Analysis of Efficiency and Impact by Deck Charging Patterns on Rock Blasting at Aruwakkalu Limestone Quarry, Sri Lanka

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Abstract

There is a potential to enhance both the efficiency and the quantity of explosives in limestone excavation utilising deck charge patterns in the Aruwakkalu limestone quarry in Sri Lanka. To achieve this a series of combinations with ANFO and deck charge patterns were simulated using a numerical analysis software named JKSimblast – 2D bench. This study entails simulating and validating the existing blasting geometry in the rock blasting practice. The fragmentation curves of the real world blast events were analysed and plotted using an AI platform called "Streyos". Subsequently, the blasting geometry was optimised by adjusting the spacing and burden with different charge amounts. A comparison was made between the explosive energy distribution figures of the simulated blast with optimised blasting geometry and the deck charging blast series. To simulate the limestone condition for the rock mass, throughout different simulations, the rock specific gravity (SG) was defined as 2.6. Optimised spacing and burden for a 10.3 m deep and 72 mm diameter blast hole pattern were found as 2.9 m and 2.4 m respectively, ensuring favourable conditions with controlled ground vibration (5 mms^{-1}) and air blast overpressure (120 dB). The optimal configuration for minimising boulder formation in the upper section of the hole was 23.17 kg of ANFO quantity per hole with a two-charge deck pattern.

Keywords: Explosive optimisation, JKSBM, Rock blasting, Limestone mining, Software simulation

1 Introduction

The main goal of a quarry's management is to reduce the cost of raw materials by meeting the plant's needs for amount and quality. Also, the entire production cycle should be as short as possible [1]. However, the limestone production blasting process faces obstacles like boulder formation and increased explosive costs [2]. Cevizci [3] has shown that when a larger percentage of boulders are formed, the costs and time required for crushing, grinding, and hauling also increase. Using an ideal explosive quantity with appropriate fragmentation not only cuts down on expenses but also minimises negative outcomes such as ground vibration, fly rocks, and excessive air blast pressure [4]. In the context of the Aruwakkalu limestone quarry in Sri Lanka, boulder formation in the upper part of the blast holes has been a significant concern, which impacts productivity.

The deck charging involves loading and placing explosive materials in a specific manner within blast holes or boreholes to achieve the desired fragmentation by using inert stemming materials or air bags. The application of the deck charging method is recognized as a novel technological advancement in the domain of surface mine blasting, designed to augment blast efficiency and decrease operational costs by many scientists across the world [5]. As described by Zarei et al. [6], the implementation of the power deck technique in surface mine blasts led to significant improvements in fragmentation and the uniformity of crushed rocks. Additionally, notable benefits included reduced bench throwing and uneven and rough toe problems with poor fragmentation, improved rock pile displacement, and decreased occurrence of fly rocks.

Moreover, from an economic standpoint, the utilisation of single and double power decks resulted in noteworthy cost reductions in terms of unit cost of rock volume. Specifically, the implementation of single power decks yielded up to a 10.7% reduction, while the adoption of double power decks resulted in an even more substantial decrease of up to 16.8%, compared to conventional mine blasting methods [6].

In addition, Roy et al. [7] concluded that the introduction of air-decking offers the advantage of increasing the effective charge length while keeping the overall quantity of explosives constant. This is achieved by using specially designed gas-bags or pre-fabricated wooden spacers to create air gaps between explosive charges.

The study aims to optimise explosive energy usage for better fragmentation results. This involves enhancing fragmentation efficacy and reducing explosive material use while minimising the negative effects of blasting activities. Through JKSimBlast – 2DBench software-assisted modelling and simulation of alternative new designs, it becomes possible to forecast explosive energy distribution, ground vibration, degree of fragmentation, air blast intensity, and ground vibration levels at varying distances in advance. This capability allows for a predictive assessment of the potential effects of different blasting configurations, aiding in the optimisation of blasting operations and ensuring compliance with safety and environmental regulations.

