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Drilling and blasting improvement in aggregate quarry at Thailand – a case study

World class infrastructure around Bangkok is developed due to medium to large aggregate quarries situated up to 200 km from Bangkok utilizing granite, limestone and basalt as resource. Aggregate consumption will be exceeding 350 MTPA by 2019. Aggregate quarry under study has proposed increased production from 2.5 MTPA to 5 MTPA. Drilling and blasting accounts for 28% of total quarrying cost based on the study of various aggregate quarries in Thailand. Powder factor values (P.F.) is 0.40 – 0.66 kg/m^3 at 80% passing over 0.5m. Considering drilling and blasting as major cost, existing practices of drilling and blasting are reviewed. Top hammer (TH) 102mm diameter drill is selected as compared to existing down the hole (DTH) 76mm diameter drill. For large quarries 6m × 7m is blasting pattern as optimized with 150mm diameter drill. Projected blast pattern is 4m × 4.75m. TH, DTH, rotary cutting and rotary crushing drills are evaluated. Some of the best practices at an aggregate quarry in Thailand for drilling include drilling accuracy, bench's surface flattening by auto leveling. Blast performance is monitored for blast fragmentation, back break. Nonelectric detonators instead of electrical detonators and bulk emulsion instead of ANFO shall be utilized for future blasting operation.

Keywords: Top hammer (TH), down the hole (DTH), powder factor (PF), auto leveling (AL), bulk emulsion, non electric detonators (Nonel).

1.0 Introduction

Construction Aggregates in Thailand consist of limestone, basalt and granite. Potential aggregate resources and working quarries are located in various regions of Thailand (Fig.1). Large aggregate quarries produce exceeding 200,000 cubic meters per month and otherwise termed as 'small size' quarries [1]. Fig.2 illustrates the predicted curves for rock consumption from the two methods used. Variables of consumption prediction are mainly on the predicted economic growth and the assumed weight factor for construction projects in Thailand. Most of large quarries are in central part of Thailand, 100km north of Bangkok. Large limestone quarries are mainly supplying limestone for manufacturing Portland cement. Geological map is shown in Fig.3. Different rock types are shown in Fig.4. Limestone deposit consists of highly weathered limestone, laminated limestone, somewhat weathered limestone and massive limestone. The aggregate quarry having limestone is producing 2.5 MTPA. This limestone quarry is planned

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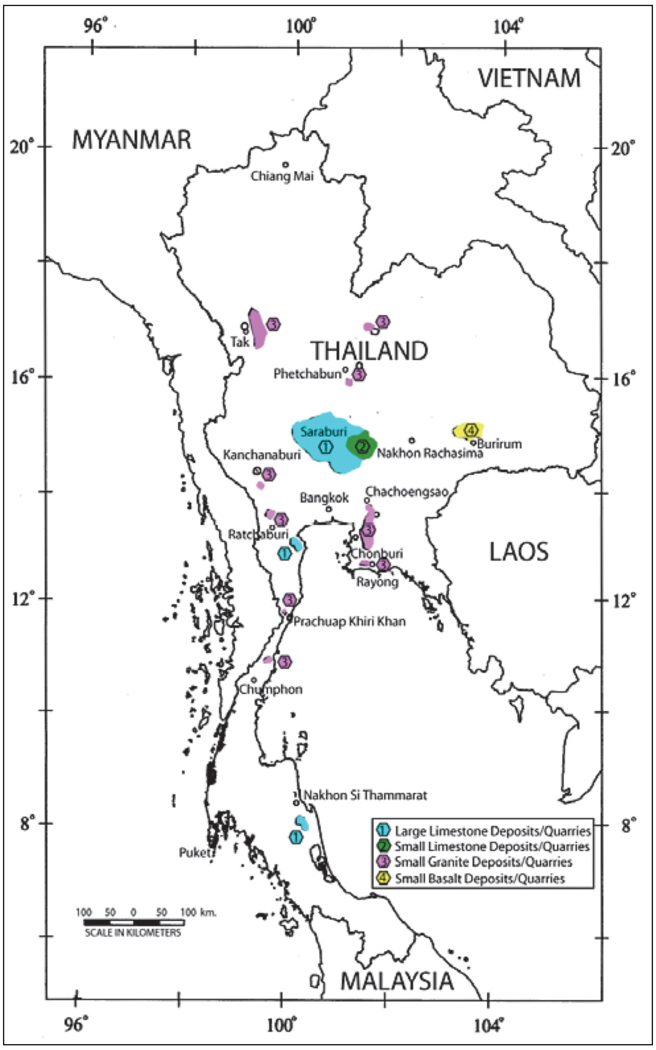


