Influence of Front Row Burden on Fragmentation, Muckpile Shape, Excavator Cycle Time, and Back Break in Surface Limestone Mines

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Abstract

Front row burden is one of the key parameter to improve the bench blasting results. Improper design of the front row burden can create nuisances in the form of ground vibration, flyrock, back break or it may responsible for breakage of improper fragment size from the rockmass. Therefore, front row burden need to be optimised on the basis of proper scientific assessment. It has been proved that there cannot be a unique blast design that would serve the varied situations prevailing in mines but site specific and customized blast designs can accommodate the different blasting environments encountered in the field under the variegated geo-mining conditions. This study was conducted to know the influence of front row burden on fragmentation, muckpile, excavator productivity and from the study it was found that front row burden range of 0.50-0.70 of designed burden resulted the improved blasting results (fragmentation, Muckpile shape parameters and final wall profile). While, front row burden range of 0.8-1 of designed burden created more congested material, uneven fragmentation and back break in high wall.

Keywords: *Blasting, Surface mines, front row burden, fragmentation, muckpile shape, back break, excavator.*

1. Introduction

Role of front row burden is absolutely crucial in providing relief to the subsequent row in a multi-row blast round. Burden distance has been defined as the shortest distance from free face at the time the hole detonates. Relief is normally considered to be either a ledge face or the internal face created by a row of holes that have been previously shot on an earlier delay (Konya 1995). If the burden is more, the explosive gases escape from stemming part without doing any effective work or the explosive energy may appear in the form of ground vibration. When burden is too small, fracturing of rock occurs rapidly and creates air overpressure, flyrock etc. Singh and Sastry (1987) and Singh et al. (1985) also explained that blasting results were greatly influenced by burden. Therefore, it is important to make sure that the burden distance is not too small or too large. Konya (1995), Jenkins (1981) and Konya (2003) also reported that back break increases when burden and stemming increase. Blair and Armstrong's (2001) observed during study that vibration, although insensitive to the burden but is not insensitive to the condition (i.e., the degree of damage) of the surrounding rock mass. In this regard, blast holes in undamaged ground produce a significantly higher vibration than blast holes in damaged ground.

There are a number of empirical relationships that have been proposed to design the bench blasting. Prominent among them are those which have linear relationships with the blast hole diameter. These relationships were most commonly used till 1980s. Later on with the advent of high degree of mechanization and blasting techniques, it has been found that nonlinear relations may predict better results (Kou and Rustan 1993).

Several empirical formulae have been proposed by the authors for calculation of burden. The hole diameter or charge diameter is included in all burden formulae (Jimeno et al. 1995). For bulk explosives, charge diameter is equal to the hole diameter. When cartridge explosives are used, the explosive does not fill the entire cross-sectional area of the blast hole. Therefore, the charge diameter is less than the hole diameter. The bench height is included in some formulae but the parameters such as hole depth and charge length are the derivatives of the bench height. Rock and explosive properties are included either directly or indirectly in the form of constants (Adhikari and Ghose 1999). Hagan (1977) that concluded from his study, that the burden should be kept close to its 'optimum value' which varied with hole diameter. Rustan et al. (1983) defined 'critical burden' as the burden at which strata gets fractured without any displacement. Hagan (1982) explained that in multi row blasts, it is essential to keep the front row burden lower to achieve proper burden relief and displacement so that subsequent rows are blasted smoothly without any difficulty.

Langefors and Kihlstrom (1963) developed a technique in which burden is reduced and spacing is increased keeping the number of holes, explosive per hole and spacing to burden ratio constant. This technique resulted

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in improving the fragmentation. Similar study was supported by Bhandari (1975). Rai (2002) believes that the burden appears to be one of the most crucial blast design parameters for better fragmentation. In multiple row blasts, the effective burden varies as per the firing sequence and delay timing between rows and between holes. The fragmentation process not only affects the local productivity and unit costs of the mining it even influences the performance of the subsequent operations (Mackenzie 1967) also. Fragmentation size and the cycle time of excavator plays a very important role in the production of mine. Blast fragmentation size and its distribution and thus blast design have been found to have a direct impact on the load and haul cycle through excavator dig time and bucket payload. Some formulae suggested for calculating burden in field scale are as given in table 1.

