Optimizing the Specific Charge for Limestone Blasting at Aruwakkalu Limestone Quarry

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Abstract

The objective of this research is aimed at optimizing the specific charge for limestone blasting at Aruwakkalu limestone quarry without leading to poor fragmentation of the blasted material. Thus, in reducing costs incurred during drilling and blasting activities, specific charge plays a vital role in open pit blast design as it affects many operational costs in mining activities. Therefore, at the quarry, specific charge is calculated for each blast and is monitored and maintained. Blasting parameters such as spacing and burden are already optimized at quarry according to the empirical formulae published by Langefors and Kihlstrom (1976).Therefore, when optimizing specific charge, it was first decided to change blasting parameters having the greatest effect on fragmentation such as spacing, burden, and charging method and evaluate the fragmentation of the blasted material because it is often difficult to optimize several blasting parameters simultaneously. Since fragment size directly affects crushing, a computer aided model called 'Split Desktop' was used to analyse fragmentation of material using digital photographs. Results of the four test blasts were analysed on cost basis. Thus, the blast geometry which resulted the lowest cost and the fragmentation within a manageable level is recommended to be practiced at the quarry in future.

Keywords: Decking Charging Method, Explosives, Fragmentation, Split Desktop

1. Introduction

Improvements in production at Aruwakkalu quarry has been mainly due to the use of heavy duty earth moving machineries, innovative processes, usage of good quality explosives, application of sophisticated computerized programs such as Quarry Optimization and Scheduling tool, Quarry Master etc.

Although these heavy capacity plant and machinery result in high operational costs due increased fuel consumption, maintenance and so on they handle larger tonnages and achieve higher productivity levels. Performance of them, especially the excavating and transporting equipment, are largely influenced by the blast results, particularly, fragment size and distribution of muck profile. Therefore, a well-designed blast plan has a great impact on the cost of mining [1].

Specific Charge refers to the quantity of explosives required to blast unit volume of rock. In other words, specific charge is a numerical indication of the explosive distribution on a bed. Generally, when the specific charge is increased, the total operating cost first reduces and again increases [1].So, the optimum specific charge would be found at the minimum operating cost. However, the specific charge value stipulated by the Geological Survey and Mines Bureau is 0.337 kg/m^3 (0.15 kg/mt) for the Aruwakkalu Limestone Quarry.

Limestone production at the Aruwakkalu quarry is mainly governed by drilling and blasting in which fracturing would greatly facilitate quarrying or excavation of limestone. The main purpose of drilling and blasting is to loosen the in-situ hard rock material so that loading machines and haul trucks can easily load and transport them respectively. Thus, the degree of fragmentation of the blasted material has to be controlled in blasts as it affects the operational cost of all mining activities such as loading, hauling, crushing and processing plant [2].

Therefore, to minimize the cost of production, optimum fragmentation from properly designed blasting pattern has to be achieved. Large fragments generated adversely affect the loading and hauling equipment and increase the frequency of sorting of oversize boulders and secondary blasting, thereby increasing the mining cost. Similarly, fines are also undesirable as it is an indication of excessive explosive consumption. It is, therefore, desirable to have uniform fragmentation, avoiding both fines and oversized fragments to optimize the overall cost of mining. In most of the surface mines, blast patterns are established through trial blasts [3].

Practicing blasting parameters at the quarry are not validated through a theoretical approach and conventionally they are still being applied. Therefore, our first task is to evaluate the existing blasting technique in a rational way.

Management opinion is that the amount of explosive used is redundant in blasting process at the present quarry. If the specific charge is reduced keeping other factors unchanged, less amount of explosives will be charged into blast holes which would result in poor fragmentation. As a result, operating costs namely loading, hauling and crushing costs may increase.

Therefore, in this research, several design models were planned changing blasting parameters such as spacing, burden, charging method (bottom charging/decking). These models have been tested at the quarry to study the impacts on specific charge and fragmentation due to the changes made in blasting parameters. Finally, a cost analysis has been carried out for each model to find the most economical blasting model.

2. Methodology

Basically, the methodology of this research can be divided into three steps.

Step1- Evaluation of the existing blasting technique.

Step 2- Conducting several test blasts with different blasting parameters.

Step 3–Fragmentation analysis for each model.

Step 4 – Evaluation of cost of test blasts.

2.1 Evaluation of the Existing Blasting Technique

Empirical relationship developed by Langefors and Kihlstrom (1976) were utilized to validate the current blasting technique at the quarry.