Fig.1: Aggregate quarries around Bangkok [1]

for expansion with target production capacity of 5 MTPA. Production capacity is to be increased without increasing substantial manpower. There is existing crushing plant of 800 TPH to meet annual requirement of 2.5 MTPA of aggregates. Additional crushing plant of equal capacity is being installed. Thus loading and transport equipment being increased proportionate to production volume. For improving overall productivity of aggregate quarry existing drilling and blasting practices are reviewed to achieve overall higher productivity.

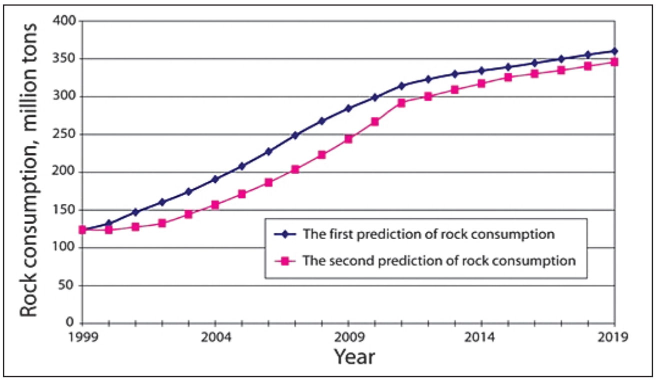


Fig.2: Aggregate rock consumption pattern in Thailand from 1999 to 2019 [1]

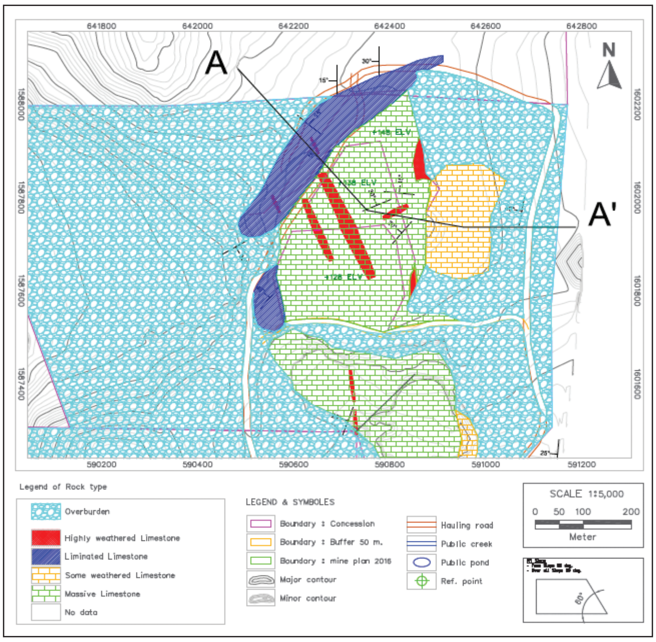


Fig.3: Geological map of aggregate quarry in Thailand [2]