Table 1. List of the formulae suggested by proponent for calculating burden in field scale

Sl. No.	Formulae	Proponent	Year	Remarks
1	$B_m = K_b.\ d$	Ash	1963	K_b = burden ratio from 20-40
2	$B_m = 0.958.\,d\sqrt{\dfrac{\rho.S}{C_a.f.(\frac{S_d}{B_d})}}$	Langefors and Kihlstrom	1978	B_m= Maximum burden (m), S=Weight strength of explosive, d= diameter of blast hole (m), C_a= Corrected blastability factor (kg/m^3), ρ = density of explosives, f= confinement of blast hole, S_d= Spacing (m), and B_d= Burden (m)
3	$B = 37.8\dfrac{(\rho_e)^{\frac{1}{3}}}{\rho_r}.d$	Hagan	1983	Density of explosive and rock, d= hole diameter
4	$B_p = 18.1\ d^{0.689}$	Rustan	1992	B_p= Practical burden, d = hole diameter
5	B_{cal}=0.012[2SG_E/SG_R+ 1.5] φ	Konya	1995	B_{cal}= Calculated burden for the first row (m), SG_E= Specific gravity of ANFO SG_R= Specific gravity of blasted rock, φ = Diameter of drill hole (mm).

Floyd (1999), on the basis of full scale trials, with use of high speed camera and borehole camera, suggested a maximum face burden of 25 times the charge diameter to prevent the over break / back break etc. Djordjevic (1998), on the basis of series of trials in open pit gold mine recommended that burden in front of a row can vary in the range of (25-40) times the blast hole diameter. Chiapetta and Borg (1983) and Chiapetta and Postupack (1995) suggested that regardless of environment in which the same explosive is used, burden velocity (which affects the muck pile displacement) always decreases with increase in burden dimension. Role of front row burden is absolutely crucial in providing relief to the subsequent row in a multirow blast round.

2. Case Description

To accomplish the objectives field studies and field data acquisition was conducted at three limestone mines. These mines are owned by different companies. Mine-A is situated in Philippines and belongs to the Lafarge cement company, Mine-B belongs to Ambuja cement, Rajasthan, India. Mine-C belongs to Grasim cement, Rajasthan, India. The views of these quarries are shown in Fig.1. The general mines bench related data are as given in the table 2.

The Quarry-A is situated in Bulaccan province of Philippines about 50 km South of Manila. The quarry was owned by Lafarge cement and operated by the Republic Aggregate Company Inc (RACI). The annual production of quarry was over 3 Mt of limestone.

The Quarry-B is situated in the region of the Aravali hills about 250 km South West of Jaipur in Rajasthan. The mining area was located in latitude N26°14″-N26°24′16″ and longitude of E 74° 13′ 34″ - E74° 14′ 39″. The location was mostly covered by the limestone deposit. The total reserve of the mine is 122.75 Mt. The mine is producing 2.4 Mt of limestone annually.

The Quarry-C belongs to Nimbahera limestone formation of Khorip group which corresponds to lower Vindhyan super group of South Rajasthan. The cement grade reserve of limestone is 126.9 Mt. The production of mine is 2.5 Mt per year.

3. Research Methodology

To ensure the research objectives, full-scale blasts were conducted with incremental variation in the front row burden (FRB) value at three different limestone mines. In this case the front row burden was studied at several designed values to get the optimum value for all three mines. It was observed that in all the three mines there were always confusion in drilling the first row of blast

Table 2. General mines parameters where study was conducted

Parameters	Mine -A	Mine -B	Mine -C
Annual production	3 Million tons	2.4 Million tons	2.5 Million tons
Compressive strength of limestone	40 MPa	145 MPa	70MPa
Specific gravity of limestone	2.4	2.7	2.65
Bench heights	6-9m	6-8m	6-8m
Loading equipment's	Front end loader ($5m^3$), Shovel ($5m^3$) and Backhoe ($3m^3$)	Backhoe (1.2 $m^3$and 2.4 m^3)	Shovel ($4m^3$)
Dumper size	35 and 50 tonne	20 and 25 tonne	35 tonne
Hole size	115mm	102mm	102mm
Explosive	ANFO	ANFO	ANFO
Initiation system	Shock tube	Shock tube	Shock tube

round because of differential FRB property. It was also found that practicing FRB in Quarry-A was 0.7B (B is designed burden), Quarry-B was 1-0.8B and Quarry-C was 1B. Hence, there was need to investigate the optimum FRB by systematically. The literature (Konya 1995; Jimeno et al. 1995; Langefors and Kihlstrom 1978) does not approve reduction in FRB below 0.5B as such, FRB value less than 0.5B was not attempted in the field scale blast. The variation in FRB was implemented in the quarries at 0.5B, 0.7B, 0.8B, 0.9B and B. The effect of each FRB on fragmentation, muckpile shape parameters, Excavator performance was analysed to optimize these blast results.
During study in different mines it was observed that the wall control was not up to the mark (high wall slanting from 70-80 degree) due to which the differential burden at the crest and toe of the bench was observed as shown in Fig 2.

