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ORIGINAL ARTICLE

Improving Blast Design for Optimum Rock Breakage and Sustainable Operations

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Abstract**:** This study was carried out to examine the effect of blast design on fragment size of blasted muck pile. The study site is located at Simpang Pulai, Ipoh, Perak, Malaysia. The preliminary study involves of a total of four blasting sessions, structural mapping of blast area, measurement of peak particle velocity (PPV), fragmentation analysis of blasted muck pile and point load test. The PPV during blasting were measured by vibration monitor located at a specific distance from blasting area. The new predicted site constants, K and β were calculated and employed as indicators for next blast. The fragmentation analysis was conducted using Wipfrag image analysis. This analysis estimates the fragments size produced in each of the four blast sessions. Finally, the strength of rock in each blast session was evaluated by using point load test and the mean Uniaxial Compressive Strength. It was found that besides blast design, the geological site constants of K and β have significant impacts on rock breakage, ground vibration and airblast during blasting.

Keywords: blast design, rock breakage, peak particle velocity

1. Introduction

In order to meet the demand in construction and other industries, minerals are needed as raw materials to be used in various applications. Thus, development in mining and quarrying industry has been widely ventured all over the world. The importance of drilling and blasting cannot be over emphasized in mining and quarrying operations as they help significantly in producing desired rock fragments needed for further processes. In addition, blasting is the most effective and widely used method of excavating hard rocks. Blasting as the first process of reducing the size of in-situ rocks also determines the efficiency of further comminution exercises and could affect the quarry production from the fragmented rock produced (Faramarzi et al., 2013).

The generation of explosive energy in a blast hole can be efficiently utilized when the blast are well-designed and could result in optimum fragmentation of the rock mass (Elevli & Arpaz, 2010). However, there is still a significant amount of energy from the blast holes that forms unavoidable effects like ground vibrations and airblasts (Elevli & Arpaz, 2010). There are various stages of rock breakage in blast hole and this include blast hole

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expanding and crushing, radial cracks and shock waves (Orica Mining Services, 2008).

The ground vibration produced from blasting may cause damage to nearer structures with high intensity of wave motion. There are two important parameters used in the assessment of ground vibrations. These are peak particle velocity (PPV) and frequency of ground vibrations. PPV is measured in mm/s and it represents the speed at which a particle of soil or rock moves or pulsates.

Empirical charge weight scaling laws are used in blasting operations to predict the ground vibration level (Orica Mining Services, 2008). Department of Mineral and Geoscience, Malaysia (DMG) has recommended the maximum allowable limit of PPV value for quarry blasting as 5 mm/s for human comforts and stability of structures.

Blasting is usually done to obtain the desired size of fragmented rock which relatively depends on the end use of the rock and the type and size of equipment for further comminution (Elevli & Arpaz, 2010). In quarrying, the size of fragmented rock must be taken into account because it could affect the whole quarry operations including loading, hauling and subsequent comminution.

The evaluation of rock fragmentation should be done to determine the particle size distribution either by using image analysis or by sieving analysis. In fact, the good fragmented rock relatively depending on geological condition of rock mass, nature of rock and explosives types (Elevli & Arpaz, 2010).

The desired and good fragmentation of rocks is needed in optimizing the comminution process and the total productivity of the quarry. The particle size distributions (PSD) in each blasting operation were analyzed by using image analysis software known as *Wipfrag*.

2. Environmental Impact of Blasting

There are two major important factors to be considered in designing a good blast: the rock mass properties (geological characteristics) and the explosive material characteristics. Nevertheless, geology-blasting interaction that is of great significance has not sufficiently investigated (Bohloli, 1997). Geological formations as they occur are not homogeneous and isotropic and even on small scale, the homogeneity varies (Bozic and Braun, 1991). Local geological conditions such as joints, bedding planes and their orientations with respect to the bench face have significant impacts on the success of a blasting operation and the energy consumption of aggregates production.

The use of blasting designs without considering these two major factors can lead to poor blasting (over-blasting or under-blasting). Fines generation and damage to adjacent rock are common problems in the case of over blasting. On the other hand, production of boulders is one of the under blasting consequences that may later result in increase of energy consumption for crushing and grinding and the total production cost. Using the right type and correct quantity of explosive materials will considerably decrease the cost of blasting operation and consequence processing.

The resultant cost of poor blasting and fragmentation can be geometrically higher than the cost of optimum blast. Accordingly, some implications of poor fragmentation due to imperfect understanding of the geology-blasting interaction have been discussed by previous authors and these includes:

- <u>Increased secondary blasting:</u> Secondary blasting of oversize is required to reduce it to a size that can be handled by the excavation machinery (Persson et al. 1994);
- <u>Reduced mucking rates:</u> The rate of loading from a draw point is directly controlled by the size and looseness of the muck (Bhandari,

1996). Extensive maneuvering is required by the excavator to load large rocks;

- Difficulties in handling and transport: The efficiency of internal mine transport, crushing and transport from the mine can be adversely affected by poor fragmentation; and
- Poor milling performance: The development of a growing application of semi autogenous grinding mills and fully autogenous mills puts increasing emphasis on the size distribution of the ore delivered from the mine. Problems arise when the size distribution varies with time and when the proportion of fines exceeds desirable levels (Winzer et al., 1983).