2 Methodology

Relevant data of blasting parameters, including but not limited to spacing, burden, bench height, drill hole diameter, bench level, floor level, under drilling, hole dip, number of rows per blast, number of holes per row, stem height, explosive height, explosive type, number of cartridges per hole and specific gravity, were systematically gathered through a data collection carried out through a Google form shared with the industry. These data serve as fundamental baseline information for the current study.

2.1 Blasting simulations for an existing pattern

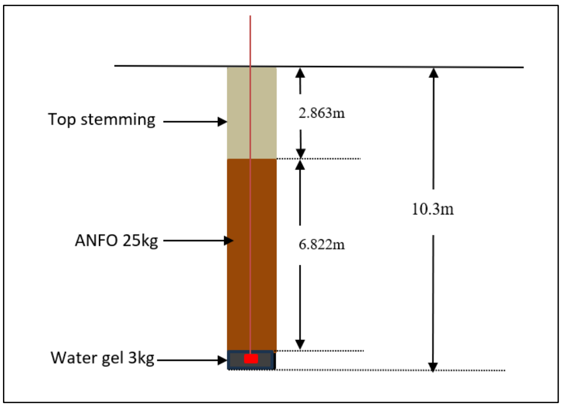

Figure 1: Existing charging pattern of blast holes

Subsequently, a blast simulation was conducted to analyse the characteristics of the pre-existing blast. The input parameters used for the simulation are provided in Table 1. Specifically, the chosen explosive type for the blast was ANFO, with a primary explosive weight of 3 kg (Fig. 1), and the blast pattern was set as staggered.

Table 1: Input blasting parameters of the existing blast

Parameter	Value
Burden (m)	2.5
Spacing (m)	2.8
Diameter of hole (mm)	72
Bench height (m)	10.3
Bench level (m)	10.3
Floor level (m)	0
Under drilling (m)	0
Hole dip (degrees)	90
No of holes per blast	100
No of rows	10
Holes per row	10
Stem height (m)	2.863
Specific gravity	2.6
Explosive quantity per hole (kg)	25

2.2 Blasting simulations

A comprehensive series of over one hundred simulations were executed in pursuit of an optimised bench blast design. The outcomes of these simulations, depicting the parameters acquired for the optimised blast design, are presented in Table 2.

Table 2: Input blasting parameters of the optimised blast

Parameter	Value
Burden (m)	2.4
Spacing (m)	2.9
Diameter of hole (mm)	72
Bench height (m)	10.3
Bench level (m)	10.3
Floor level (m)	0
Under drilling (m)	0
Hole dip (degrees)	90
No of holes per blast	100
No of rows	10
Holes per row	10
Stem height (m)	2.863
Specific gravity	2.6
Explosive quantity per hole (kg)	25