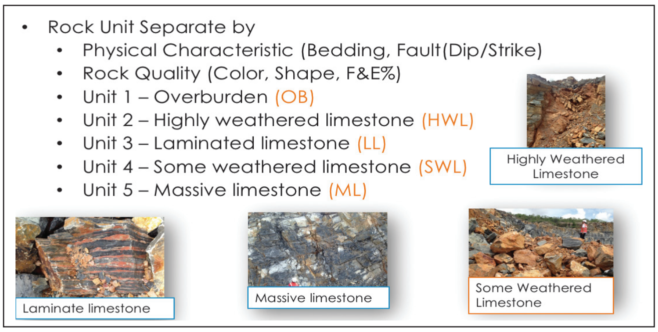


Fig.4: Type of rock at limestone aggregate quarry [2]

2.0 Review of drilling and blasting practices in Thailand

Quarrying cost of various large quarries is reviewed and analysis is shown in Fig.5 consisting of loading, hauling, drilling and blasting, hammering or secondary breaking and crushing. Drilling, blasting and hammering accounts for 28% of total cost.

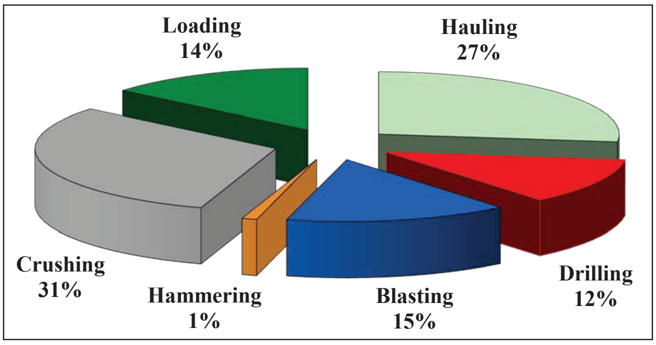


Fig.5: Quarrying cost analysis in Thailand [1, 3,4]

Blasting data of several large quarries in Thailand is analyzed and plotted as graphical curves in Fig.6. There appears to be a strong correlation between the fragment size of limestone and the weight of explosive (AN-FO), specified as powder factor. The range of powder factor values (P.F.) is 0.40 – 0.66 kg/m^3. The average fragment size, taken the values from observed field data at 80% passing, is 0.5m (plus or minus 0.05m).

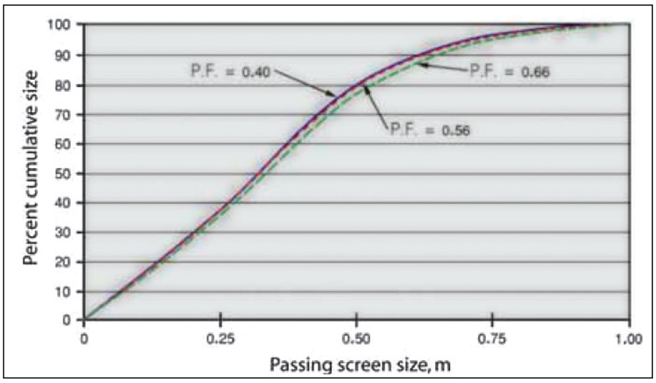


Fig.6: Comparison for the fragment sizes and the explosives used in bench blasting [3]

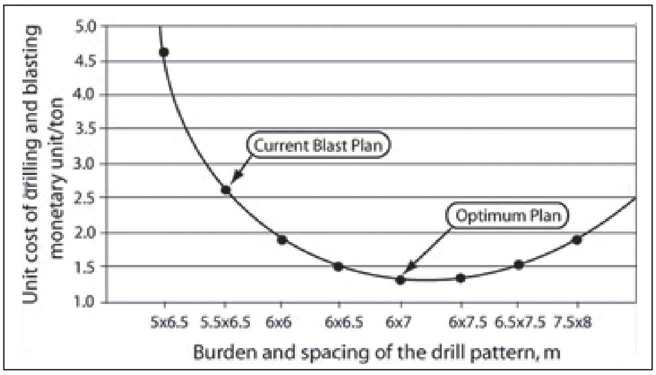


Fig.7: The trial plots for the optimization of drilling & blasting costs of a large limestone quarry [3]

In a specific quarry, the height of drill hole in the bench blasting is normally fixed due to the capacity of the drill machine. To optimize the costs of operation, the mining engineer can adjust or select the plan views. Fig.7 illustrates the trial plots of several plan views in one specific blast pattern. The lowest point of unit cost of drilling and blasting in the graph is the optimum plan. In this case, optimum plan is 6m × 7m with 150mm diameter holes.