Environmental impacts associated with the blasting operations at the quarry are mainly related to noise, vibration and fly rock. The magnitude and extent of the disturbances as dictated by various factors relating to the design and controls of the blasting operation are discussed in the next sections.

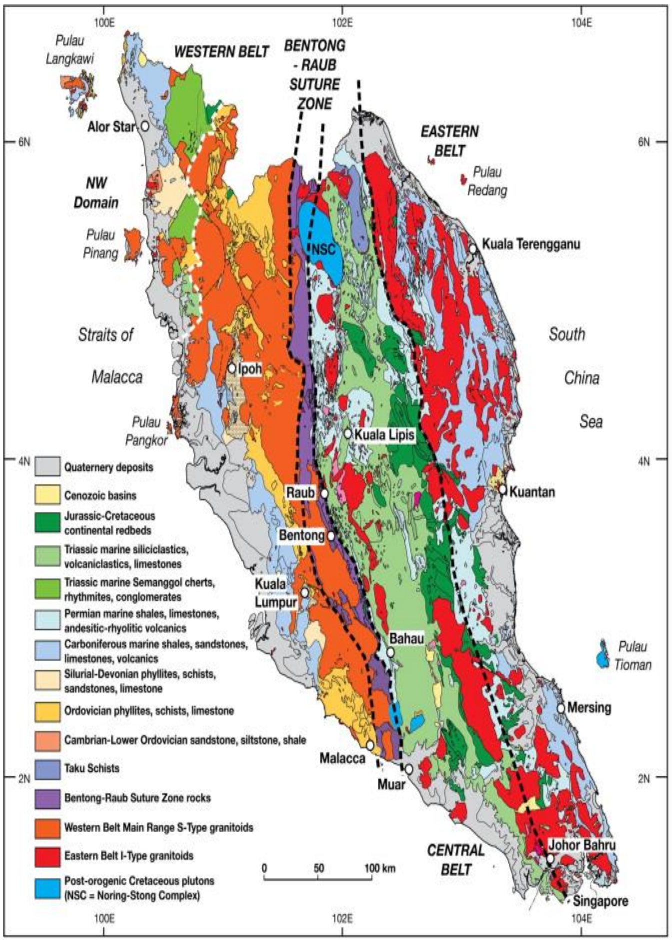


Figure 1: Geological formation of Peninsular Malaysia (Tate et al., 2009)

3. The Site

It has been long recognized that the geology of the Peninsular Malaysia is characterized by three North–South longitudinal belts, the Western Belt, Central Belt and Eastern Belt based on distinct differences in stratigraphy, structure, magmatism, geophysical signatures and geological evolution (Metcalfe, 2013) as illustrated in Figure 1.

Accordingly, the largest amounts of limestone in Malaysia are found at Simpang Pulai and Kinta Valley area. The whole of the Kinta Valley is underlain with limestone, the major bedrock present in the form of hills above and under the ground. Kinta Valley's limestone is a meta-sedimentary-rock and is believed to have been formed between the Triassic (230-190 million years) to Permian (280-230 million years) periods (Gough, 2013).

The site chosen for this study is located at Simpang Pulai, Ipoh, Perak, Malaysia in which the geological setting was predominantly formed by a marble rock-type based. At current, the marble group produced within this site is considered as associated with hydrothermal structures controlled by faults and by consequence is not anymore considered as of stratigraphic origin.

The general dipping of 20º to 25º South is also confirmed with clearly identified smaller scale folds which explain the origin of the dipping changes observed along the various drill holes. These folds are marked by the presence of symmetries in the marble type successions. The deposit is clearly divided into two groups in term of MgO distribution.

4. Results and Discussion

The peak particle velocity (PPV) and airblast during blasting were measured by using a seismograph. This device consists of microphone and geophone or accelerator. The data was recorded in one acoustic and three seismic channels. The vibration monitor was located near the guard house which range at approximately 800 meter from blasting area.

4.1 Analysis of Blasting Performances

4.1.1 Point Load Test

The samples were randomly collected after the blast. Table 1 summarized the results from point load test relative to the strength of marble in each session.

Table 1: Summary of data on point load test

Blast Session	Type of Rock	Point Load Index (MPa)	Uniaxial Compressive Strength (MPa)	Strength of Rock
1	Limestone	7.22	108.23	Medium
2	Limestone	3.34	50.05	Soft
3	Limestone	3.74	56.11	Soft
4	Limestone	3.92	58.73	Soft

Based on the point load test, it was be concluded that the limestone in this area are categorized as soft rock. The strength of rock is important during selection of explosives owing to the fact that different types of explosives exhibit different degrees of effectiveness to break rocks.

4.1.2 Blast Parameter and Rock Mass

The study on geological condition of rock mass prior to the blasting was carried out in four separated sessions. The condition of rock mass is assumed as homogeneous. During these sessions, a total of 109 blast holes with diameter of 89 mm each were detonated.

In general, the drilling process runs smoothly since fewer cavities were found. The depths of the holes were between 11.2 – 13.7 m including 0.9 m sub-drill. The charged weight per blast holes were set at between 40 – 100 kg, which produced up to 8000 m^3 of aggregates for each blasting session. The powder factor was recorded in the range of 0.3 kg/m^3. Table 2 summarized the data.

