Optimization of blasting geometry and explosive quantity in control blasting for dimension stone extraction

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Abstract
Dimension stone industry is a widespread market in the globe and has shown promising trends for expansion in the recent years. Dimension stones can be defined as, natural stones that have been selected and extracted to produce stones of precise size and shape. Products of dimension stones have been used for construction engineering practices and various other ornamental purposes. The available extraction practices for dimension stones can be categorized mainly into mechanical cutting and splitting techniques. Pre-split blasting is one of the splitting techniques that can be utilized to liberate dimension stone blocks from the rock deposit. The major drawback of utilizing explosive blasting in dimension stone extraction is the possibility of having high amount of wastes as a result of unnecessary fractures from the excessive explosive energy. By studying the relationship between blasting geometry and explosive quantity towards forming fractures in the selected ornamental stone, the aforementioned issue can be addressed to some extent. Software simulations were done to determine the blast design's ideal parameters for achieving an effective explosive energy distribution in the rock mass. Validation of the obtained simulation results through a field blast can be suggested as further development in the study area.

Keywords: Ornamental natural stone, Blasting simulation, Pre-split blasting, Explosive energy, Hard rock fracturing

1. Introduction

Blasting is widely adopted in different engineering practices especially in mining, construction, and tunnelling to break the rocks as a low-cost excavation method. However, blasting does have its disadvantages such as excessive ground vibrations, fly rocks, air blast, etc. Therefore, to overcome these problems control blasting techniques has been developed over the years which enables to eliminate those problems to a certain extent. Two main types of parameters influencing the blasting event, controllable parameters, and uncontrollable parameters. In situ or rock parameters are uncontrollable while blasting parameters can be controlled. Those controllable parameters can be listed as spacing, burden, powder factor, stemming height, stemming material, initiation method, etc. By modifying these controllable parameters blast output can be altered depending on the requirement [1], [2]. From the literature four main control blasting techniques can be identified as are pre-split blasting, trim blasting, smooth blasting (Buffer blasting), and line drilling. Purpose of control blasting is to manipulate the explosive energy so that intended rock fractures are obtained while omitting the problems generated during the blasting [3].

Control blasting applications can be found in road projects, dimension stone quarrying, trench blasting, tunnel face blasting, rock wall stabilizations etc [4], [5]. Among those applications dimension stone quarrying is an area where control blasting can be effectively adopted. Dimension stone is a block of stone which has a specific dimension in width, length, and height. Those stones are used to prepare internal and external wall claddings, floors and paving, monuments and memorials, natural slabs, kerbs, tiles, building blocks, building facing, etc. Rock types such as granite, marble, limestone, sandstone, and slate are the most suitable to be used as dimension stones due to their properties such as durability, texture, homogeneity, color variations, resistance to weathering, suitability for polishing and carving, etc [6]. The methods to extract dimension stones can be broadly categorized as splitting practices and cutting practices. As the splitting methods Plugs & feathers, mechanical splitting, expansive mortar (expansive cement) and controlled blasting can be listed and as the cutting methods jet flame cutting, diamond wire sawing, water jet cutting, chain arm sawing and diamond belt cutting can be listed [7]. Pre-split blasting is the most suitable method to be used because it will help to minimize the waste rock and crack generations. The minimization of fracturing in dimension stone is important because the presence of fractures will significantly decrease the quality of dimension stone while increasing the waste generation [8].

In Sri Lanka also there are few dimension stone quarries which produce dimension stones by using cutting methods in large scale. In few metal quarries there are certain portion isolated rock masses which are rich with granites have identified so it can be used to produce dimension stones in a smaller scale. Since adopting cutting methods require higher investment if the pre-split blasting can be used for the extraction of dimension stones from those quarries, then the capital cost can be significantly reduced. Therefore, developing an appropriate blast design for dimension stone extraction can lead to economic extraction of these stones which will eventually help to expand the dimension stone industry in Sri Lanka.

To understand the influence of explosive energy to the rock mass and blast simulation purposes JKSimBlast software "2D Bench" model can be effectively used [9]. 2D bench model is specifically designed to perform the bench blasts.

2. Methodology

Blasting operations are simulated by using the JKSimblast software while changing the blasting parameters and come up with an optimized blast design. To start the designing the details of the block size is required and it provided as follows.

