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A Case Study On Controlled Blasting In Marble Mine

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ABSTRACT

Mining is the process of economically extracting minerals from the Earth's crust. The mining sector has several India's mining sector is crucial for the country's economy, providing raw materials for industries like steel, cement, and manufacturing. Efficient excavation methods are essential for mining operations, as drilling and blasting are the cheapest methods. Proper blast design is essential to minimize harmful effects and ensure safety. Common safety concerns include ground vibrations, fly rock, noise, premature detonations, and air or dust pollution. Air decks can improve explosive efficiency, and blast design parameters can be classified into explosive characteristics, rock characteristics, and blast geometry and initiation sequence. Controlled blasting is essential in dimensional stone mining and marble mining, as it reduces revenue from inferior dimensions of finished product. A study investigated various blasting techniques and found that existing techniques were satisfactory for controlling blasting nuisances. A new initiation pattern for blasting in overburden extraction produced less vibration and reduced damage to marble.

Keywords: Blasting Techniques, Mining, Marble Mining, Controlled Blasting.

I. INTRODUCTION

1.1 General

Mining in India is characterized by a complex interplay of historical, economic, environmental, and social factors. The country is blessed with variety of mineral resources, including zinc, copper, aluminum, iron ore, manganese, limestone, magnesium and various precious and semi-precious stones. These minerals are available across length and breath of country with some areas being particularly concentrated in specific resources.

The mining sector plays a significant contribution in India's economy, supplying raw materials for key industries such as steel, cement, and manufacturing. Additionally, it caters the significant need of employment, both directly within mining operations and indirectly in related sectors and services. As the drilling and blasting is the cheapest method of mining its efficient excavation methods are essential to meet this demand. These techniques not only facilitate the fragmentation of rock, shape of remaining rock but also influence the overall efficiency of mining operations.

The efficiency of drilling and blasting process depends upon the optimum explosive initiation which leading to expansion and creating cracks in the rock. The solitary aim is to maximize utilization of energy only for rock fragmentation not for vibration and other undesirable effects.

In conventional blasting, the detonation of explosives releases a significant amount of both effective and non-effective energy. Effective energy is beneficial for breaking rock in mining and construction, while non-effective energy can lead to harmful consequences, including damage to human life and the environment. Common safety concerns associated with blasting include ground vibrations, fly rock, noise, premature detonations, and air or dust pollution.

To avoid the harmful effects proper blast design is imperative. The process involve designing such a blast with precise delay, which control the direction of explosive throw, distribution of explosive energy. One of the major factor is matching the explosive with rock characteristics. By focusing on these factors, it is possible to enhance safety and minimize environmental impact while keeping operating costs low and maximizing the utilization of rock resources.

Furthermore, the use of air decks at strategic locations within the blast holes can significantly improve explosive efficiency. In specific cases involving draglines and shovel-dumper operations, an effective cast ratio

(ECR) increase of 30% or more can be achieved, demonstrating the potential for optimizing blasting practices in mining operations.

Blast design parameters can be classified into three main categories, 1) explosive characteristics, 2) rock characteristics, and 3) blast geometry and initiation sequence. Rock characteristics that cannot be controlled by the blast designer are termed uncontrollable parameters. In contrast, explosive characteristics, blast geometry, and initiation sequences are controllable parameters that must be tailored to fit the specific geo-mining conditions of a site.

In Indian mines, due to site specific parameters blast design depends on a trial-and-error approach. Designers adjust blast parameters until satisfactory results are achieved. However, there are instances when mines fail to meet desired outcomes, leading to the referral of persistent blasting issues to research organizations. Common challenges encountered in surface mining include the presence of boulders (oversized fragments), fines (undersized fragments), toe and back break issues, hard digging, ground vibrations, air overpressure, and fly rock.

To minimize the risks related to fly rock and excessive throw, it is crucial for miners to implement proper blast design techniques, such as controlling the direction of explosive throw, optimizing the distribution of explosives within the blast holes, and selecting explosives that closely match the rock's characteristic impedance. By carefully managing these factors, mine operators can enhance safety, minimize environmental impact, and maintain highproductivity levels while ensuring the sustainable extraction of mineral resources.