Table 2: Blast design parameters for blast sessions

Description	Details			
	Session 1	Session 2	Session 3	Session 4
Geologic condition observed at site	• Joints and faults • South-West and North-East dipping • Dry holes	• Faults and joints • North-East and North-West dipping • Moderately weathered • Dry holes	• Joints and bedding • Moderately weathered • North-East and East-South dipping • Dry holes	• Joints • Moderately weathered • East-South dipping • Dry holes
No. of holes	27	20	21	41
Diameter of holes (mm)	89	89	89	89
Bench height (m)	11.29	10.38	11.29	12.8
Depth of holes (m)	12.19	11.28	12.19	13.7
Spacing (m)	4.27	4.27	4.27	4.27
Burden (m)	3.96	3.96	3.46	3.96
Stemming (m)	2.40	2.40	2.40	2.40
Sub-drill (m)	0.90	0.90	0.90	0.90
Explosive weight (kg)	48.48	44.36	48.96	56.48
Blasted volume (m^3)	5,154	3,510	3,502	8,874
Powder Factor (kg/m^3)	0.27	0.27	0.31	0.28

4.1.3 Fragmentation Analysis

The fragmentation is described in terms of geometrical characteristics of the particles i.e., size, angularity or roundness. The cumulative size distribution function (CDF) and/or particle size distribution (PSD) provides a complete description of the former. It is either obtained from physical sieving of the material, which is very costly in large-scale blasts, or by non-physical sieving methods such as image analysis (i.e., WipFrag software).

The CDF is the 'fraction of mass P passing a screen with a given mesh size x' (Ouchterlony, 2003). Percentage of passing material from each mesh, P(x), varies between 0 to 100% as illustrated in Figure 2.

Several distinctive quantities are extracted from the curve as follows:

- X_{50} = a measure of the average fragmentation, i.e. mesh size through which half of the material passes, X_{50} is a central production measure;

- X_N = other percentage related block size numbers in use (e.g.: N=20, 30, 80, 90 etc);
- P_O = percentage of fragments larger than a typical size X_O (e.g.: P_O is related to the handling of big blocks by trucks or the size of blocks that the primary crusher cannot accept;
- P_F = percentage of fine material smaller than a typical size X_F.

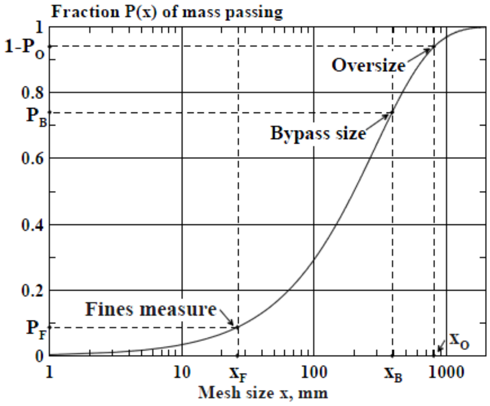


Figure 2: Typical example of particle size distribution graph

It is worth highlighting that in large-scale production sites, the focus is normally to the P_O, in which arise due to problems caused by boulders (big size rock breakage) at the crusher feed. Based on the observation after blast, the fragments produced were generally blocky and required secondary breakage due to the formation of big boulders before being fed into jaw crusher.

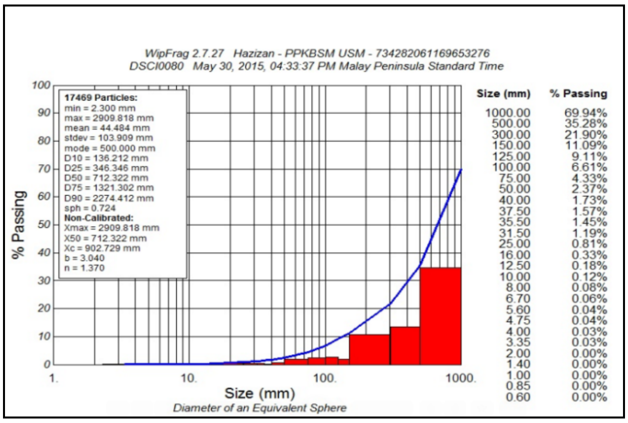
To analyze the degree of fragmentation of blasted rock, a post-blast muck pile images were analyzed by using Wipfrag image analysis. The results obtained were displayed in a form of particle size distribution graph (PSD) of % passing against the size of particles. All the results obtained in PSD graph are presented in Table 3.

Table 3: Summary of PSD graph results for blast session.

Description	**Details**			
	Session 1	**Session 2**	**Session 3**	**Session 4**
Geologic condition observed at site	• Joints and faults • South-West and North-East dipping • Dry holes	• Faults and joints • North-East and North-West dipping • Moderately weathered • Dry holes	• Joints and bedding • Moderately weathered • North-East and East-South dipping • Dry holes	• Joints • Moderately weathered • East-South dipping • Dry holes
No. of holes	27	20	21	41
Diameter of holes (mm)	89	89	89	89
Bench height (m)	11.29	10.38	11.29	12.8
Depth of holes (m)	12.19	11.28	12.19	13.7
Spacing (m)	4.27	4.27	4.27	4.27
Burden (m)	3.96	3.96	3.46	3.96
Stemming (m)	2.40	2.40	2.40	2.40
Sub-drill (m)	0.90	0.90	0.90	0.90
Explosive weight (kg)	48.48	44.36	48.96	56.48
Blasted volume (m^3)	5,154	3,510	3,502	8,874
Powder Factor (kg/m^3)	0.27	0.27	0.31	0.28

Based on the images processing generated by Wipfrag (as shown in Figures 3 to Figure 6), it was found that the rock fragments were not uniform in size as represented by the value of *n.* Subsequently, this finding denotes that the variation of uneven fragmented sizes as a result of blasting may constitute a major problem as depicted in Figures 3 to Figure 6 respectively.

