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# IMAGE PROCESSING BASED ASSESSMENT OF EXPLOSIVE ENERGY DISTRIBUTION IN MINE BLAST - CASE STUDY

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## Abstract

In an opencast mine, blasting can be considered as the most important activity. Proper usage of explosive energy to displace burden can result in considerable savings to operations, which normally depend on mechanical means for material removal. Optimization of explosive energy in blast design is achieved with the effective utilization of explosive energy in a blasthole. Occurrence of blast is so rapid that the naked eye cannot detect the process. A high-speed video camera can provide the progress of blast in millisecond time scale needed to analyze the happenings in the blast. The present paper aims to assess the performance of a blast with respect to the energy distributed around a blasthole and burden rock movement.

## 1. Introduction

There are many technical advancements in the field of Numerical modelling and simulations leading to design of blasts with higher efficiency and with less number of trail blasts. Even though they are designed to achieve maximum efficiency, the case is not so. From the literature available, it is evident that only a fraction of explosive energy is utilized for the effective fragmentation and displacement of burden rock [1]-[3].

Blast is said to be optimal if it utilizes explosive energy efficiently with optimum fragmentation and displacement of fragmented rock mass [4]-[7]. The displacement should be in such a way that the muckpile formed should

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be convenient for the further mining operations followed after blasting viz., shoveling and hauling. The studies were conducted in a limestone mine belonging to Southern India (Figure 1).

**Figure 1.** View of limestone mine.

Dissipation of shock wave energy being high in crushed zone, its magnitude beyond this zone cannot be the relevant parameter to cause damage to surrounding rock mass. Gas energy should therefore be responsible for damaging the peripheral rock structure beyond the crushed zone [8].

## 2. Methodology

In total, seven blasts were studied from the field. Various parameters of blasts conducted were summarized below in Table 1. Blast holes drilled were of 115mm diameter with depths varying from 6m to 9.25m.

**Table 1.** Summary of blast.

| Specifications | Blast Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Bench height (m) | 7.00 | 7.00 | 7.00 | 9.25 | 6.00 | 7.00 | 7.00 |
| 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 | 30 | 24 | 18 | 18 | 20 | 14 | 10 |
| Explosive/ Hole (kg) | 37.5 | 35.0 | 37.0 | 51.4 | 25.0 | 30.4 | 28.3 |
| Total Exp. Charge (kg) | 1125 | 841 | 658 | 925 | 492 | 425 | 283 |
| Stemming (m) | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |

Blasts are studied for the mine with the following geotechnical and geological properties (Table 2).

**Table 2.** Properties of Mine.

| Material of mine | Limestone |
|---|---|
| Uniaxial compressive strength(MPa) | 250 |
| Density (kg/m3) | 45-60 |
| Young's modulus (GPa) | 60-80 |
| Poisson's ratio | 0.2-0.3 |
| Vertical spacing between joints (m) | 3 |
| Horizontal spacing between joints (m) | 6-9 |

The instrument used for High-speed videography analysis is of $S$-motion model camera, which can record at 1000 frames per second, is as shown in Figure 2.

$S$-Motion is a compact and portable camera used for applications in industrial research in various fields such as biomedical industry, car crash testing and in defense applications. High speed videography technique for the evaluation of blasts in mining industry pioneered by [9], has emerged into an efficient blast evaluation tool with the efforts of [3], [10].

**Figure 2.** High speed video camera of 1000fps capacity.

In the available methods for field studies, High-speed velocity analysis tops the list because of its millisecond time scale. It can be used to obtain the causes of misfires, effects of gas venting, delay intervals between holes, muck profiles and many more in blasting studies [9]-[12]. To record the face movement the camera axis should be less than 15 degrees of the high wall to aid in motion calculations. To record the actual firing time of individual holes, detonation indicators should be used [13].

In a production blast, the change in output is difficult to trace back to which variable or the combination of variables attributed to the change in output. Sequences of a blast with respective timing intervals from the point of initiation are shown in Figure 3.