The discussion on blasting, its fragmentation, it damages, its impacts are generally limited to conventional open cast mining, however the blasting used in dimensional stone mining carry its own challenges as the effect of blasting is very risky in dimensional stone itself and also any blasting in overburden can create fractures in stone also, which can greatly reduce its selling price. In light of this phenomenon the controlled blasting is very essential in dimensional stone industry, both in stone (it any) and also in overburden.

1.2 Objectives

1. To investigate various controlled blasting techniques used in marble mines.
2. To optimize various blast design parameters considered for controlled blasting.
3. To minimize blast nuisances such as ground vibration, air over pressure and flyrock.
4. To study various impacts of blasting on remaining rock while blasting in overburden.

1.3 Methodology

The following actions have been taken in order to meet the study's objectives.

1.4.1 Field work

a) Identification of the problem i.e. the identification and defining the problem.

b) Mine visit (Jain Irons Mines) observation and study of the operation of the machineries.

c) Collection of vibration data and samples from mine manually.

d) Analysis of the data and the system to find out the root cause of the problem.

1.4.2 Laboratory Work

The laboratory examination of compressive strength was performed by universal testing machine , tensile strength by Brazilian test, point load index by point load index tester for analyzing samples collected during fieldwork.

a) A UTM is a versatile piece of equipment used in materials testing to evaluate the mechanical properties of a variety of materials. Compressive Testing measures the force required to compress a material until it deforms or fractures, providing data on its compressive strength and behavior under load.

b) The Brazilian Test, also known as the Brazilian Tensile Test or the Brazilian Split Test, is a method used to determine the tensile strength of materials,particularly brittle materials such as concrete, rock, and ceramics.

c) A Point Load Index Tester is used to determine the Is of rock samples, which is an indicator of the rock's strength and can be used to estimate its UCS. This test is widely used in geotechnical and mining engineering due to its simplicity, rapid execution, and minimal sample preparation requirements.

2. REVIEW OF LITERATURE

Ozer *et al.* (2012) primarily investigated the impact of delay time sequences and charge per delay for analysis of ground vibration. In the study they used data of 127 holes for blasting pattern, blast hole design and explosive charge for the status. In another phase they introduced modification in blast geometry, sequence of delay and quantities of explosives. They found significant reduction in ground vibration in later case.

Lal *et al.* (2012) The study focused on optimizing blasting techniques to improve productivity while minimizing vibration levels. A total of 82 blasts were conducted, and data from 347 blast vibrations were collected for analysis. Initially, the nonel initiation system was used, but subsequently, electronic delay detonators were introduced to achieve desired blasting outcomes. Initially, blasts utilized 100 kg of emulsion explosives distributed across 4blast holes, with each detonated using 25 kg of explosive per delay. In contrast, blasts using electronic delay detonators involved a maximum of 792 kg of explosives, with 56 kg per delay. The recorded vibration data remained below 10 mm/s, demonstrating effective control. The optimized blast design resulted in excellent fragmentation. Techniques such as simultaneous initiation of two rings and a phased approach starting with the bottom section followed by the top slice after decking the ore body proved highly successful in this mining operation.

Singh *et al.* (2012) studied on the stability of waste dump impacted due to blast vibration. They monitored the blast induced vibration on various sites on the waste dumps for present blasting framework and their suggested framework. The reported that at 123 instance they recorded the readings. They found that no significant damage to the waste dump was found, except minor local displacements in loose material.

Rosenhaim *et al.* (2012) investigated the effect of burdens and spacing on the attenuation of ground vibration specifically in over burden blasting. They found in the study that as compared to blasting in coal, the overburden which is generally is sedimentary rock require less energy and low powder factor (approx. 150gm/m^2) and larger spacing and burden. The blast, both in coal and overburden were monitored by seismograph and derived attenuation equations.