The existing drill at selected limestone aggregate quarry is 76mm diameter. Higher diameter of 102mm drill is also suitable for enhanced production. Thus projected optimum plan for 76mm diameter drill is 3m × 3.5m and for 102mm diameter drill is 4m × 4.75m. Fig.8 shows optimum pattern for small and medium size quarries as 2m × 3m and 2.5m × 3.5m which is comparable with projected blast pattern based on large limestone quarries.

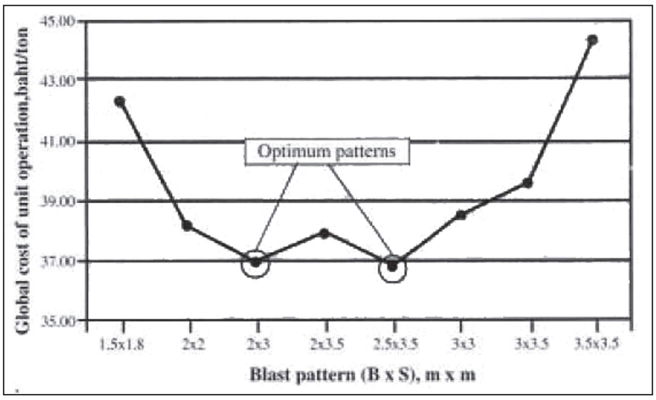


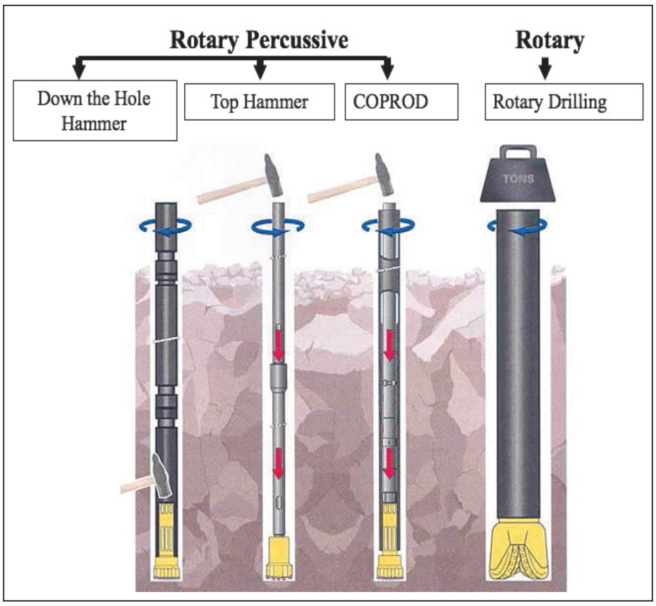
Fig.8: Optimum pattern for small to medium limestone quarries in Thailand [4]

For optimizing blasting pattern, desired fragmentation with minimum powder factor is essential for achieving overall reduction in cost of drilling and blasting [5-12]. Geological conditions, type of rock, discontinuities also affect while optimization of blast design [13-20].

3.0 Selection of drill

Various drilling methods and application of drills in different rock types is reviewed. Top hammer and down the hole drills are most suitable for limestone deposits considering compressive strength of rock. Existing drill is down the hole drill.