Fig 1. Quarries view where study was conducted

Furthermore it is consequential to state that the provision of inclined drilling was not available in any mine hence, decrement reduction in FRB was implemented. For quantification of fragmentation in the blasted muckpiles, widely acclaimed, and, state-of-art digital image analysis technique was deployed (Rustan 1998; Kanchibotla et al 1999; Ouchterlony et al 2006; Choudhary and Rai 2013). With the use of digital camera, a series of high resolution photographs were captured on the blasted muckpiles to cover the entire excavation history of each blast. For quantification of the fragmentation the field-captured photographs were processed and analysed by Fragalyst™ (Raina 2002), commercially proven and indigenously developed image analysis software based on the principles of granulometry.
The diggability of loading machines is affected with respect to degree of fragmentation in the muckpile shape parameters (throw, drop and lateral spread). Hence, the cycle time of the pay loaders/hydraulic excavators excavating the muckpile was categorically recorded throughout the excavation using precise stopwatch so that realistic cycle time data could be taken as an index to the blast performance.

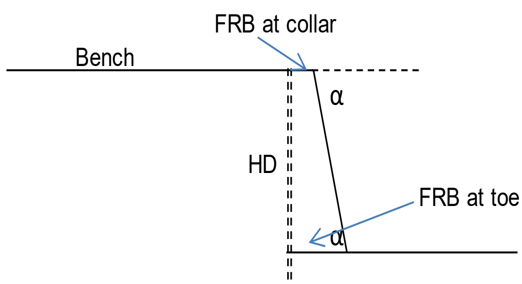

Fig 2. Shows differential FRB at top and bottom of bench (HD = FRB tan (α); FRB at bench toe = FRB at crest + (HD / tan (α)); HD= hole depth, α = bench slope angle)

4. Results of Effect of Front Row Burden

4.1. Front row burden investigations and results (Mine-A)

In this mine all the blasts were drilled on staggered drilling pattern and fired on V-type firing pattern with inter-row delays. The blast holes were bottom initiated with shock tube initiation system. Blasts A-1 and A-2 were the base line blast which were fired at front row burden of 0.7B. The remaining blast design parameters were almost identical with the base line blasts but the variation were made in the front row burden (0.5B-0.7B) as shown in table 3. The complete results are tabulated in table 3.

On perusing the fragmentation results for the existing blast A-1 and A-2 (table 3) the values of k_{90} varies from 0.55-0.75 m which is larger than the optimum fragmentation size (k_{opt}) of 0.35m (for FEL bucket size of 5 m^3). The muckpile profile was also not proper so dozer was used extra time for spreading of the muck (Fig 3). The boulder (oversize) generation in the collar region (Fig 4), the inordinate increase of the muckpile heap (because of poor relief) along the back rows (Fig 5), back break at the final wall (Fig 6) were also observed. Here it may be important to interpret that because of increased FRB (0.7B) the blast was devoid of progressive relief and due to extreme congestion the fragmentation along the back rows suffered badly and created the said issues.

Table 3. Front row burden variation in Mine-A

Parameters	Blast Number						
	A-1	A-2	A-3	A-4	A-5	A-6	A-7
Front row burden (FRB), m	2 (0.7B)	2.1 (0.7B)	1.7 (0.6B)	1.7 (0.6B)	1.4 (0.5B)	1.4 (0.5B)	1.5 (0.5B)
Burden (m)	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Spacing (m)	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Depth of holes (m)	6.5	6.5	6.5	6.5	6.5	6.5	6.5
No. of holes	86	44	37	29	47	65	39
No. rows	6	5	5	4	5	5	5
Total Explosive (kg)	2846	1450	1224	950	1536	2124	1275
Throw (m)	6.39	7.3	7.13	7.5	10.15	12	9.7
Dozing time (hrs)	13	7	9	5	0	0	1
Front end loader cycle time (s)	49	50.3	48.5	48.5	48.7	47.4	49
PF (kg/t)	0.25	0.20	0.24	0.25	0.23	0.23	0.22
Uniformity index, n	2.73	3.08	2.98	3.31	3.05	3.13	3.00
k_{20} (m)	0.25	0.20	0.18	0.15	0.14	0.13	0.11
MFS, k_{50} (m)	0.36	0.29	0.27	0.24	0.19	0.15	0.16
k_{80} (m)	0.49	0.38	0.35	0.33	0.25	0.18	0.21
k_{90} (m)	0.75	0.55	0.52	0.48	0.36	0.33	0.31