Rosenhaim *et al.* (2013) used seismograph and monitored the ground vibration by changing the ground vibration by changing distances from blast sites ranging from 35 to 1100m along with comparing changes in blast design, initiation sequences and delay combinations. They studied various firing patterns and found that in serpentine sequence, in case of drill holes deeper than 4m, there was difficulties and required additional drilling and blasting due to incomplete excavation at bottom of hole, which causing higher ground vibration, noise, air over pressure (fly rock). Where as in parallel initiation sequence there was improved fragmentation, no re-drilling and blasting and reduction in ground vibration, noise and fly rock. Another sequence called diagonal method showed similar results to parallel sequences. Simultaneous multiple hole firing at 8ms interval and employing a higher charge weight per delay in both cases as compared to serpentine method.

3. FIELD AND LABORATORY INVESTIGATIONS

This chapter involves the three phases: the first one is the study area which involves the site location and geology of the mine, second one is the field investigation which involves the study of data in the field such as controlled blasting techniques, blast parameters, types of explosive, types of delay element, types of initiation sequence and sample collection and the third one is the laboratory investigation which involves the analysis work on samples collected in the field like measurement of compressive strength, tensile strength and point load index.

3.1 Study Area

3.1.1 Site location

The mining area is situated near village Rishabhdev Tehsil Rishabhdev, Distt. Udaipur. The approximate distance from Rishabhdev to mine area is 8 Km. Som River is flowing in the south at a distance of 15 KM from the mining area. The chrysotile variety of asbestos is known to around villages and near by area in the form of cross fibre veins forming ribbons or irregular stock-works. Green marble is the trade name of serpentine marble. This area is having number of mines for extracting Green marble, surrounded very thickly in the particular area of Odwas, Masaro ki Obri and other small clusters.