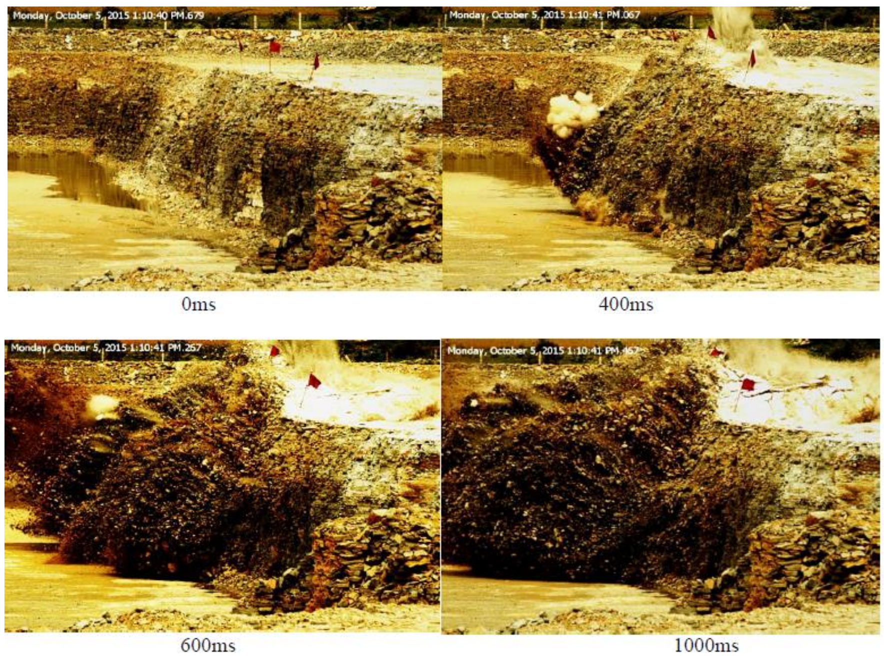


**Figure 3.** Sequence of a blast with specified delay intervals: limestone.

Blasts were studied for High-speed videography were then simulated with the help of JK Sim Blast software. Simulations were carried out in 2D-bench and the analysis for energy distribution was done in 2D-view. Flow chart for obtaining blast energy distribution is depicted in Figure 4. The flow chart process is repeated for all (07) seven blasts.

**Step 1.** Burden, total explosive Charge, bench height etc. are used as inputs for blast simulation.

**Step 2.** From the data available from the field studies, simulation of the blast is carried out in the software.

**Step 3.** Energy distribution as MJ per cubic meter is obtained as an output from the software.

**Step 4.** From the relative area values in the energy distribution output, Energy in MJ is obtained.

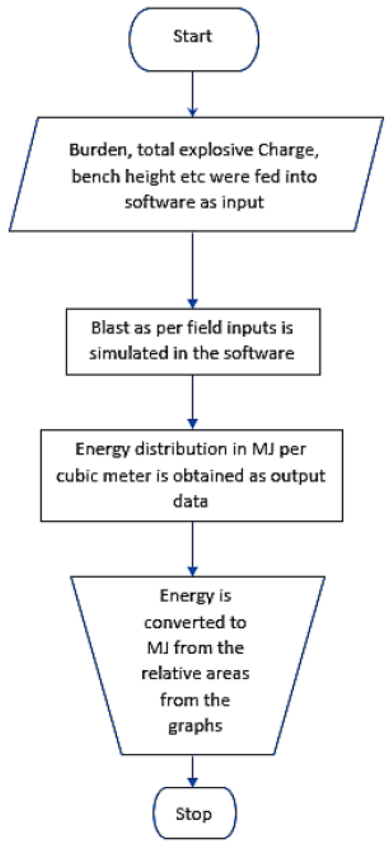


**Figure 4.** Methodology of obtaining the energy distribution.

Typical outputs of energy distribution are shown in Figure 5. Uneven distribution of energy in a shot may lead to problems such as misfires, poor fragmentation, tight muckpiles, excessive cratering, backspills and toe problems [3].

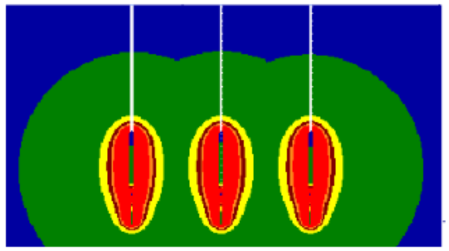

**Figure 5.** Energy distribution obtained from the software.

From the analysis made the output, energy distributed over an area in Mega Joules per cubic meter, was obtained. From the energy distribution scales obtained (Figure 6), regions are marked with respective energy levels.