The standard size of the block is decided as 2m x 2m x 2m with the total volume of 8 m^3. It is planned only to do the vertical blast so for the horizontal separation cutting mechanism has to be adopted. At the initial stage the rock slab of 2m wide, 2m deep and 10m in length need to be extracted and in the next phase separated rock slab is further divided into 2m lengths to achieve the appropriate block size.

2.1 Software simulations

Energy distribution of the blasts should be thoroughly investigated in order to get the optimum blast design while creating a fracture between holes with minimum damage to the rock mass. JKSimBlast software is used to study and analyze the energy distribution of the designed blasts. Throughout the experiment following parameters are kept constant,

I. Burden (2.25m)
II. Borehole depth (2.25m)
III. Borehole diameter (40 mm)
IV. Hole angle (90 degree)

Following parameters are varied and their influence on the energy distribution is examined.

I. Explosive type
II. Charging pattern
III. Spacing
IV. Initiation method

Since it is not possible to vary all the parameters together at once the following procedure (Figure 1) was used in order to achieve the optimum blast design.

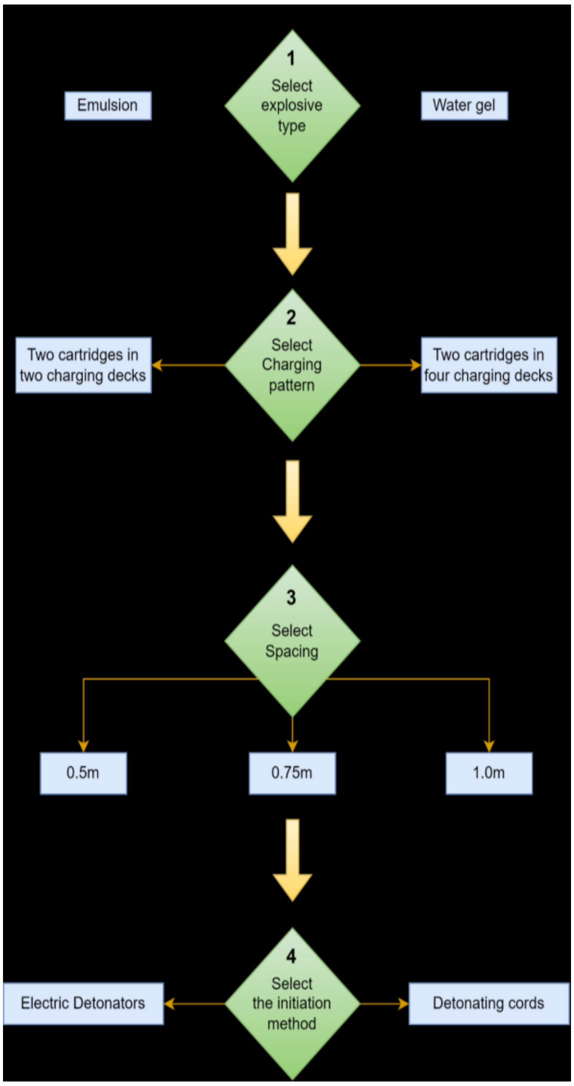


Figure 1: Process for parameter selection

2.1.1 Selection of explosive type

Suitable explosive type was selected based on their energy distribution analysis of single blast hole. Emulsion explosive and water gel explosive were compared since they are embedded in the software and available in the local market.

2.1.2 Selection of charging pattern

Effect of the charging pattern on the energy distribution is studied by comparing two blasts. Two blasts were designed by keeping all parameters constant except charging pattern. Each blast hole charged with 0.38 kg of emulsion as shown in following figure 2 and figure 3.