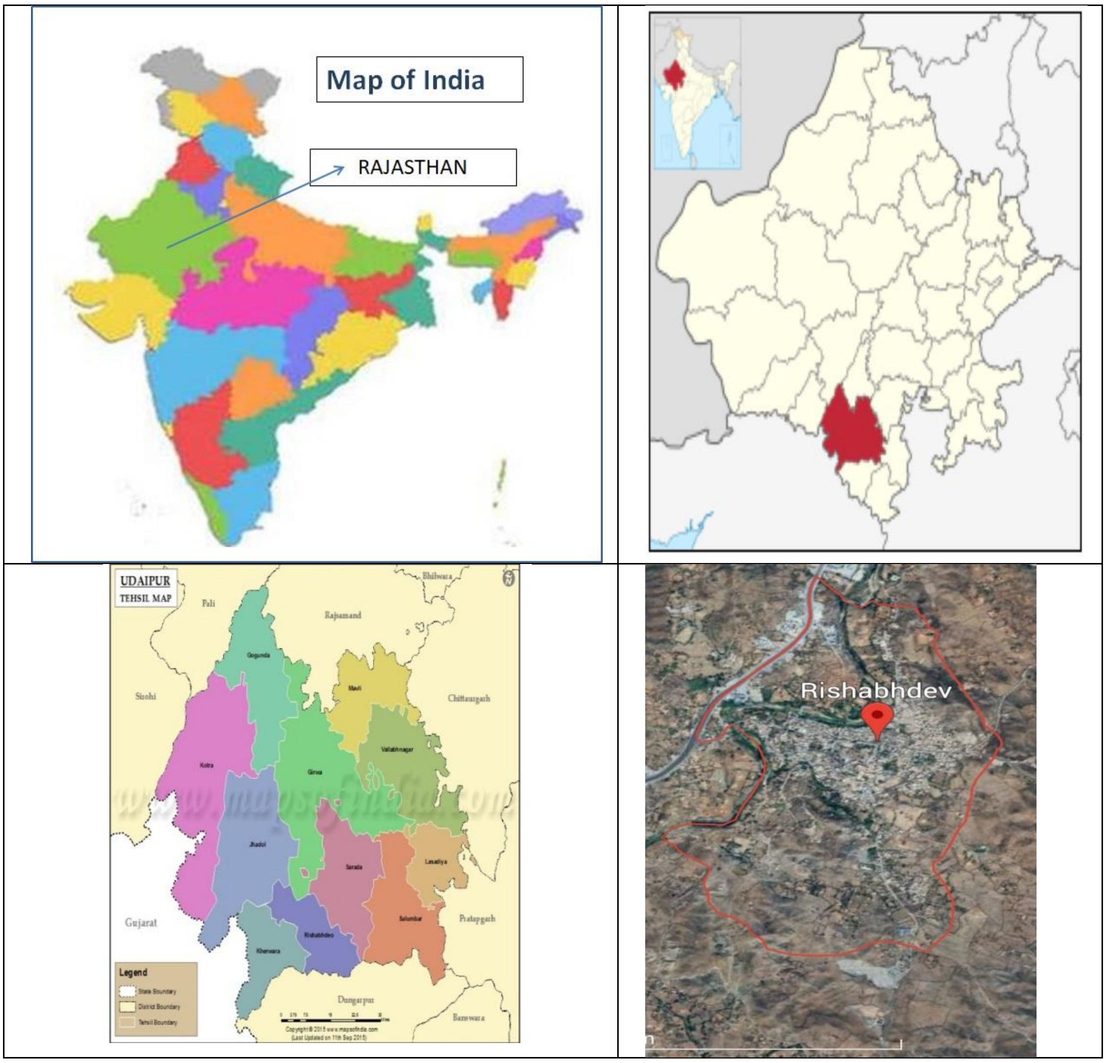

Figure 3.1 Location map of present study area

3.2.1 Blasting and its monitoring

For the purpose of the study the blasting practices as per the objectives of this study, the site area in Rishabhdev was visited. The present practices for the analysis purpose were studied and scope of improvement was assessed. Accordingly the plan of monitoring procedure, site, sequences and other important parameters were ascertained. In addition to those, the number of readings was decided as eight.

3.2.1.1 Methods of mining and blasting practices

Study area is a Serpentine marble mines, when the conventional mining by wire saw is being practiced for marble production and for OB removal drilling and blasting is practiced. The blasted muck is loaded by JCBs into trucks and subsequently dumped at nearly dump sites.