Table 1 shows comparison of different drilling methods. COPROD drilling machines require highest investment for drilling string which is recurring expenditure and for replacing the same reduces availability. Operation of COPROD drilling machine require highly skilled operator which may not be available in mining areas. DTH drilling machine has lowest penetration rate resulting in lowest production capacity and highest fuel consumption. Top hammer has advantages of lowest fuel consumption and low string investment. Top hammer has very good penetration rate and is operator friendly. Table 1 shows some typical basic criteria's which



Method	Uniaxial Compressive Rock Strength Mpa	Hole Diameter Inch
Top hammer	100 - 500	1 - 9
Down the hole hammer	100 - 500	3.5 - 9
Rotary crushing	100 - 500	5 - > 15
Rotary cutting	0 - 100	1 - 15

Fig.9: Different types of drills and their application

are useful to decide whether a "top hammer" or a "down the hoie" drilling method is the right choice for a quarry. Top hammer has proved experience of higher penetration rate, less fuel consumption and investment for drill rig and drill string is low. DTH drill is suitable for complex geology or difficult working conditions and higher bench heights. Operator needs to be trained regularly.

Table 1: Comparison of different drilling methods

Drill Method	Top Hammer	DTH	COPROD
Penetration Rate	OOOO	OOO	OOOOO
Straight holes	OOO	OOOOO	OOOO
Hole depth	OOO	OOOOO	OOOO
Production capacity	OOOO	OOO	OOOOO
Low fuel consumption	OOOOO	OOO	OOOOO
Economic drill string life	OOO	OOOO	OOOOO
Low investment for drill string	OOOOO	OOOO	OOO
Suitable for difficult conditions	OOO	OOOO	OOOOO
Operator friendly	OOOO	OOOOO	OOO

OOOOO Very Good   OOOO Good   OOO Fair

Fig.10 shows further selection process where rotary cutting drill machines are suitable for hole diameter less than 50mm. Rotary crushing drills are suitable for hole diameter is more than 203mm.

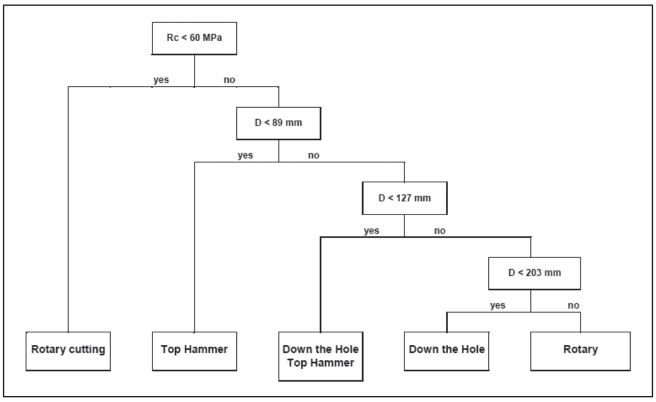


Fig.10: Selection of drill based on hole diameter

A study is conducted for various mines in India and with respect to bench height and minium and maximum bench height. Bench height for aggregate quarry under study is between 8m to 12m. Thus suitable hole diameter is 80mm to 183mm considering 8m as minimum bench height. For improving productivity 102mm diameter drill is selected.

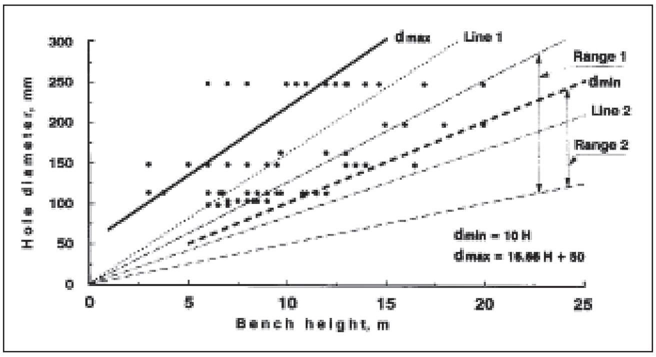


Fig.11: Bench height and hole diameter consideration [21]

Thus considering Figs. 9,10 and 11 and Table 1, top hammer drill of 102mm drill is selected instead of existing 76mm diameter DTH drills.

4.0 Improvement using advanced features of drilling machine

Fig.12 shows basic features of drilling in limestone bench. Each parameter is given importance so that blast design is done with more accuracy.