It was also found that the maximum fragmented size produced varies between 900 mm to 3200 mm. Generally, almost 25% (or D_{75}) of rock breakage produced after blast were larger than the jaw crusher feed size (800 mm) and thus required secondary breakage by hydraulic hammer or secondary blasting.



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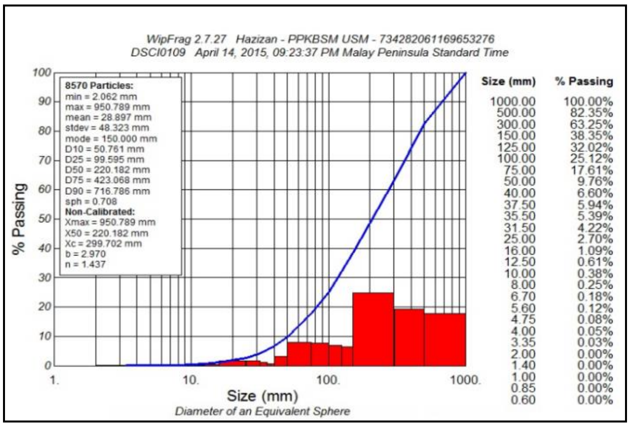
17469 Particles:
min = 2.300 mm
max = 2909.818 mm
mean = 44.484 mm
stdev = 103.909 mm
mode = 500.000 mm
D10 = 136.212 mm
D25 = 346.346 mm
D50 = 712.322 mm
D75 = 1321.302 mm
D90 = 2274.412 mm
sph = 0.724
Non-Calibrated:
Xmax = 2909.818 mm
X50 = 712.322 mm
Xc = 902.729 mm
b = 3.040
n = 1.370
```

