having the features of downloading/conversion of data to PC non - volatile memory. Use of point and click measurements in software is a practical tool for measurements for recording videos Chiappetta et al. (1988),[6] Chiappetta et al. (1990),[7] Sastry et al. (2013).[8]

Following are the features of the camera adopted:

- It is capable to capture up to 1000 fps
- It has 2 lens
  - One can capture up to 70mm
  - The other external lens can capture from 70mm to 300mm
- The camera has MMC card of 8Gb (can capture a video up to 5 - 6s).

Data obtained from High speed photography is used to determine Chiappetta et al. (1987),[9]

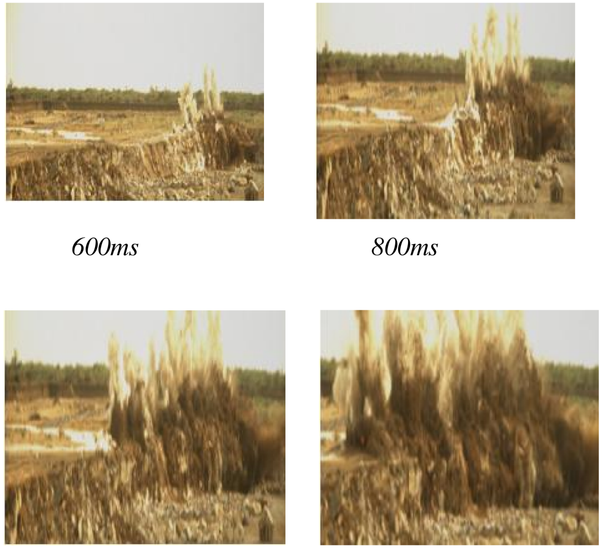
- Causes of misfires
- Poor loading practices
- Poor firing practices
- Effects of gas venting
- Delay intervals between holes
- Optimum initiating system
- Massive ground movement
- Source of oversize
- Explosive efficiency
- Optimum explosive rock burden combination
- Muck profiles

Studies carried out by Sastry and Chandar (2015) [10] further established the role high speed videography in assessing the performance of gas energy wastage through stemming zone and the major joints in bench face.

Full scale studies carried out by Sastry et al. (2015)[11] established a clear correlation between fragmentation and bench height, as per the analogy developed by Ash(1975).[12] This study also revealed clearly the escape of gaseous energy through major jointing in the benches.

Sequence of some typical blasts with the respective timing intervals from the point of initiation in three limestone mines are shown in Figures 3, 4 and 5. From the analysis made by these videos, it is observed that there was a similarity in the average velocity of burden rock mass in Limestone Mines - B and C.