Following features are selected for improving drilling accuracy:

- Setting out
- Checking holes for following features
- Straightness
- Angle and direction (azimuth) of inclination
- Depth
- Checking holes
- Collar position

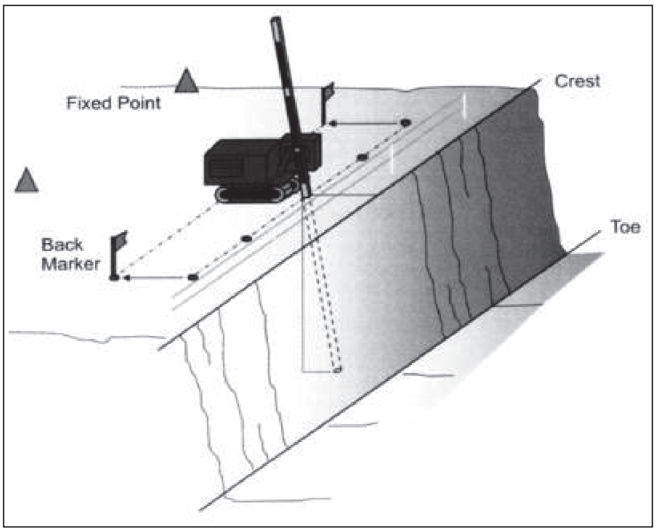


Fig.12: Basic features of drilling in limestone bench

4.1 Bench's surface flattening by Auto Leveling

Many times during bench blasting floor of bench becomes uneven which affects loading and hauling efficiency. Safety becomes matter of concern due to bad road condition. Future drilling efficiency is also affected. It is essential to flatten surface bench.

(a) Bench condition before

(b) Bench condition after

Fig.13: Bench condition before and after correction by using auto level

Fig.14 shows bench condition before.

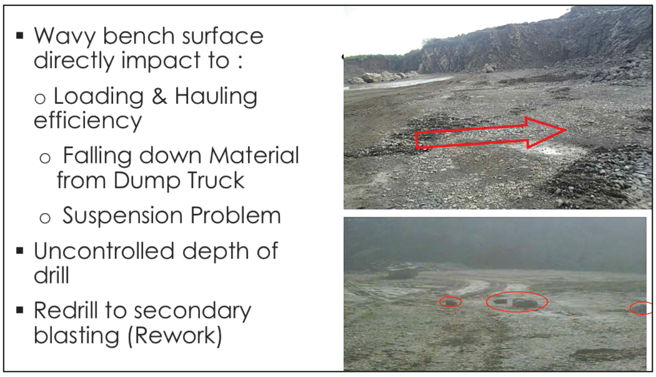


Fig.14: Bench condition before

Auto Leveling (Pentax) usage to know difference height between each drill hole.

(a) Auto level instrument (b) Measuring height (c) Making blast pattern

Fig.15: Measuring height using auto level instrument and making blast pattern

TABLE 2: RESULTS OF MEASURING PENTAX TOOL HOLE DEPTH CALCULATION

Location	:	B2	Subdrill	:	m
High of Bench	:	9.2m	Steaming	:	3.5m
Pattern	:	4.2 × 5.5m			
Heigh of refernsi	:	1.28 (Bench Mark)			

From south - north

No	Pentax A	Row A (m)	Pentax B	Row B (m)
1	1.21	9.3	0.93	9.6
2	1.23	9.3	0.92	9.6
3	1.17	9.3	0.99	9.5
4	1.01	9.5	0.91	9.6
5	0.83	9.7	0.71	9.8
6	0.7	9.8	1.02	9.5
7	1.37	9.1	0.9	9.6
8	1.4	9.1		

Corrective Drilling: Based on results of Pentax tool, drill pattern is planned.