```
Size (mm)   % Passing
  1000.00     69.94%
   500.00     35.28%
   300.00     21.90%
   150.00     11.09%
   125.00      9.11%
   100.00      6.61%
    75.00      4.33%
    50.00      2.37%
    40.00      1.73%
    37.50      1.57%
    35.50      1.45%
    31.50      1.19%
    25.00      0.81%
    16.00      0.33%
    12.50      0.18%
    10.00      0.12%
     8.00      0.08%
     6.70      0.06%
     5.60      0.04%
     4.75      0.04%
     4.00      0.03%
     3.35      0.03%
     2.00      0.00%
     1.40      0.00%
     1.00      0.00%
     0.85      0.00%
     0.60      0.00%
```

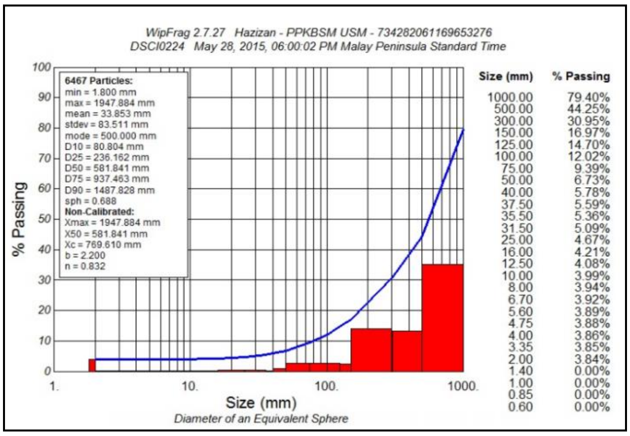
Figure 3: Particle size distribution graph for blast session 1


WipFrag 2.7.27 Hazizan - PPKBSM USM - 734282061169653276
DSCI0109 April 14, 2015, 09:23:37 PM Malay Peninsula Standard Time

8570 Particles:
min = 2.062 mm
max = 950.789 mm
mean = 28.897 mm
stdev = 48.323 mm
mode = 150.000 mm
D10 = 50.761 mm
D25 = 99.595 mm
D50 = 220.182 mm
D75 = 423.068 mm
D90 = 716.786 mm
sph = 0.708
Non-Calibrated:
Xmax = 950.789 mm
X50 = 220.182 mm
Xc = 299.702 mm
b = 2.970
n = 1.437

Size (mm)	% Passing
1000.00	100.00%
500.00	82.35%
300.00	63.25%
150.00	38.35%
125.00	32.02%
100.00	25.12%
75.00	17.61%
50.00	9.76%
40.00	6.60%
37.50	5.94%
35.50	5.39%
31.50	4.22%
25.00	2.70%
16.00	1.09%
12.50	0.61%
10.00	0.38%
8.00	0.25%
6.70	0.18%
5.60	0.12%
4.75	0.08%
4.00	0.05%
3.35	0.03%
2.00	0.00%
1.40	0.00%
1.00	0.00%
0.85	0.00%
0.60	0.00%

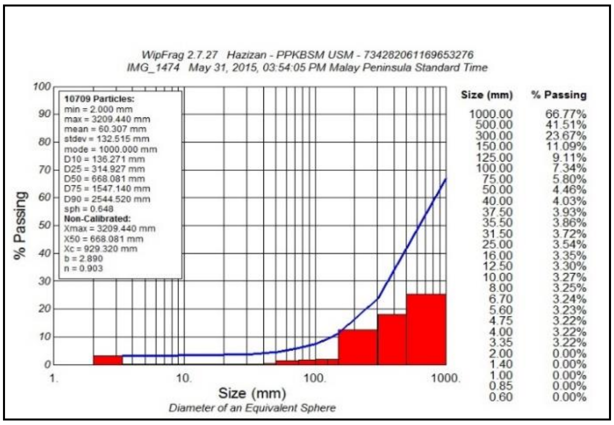
Figure 4: Particle size distribution graph for blast session 2


WipFrag 2.7.27 Hazizan - PPKBSM USM - 734282061169653276
DSCI0224 May 28, 2015, 06:00:02 PM Malay Peninsula Standard Time

6467 Particles:
min = 1.800 mm
max = 1947.884 mm
mean = 33.853 mm
stdev = 83.511 mm
mode = 500.000 mm
D10 = 80.804 mm
D25 = 236.162 mm
D50 = 581.841 mm
D75 = 937.463 mm
D90 = 1487.828 mm
sph = 0.688
Non-Calibrated:
Xmax = 1947.884 mm
X50 = 581.841 mm
Xc = 769.610 mm
b = 2.200
n = 0.832

Size (mm)	% Passing
1000.00	79.40%
500.00	44.25%
300.00	30.95%
150.00	16.97%
125.00	14.70%
100.00	12.02%
75.00	9.39%
50.00	6.73%
40.00	5.78%
37.50	5.59%
35.50	5.36%
31.50	5.09%
25.00	4.67%
16.00	4.21%
12.50	4.08%
10.00	3.99%
8.00	3.94%
6.70	3.92%
5.60	3.89%
4.75	3.88%
4.00	3.86%
3.35	3.85%
2.00	3.84%
1.40	0.00%
1.00	0.00%
0.85	0.00%
0.60	0.00%

Figure 5: Particle size distribution graph for blast session 3


WipFrag 2.7.27 Hazizan - PPKBSM USM - 734282061169653276
IMG_1474 May 31, 2015, 03:54:05 PM Malay Peninsula Standard Time

10709 Particles:
min = 2.000 mm
max = 3209.440 mm
mean = 60.307 mm
stdev = 132.515 mm
mode = 1000.000 mm
D10 = 136.271 mm
D25 = 314.927 mm
D50 = 668.081 mm
D75 = 1547.140 mm
D90 = 2544.520 mm
sph = 0.648
Non-Calibrated:
Xmax = 3209.440 mm
X50 = 668.081 mm
Xc = 929.320 mm
b = 2.890
n = 0.903

Size (mm)	% Passing
1000.00	66.77%
500.00	41.51%
300.00	23.67%
150.00	11.09%
125.00	9.11%
100.00	7.34%
75.00	5.80%
50.00	4.46%
40.00	4.03%
37.50	3.93%
35.50	3.86%
31.50	3.72%
25.00	3.54%
16.00	3.35%
12.50	3.30%
10.00	3.27%
8.00	3.25%
6.70	3.24%
5.60	3.23%
4.75	3.22%
4.00	3.22%
3.35	3.22%
2.00	0.00%
1.40	0.00%
1.00	0.00%
0.85	0.00%
0.60	0.00%

Figure 6: Particle size distribution graph for blast session 4

On the other hand, the PSD graph shows that D_{50} diverges between 200 mm to 700 mm showing that more than half of the rock breakage sizes passed through the jaw crusher. In overall, the size distributions of particles were poorly uniform since the values of n were falled between 0.8 – 1.4 with the characteristic size of particles, X_c varying between 300 mm to 900 mm respectively.

Owing to the fact that the limestones in this area are categorized as soft rock, then the explosives with low VOD such as ANFO are sufficient enough to blast the sedimentary rock. However, the fragmentation analysis shows that each of blast sessions were not in optimum condition. From analysis done, each blast session requires at least 25% of its particles to undergo secondary breakage.

On contrary, more than 50% of the particle sizes will pass the feed of 800 mm jaw crusher. The uniformity index of the PSD is mostly ranging from well graded size distribution (ratio of larger block to the smaller block is 1:8) to moderately poorly uniform size distribution (ratio of larger block to the smaller block is 8:1). It was also stipulated that the above issues can be minimized by a proper blast design, drilling and suitable type of initiation system.

4.1.4 Peak Particle Velocity (PPV)

The scale distance, $D/\sqrt{W}$ is derived from combination of distance and explosive charge weight. This empirical formula as given in Equation 1 contains site constants, K and β which allow for the influence of local rock characteristics (Morhard, 1987). This is due to ground vibrations which is related to the quantity of explosive used and the distance between the blast area to structures as well as geological and geotechnical conditions of the rock units (Olofsson, 1988; Taqieddin, 1986).

$$\mathbf{PPV = K(D/W^{1/2})^{-\beta}} \qquad \text{(Eq. 1)}$$

Where,

- PPV= peak particle velocity (mm/s);
- D = distance from blast area to the nearest structures (m);