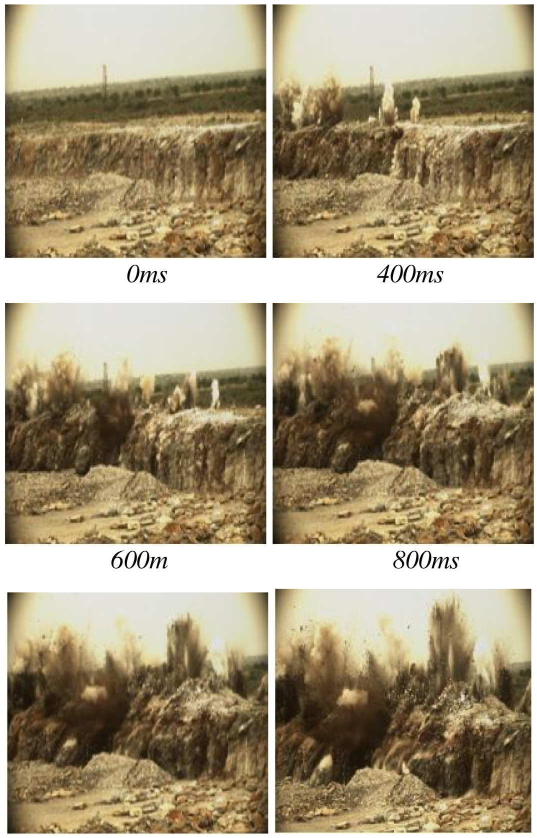
0ms *400ms*



600ms *800ms*

1000ms *1200ms*

Figure 3: Sequence of a blast with specified delay intervals: limestone mine - A



0ms *400ms*

600m *800ms*

1000ms *1200ms*

Figure 4: Sequence of a blast with specified delay intervals: limestone mine - B

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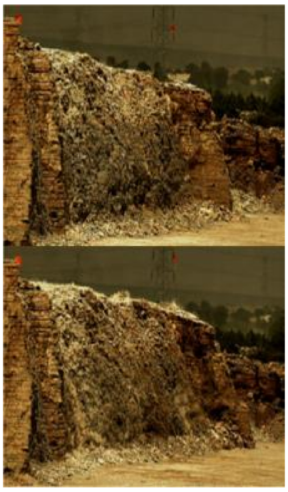


0ms *400ms*

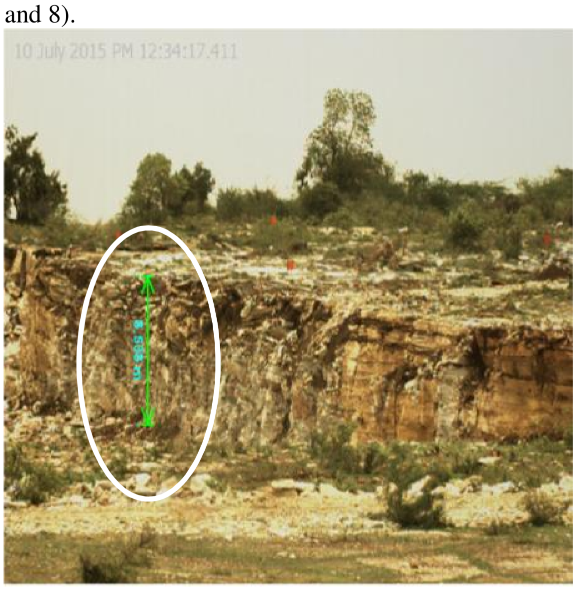
600ms *800ms*

1000ms *1200ms*

Figure 5: Sequence of a blast with specified delay intervals: limestone mine – C

3. Results and Discussion:

ProAnalyst software was used to track down the rock movement of bench face, find the escape of gaseous energy through stemming zone, and measure the displacement of rock from the bench face and angle of rock trajectory. Also the height of the benches or throw of material was found digitally (Figures 6, 7 and 8).



Height of the bench obtained as 8.538m

Tracking of burden rock mass during blast

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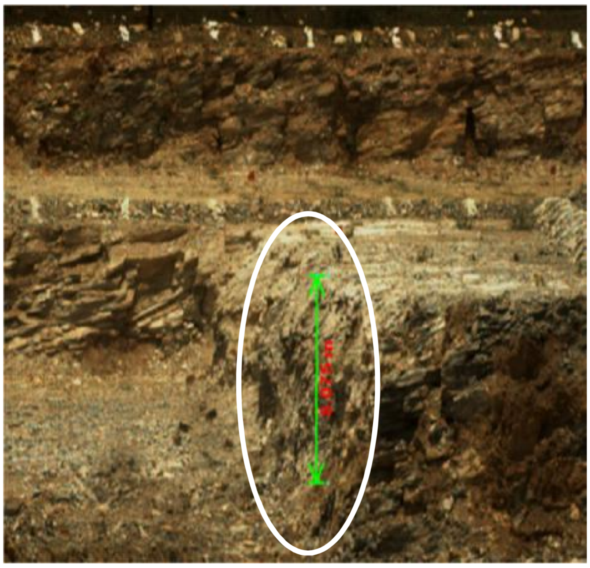
Displacement of rock movement

Figure 6: Analysis made for a blast in limestone mine - A



Height of the bench obtained as 8.075m

Tracking of burden rock mass during blast

Displacement of rock movement obtained as 6.637m

Figure 7: Analysis made for a blast in limestone mine - B

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Height of the bench obtained as 7.038m

Tracking of burden rock mass during blast

Displacement of rock movement obtained as 3.945m

Figure 8: Analysis made for a blast in limestone mine - C

Also the escape of gas energy from the bench face, due to geological discontinuities was also analyzed (Figure 9).