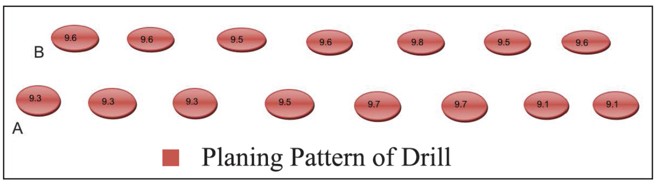


Fig.16: Planning of drill hole pattern as corrective drilling

Drilling based on measuring of Auto leveling Pentax

Drilling based on measuring of Auto leveling Pentax

Fig.17: Drilling based on measurement of Pentax tool and control depth of drill

4.2 LIDAR TECHNOLOGY FOR LIMESTONE QUARRY

Lidar technology is selected for complete survey of quarry faces [22]. With increase in limestone production from 2.5 MTPA to 5 MTPA, blasting performance needs to be optimized for crucial parameters of fragmentation and gradation. Limestone is classified as weathered, highly weathered and massive limestone on the basis of earlier exploration. Based on geological strength index, limestone is classified as blocky, very blocky, blocky/seamy and disintegrated. Geological strength index and powder factor are further correlated to optimize blast performance [23].

5.0 Measures for improving blast performance

Each blast is monitored by taking photographs of blasted muckpile from different locations.

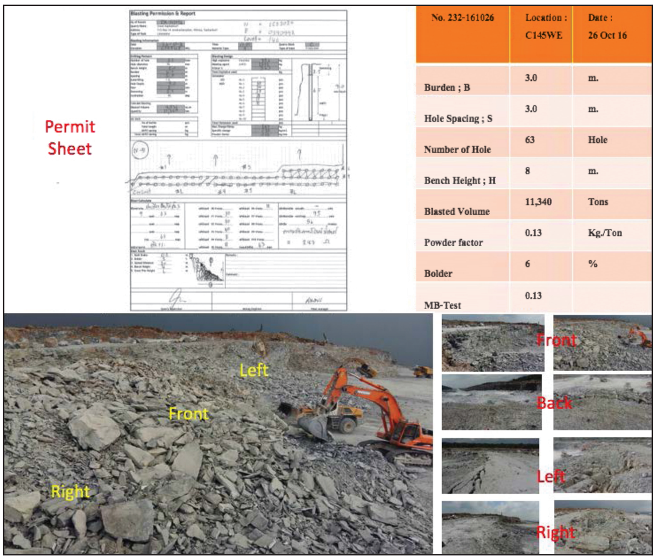


Fig.18: Blast fragmentation monitoring

Blast design data of each blast is recorded. Fragmentation is analysed using image analysis software. Fig.19 shows measurement of back break which helps for planning next rows of blasting and improving further blast performance.

Fig.19: Backbreak measurement process after blasting

Other measures for improving blast performance are as under:

1. Usage of nonel detonators instead of electric detonators for reducing environmental impact (Air overpressure, flyrock and ground vibration) due to blasting and improving fragmentation.
2. Use of bulk emulsion instead of ANFO with expanded pattern due to higher energy and also water resistance for watery holes.

6.0 Conclusions

1. Selection top hammer drill of 102mm dia instead of 76mm dia has helped to increase yield per hole reducing drilling and blasting cost.
2. Operation of COPROD drilling machine require highly skilled operator which may not be available in mining areas.
3. DTH drilling machine has lowest penetration rate resulting in lowest production capacity and highest fuel consumption.
4. Top hammer has advantages of lowest fuel consumption and low string investment.
5. Top hammer has very good penetration rate and is operator friendly.
6. Auto leveling (Pentax) with corrective drilling is useful for correcting floor of bench condition,
7. Larger size blasts are possible by use of bulk emulsion instead of ANFO explosives
8. Nonel detonators instead of electric delay detonators have improved environmental effect due to blasting
   - Reduction in ground vibration
   - Reduction in AOP
9. Blast performance monitoring is done every month for experimentation for improvement in blast performance.
10. Lidar technology is used for rock mass classification. Based on geological strength index, limestone is classified as blocky, very blocky, blocky/seamy and disintegrated.
11. Geological strength index and powder factor are further correlated to optimize blast performance.

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