Fig 3. Front end loader assisted by dozer

Fig 4. Boulder generation in the collar region

Fig 5. Muckpile heap along the back rows

Fig 6. Back break at the final wall

To improve the blast results the FRB was reduced to 0.6B and the improvement were observed in the blast results which can be seen in the table 3. Further the FRB was reduced to 0.5B and observed remarkable improvement in fragment size results (k_{50} 0.15-0.19 m; k_{90} 0.3-0.36 m) increase in the throw of blasted muckpile which assisted the muckpile loosening, absence of back break (Fig 7 and 8). The improvement in the blast performance results can be owed to reduction in FRB which led to decrease in differential burden from bench crest to toe. Due to which progressive relief occurred with the advancement of the blast. This led to the good fragmentation with proper burden relief and movement.

Fig 7. Improved muckpile parameters

Fig 8. Blasted muck loading by FEL

4.2. Front row burden investigations and results (Mine-B)

In this mine all the blasts were drilled on staggered drilling pattern and fired on V-type firing pattern with inter-row delays. The blast holes were bottom initiated with shock tube initiation system. Blasts B-1 and B-2 were the base line blasts which were fired at front row burden of 1B and 0.9B simultaneously. The remaining blast design parameters were almost identical with the base line blasts but the variations were made in the front row burden (0.5B-1.0B) to see its influence on blasting results. The complete results are tabulated in table 4.

On perusing the table 4 it is clear that the base blasts results are not satisfactory. The k_{90} values ranged from 0.77-0.9 9m which is much larger than the optimum fragmentation size (k_{opt}) range of 0.20-0.27 m (for the backhoe bucket size of 2.4 m^3). Throw distances in these blasts were almost negligible which is good for the backhoe but increased cycle time of excavator may be attributed to improper fragment size results. Here it may be important to interpret that because of increased FRB (1-0.9 B) the blast was devoid of progressive relief and due to extreme congestion the fragmentation along the back rows suffered badly in terms of generation of boulder (oversize) (Fig 9), muckpile without any movement and back break at the end of the wall (Fig 10).

To improve the blast results the FRB was reduced to 0.8B and 0.6B and the improvement were observed in the blast results which can be seen in the table 3. The FRB was further reduced to 0.5B and observed remarkable improvement in fragment size results at collar region and inside the muckpile (k_{50} 0.16-0.27 m; k_{90} 0.29-0.40 m), final wall profile for these blasts was also better and free from any major back break (Fig 11 and 12). The improvement in the blast performance results can be allocated to reduction in FRB which led to decrease in differential burden from bench crest to toe. Due to which progressive relief occurred with the advancement of the blast. This led to the good fragmentation with proper burden relief and movement.

Table 4. Front row burden variation in Mine-B

Parameters	Blast Number						
	B-1	B-2	B-3	B-4	B-5	B-6	B-7
Front row burden (FRB) (m)	3 (1B)	2.7 (0.9B)	2.4 (0.8B)	1.8 (0.6B)	1.8 (0.6B)	1.5 (0.5B)	1.5 (0.5B)
Burden (m)	3	3	3	3	3	3	3
Spacing (m)	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Depth of holes (m)	8.5	7.5	8	8.5	7.5	8	8
No. of holes	9	15	10	13	15	12	21
No. of rows	2	2	2	2	2	3	4
Charge length (m)	5	4.5	5.5	5.5	4	4	5.3
Total explosive (kg)	338	503	346	488	503	415	727
PF (kg/t)	0.22	0.24	0.20	0.22	0.21	0.18	0.18
Backhoe cycle time (s)	23.34	23.63	21.22	19.12	21.2	19.35	20.78
Throw (m)	0	0	4.7	6	5.5	7	7
Uniformity index, n	2.13	2.37	4.20	3.70	3.06	3.3	3.17
k_{20} (m)	0.24	0.20	0.26	0.23	0.19	0.17	0.11
MFS, k_{50} (m)	0.41	0.33	0.38	0.33	0.28	0.27	0.16
k_{80} (m)	0.61	0.45	0.43	0.39	0.36	0.33	0.21
k_{90} (m)	0.99	0.77	0.66	0.53	0.44	0.48	0.29