Burden

Burden is the most critical dimension in blast designing. It is the distance to the free face of the excavation from the bore hole. An empirical formula for approximating a burden distance to be used on a first trial shot [4].

$$B = \left(\frac{2SG_e}{SG_r} + 1.5\right) D_e \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where,

B = Burden (ft)

SG_e = Specific gravity of the explosive

SG_r = Specific gravity of the rock

D_e = Diameter of the explosive cartridge (Inches)

For Aruwakkalu Quarry,

$SG_e = 1.29$ and $SG_r = 2.40$

D_e = 2.5" (64mm, assuming a coupling ratio of 1)

After charging WaterGel, ANFO is added as the secondary explosive and the drill hole is stemmed. Therefore, hole is completely packed. So, coupling ratio is assumed as 1.

The initially calculated burden should be adjusted because of the geological variations and the rock being not homogeneous. There are two correction factors

- Correction factor for deposition (K_d)
- Correction factor for structure (K_s)

The corrected burden distance can be computed from the following equation [3].

$$B_{corrected} = B * K_d * K_s \ldots\ldots\ldots\ldots\ldots(2)$$

These factors vary with rock types.

K_d and K_s factors related to different rock fragmentation are given in Table 1.

Table 1 - Rock Types with Factors [5]

Rock Deposition	K_d
Bedding steeply dipping into cut	1.18
Bedding steeply dipping into face	0.95
Other case of deposition	1.00
Rock Structure	K_s
Heavily cracked, frequent weak joints, weak cemented layers	1.30
Thin, well-cemented layers with tight joints	1.10
Massive intact rock	0.95

Spacing

Initiation timing and stiffness ratio strongly influence spacing. Spacing is the distance between two holes in the same row. When the spacing is too close, it induces occurrence of air blast and fly rock. Therefore, an excessive increase of spacing would also be the cause of reduction of the degree of fragmentation [3].

There are 4 types:

- Instantaneous initiation, with the stiffing ratio greater than 1 however, less than 4,

$$S = \frac{L+2B}{3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where,
S: Spacing (m)
L: Bench height (m)

- B: Burden (m) Instantaneous initiation, with the stiffing ratio equal to or greater than 4,

$S = 2 * B$……………..……..……..(4)

- Delayed initiation, with the stiffing ratio greater than 1 but less than 4.

$S = \frac{L+7B}{8}$…………………………...….(5)

- Delayed initiation, with the stiffing ratio equal to or greater than 4

$S = 1.4 * B$…………………………......(6)

Specific Charge

Specific charge is defined as explosive in kilograms per one cubic meter of rock. Basically, it expresses the explosive consumption and it depends on explosive charge per hole spacing, burden and bench height.

Specific charge variation in 2016 is shown in Figure 1.

$q = \frac{Q}{B*S*H}$ ……………………….…….(7)

Where,

q – Specific charge Kg/m^3 of rock

Q – Total explosive charge per hole (kg)

B – Burden (m)

S – Spacing (m)

H– Bench height (m)

Explosives and Detonators

The major types of explosives used in charging blast holes in bench blasting are as follows,

- Primary Explosive: WaterGel Explosive Cartridges (each 125 g)
- Secondary Explosive: ANFO (Ammonium Nitrate + Fuel Oil)
- Electric Detonators (0-9 delay numbers with 25 ms increments)

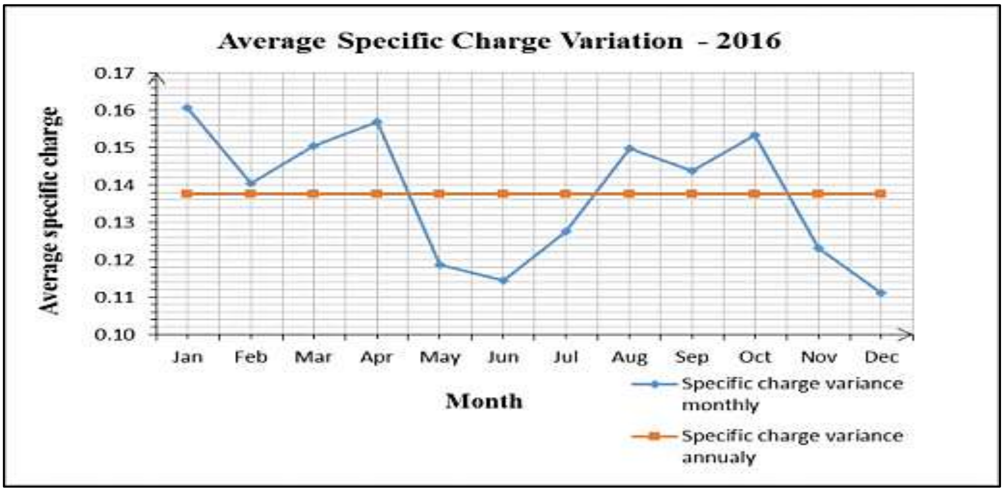

Figure 1 - Average Specific Charge Variation Graph

Field Experiments

Parameters which have not been changed during all the test blasts are tabulated in Table 2.