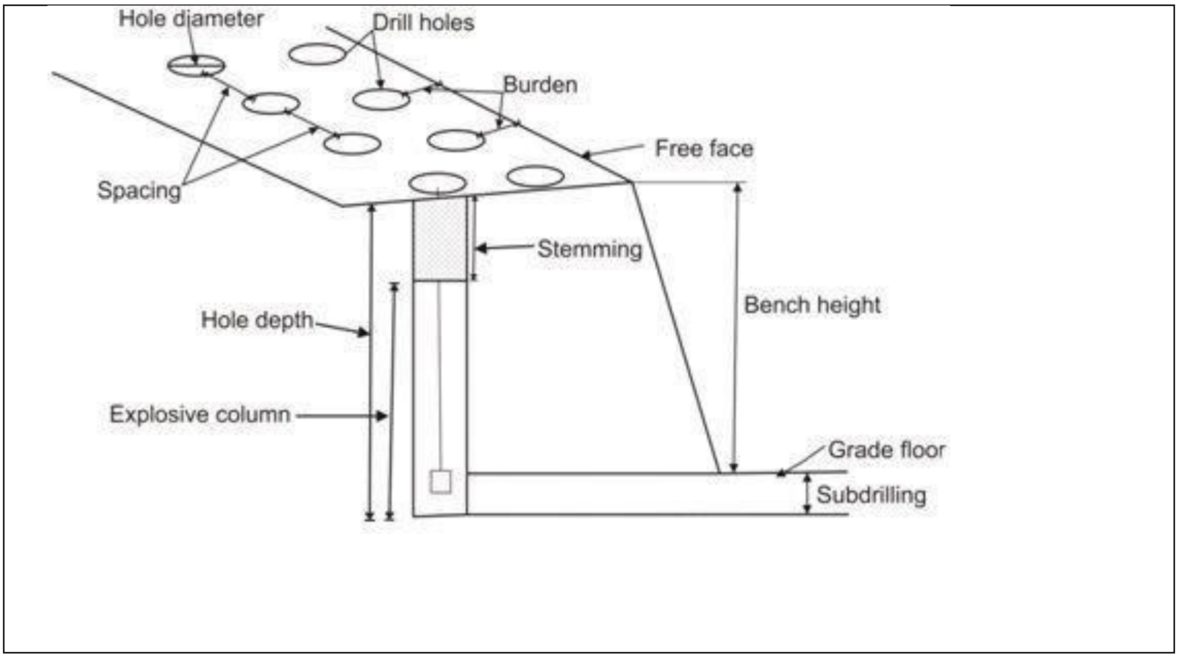

Figure – 3.2 Blast geometry in Multi Hole Bench Blasting

3.2.1.2 Blasting

1) **Blast Hole Depth and Diameter**
    - Blast hole depth – varied from 6.1 m to 6.3 m
    - Hole diameter – 115mm
2) **Burden and spacing**
    - The burden and spacing are kept around 2.5 m & 3 m
3) **Charging length, Decking length and Stemming length**

The length of charging typically varies on the hardness of strata, as the strata becomes hard the length of charge increase whereas decking length reduces. The scope of improvement was assessed in this, as the blasting can be optimized by adjusting charging length, decking length and stemming length as per varying strength of rock.

3.2.1.3 Experimentation work for blasting

Like any other shallow, medium size, hard rock mine, here also the blast design was deployed as conventional blast parameters which include bench height, hole diameter, depth, spacing, burden, subgrade drilling, steaming and initiation techniques. The fig. 3.1 and table 3.2 shows the blast design parameters in the OB removal at study area.

Tabel 3.2 Blast design parameters applied at mines

S. NO.	Parameter	Value
1.	Bench height (m)	6-8
2.	Hole diameter (mm)	115
3.	Hole depth (m)	5.5
4.	Subdrilling (m)	0.5-7.6
5.	Burden (m)	3-5
6.	Spacing (m)	3.5-4.5
7.	Stemming (m)	4.5
8.	Types of explosives	(i)ANFO (ii)SME
9.	Charge per hole (kg/hole)	51.85
10.	Hole inclination	Vertical

3.2.1.4 Vibration monitoring

After ascertaining the distance between the blasting site and the monitoring stations the ground vibration parameters were measured with the Blastmate III Seismograph vibration instrument, as shown in Figure 3.6.

Figure 3.6 Instruments used in ground vibration measurements

3.1.2.5. Software used for laboratory investigations

For the purpose of laboratory work, for analyzing the acquired field data for vibration BLASTWARE SOFTWARE and FLYROCK PREDCTOR were used.

Blastware software: This program is a component of a seismograph that was utilized during field work to analyze the vibration data from various explosions. Blastware software also includes capabilities for managing event files, such as the ability to print event reports and do FFT frequency analysis.This application was placed on a portable computer, allowing the recorded data to be retrieved and evaluated daily. Vibration measurements were initially extracted using BLASTMATE III, and then analyzed using the Blastware program.

Flyrock predictor: With the input like charge mass, weight and stemming height and also by including sight constants, if any, the fly rock predictor produces the design of own fly rock qualification which can determine the safe clearing distance and the crucial range of weights and steaming lengths, when both the scenario occurs like safe and dangerous. It also investigates the zone of fly rock travel.

3.3 Laboratory Experimentation

To access the effect of vibration on the rock, some laboratory investigations were planned in addition to the vibration data analysis through blastware software and fly rock predictor. Rock samples were taken, prior to blasting and post blasting in both the cases of field experimentation. To study the effect on rock, the compressive strength, tensile strength, and point load index was used as parameter for pre and post suggestion in blasting patterns.

3.3.1 Measurement of Compressive strength

The rock samples in form of core samples were tested on the Universal Testing Machine (UTM) in the laboratory for standard Uniaxial compressive strength. The figure 3.7 is showing the testing at the universal testing machine in laboratory.

3.3.2 Measurement of Tensile Strength

The core samples were tested for Brazilian test on same universal testing machine in the laboratory as shown in the figure 3.