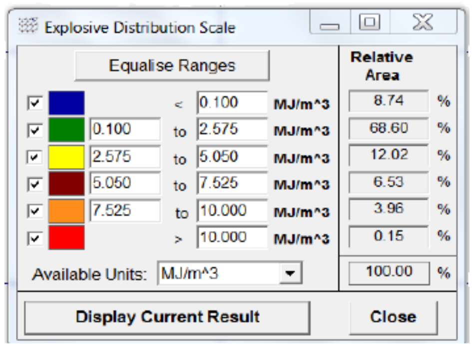


**Figure 6.** Explosive energy distribution scale.

## 3. Results and Discussion

The blasts which were captured in High speed video camera were analyzed with the help of ProAnalyst, a motion sensing and analysing software. From the software blasts were analyzed for the correctness of delay patterns, misfires, massive ground movement, height of the bench and throw of material etc. Gas energy wastage due to structural discontinuities was noticed with larger throw as the joints are not parallel to the blast [14]. Velocity of rock mass was determined at various levels along the section such as stemming, explosive column, primer and toe (Table 3).

**Table 3.** Velocities at various sections.

| Section | Blast-1 | Blast-2 | Blast-3 | Blast-4 | Blast-5 | Blast-6 | Blast-7 |
|---|---|---|---|---|---|---|---|
| Stemming | 4.20 | 5.60 | 5.30 | 3.17 | 4.31 | 4.22 | 2.27 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Air deck | – | 6.20 | 8.81 | 7.96 | 6.46 | 5.23 | – |
| Charge Column | 7.10 | 12.30 | 8.88 | 10.88 | 7.16 | 13.38 | – |
| Toe | 6.50 | 8.60 | 8.67 | 10.12 | 4.52 | 6.51 | 6.77 |

Velocities obtained are less at stemming zone due to the absence of explosive charge in the stemming region. Also the toe portions even though containing higher density explosive, i.e. primer, show slight decrease in throw. Resistance offered from the intact rock at toe may be the reason for the decrease (Figure 7).

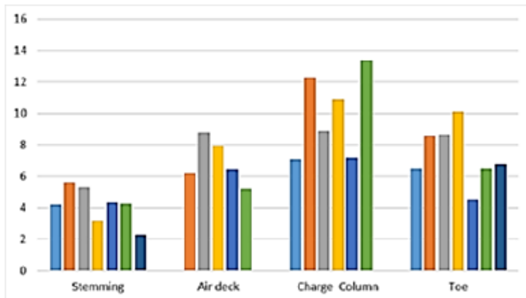


**Figure 7**. Velocity (mm/s) of rock mass at different levels.

Greater BH/B ratio indicates the more flexure the bench in the beam analogy as proposed by [15]. In shorter benches which are having a height of 6 and 7 meters the concept of beam bending anology suited better than in case of larger benches (Figure 8). In the case of larger benches the maximum velocity of rock mass was observed at the middle of explosive column instead of the centre of the bench section where the stiffness is minimum.

Normal bench Taller bench

**Figure 8**. Beam bending mechanism observed in bench.

As the dimensions are not the same in all the blasts, it is corrected approximately considering only the surroundings of blastholes. Regions at various sections are marked as Region 1, Region 2, Region 3, Region 4 for regions of stemming, airdeck, toe and explosive column. From the known values of dimensions of bench, volume of bench is calculated. It is used to find the energy (GJ). Energy is then converted into (kcal) which can be used for deriving the relation (Table 4).

**Table 4.** Energy calculated at various sections.

| Specifications | Blast 1 | Blast 2 | Blast 3 | Blast 4 | Blast 5 | Blast 6 | Blast 7 |
|---|---|---|---|---|---|---|---|
| Energy (GJ) | R1 | 7.2 | 5.8 | 4.0 | 4.7 | 3.5 | 1.8 |
| | R2 | 5.5 | 7.1 | 2.9 | 3.3 | 2.5 | 1.2 |
| | R3 | 4.8 | 4.7 | 2.3 | 2.7 | 2.0 | 1.0 |
| | R4 | 23.5 | 13.5 | 16.1 | 18.1 | 13.9 | 7.0 |

where, R1, R2, R3, R4 are Region-1, Region-2, Region-3, Region-4, respectively.