Mine - A

Mine - B

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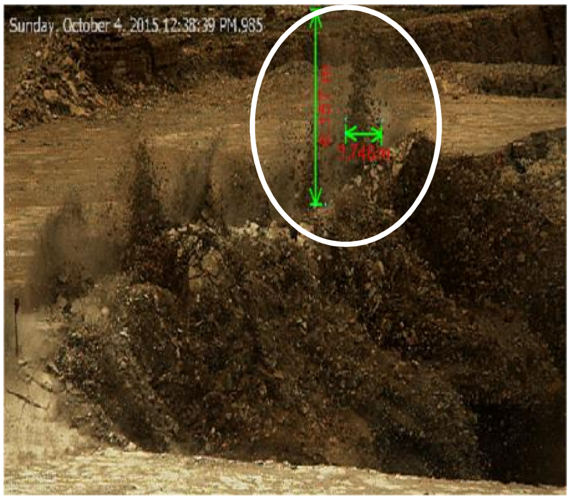
Mine - C

Figure 9: Escape of gaseous energy from the bench face

The escape of gas energy through stemming zone was observed in all three limestone mines (Figure. 10).

Mine - A

Mine - B



Mine - C

Figure 10: Analysis of stemming ejection (smallest and largest funnels observed)

The velocity of burden rock mass movement during the blast was observed for some of the blasts conducted (Table 2). The average velocity of bench movement from all the blasts conducted in respective mines was determined to be 15.25m/s in Mine - A, 8.265m/s in Mine - B and 8.876m/s in Mine - C. From the results obtained it is observed that Mine - A with average bench height of 9m is predominantly giving faster moment to burden rock mass compared to that of Mine - B and Mine - C with average bench heights of 8m and 7m respectively. Therefore, from the results it is concluded that with a maximum value of 9m average bench height, the velocity of bench movement will be maximum in Mine - A compared to Mines - B & C whose bench heights are 8m and 7m respectively.

With increase in bench height to burden ratio, velocity of burden rock is observed to increase. Greater BH/B ratio indicates the more flexure the bench in the beam analogy as proposed by Ash (1973).[13] In Mine - A, it is observed from the High Speed Videography analysis that Blast - 4 with 68 blastholes and a maximum Bench Height to Burden (BH/B) ratio of 3 has maximum velocity of rock movement, of about 27.8 m/s compared to Blasts - 2 and 3 with similar BH/B ratio with blastholes 53 and 59 respectively. Similarly in Mine - B, Blast - 5 with 63 blastholes and a maximum BH/B ratio of 2.67 resulted in a maximum velocity of rock movement about 10.3m/s compared to Blast - 1 with similar BH/B ratio with 34 blastholes. In Mine - C, Blast - 5 with 39 blastholes and a maximum BH/B ratio of 2 resulted in maximum velocity of rock movement 12.6m/s compared to Blasts - 1, 2, 3 and 4 whose blasthole depth is lesser than Blast - 5. From the analysis made, it is concluded

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that as BH/B ratio increases, the velocity of rock movement increases due to reduced stiffness of bench (Table 2).

Table 2: Comparison of velocity of rock movement with Bench Height to Burden ratio

Limestone Mine - A

Parameters	Blast Number			
	1	*2*	*3*	*4*
Displacement (m)	15.1	7.74	8.44	18.07
Time (s)	1	0.8	1	0.65
Velocity (m/s)	15.1	9.67	8.44	27.8
BH/B ratio	2.67	3	3	3

Limestone Mine - B

Parameters	Blast Number				
	1	*2*	*3*	*4*	*5*
Displacement (m)	7.09	6.64	7.45	9.27	5.01
Time (s)	1	0.81	0.9	0.9	0.7
Velocity (m/s)	7.09	8.25	8.28	10.3	7.12
BH/B ratio	2.67	2.34	2.5	2.67	2

Limestone Mine - C

Parameters	Blast Number					
	1	*2*	*3*	*4*	*5*	*6*
Displacement (m)	3.94	3.71	2.69	2.67	2.47	1.41
Time (s)	0.46	0.42	0.33	0.3	0.19	0.23
Velocity (m/s)	8.58	8.88	8.16	8.89	12.6	6.15
BH/B ratio	2	2	2	2	2	1.71