3.7. Compressive Strength Test **Fig 3.8 Brazilian Test**

3.3.3. Measurement of Point Load Index

The collected rock samples were tested for point load index test in the laboratory as shown in the figure 3..9

Fig 3.9 Point Load Index tester

4. RESULTS AND DISCUSSION

To meet the objectives, ground vibrations and noise were monitored using an Instantel make Seismograph, and the fly rock was visually examined and quantified for distance from the blast site.

4.1 Vibration Analysis

This section discusses analysis of data from field investigation. During the study, sixteen blast recordings were collected. Eight results were collected from the previous firing pattern, whereas eight were taken once the firing pattern was suggested for improvement. These records are presented in subsequent para.

4.1.1 Vibration data for exiting firing pattern

During the study, eight blasts were recorded by using a seismograph. Table 4.1 shows the recorded values of ground vibration. The table includes blast number, blast parameters, amplitudes of vibration components for transverse, vertical, and longitudinal directions, peak vector summation of vibration components (PVS), peak particle velocity (PPV), maximum charge per delay (Q) for each blast, absolute distance, noise level, and fly rock.

4.1.1.1 Analysis of blast vibration data

The ground vibration data, including peak particle velocity (PPV), distance between the blast site to the monitoring station, and explosive charge per delay, were evaluated to better understanding of the impact of ground vibrations caused by blasting at study area.

Table 4.1 Details of blast ground vibration monitoring at study area

Blast No.	Blast Parameters	Max Charge per Delay (kg)	Distance (m)	Vibration Monitoring				AOP (dB)	Flyrock (m)
				Tran Peak (mm/s) at Frequency	Vert Peak (mm/s) at Frequency	Long Peak (mm/s) at Frequency	PVS Peak (mm/s)		
1	Dia= 115 mm Depth = 6 m B = 2.5 m S = 3.0 m Stemming = 2 m Holes = 6	16.68	100	3.334 114 Hz	2.467 54 Hz	5.036 146 Hz	5.237	109.0	20
2	Dia= 115 mm Depth = 6 m B = 2.5 m S = 3.0 m Stemming = 2 m Holes = 8	19.46	100	5.289 57 Hz	2.877 49 Hz	5.423 43 Hz	6.244	109.0	22
3	Dia= 115 mm Depth = 6 m B = 2.5 m S = 3.0 m Stemming = 2 m Holes = 6	16.68	100	4.185 128 Hz	2.901 93 Hz	4.564 146 Hz	5.093	108.9	19
4	Dia= 115 mm Depth = 6 m B = 2.5 m S = 3.0 m Stemming = 2 m Holes = 6	16.68	100	1.529 73 Hz	2.924 39 Hz	3.405 37 Hz	4.049	112.2	20
5	Dia= 115 mm Depth = 6 m B = 2.5 m S = 3.0 m Stemming = 2 m Holes = 8	19.46	50	7.669 38 Hz	4.075 64 Hz	8.709 32 Hz	10.56	119.8	21
6	Dia= 115 mm Depth = 6 m B = 2.5 m S = 3.0 m Stemming = 2 m Holes = 6	16.68	100	2.667 >100 Hz	1.905 24 Hz	4.826 73 Hz	4.961	112.0	20
7	Dia= 115 mm Depth = 6 m B = 2.5 m S = 3.0 m Stemming = 2 m Holes = 8	16.68	50	6.096 51 Hz	2.921 34 Hz	5.207 39 Hz	6.856	117.0	20
8	Dia= 115 mm Depth = 6 m B = 2.5 m S = 3.0 m Stemming = 2 m	16.68	50	3.556 85 Hz	2.159 85 Hz	6.477 85 Hz	6.827	110.7	22

	Holes = 6									

4.1.1.2 Safe charge for protection of structures

The ground vibration produced is proportional to the quantity of charge per delay employed in the blast holes. It has a critical value at which it produces the best output; amounts more than that value cause more ground vibration.