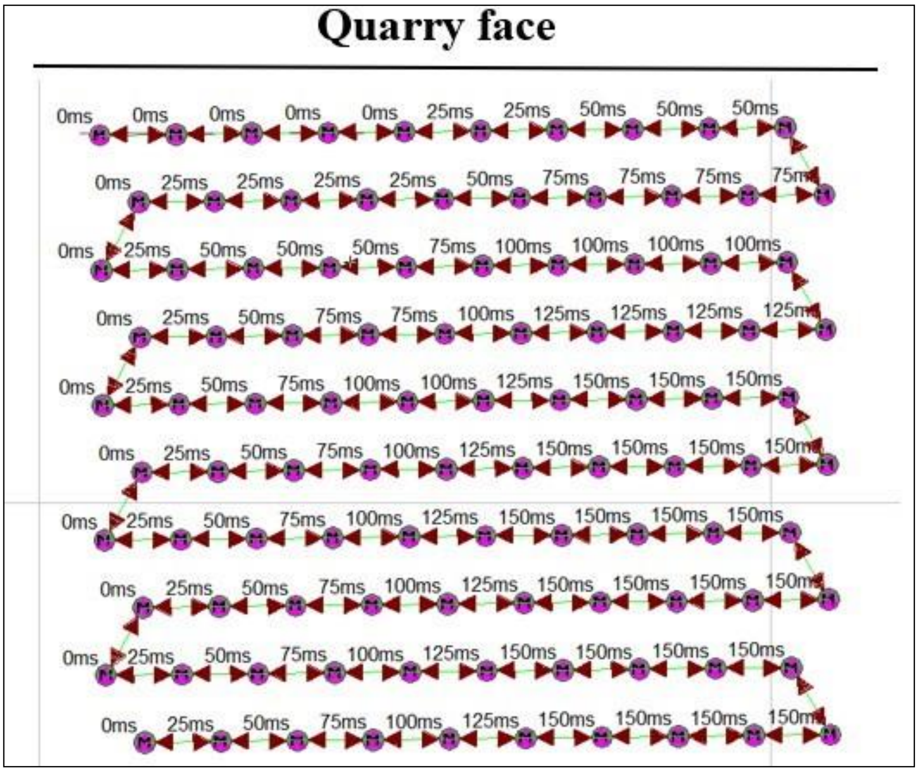

Figure 2: Downhole delay pattern with delay time for existing blast simulation

2.3 Blasting simulations for changing the amount of ANFO per blast hole

A comprehensive series of simulation sets was prepared to assess the ideal ANFO quantity per blast hole of the optimised blast. The optimised blasting parameters remained constant while altering the quantity of ANFO, ranging from 22 kg to 26 kg.

2.4 Blasting simulations for deck charging pattern

Two blasting scenarios were prepared with explosive energy distribution to assess the impact and efficiency of the number of decks. These scenarios involved charging patterns comprising one, two, three, and four decks.

2.4.1 ANFO quantity per hole is kept constant

During the simulations, the stemming height is adjusted to accommodate the deck patterns with a 0.5 m separation between decks. The ANFO height is divided into equal sections to facilitate the placement of decks (Fig. 3).

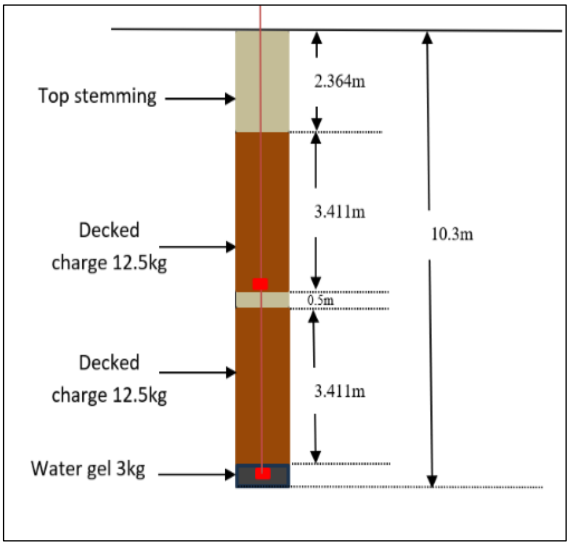

Figure 3: Two-deck charging pattern of holes - ANFO quantity per hole is kept constant

2.4.2 ANFO quantity per hole is reduced

Throughout the simulations, the stemming height remains constant (Fig. 4), and decks are created with a 0.5 m separation stemming column between each deck. The ANFO quantity varies as follows:

- 25 kg, 23.17 kg, 21.33 kg and 19.05 kg

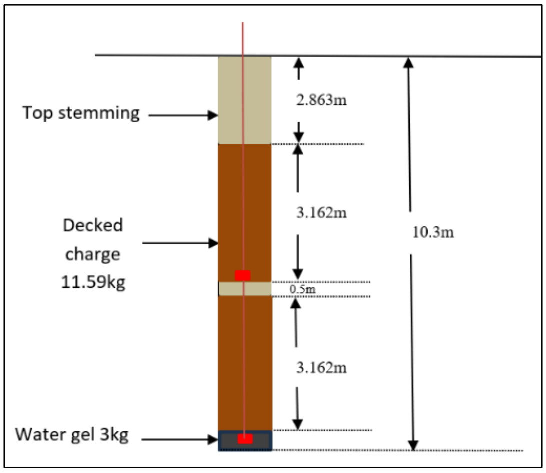

Figure 4: Two-deck charging pattern of holes - ANFO quantity per hole is reduced

2.5 Conducting test blast for existing blast

A designated area measuring 25 m x 25 m was selected at the Aruwakkalu site to conduct a test blast.

Figure 5: Selected 25 m × 25 m area for test blast (8.263781N, 79.826287E)

2.6 Actual fragmentation analysis using Streyos visual AI platform

The drone photographs were subjected to fragmentation analysis using the "Streyos" visual AI platform, enabling a comparison between the predicted fragmentation and the actual observed fragmentation. For a blast, over fifty photographs were taken, and approximately fifteen selected photographs were further analysed using the Streyos platform to assess the fragmentation characteristics accurately.

3 Results

3.1 Simulation results of blasting geometry

Table 3: Simulation results of the existing blast pattern

Parameter	Value
Volume (m³)	7210
Tonnage (tons)	18746
Percentage passing through ø 0.5 m sieve	49%

Table 4: Simulation results of the optimised blast pattern

Parameter	Value
Volume (m³)	6953
Tonnage (tons)	18077.8
Percentage passing through ø 0.5 m sieve	49.9%

3.2 Simulation results of ANFO quantity changes

Table 5: Simulation results of ideal ANFO quantity per hole

Parameter	Value
Volume (m³)	7200
Tonnage (tons)	18720
Percentage passing through ø 0.5 m sieve	49%
ANFO quantity per hole (kg)	23.174

3.3 Explosive energy distribution of deck charging patterns

3.3.1 ANFO quantity per hole is kept constant.

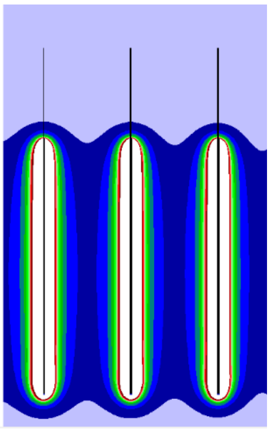

Figure 6: Vertical explosive energy distribution for single deck charging pattern

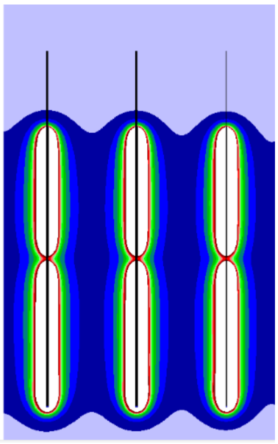

Figure 7: Vertical explosive energy distribution for two charging decks pattern

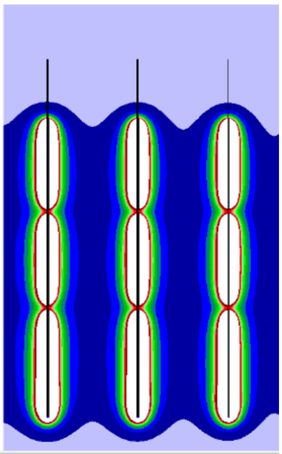

Figure 8: Vertical explosive energy distribution for three charging decks pattern