- K, β = site constants related to site and rock properties for estimation purposes; and
- W = Effective charges mass per delay or maximum instantaneous charge (kg).

The PPV values were recorded during blasting in which the vibration monitor was located at the distance, approximately 800 m from the point of blast. Twelve values were taken to determine the value of predicted site constant K and β based on the geologic condition of the rock mass as shown in Figure 7. A scaled distance, *D/√W* is an important dimensionless parameter that inversely proportional to the PPV. In other term the greater the PPV, the shorter the scaled distance.

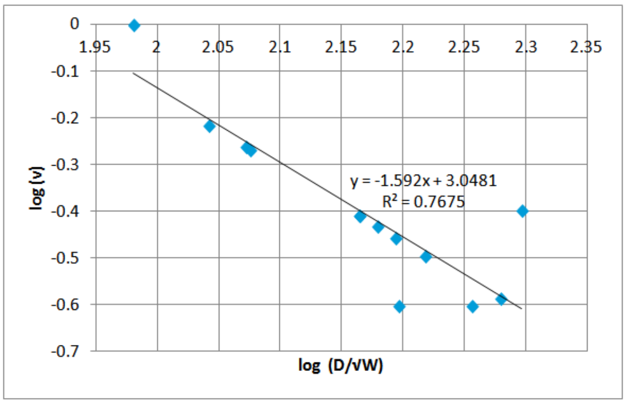


Figure 7: Regression Model Analysis Graph for log (v) against log (D/√W)

Based on Figure 7, the equation obtained is as follows:

$$\mathbf{y = -1.592x + 3.0481} \qquad \text{(Eq. 2)}$$

In order to calculate the value of site constant K and β, Equation 3 is used by taking the substitution of Equation 2:

$$\mathbf{\log v = -\beta\ [\log (D/\sqrt{W})] + \log K} \qquad \text{(Eq. 3)}$$

This can be written in the form of a straight line as

$$\mathbf{y = mx + c} \qquad \text{(Eq. 4)}$$

where, β = 1.592, K = 1117.12

Thus the new value of site constants K and β were determined as 1117 and 1.6 respectively as shown by Equation 5:

$$\mathbf{PPV = 1117\left(\frac{D}{\sqrt{W}}\right)^{-1.6}} \qquad \text{(Eq. 5)}$$

where,

D = Distance of vibration monitor to point of blast (m)
W = Mass of charge per delay (kg)

The PPV of each blast session was monitored by using vibration monitor located at a specific distance from blasting area. Of all the PPV values obtained, it was recorded at 0.25, 0.28, 0.32 and 0.29 mm/s respectively. Alternatively, a slightly higher value between 0.50 to 0.99 mm/s were derived using the predicted site constants, K=1117 and β=1.6. Nevertheless, those values were still found to be in accordance to the maximum permissible limit of 5 mm/s.

Since both values are relatively dependent of rock mass characteristics at the local site (as compared to the generalization of K=1140 and β=1.6 values by Australian Standard that widely employed for blasting activities in Malaysia), the results are more reflecting to the actual site conditions.

The nearest structure is located at 802 m from blast area. Thus, based on the new empirical formula, the predicted value of PPV expected are as follows:

When, W_{max} = 56.48 kg then, v = 0.64 mm/s
W_{min} = 44.36 kg then, v = 0.52 mm/s

Accordingly, based on Equation 5, the value of predicted PPV was found to be 0.64 mm/s at a maximum charge per hole (W_{max}) and 0.52 mm/s when using a minimum charge per hole (W_{min}) respectively. It can be concluded that both values do not exceed the requirement standard set by the Department of Minerals and Geosciences, Malaysia (i.e., <5 mm/s).

4.2 Blasting Vibration Limit

It is worth highlighting that the United States Bureau of Mines (USBM) stipulated that a maximum safe blasting limit adjacent to a structure is 50.8 mm/s PPV with a 95% confidence limit with some adjustment according to the type and nature of the structure. The threshold of vibration is about

0.2-0.5 mm/s PPV and a level of 20 mm/s would cause cosmetic damage.

Accordingly, most specifications of recommended and acceptable PPV level are in favor with the value of 6 mm/s. It is clear that compliance with these limits will mean that structural damage is very unlikely, although cosmetic damage is still possible.

In Malaysia, no specific guideline has been produced pertaining to vibration and noise level on rock blasting. The Department of Mineral and Geoscience, Malaysia however, has imposed limits in the range of 5-10 mm/s for blast vibration. To date, the best approach to predict blast induced ground vibrations level is to use scaled distance technique.

This approach provides quarry operators with great flexibility in the use of explosive regarding to distance and charge weight to control ground vibrations induced during blasting (Elseman, 2000). When the suitable scale distance has been determined, quarry operators can reduce the number of holes per delay. If the design is already reduced to one hole per delay, then they can try decking the blast holes and fire each blast hole with two or more delay patterns provided the amount of explosive charge per delay do not exceed the maximum charge per delay as calculated using scaled distance formula in order to reduce ground vibrations.

Instead of reducing explosive charge, quarry operators may redesign the blast, so that less energy per hole is required to fragment the rock. This can be achieved by changing the hole spacing, the burden and even the hole diameter provided the powder factor (the amount of explosive used per cubic meter) applied is sufficient to fragment the rock (Konya and Walter, 1990). Therefore, the application of the scale distance approach does not only prevent undesirable side effects of blasting (i.e., ground vibrations) but also promote a safe and good blasting practice and thus enhances the sustainability of quarry activities in a longer run.