From the works of [10], it is observed that velocity is a function of burden over energy upon cube root. He derived a relation as given below (Equation 1).

$$V = 25 \times \left(\frac{\text{Burden}}{(\text{Energy})^{1/3}}\right)^{-1.17} \tag{1}$$

where,

$V$ = Velocity of burden rock mass (m/s)

Energy = Kilocalories per foot of explosive column (Kcal)

$\text{Energy} = 0.4545 \times D^2 \times ABS$

$D$ = Hole diameter (Inches)

$ABS$ = Absolute bulk strength (cal/cc)

$ABS = AWS \times \rho_e$

$AWS$ = Absolute weight strength (cal/g)

$\rho_e$ = explosive density (g/cc)

A similar comparison is made in this paper except that the energy per foot of the explosive column is replaced with the energy available at a section in kcal (Table 5).

**Table 5.** Comparison of burden rock movement with burden and energy.

| Blast Number | Burden rock movement | Burden/(Energy)$^{1/3}$ |
|---|---|---|
| Blast 1 | 6.51 | 0.291 |
| | 5.23 | 0.320 |
| | 4.22 | 0.330 |
| | 13.38 | 0.190 |
| Blast 2 | 6.20 | 0.314 |
| | 8.60 | 0.293 |
| | 5.60 | 0.336 |
| | 12.30 | 0.236 |
| Blast 3 | 8.67 | 0.314 |
| | 8.81 | 0.293 |
| | 5.30 | 0.333 |
| | 8.88 | 0.236 |
| Blast 4 | 3.17 | 0.424 |
| | 10.88 | 0.223 |
| Blast 5 | 4.31 | 0.340 |
| | 6.46 | 0.380 |
| | 4.52 | 0.400 |
| | 7.66 | 0.240 |
| Blast 6 | 4.57 | 0.370 |
| | 2.89 | 0.410 |
| | 2.67 | 0.450 |
| | 8.70 | 0.230 |
| Blast 7 | 2.27 | 0.470 |
| | | |
| | 6.77 | 0.300 |

From the graph plotted between velocity of burden rock and burden over energy upon cube root (Figure 9). Further, the relation for velocity with energy was established with 82 percent coefficient of determination which can be applicable for limestone mine deposits (Equation 2).

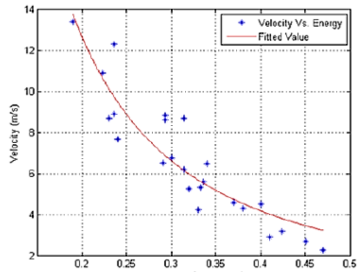


**Figure 9.** Energy distribution in taller and shorter benches.

$$V = 0.9676 \times \left(\frac{\text{Burden}}{(\text{Energy})^{1/3}}\right)^{-1.598} \tag{2}$$

MSE (Mean-Square Error), MMSE (Root-Mean-Square Error), and NRMSE (Normalized Root-Mean-Square Deviation Error) of the relation were found to be 1.39, 0.24, and 0.022, respectively.

Similarly, equations for 95% confidence with upper bound and lower bound are depicted in Equations 3 and 4, respectively.

Upper bound:

$$V = 1.39 \times \left(\frac{\text{Burden}}{(\text{Energy})^{1/3}}\right)^{-1.276} \tag{3}$$

Lower bound:

$$V = 0.5455 \times \left(\frac{\text{Burden}}{(\text{Energy})^{1/3}}\right)^{-1.919}. \tag{4}$$

## 4. Conclusions

Stemming ejection from taller benches is less compared to the shorter ones, with the better utilization of explosive energy. In addition, taller benches due to less stiffness and well-distributed energies had greater throw with better utilization of explosive energy. Blast with a bench height of 9.25m is having a lesser stemming ejection of 1.207m compared to 3.764m with a bench height of 7m, indicating that taller benches result in lesser wastage of gas energy.

In general, the rock movement is higher in the centre of the bench. However, in taller benches, the high-speed videography analysis showed the maximum movement of the burden rock shifting towards the toe portion of the bench, which is very much desirable.

Blasts with 1m air deck resulted in lesser velocities of 7.66m/s, 8.70m/s and 6.77m/s, compared to blast without air deck technique having velocity of 13.38m/s. With the increase in rock mass movement funneling was observed to decrease. As energy is not misused for funneling, more energy is utilized in displacing the rock mass. A relation between the energy at a section and the burden rock movement was established which can be applicable for limestone mines. The relation finds its application in determining the safe distances for equipment and working personnel.

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