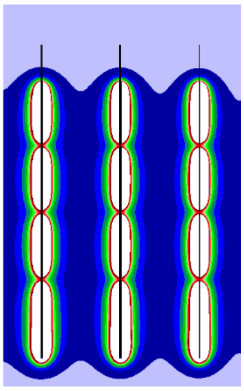

Figure 9: Vertical explosive energy distribution for four charging decks pattern

3.3.2 ANFO quantity per hole is reduced

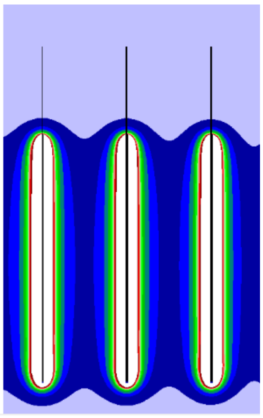

Figure 10: Vertical explosive energy distribution for single charging deck pattern

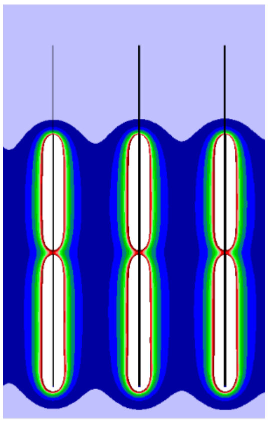

Figure 11: Vertical explosive energy distribution for two charging decks pattern

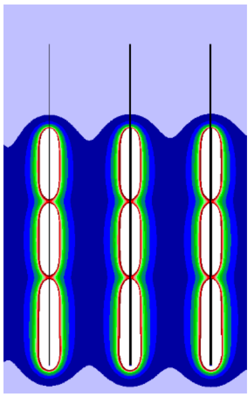

Figure 12: Vertical explosive energy distribution for three charging decks pattern

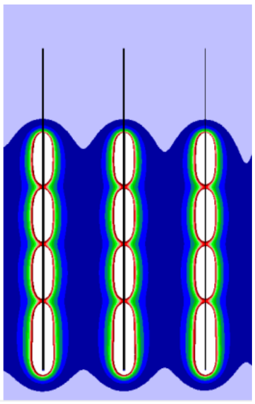

Figure 13: Vertical explosive energy distribution for four charging decks pattern

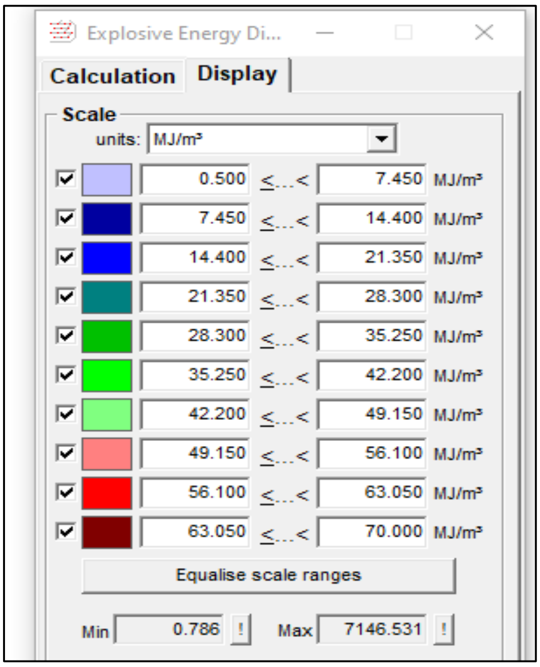

Figure 14: Scale range of static vertical energy distribution of explosive charge for the optimised blast