It should be noted that ground vibration depends on the maximum charge weight per delay, and not the total charge weight, provided the delay interval is significant. For a free face average rock blasting, Australian Standard (Australian Standard AS2187.2, 1993) has developed a Scale Distance chart derived from the above equation by taking K and β as 1140 and 1.6 respectively.

Figure 8 illustrates the calculated PPV value at the nearest structure/interest point at approximately 802 m from the blast point). By using the new calculated site constants K and β of 1117 and 1.6 respectively, it was found that the predicted PPV value anticipated at 1.00 mm/s which is within the recommended level by the Department of Mineral and Geoscience, Malaysia.

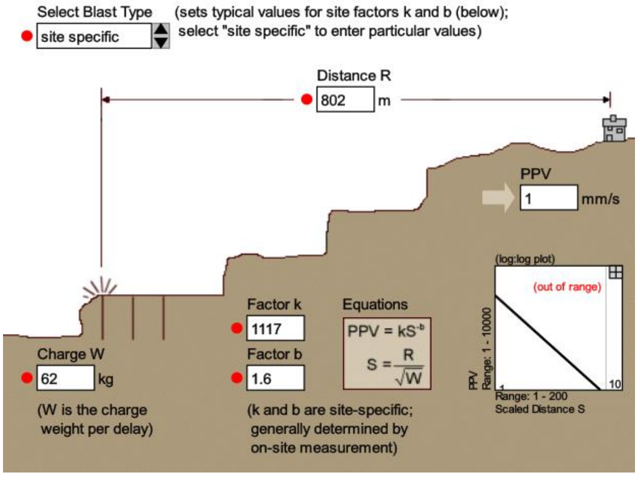


Figure 8: Bench Blasting - Peak Particle Velocity (PPV) for Assessment of Structural Damage Potential (adapted after Edumine, 2015). Note: the nearest structure located at nearest building at approximately 802 m from blasting point and the predicted site constants of K=1117, β=1.6 is employed.

Currently, the blasting is to be conducted with 13 m benches using 89 mm diameter blast holes. Since the prevailing condition found at site is highly weathered and fair cracked dry rock, it has been decided to use bulk ANFO with emulsion cartridges as primer. The overall density of compacted ANFO and the primer is 0.85 g/cm^3 and the powder factor of

0.3 kg/m^3 was used. The new drilled blast holes pattern is proposed in a staggered pattern forming equilateral triangles while the drill subjected to be 10° inclined. The appropriate new charged weight per blast holes was calculated at 62 kg of ANFO at specific burden of 3.8 m and spacing of 4.4 m respectively.

4.3 Airblast Level Limit

Noise generated by blasting is related to air blast as large quantity of expanding gases dissipates the energy in the atmosphere thereby generating shock waves. Audible noise, being part of the pressure wave, occurs at the same time as the air blast. It is of very short duration and can cause structural damage and human discomforts when it reaches its peak action level depending upon the distances involved.

In Malaysia, no particular standard pertaining to noise level from operation has been adopted. However, monitoring data gathered by the Department of Mineral and Geoscience, Malaysia indicate that the levels are consistent with the standards adopted by other countries such as USA, UK, Canada and Australia recommended safe and nuisance levels which range from 115 to 136 dB. Thus for the study, these standards are adopted as guidelines in assessing the blasting operations in Malaysia.

Accordingly, noise levels at various locations of concerned may be calculated using Equation 6.

$$\mathbf{A = 165 - 24 \log_{10} (R/Q^{1/3})\ dB} \qquad \text{(Eq. 6)}$$

Where, A = Overpressure for confined charges (dB);
R = distance from point to structure (m), and
Q = maximum explosive charge per delay (kg).

Based on the proposed new blast design, the staggered drilling method of blasting used in the production blast shall utilize about 62 kg of maximum instantaneous charge (MIC) as compared to approximately 50 kg of existing MIC which has been proven to produce undesirable breakage.

With regard to this value of MIC, the airblast level at various sensitive locations of concerns was found evaluated to be 95 dB. Based on the permissible ground vibration level between 5-10 mm/s and airblast level between 124 to 132 dB, the projected vibration and airblast at the localities of concerned are below the limit of the guidelines level and therefore not likely to pose any immediate human discomfort and structural damage.

4.4 Flyrock

Geology, rock conditions or improper blasting design can lead to flyrock problem. Flyrock is produced when there is too much explosive energy for the amount of burden, when stemming is inadequate, or when the explosive energy is too rapidly vented through a zone of weakness. Although flyrock is an unlikely hazard to the surrounding, adopting suitable blasting method is important.

In consideration of its impact to the environment, the quarry will utilized an environmental friendly blast initiation system in its blasting operation. A suitable working platform level will be developed initially. This will enable a multi-row blast pattern to be implemented at the quarry.

The ignition system recommended for the production blast design is NONEL system with multi row blasting and a delay per hole design. In view of the proposed blast design, Pal and Ghosh (2002) studied the optimization of blasting pattern implemented at opencast project for control of ground vibration, airblast and fly rock with better production and productivity. Their study revealed that with proper design of blast parameters, desired fragmentation sizes and vibration levels can be achieved but flyrock needed good and systematic supervision. They suggested the use of non-electric initiation system instead of detonating fuse; this increased the cost but gave back in productivity reducing chances of misfire, flyrock and achieved proper fragmentation with reduced sub-grade drilling. The direction of inclination is also very important. They suggested a blast design for right balance between environmental aspects and productivity criteria.