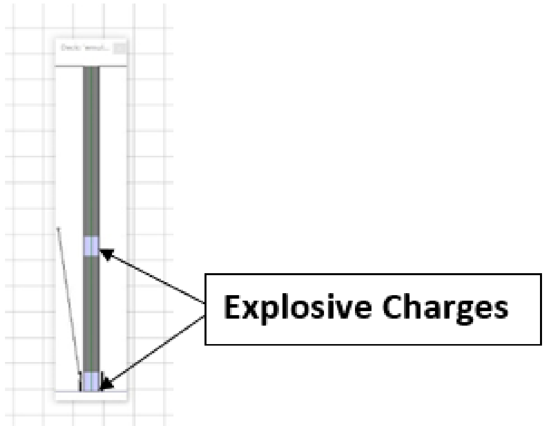


Figure 2: Blast hole with charged at two places

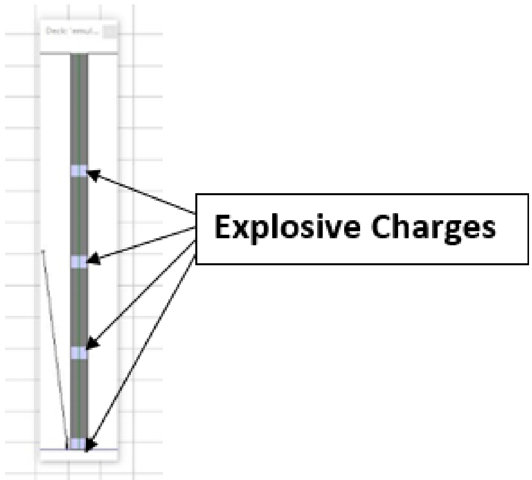


Figure 3: Blast hole with charged at four places

2.1.3. Selection of spacing

After selecting the best energy distribution pattern from the above process using that to identify suitable charging method three blast designs were designed to study the effect of spacing on the energy distribution. All parameters except spacing are kept constant throughout the three blasts. Spacing of the blasts were set as 0.5m, 0.75m and 1m.

I. 1st blast – 20 holes with 0.5m spacing
II. 2nd blast – 14 holes with 0.75m spacing
III. 3rd blast – 10 holes with 1m spacing

2.1.4. Selection of Initiation method

When considered about the available resources both in software and field either Detonating Cord (DC) or Electric Detonators (ED) can be used as the initiation method. Since both methods can facilitate simultaneous blasting without delays their cost and charging time consumption considered to select the best method.

3. Results

3.1 Charging pattern

The energy distribution of blast holes with two different charging systems were obtained as Figure 4.

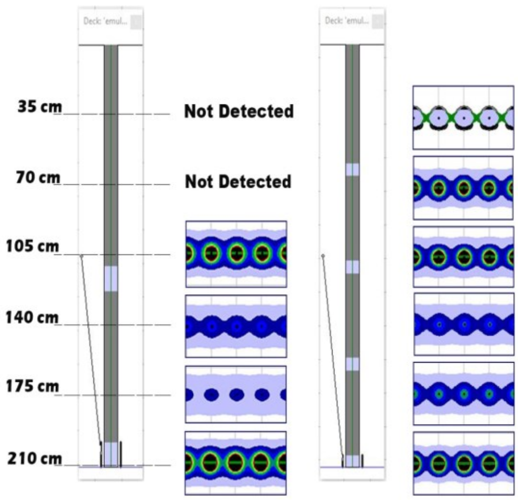


Figure 4: Energy distribution at different levels in two charging methods

3.2 Spacing

Energy distribution of the three blasts (A, B, C) were obtained as following figure 4. Spacing of the blast designs A, B, and C are 0.5m, 0.75m, and 1m respectively (Figure 5).

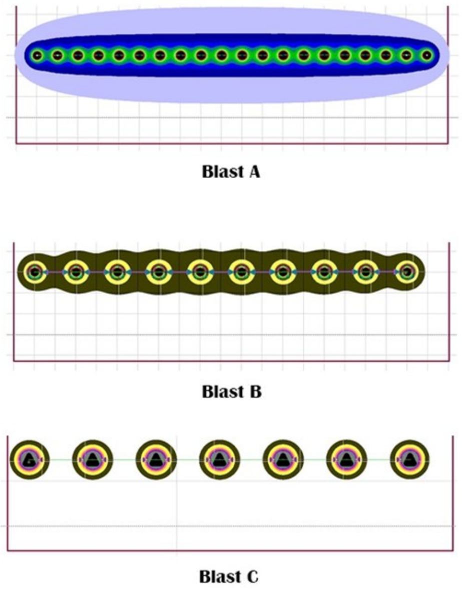


Figure 5: Energy distributions in different hole spacing configurations

3.3 Initiation method

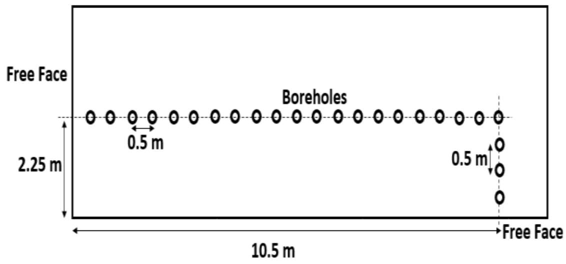
According to the cost analysis, using detonating cords is cost effective (Table 1).