3.4 Actual fragmentation analysis using Streyos visual AI platform of existing blasting geometry

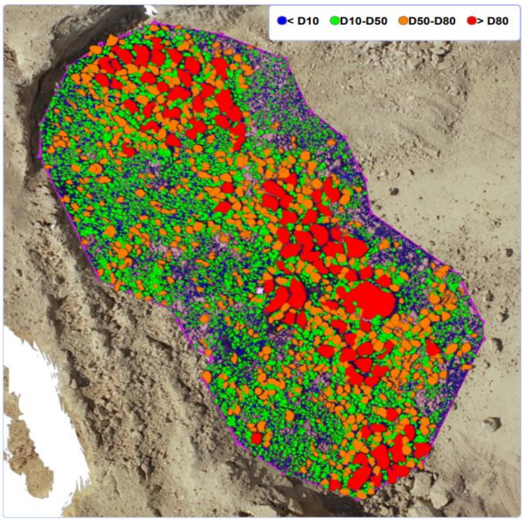

Figure 15: Muck pile area analysis for the test blast

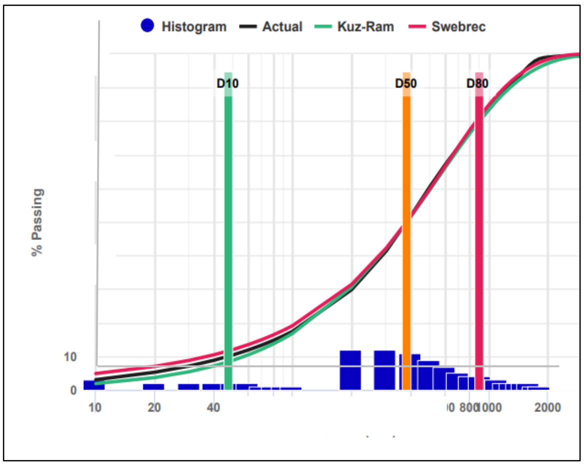

Figure 16: Fragmentation analysis for the test blast

Percentage passing through ø 0.5 m sieve - 49.5%

4 Discussion

In this research, the process of selecting an optimised blast design incorporates a comprehensive assessment of the variations in the following parameters:

1. Volume
2. Tonnage
3. Percentage passing through ø 0.5 m sieve by Jaw Crusher
4. Ground vibration
5. Air blast intensity

When investigating the reduction of ANFO quantity per hole, the variation in the percentage of material passing through ø 0.5 m sieve between the existing quantity and the reduced 23.17 kg quantity was found to be negligible (Table 3, Table 4).

Hence, the explosive cost was effectively reduced as a result of decreasing the ANFO quantity for the existing blast.

The fragmentation analysis of the existing blasting geometry showed no statistically significant difference between the results obtained from the simulation (Table 3) and the actual field observations (Fig. 16). Therefore, variations in specific gravity across different locations within the Aruwakkalu site can be neglected, and a value of 2.6 may be assigned as the constant specific gravity throughout different simulations.

There was no statistically significant difference observed in the explosive energy distribution figures (Fig. 6 and Fig. 10, Fig. 7 and Fig. 11, Fig. 8 and Fig. 12, Fig. 9 and Fig. 13) between scenarios where the stemming height was changed, and those where the stemming height remained unchanged. Hence, the efficacy and influence of deck charging patterns on rock blasting have exhibited equivalent enhancements within both of the aforementioned classifications.

The study revealed that using four charging decks resulted in improved energy distribution (Fig. 13) than single deck charging pattern (Fig. 10) and better fragmentation compared to using a single deck, two charging decks, or three charging decks (Fig. 10, 11 and 12). However, considering time considerations and labour costs under the practical situation, the utilisation of two charging decks can be suggested as the most viable and effective option among the choices.

Determining the efficient deck charging pattern (single, two, three, or four) depends on various factors, including the specific blasting objectives, geological conditions, desired fragmentation, and vibration control requirements.

5 Conclusions

Based on the research findings presented in this study, the following conclusions can be drawn.

- A burden of 2.4 m and a spacing of 2.9 m can be utilised to optimise blasts.
- Within the context of optimised blasting geometry, it is feasible to employ a reduced quantity of 23.17 kg of ANFO per blast hole, thereby replacing the previously utilised 25 kg.
- The occurrence of boulder formation in the upper section of the blast hole is comparatively diminished in Fig. 13 when contrasted with Fig. 10.
- In the scenario where the top stemming height remains constant, the quantity of 23.17 kg is attained through the application of a two-deck charging pattern. Considering factors encompassing time and labour expenditures, it is advisable to endorse the utilisation of the two-deck charging pattern as a proficient and effective choice.

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