Fig 9: Large boulder generation

Fig 10: Excessive congestion, back break

Fig 11: Well displaced muckpile

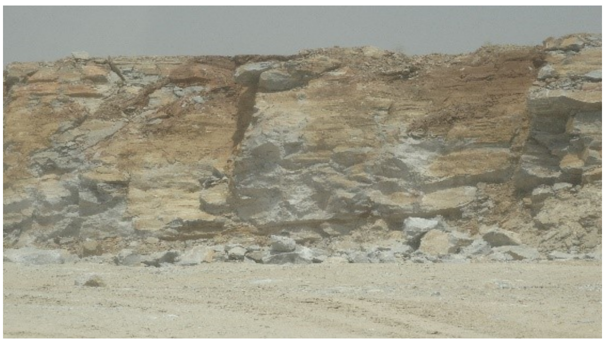

Fig 12: Good final wall profile

4.3 Front row burden investigations and results (Mine-C)

In this mine all the blasts were drilled on rectangular drilling pattern and fired on line firing pattern with inter-row delays. The blast holes were bottom initiated with shock tube initiation system. Blasts C-1 and C-2 were the base line blasts which were fired at front row burden of 1B. In this case due to the highly jointed rock FRB value changes up to 0.7B only. The results are tabulated in table 5.

It is evident from the table 5 that the FRB is varies from 2.5 to 4.5 which are 0.7B to B. In this mine the blast were designed at single row to see the effect of geology. Blast C-1 to C-4 was conducted on the upper layered, fractured benches while blasts C-5 to C-7 was conducted at the lower benches where only upper part was fractured. The results indicate that FRB is much higher in all the cases but fragmentation size is not much affected. Higher FRB (1B to 0.8B) generated back break in final wall (Fig 13) while at 0.7B no back break, loose material was observed (Fig 14).

Table 5: Front row burden variation in Mine-C

Parameters	Blast Number						
	C-1	C-2	C-3	C-4	C-5	C-6	C-7
Front Row Burden (FRB) (m)	4.2 (1B)	4.5 (1B)	4 (0.8B)	4 (0.8B)	3 (0.7B)	2.5 (0.7B)	2.6 (0.7B)
Burden (m)	4.2	4.5	5	5	4.2	3.5	3.8
Spacing (m)	7	7	7	7	7	4.5	3.8
Depth of holes (m)	7.5	7.5	7.0	7	7.5	7.5	7.5
No. of holes	6	11	8	6	8	18	35
No. rows	1	1	1	1	2	3	5
Total explosive (kg)	214	395	258	217	285	630	1050
Backhoe cycle time (s)	23.7	23.3	22.5	22.5	21	21	21
PF (kg/t)	0.08	0.06	0.07	0.08	0.07	0.07	0.10
Throw (m)	0.5	0.5	1	2	4	7	5
Uniformity index, n	3.40	4.2	3.4	3.10	3.3	3.4	3.97
k_{20}(m)	0.16	0.15	0.12	0.15	0.08	0.14	0.09
MFS, k_{50}(m)	0.21	0.18	0.16	0.18	0.10	0.17	0.12
k_{80}(m)	0.24	0.22	0.21	0.24	0.13	0.21	0.17
k_{90}(m)	0.38	0.35	0.29	0.36	0.22	0.29	0.22

Fig 13. Back break observed

Fig 14. Good fragmentation

4.4 Investigation of effect of front row burden on fragmentation

Curves for fragment size vs cumulative passing for each blast round is obtained after processing of field captured photographs using Fragalyst™ software. From the Rosin Rammler distribution curve, fragment size of k_{20} (Fine size), k_{50} (Mean fragment size, MFS), k_{80} and k_{90} (Courser size) are taken for analysis. These curves were manually plotted on one sheet (Fig 15) in order to compare the fragment size distribution results.