In Mine - A, Vertical drilling was adopted for blastholes in one blast (Blast - 2) out of five blasts conducted. From the analysis made by ProAnalyst software, it is observed that the Blast - 2 with vertical drilled holes has lesser velocity of rock movement about 9.67m/s compared to Blast - 4 with inclined holes which is having a velocity of 27.8m/s, in which both the blasts have similar volume of about 162m^3. Similarly in Mine - B, one blast (Blast - 5) drilled with vertical blastholes resulted in a lesser velocity of rock movement about 7.12m/s compared to Blast - 4 with inclined holes resulted a velocity of 10.13m/s, in which both the blasts have similar volume of about 99m^3. In Mine - C, one blast (Blast - 6) with vertical blastholes resulted in a lesser velocity of rock movement of about 6.15m/s compared to other blasts with inclined holes whose velocity of rock movement is about 8m/s (Table 3). Typical method of drilling adopted in three Limestone Mines is depicted in Figure 11.

Inclined drilling

Vertical drilling

Figure 11: Method of drilling adopted

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From the analysis made, it is observed that in mine - A, Blast - 3 with lesser charge factor of 0.29kg/m^3 is having a lesser velocity of 8.44m/s compared to Blast - 1 with higher charge factor of 0.34kg/m^3, which resulted in velocity of rock mass of about 15.1m/s. Similarly in Mine - B, Blast - 1 with lesser charge factor of 0.31kg/m^3 resulted in lesser velocity of 7.09m/s compared to Blast - 5 with higher charge factor of about 0.34kg/m^3 having a velocity of rock mass about 10.3m/s. Also in Mine - C, Blast - 3 with minimum charge factor of 0.2kg/m^3 resulted in lesser velocity of 8.16m/s compared to Blast - 5, whose charge factor is 0.26kg/m^3, which is the highest amongst all other blasts, resulted in a maximum velocity of rock mass about 12.6m/s. It could be concluded that with the increase in charge factor, there will be an increase in burden rock movement (Table 3).

Study revealed that 8m bench height resulted in 6.157m gas ejection whereas bench height with 7m resulted in 7.24m gas ejection which could be interpreted as lesser gas energy wastage with taller benches. This phenomenon could be correlated with the finer fragmentation resulting from taller benches from the model scale studies carried out by Sastry (1989),[13] indicating better utilization of explosive energy in taller benches.

Table 3: Comparison of velocity of rock movement with charge factor

Mine - A

Parameters	**Blast Number**			
	1	***2***	***3***	***4***
Type of hole	Inclined	Vertical	Inclined	Inclined
Volume (m^3)	144	162	170.1	162
Charge Factor (kg/m^3)	0.34	0.34	0.29	0.29
Velocity (m/s)	15.1	9.67	8.44	27.8

Mine - B

Parameters	**Blast Number**				
	1	***2***	***3***	***4***	***5***
Type of hole	Inclined	Inclined	Inclined	Inclined	Vertical
Volume (m^3)	144	115.5	135	144	99
Charge Factor (kg/m^3)	0.31	0.32	0.34	0.34	0.34
Velocity (m/s)	7.09	8.25	8.28	10.3	7.12

Mine - C

Parameters	**Blast Number**					
	1	***2***	***3***	***4***	***5***	***6***
Type of hole	Inclined	Inclined	Inclined	Inclined	Inclined	Vertical
Volume (m^3)	147	147	126	147	147	147
Charge Factor (kg/m^3)	0.26	0.25	0.24	0.25	0.26	0.2
Velocity (m/s)	8.58	8.88	8.16	8.89	12.6	6.15

4. Conclusions:

- High speed video camera is useful to track down the trajectories of fragmented material from the bench. It is a useful tool to find out the movement of the bench faces. The wastage of gaseous energy through ejection of stemming material could be tracked down for assessing performance of blasts.
- From the results, it is observed that with the increase in Bench Height to Burden Ratio there is an increase in velocity of rock mass.
- Incline blastholes resulted in higher rock mass velocity compared to vertically drilled blastholes.
- High Speed Videography analysis indicated that, increase in the charge factor results in higher burden rock movement.
- Study revealed that 8m bench height resulted in 6.157m gas ejection whereas bench height with 7m resulted in 7.24m gas ejection which could be interpreted as lesser gas energy wastage with taller benches.

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