Table 2 –Constant Parameters

Parameter	Description
Blasted tonnage	4000 mt
Bench height	9 m
Hole length	34 ft (10.4 m)
Hole diameter	76 mm
Hole inclination	vertical
Delay interval	25 ms
Primary explosive	WaterGel
Secondary explosive	ANFO
No of rows	4
Drilling pattern	Staggered

2.2 Conducting Test Blasts

The summaries of test blast parameters are presented from Table 3.1 to Table 3.4.

Table 3.1 - Summary of Parameters

Description	Test Blast 1
Date of Blast	2016.12.17
Time	1.00 pm
Material type	Usable (High Grade Limestone)
Blast location	ISURU Side (95451E,339433N)
No of holes	23
Spacing (m)	2.8
Burden (m)	2.5
Water Gel	
No of holes	23
Cartridge weight (kg)	0.125
WaterGel per hole (kg)	1.25 (10 Cartridges)
WaterGel per blast (kg)	28.75
Ammonium Nitrate +Fuel Oil	
ANFO per hole (kg)	25
ANFO per blast (kg)	575
Diesel (L)	46
Electric Detonators	
Delay (25 ms)	3 6
	5 6
	7 6
	9 5
Total No of delays	23
Charging method	Bottom charging

Table 3.2 – Summary of Test Blast 2 Parameters

Description	Test Blast 2
Date of the blast	2016.12.27
Time	1.00 pm
Material type	Usable (High Grade Limestone)
Blast location	ISURU Side (95791E,339562N)
No of holes	33
Spacing (m)	2.5
Burden (m)	2.0
Water Gel	
No of holes	33
Cartridge weight (kg)	0.125
WaterGel per hole (kg)	0.75 (6 Cartridges)
WaterGel per blast (kg)	24.75
Ammonium Nitrate +Fuel Oil	
ANFO per hole (kg)	12.5
ANFO per blast	412.5

(kg)		
Diesel (L)		34
Electric Detonators		
Delay (25 ms)	3	16
	5	16
	7	16
	9	18
Total No of delays		66
Charging method		Deck charging

Table 3.3 – Summary of Test Blast 3 Parameters

Description		Test Blast 3
Date of Blast		2017.01.11
Time		1.00 pm
Material Type		Usable (High Grade Limestone)
Blast Location		EDC Side (95582E,339710N)
No of Holes		18
Spacing (m)		3.3
Burden (m)		2.8
Water Gel		
No of holes		18
Cartridge weight (kg)		0.125
WaterGel per hole (kg)		1.25 (10 Cartridges)
WaterGel per blast (kg)		22.5
Ammonium Nitrate +Fuel Oil		
ANFO per hole (kg)		25
ANFO per blast (kg)		450
Diesel (L)		36
Electric Detonators		
Delay (25 ms)	3	5
	5	5
	7	4
	9	4
Total No of delays		18
Charging method		Bottom charging

Table 3.4 – Summary of Test blast 4 Parameters

Description		Test Blast 4
Date of blast		2017.01.25
Time		1.00 pm
Material type		Usable (High Grade Limestone)
Blast location		EDC Side (95600E,339750N)
No of holes		18
Spacing (m)		3.3
Burden (m)		2.8
Water Gel		
No of holes		18
Cartridge weight (kg)		0.125
WaterGel per hole (kg)		1.25 (10 Cartridges)
WaterGel per blast (kg)		22.5
Ammonium Nitrate +Fuel Oil		
ANFO per hole (kg)		25
ANFO Per Blast (kg)		450
Diesel (L)		36
Electric Detonators		
Delay (25 ms)	3	10
	5	10
	7	8
	9	8
Total No of delays		36
Charging method		Deck charging

2.3 Fragmentation Analysis

To get an idea about the degree of fragmentation, digital photographs of each blast were ultimately analyzed with 'Split Desktop' software using an explosive containing box with a length of 400 mm as a reference. (Reference object is indicated in blue color) (Figure 2).