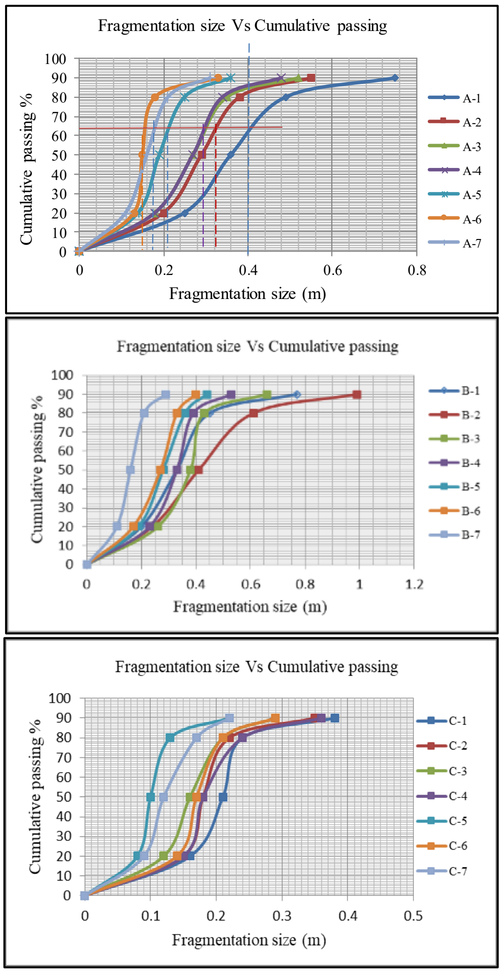

Fig 15. Composite fragment size distribution curve for Mine-A, B and C

A perusal of Fig. 15 clearly appraises the improvement of blast performance. The relative improvement of blast performance A-1 to A-7 to this end it is observed that by reducing the front row burden the curves become steeper which reduces the spread of the curves. Steepest curves are observed for the blasts (0.5B) and the most flat curves are observed at 0.7B. Intermediate steepness and spread of curves are witnessed for the blast A-3 and A-4 (0.6B). Flatness and spread of the curve indicates non uniformity of fragmentation, whereas steep and less spread curves reveal uniformity in fragment size distribution. Hence, it may be precisely understood that by reduction in the FRB fragmentation in the muckpile was uniform and good. Additionally, it may be observed from the curves that increased flatness for the base line blast reveals the spread of the maximum fragment size much beyond the optimum fragment size. Similar trends and results are observed for Mine-B and Mine-C where the reduction of FRB was done from 1B to 0.5B and 1B to 0.7B respectively. The fragmentation analysis results of FRB vs MFS for all the mines are graphically illustrated in Fig 16. It is evident from the figures that mean fragment sizes increases as the front row burden increases in all the cases.

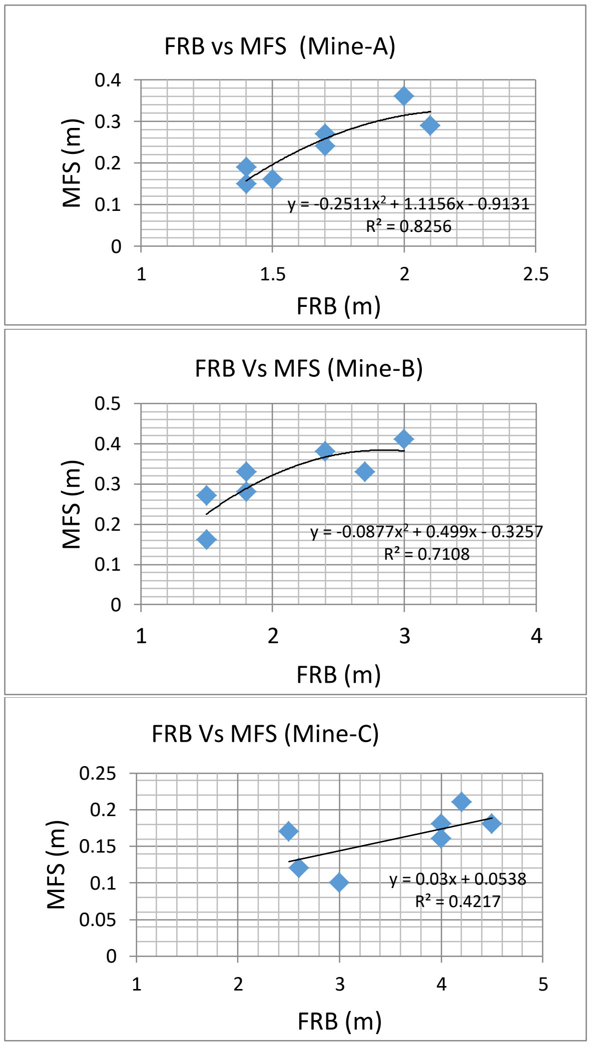

Fig 16. Front row burden (FRB) Vs Mean Fragment size (MFS) curve for Mine-A, B and C

4.5 Investigation of effect of front row burden (FRB) on excavator cycle time (ECT)

Front row burden vs excavator cycle time relationship for analyzed blasts is deduced from tables 3, 4 and 5. The results are plotted graphically and are shown in Fig 17.