Table 1: Cost estimation comparison in DC & ED initiation methods

	Detonating cords	**Electric detonators**
Unit Price (Rs.)	57 per meter	127.54
Amount per a drillhole	1.6 m	3 units
Cost per a drillhole (Rs)	91.2	382.62

3.4 Final design

Final blast design is obtained after analysing the data. This is designed for a bench which have open face in two sides.



The plan view of the bench (Figure 6), 3D views (Figure 7) and the final blasting parameters can be found in the following table 2.

Figure 6: Plan view of the blast bench with dimensions

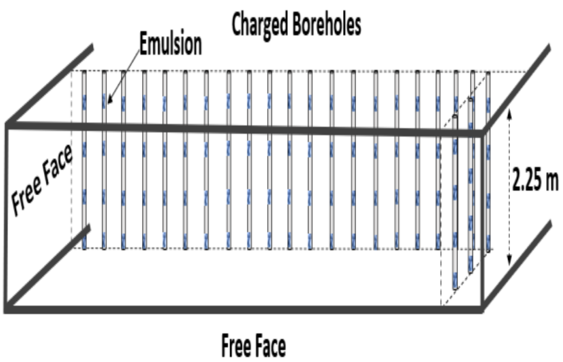


Figure 7: 3D view of the bench after charging the explosives according to blast design

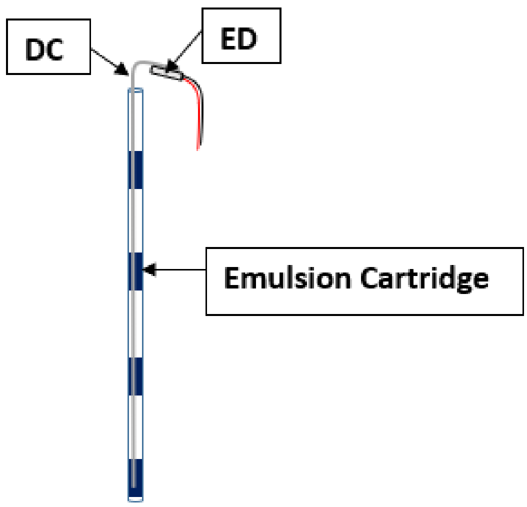


Figure 8: Cross-section of one borehole after charging the explosives.

The resulted energy distribution from the blast can obtained as in the following Figure 9 and energy levels colour variation from Figure 10.