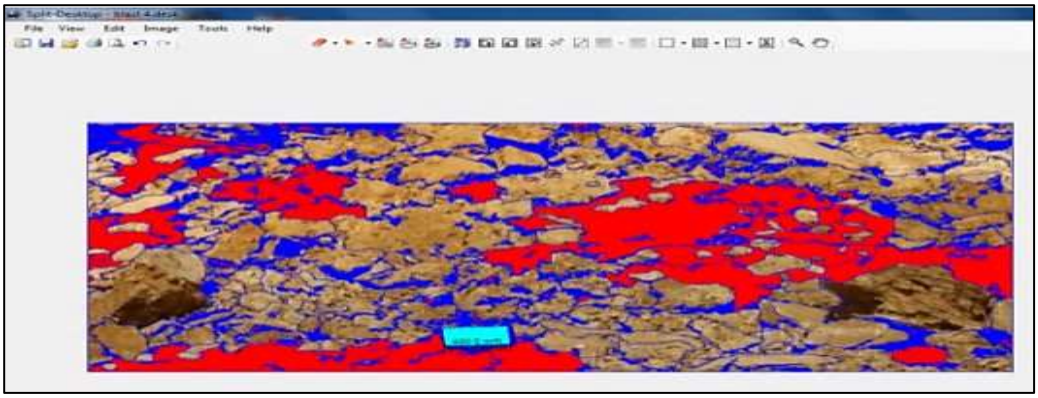

Figure 2 - Delineated Image by SPLIT Software

2.4 Cost Analysis

Cost of each blast is calculated considering the norms given in Table 4 which have been identified as main cost factors.

Table 4 – Unit Cost Factors

Description	Unit Cost (Rs)
WaterGel per blast (kg)	632.14/kg
ANFO per blast (kg)	128/kg
ED	99.46
Diesel (L)	95/L
Labour	400 / Person
Drilling (m)	282.01/m

3. Results

Results of spacing and burden calculations for the Aruwakkalu Quarry are as follows:

Burden (B) is given by Equation 1,

$$B = \left(\frac{2SG_e}{SG_r} + 1.5\right) D_e \ldots\ldots\ldots\ldots (1)$$

For HLL Aruwakkalu Quarry,

$SG_e = 1.29$, $SG_r = 2.40$

$$B = \left(\frac{2*1.29}{2.40} + 1.5\right) * 2.5 = 6.4\text{ft}$$

Hence, first trial burden comes with a value of

B = 6.4 ft.(~1.95m)

$$B_{corrected} = B * K_d * K_s \ldots\ldots\ldots\ldots (2)$$

For HLL Aruwakkalu Quarry,

$K_d = 1.00$ (Almost parallel deposition)

$K_s = 1.30$ (Weakly cemented layers)

$B_{corrected}$ = 6.4 ft * 1.00 * 1.30

= 8.32 ft (2.53 m)

$B_{corrected}$ = 2.5 m

This perfectly matches with the currently practiced actual value (2.5 m burden)

Spacing (S);

At Aruwakkalu Quarry, charges are delayed and stiffness ratio is higher than 1 and lesser than 4.

$S = \frac{L+7*B}{8}$..............................(3)

(29.5+7*8.32)/8 = 10.968 ft (3.3 m)

Adjusted/Corrected spacing should lie within ±15% of the calculated value.

Hence,

HLL norm of spacing =2.8 m (3.3-3.3*15%)

Results of each test blasts was summarized as follows in Table 5 under their Specific charge, total cost and the 80% passing particle sizes of sieve analysis.

Table 5 – Results of Four test blasts

Test Blast No	Specific charge (kg/m³)	80% passing particle size (mm)	Total cost (Rs.)
1	0.15	758.51	167,488.40
2	0.11	579.54	176,625.66
3	0.12	730.00	131,425.70
4	0.12	682.58	133,215.98

4. Discussion

Four test blasts were carried out to evaluate the impact of burden, spacing and charging method in limestone blasting at Aruwakkalu quarry. First test blast was mainly conducted to get a basic idea about the blasting procedure at the site and also to analyse the resultant particle size distribution. At Aruwakkalu, it normally follows bottom charging method where ten WaterGel cartridges are charged at the bottom during production blasts.

In the second blast, deck charging method was used because the amount of explosive per hole had been reduced. Decking was applied with three watergel cartridges at the bottom and three cartridges at the middle of the borehole and gaps between two primary explosive charged locations are filled with ANFO. According to sieve analysis graph, 80% passing particle size is 580 mm. Further, it requires additional ten holes to be drilled to obtain the same production as in test blast 1.

In the third test blast, both burden and spacing have been increased more than the traditional norms keeping amount of explosives and charging method unchanged. As spacing and burden are larger, required tonnage could be achieved with lesser number of blast holes. As shown in the Figure3, 80% passing size of the feed is at 730 mm.