On plotting the FRB vs ECT results (Fig 17) for mines A, B and C, it is noticeable that excavator cycle time trend shows optimization with reduction in the FRB for mine-A, B and C. Optimum cycle time is almost 48.5s for Mine-A (where front end loader was deployed), 20s.for Mine-B and 21s for Mine-C (where backhoe of different sizes deployed) at FRB of 0.5B, 0.5B and 0.7B respectively. This corroborates the earlier findings on assessment of fragment size results vis-a-vis FRB. This means that with decrease in FRB blasting results were improved. Due to improvement in blasting results excavator cycle time also improved. Improvement in fragment size has also been published by various researchers (Marton and Crookes 2000; Rai et al. 2012; Afeni 2009; Bahrami et al. 2011) who laid adequate stress on assessment of fragmentation by excavator performance results.

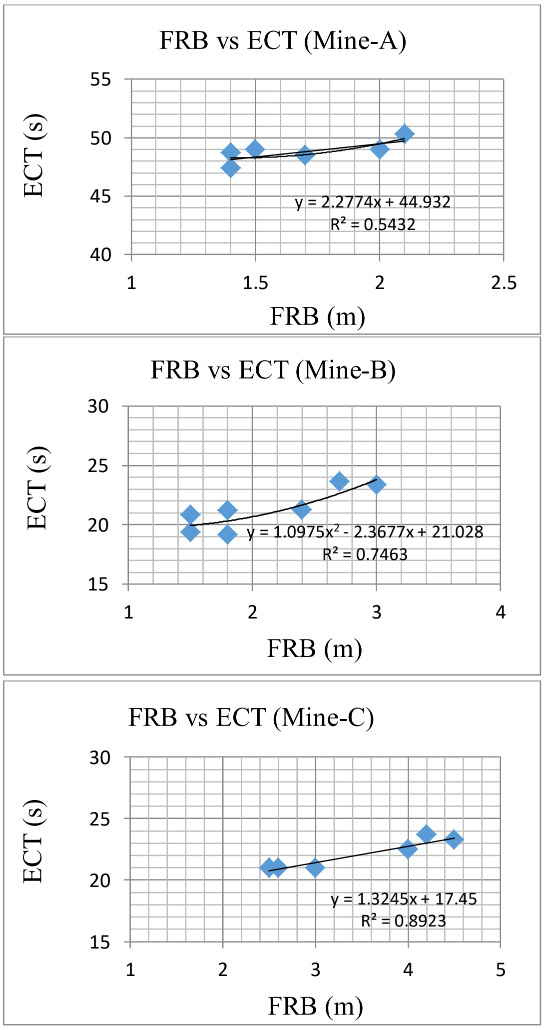

Fig 17. Front row burden Vs Excavator cycle time curve for Mine-A, B and C

5. Conclusions

The following conclusions may be drawn from the present study:

- The improved fragmentation results in all the mines have been observed at front row burden range of 0.5-0.7 of designed burden although there are changes in geological and geo-mechanical properties of limestone deposit.
- Front row burden range of 0.5-0.6 of designed burden value has been found to be yielding favourable results in terms of effective utilization of excavators.
- When the front row burden is greater than 0.7 of designed burden value the muck is congested, broken rock is boundary, less throw and spread of the broken material.
- Muckpile shape parameters (throw, drop and lateral spreading) show deterioration with increase in the value of front row burden beyond 0.5-0.7 of designed burden value.
- Deterioration in muckpile shape parameters due to increase in front row burden naturally implies poor throw and spreading of muck, which entails higher dozing hours especially for front end loader, which has poor diggability.
- When front row burden is equal to burden (B) then there is appearance of back breaks.

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References

Adhikari GR, Ghose AK (1999) Various approaches to blast design for surface mines, *Journal of mines, metals and fuels* 47(1-2):24-30.

Ash RL (1963) The mechanics of rock breakage, pt I-IV, Jour. Pit & Quarry, V.56, :98-131.

Bahrami A, Monjezi M, Goshtasbi K, & Ghazvinian A (2011) Prediction of rock fragmentation due to blasting using artificial neural network, *Journal Engineering with Computers* 27(2):177-181.

Bhandari S (1975) Studies on rock fragmentation by blasting, Ph.D. Thesis, University of New South Wales.

Blair DP, Armstrong LW (2001) The influence of burden on blast vibration, *Fragblast* 5(1-2):108-129.

Afeni BT (2009) Optimization of drilling and blasting operations in an open pit mine-the SOMAIR experience, *Mining Science and Technology (China)*19:0736-0739.