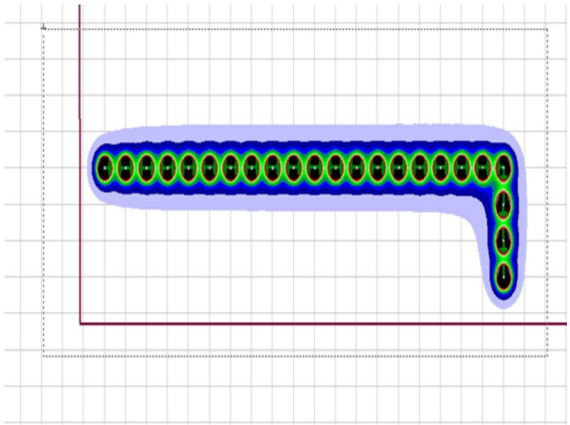


Figure 9: Energy distribution of the final blast design

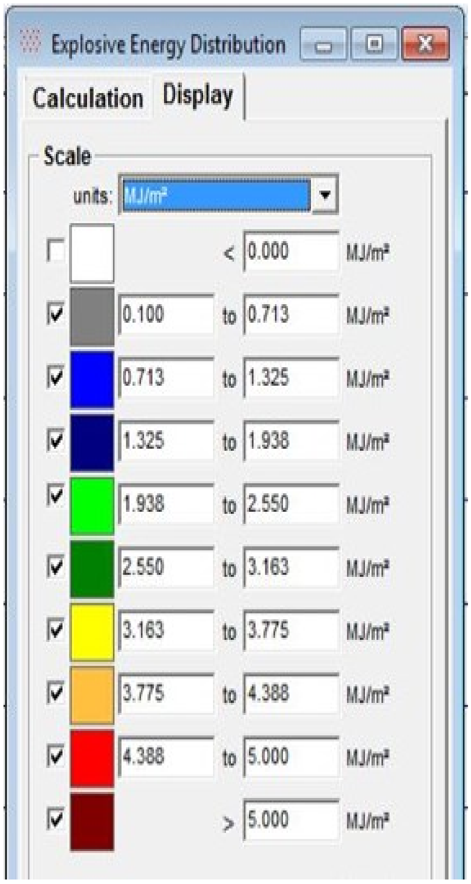


Figure 10: Energy levels colour variation

4. Discussion

Compared with the water gel explosives emulsion explosives will generate less ground vibrations and air blast over pressure [10]. According to the energy distribution emulsion explosives release slightly less energy to the rock mass compared with water gel explosives. Therefore, emulsion explosives were selected as the suitable explosive type to be used in the pre-split blast. As well as the charging pattern have significant impact on the energy distribution throughout the hole length of the blasthole. Therefore, the charging pattern with explosives at four places in blasthole was selected for the blast since it provides good spread of the energy throughout the blasthole.

Based on the minimum energy require for fracture generation in the rock spacing for the blast is finalized as 50 cm between holes and considering the cost, safety, time consumption and handling easiness detonating cord was selected as the initiation method. The final blast design parameters are included in the Table 2.

Table 2: Final blast design parameters

Blasting parameter	**Nos**
Burden	2.25 m
Spacing	0.5 m
Hole depth	2.25 m
Hole diameter	40 mm
Hole angle	90 degrees
No of holes	23
Emulsion explosive	8.74 kg (23 cartridges)
Electric detonators	23
Detonating Cord	36.8 m

As mentioned above few parameters were kept constant. The Diameter is maintained constant because in the industry the explosives are used as cartridges and those cartridges has a fixed diameter. Therefore, the explosive deck diameter is always maintained constant. In addition, the normal handheld hammer drills used in Sri Lankan quarries can drill the holes in range of 30 to 40 mm diameter. So even though lesser diameter is used for the designing purpose it is not possible to have it in the practical scenario. Burden, hole height and hole angle kept constant in order to obtain required block size (2*2*2 m^3) to produce dimension stones.

Several limitations have identified while designing using JKSimBlast software. The major concern is that the software is considering the rock as homogeneous, and it doesn't take account the fractures or other discontinuities and composition. So, it can cause that the energy distribution obtain from the software can be differ from the practical implementation. Another issue is that the blast design cannot be done using both horizontal and vertical drillholes. Therefore, only vertical drilling was designed. When analysing the energy distribution, the energy distributions cannot be obtained in vertical direction. So, plan view of energy distribution had to take in several levels of the drillhole to study the whole energy distribution thorough the drillhole from top to bottom. In the other hand JKSimBlast software does not provide functions to change coupling ratio. Therefore, the hole diameter cannot change while keeping the explosive deck diameter constant in the software.

Throughout the study only vertical direction is considered due to practical and designing difficulties which are,

- Lack of horizontal drilling equipment in quarries.
- Lack of skilled drillers to drill horizontal holes in quarry sites.
- Inability to achieve 100% vertical drilling from handheld drills in quarries.
- Design cannot be done in both horizontal and vertical directions simultaneously in JKSimBlast software.

Advantages of using controlled blasting for dimension stone extraction can be listed as follows.

- Can be cost efficiently adopted in hard rock extraction.
- Less capital cost for the initiation of the project
- High production rate compared to other splitting techniques.

5. Conclusions

Emulsion explosives are recommended to be used for the given application as charging with given intervals resulted better energy distribution throughout the entire length of the blasthole. A 0.5 m spacing between blastholes with detonating cord initiation has proved cost effective and efficient compared to other initiation systems and parameters. Therefore, pre-split blasting technique can be effectively utilized in dimension stone extraction by careful selection of the blasting parameters through appropriate software simulations, facilitated by results validation prior to implementations.

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