Table 4.2 Safe charge per delay at various distance

Distance (m)	Safe charge per delay (kg)
100	7.08
150	17.61
200	31.11
250	50.58
300	72.81
350	99.01
400	129.08
450	161.06
500	206.8

This vibration might cause harm to surrounding structures. The safe quantity of charge per delay was established by observing ground vibration from many explosions. Table 4.2 shows the safe charge per delay suggested for keeping vibration levels below 7 mm/sec at various distances from the explosion.

4.1.2 Vibration data for firing pattern after suggestions

After the analysis of existing pattern we recorded data for vibration after some suggestions. During the research, 8 explosions were recorded for improvised firing pattern using the seismograph. Table 4.3 shows the recorded value of ground vibration.

4.1.2.1 Analysis of blast vibration data

The ground vibration data, including peak particle velocity (PPV), distance from the blast site to the monitoring station, and explosive charge per delay for various blasts, was evaluated to better understand the impact of ground vibrations caused by blasting at study area The data is represented by the following predictor equation in terms of scaled distance and PPV (peak particle velocity), which is recommended for use in estimating safe explosive charge per delay in order to maintain the vibration level within safe limits.

PPV = 113.8 (Scaled Distance)-0.890

The prediction of particle velocity requires that the average and upper bound values be well known. The 50% average line is the line about which the recorded data are gathered. The 95% prediction limit line is a line generated from the standard error and data distribution curve as shown in thw figure 4.2.

4.2 Results For Laboratory Investigations

4.2.1 Compressive Strength

Rock samples after blasting in both cases pre and post improvement suggestions were tested for standard Uniaxial compressive strength are presented in Table 4.6. The results shows good improvement after suggestions

Table 4.6 Results of Compressive Strength

Samples from site	Result (Mpa)	
	Before Blasting	After Blasting
Pre suggestion	52.55 Mpa	45.55 Mpa
Post suggestion	54.25 Mpa	50.93 Mpa

4.2.2 Tensile Strength

Tensile strength tests were conducted on samples collected before and after blasting in both cases to evaluate the impact on rock properties. The results are presented in table 4.7

Table 4.7 Results of Tensile Strength

Samples from site	Result (Mpa)	
	Before Blasting	After Blasting
Pre suggestion	3.931 Mpa	3.753 Mpa
Post suggestion	3.735 Mpa	3.506 Mpa

The results show clear improvement in suggested option.

4.2.3 Point Load Index

Point load index tests were conducted on samples collected before and after blasting to assess the impact on rock integrity. The results are summarized in Table 4.8

Table 4.8 Results of point load index

Samples from site	Result (Mpa)	
	Before Blasting	After Blasting
Pre suggestion	2.289 Mpa	1.837 Mpa
Post suggestion	2.295 Mpa	2.059 Mpa

In this case also the results show improvement in rock integrity after implementing the suggestions.

5. CONCLUSIONS

As compared to conventional mining in the marble mining the blasting is very much restricted due to its possible impact on remaining rock which greatly reduces the revenue from inferior dimensions of finished product. However some of the mine have started the controlled blasting techniques in past which is also not being used now days and the complete extraction of marble is carried out by non-explosion techniques such as wire saws, chain saw, blind cut etc.

However it is imperative to use blasting in overburden extraction. The blasting in overburden can also lead to damage the marble or widen the natural cracks. The present study on the above background and on decided objectives draws following conclusion.

1. The study investigated various blasting techniques used and concluded that there is no controlled blasting Techniques used for production of marble, however the techniques used for overburden removal were studied.
2. For controlling the blasting nuisances existing blasting techniques were studied and were found satisfactory, however scope of improvement was found in the initiation techniques.
3. For the analysis and suggestion, a new initiation pattern for blasting in OB was suggested. It was found that the suggested initiation patterns was producing less vibration and overall creating less chances of damage on marble.
4. Various impact on remaining rocks were also analyzed for blast vibration, compressive strength , tensile strength and point load index in pre and post suggestions and it was found significant improvement in all the cases. Thus it can be inferred that due to less vibration, better compressive strength, tensile strength and point load index after opting suggestions in initiation system that the option is suitable for implementation.

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