Chiapetta RF, Borg DG (1983) Increasing productivity through field controls and high-speed photography, Proc. First International Symposium on Rock Fragmentation by Blasting, Lulea, Sweden :301-331.

Chiapetta R F, Postupack C (1995) An update on causes and recommendations for controlling coal damage when blasting overburden, *Proc. Explo-95, Brisbane, AusIMM*: 345-360.

Choudhary BS, Rai P (2013) Stemming Plug and Its Effect on Fragmentation and Muckpile Shape Parameters, *International Journal of Mining and Mineral Engineering* 4(4): 296-311.

Djordjevic N (1998) Optimal blast fragmentation, *Mining Magazine* 178.2: 121-125.

Floyd JL (1999) Explosive energy relief – The key to controlling over break, *Procs. Int. Conf. Explo* (99):147-153.

Hagan TN (1977) Good delay timing -prerequisite of efficient bench blasts, *International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts* 15(3):47-54.

Hagan TN (1982) Controlling blast-induced cracking around large caverns. International Society for Rock Mechanics and Rock Engineering, ISRM International Symposium. Aachen, West Germany.

Hagan TN (1983) The influence of controllable blast parameters on fragmentation and mining costs, *Proceedings of the 1st international symposium on rock fragmentation by blasting* 1:31-51.

Jenkins SS (1981) Adjusting blast design for best results, *Pit and Quarry, Rotterdam*, Balkema.

Jimeno CL, Jimeno EL, Carcedo FJA (1995) Drilling and Blasting of Rocks, A.A. Balkema, Rotterdam, the Netherlands.

Kanchibotla SS, Valery W, Morrell S (1999) Modelling fines in blast fragmentation and its impact on crushing and grinding, *Explo '99–A conference on rock breaking, The Australasian Institute of Mining and Metallurgy*, Kalgoorlie, Australi 137-144.

Konya CJ (1995) Blast Design, Pub. by Intercontinental Development Corporation, Ohio 44064, USA.

Konya CJ (2003) Rock blasting and over break control (2nd ed). USA: National Highway Institute, FHWA-HI-92-001.

Kou S, Rustan PA (1993) Computerized design and results of bench blasting, Procs. 4th Int. Symp. on Rock Fragmentation by Blasting (FRAGBLAST-4), Vienna, Austria:263-271.

Langefors U, Kihlstrom B (1963) The Modern Technique of Rock Blasting, AlmqvistWiksells, Uppsala :258–295.

Langefors U, Kihlstrom B (1978) The Modern Technique of Rock Blasting, John Wiley, N. York.

Marton A, Crookes RA (2000) Case study in optimizing fragmentation, *The AusIMM Procs* 1 :35-43.

Mackenzie A. (1967) Optimum Blasting. Twenty-Eighth Annual Mining Symposium. University of Minnesota, Minneapolis. 181-188.

Ouchterlony F, Olsson M, Nyberg U, Andersson P, Gustavsson L (2006) Constructing the fragment size distribution of a bench blasting round, using the new Swebrec function, International Symposium on Rock Fragmentation by Blasting, FragBlast8. Santiago Chile, Australia :332–343.

Rai P (2002) Evaluation of effect of some blast design parameters on fragmentation in opencast mine. Ph.D. thesis, Banaras Hindu University, Varanasi.

Rai P, Yang HS, Choudhary BS (2012) Formation of Slot Cut for Creating Free Face in Solid Limestone Bench-A Case Study, *Powder Technology* 228:327-333.

Rustan PA (1992) Burden, spacing and borehole dia at rock blasting, *International Journal of Surface Mining, Reclamation and Environment* 6 :141-149.

Rustan PA (1998) Automatic image processing and analysis of rock fragmentation-Comparison of systems and new guidelines for testing the systems, *Joural Fragblast* 2:15-23.

Rustan PA, Vutukuri VS, Naartijvari T (1983) The influence from specific charge, geometric scale and physical properties of homogeneous rocks on fragmentation, Procs. *Proceedings of the 1st international symposium on rock fragmentation by blasting* 1: 115-142.

Singh DP, Sastry VR (1987) An investigation in to the effect of blast geometry on rock fragmentation. *6th ISRM congress*, Montreal, Canada: 721-725.

Singh DP, Sastry VR, Suresh CV (1985) Fragmentation in jointed rock material-A model scale investigation. National Seminar, Indigenous Development of Mining Explosives and Accessories, Policies and Programme, New Delhi, India.