The only difference between third and fourth test blasts is the method of charging. In the fourth test blast, deck charging method was again adopted to check whether fragmentation could be improved by doing so. According to the size distribution graph, 80% passing size was found to be 683 mm. Thus, it has indicated a slight difference in the size distribution curve due to the change in charging method.

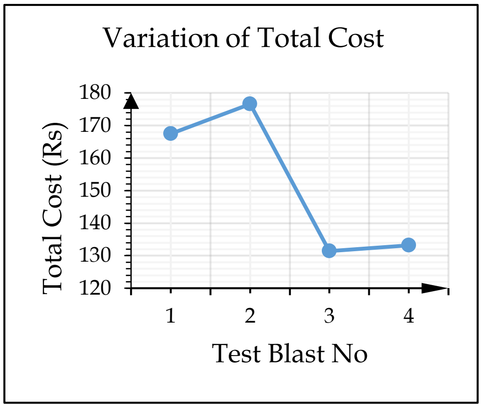

Figure 3 - Total Cost Variation

Variation of the total cost for each test blast can be depicted as above. Total blasting cost has increased in the second blast due to excess drilling cost for additional blast holes.
In third and fourth blasts, the total cost has been reduced due to less drilling and explosive cost.

All the test blasts except first one result in a lower specific charge because the total amount of explosives required in successive test blasts has been reduced. Also, the blasted tonnage is same for each test blast thus corresponding specific charge value will become lower. No changes were noticed in the specific charge during the last two test blasts because only the charging method has been changed.

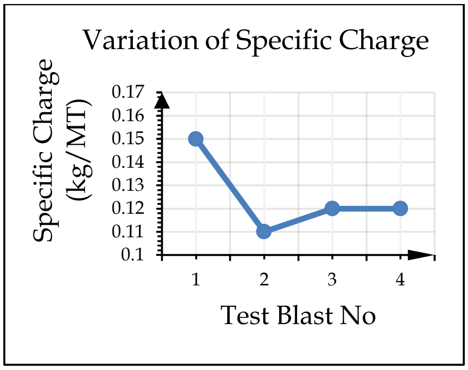

Figure 4 - Specific Charge Variation

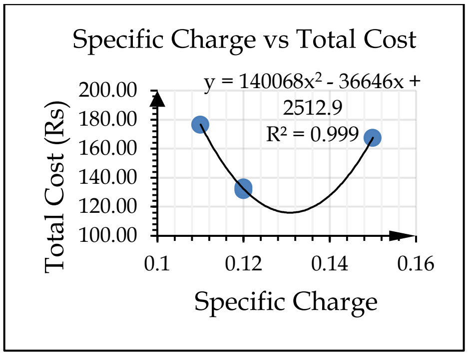

Figure 5 - Specific Charge vs Total Cost

As the graph suggests, the total cost of blasts will be minimum when the specific charge is close to 0.13. Readings related to test blast 3 and 4 become overlapped as specific charge is same between them. The coefficient of determination close to 1 indicates that the regression line perfectly fits the data.

5. Conclusions

According to the validation of the rock blasting process at Aruwakkalu quarry, average specific charge is 0.15 kg/m^3 which is same as stipulated by the Geological Survey and Mines Bureau. Also, it indicates that blasting parameters such as spacing and burden are already optimized as per the Langefors and Kihlstrom (1976)'s Swedish new method of open pit blasting.

Fragmentation analysis of the second test blast gives the best fragmentation curve as drill holes are blasted more closely. However, this approach predicted relatively higher total costs in drilling and blasting since there will be more holes to be drilled, charged and blasted when the modified blasting design parameters are applied. Also, it is time consuming as decking charging method is applied.

In this research, main focus was on 80% passing particle size whether it is below the crusher input size (800 mm). Presence of 20% of boulders will be useful during wet season because boulders contain less moisture. Therefore, boulders can be further crushed and mixed with wet material to reduce moisture level. Hence, 80% of the whole blast should be able to fed into the crusher, without leading to blind effect. All the test blast results indicate that 80% passing particle size of muck piles is compatible with the crusher input size.

When third and fourth test blasts are compared, fragmentation has been improved in fourth test blast due to greater explosive distribution within the blasting bed by decking and also it results a slight increase in the total cost due to additional electric detonators. When the time elapsed for explosive charging is considered, applying decking is more time consuming and resultant improvement in fragmentation is also not commendable. Therefore, blast geometry mentioned in the third test blast will be more effective than others when cost and charging time are concerned.

However, finding a relationship among specific charge and other related blasting parameters could not be completed due to lack of data and time constraint. Therefore, further study should be carried out to derive such a relationship for limestone blasting at Aruwakkalu Quarry.

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