The multirow blasting design requires a careful selection of the in-the-hole millisecond (ms) delays built in the detonators. The use of millisecond delay intervals between adjacent holes in a single row will minimize ground vibrations, air blast and flyrock and increase fragmentation. Good fragmentation is achieved when each charge is given sufficient time to break its quota of burden from the rock mass before the next charge detonates; the second and subsequent charges can then shoot to free additional face sequentially.

4. Conclusions

Based on the site observations and results as well as proper blast design, it was found that the geological structures (i.e., site constants of K and β) are important factors to take into account in blast designs. The breaking process in rock mass primarily occurs along significant bedding planes and secondarily across the beds themselves. If the joints are widely in spaced, the breakage may take place across a sequence of beds rather than along joint planes. Since joints and faults are prevalent in the study area, the selection of explosives and initiation system should be judiciously made.

The fragmentation analysis shows that each of blast sessions were not in optimum condition while the uniformity index of the particle size distribution is mostly ranging from well graded size distribution.

Therefore, a good blast design must be adopted with respect to the site specific constants that act as the level of natural restriction of rock in-situ. With this, damage that may result to the structures in close proximity of quarries by induced vibrations, airblast, and excessive flying rocks can be significantly minimized. The technology of rock blasting is highly developed, and when blasting is properly conducted, most environmental impacts should be negligible.

By adopting widely recognized and well-documented limits on ground motion and air concussion, direct impacts from ground shaking and air concussion can be effectively mitigated.

Furthermore, efficient blasting also promotes good fragmentation (in term of desirable size reduction) and hence promotes low energy consumption, higher productivity and overall sustainable and safe quarrying and mining operations.

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References

Australian Standard AS2187.2-1993 (1993), '*Explosives—Storage and use Part 2: Use of explosives*', Standards Australia: Sydney.

Bhandari, S. (1996), Changes in fragmentation processes with blasting conditions, Rock Fragmentation by Blasting, *Fragblast 5*, pp. 301-309, A.A. Balkema: Montreal.

Bohloli, B. (1997), Effects of the geological parameters on rock blasting using the Hopkinson split bar, *International Journal of Rock Mechanics and Mining Sciences*, vol. 34 (3-4), pp. 32 (e1–9)**.**

Bozic, B. and Braun K. (1991), Tectonic fabric and blasting in dolomite rocks, In the 7th International Congress on Rock Mechanics, *ISRM*, Aachen, Germany.

Edumine (2016), http://www.edumine.com/xtoolkit/xmlicon/PPVThresholds.htm, accessed 25 May 2016.

Elevli, B. and Arpaz, E. (2010), Evaluation of parameters affected on the blast induced ground vibration (BIGV) by using relation diagram method (RDM), *Acta Montanistica Slovaca*, 15(4), pp.261–268.

Elseman, I.A. (2000), Measurement and analysis of the effect of ground vibration induced by blasting at the limestone quarries of the Egyptian Cement Company, In *ICEHM2000*, Cairo University, pp. 54-71.

Faramarzi, F., Mansouri, H. and Ebrahimi, F. M. A. (2013), A rock engineering systems based model to predict rock fragmentation by blasting, *International Journal of Rock Mechanics and Mining Sciences*, vol. 60, pp.82–94.

Gough, J. (2013), Ipoh Limestone: An Environmental Management Challenge, *Ipoh's Community Newspaper*.

Konya, C.J. and Walter, E.J. (1990), *Surface Blast Design*, Prentice Hall: New Jersey.

Morhard, R.C. (1987), *Explosives and rock blasting*, Atlas Powder Co.: Dallas, Texas, USA.

Metcalfe, I. (2013), Tectonic evolution of the Malay Peninsula, *Journal of Asian Earth Sciences*, vol. 76, pp.195–213.

Olofsson, S.O. (1988), *Applied Explosives Technology for Construction and Mining*, Apples: Sweden.

Orica Technical Services (2008), *Safe and Efficient Blasting in Quarries*, May 2008.

Ouchterlony, F. (2003), Influence of blasting on the size distribution and properties of muckpile fragments, a state-of-the art review. MinFo Project P2000-10: energy optimisation in comminution. Lulea University of Technology, Swebrec, pp. 81–95.

Pal, U.K. and Ghosh, N. (2002), “Optimization of blast design parameters at Sonepur Bazari opencast project”, *The Indian Mining & Engineering Journal*, September, pp. 36-41.

Persson, A., Holmberg, R. and Lee, J. (1994), *Rockblasting and explosives engineering*, CRC Pres.: USA.

Taqieddin, S.A. (1986), Ground vibration levels: Prediction and parameters, *Mining Science and Technology*, vol. 3, pp.111-115.

Tate, R.B., Tan, D.N.K. and Ng, T.F. (2009), Geological Map of Peninsular Malaysia, In Hutchison, C.S., Tan, D.N.K. (Eds.), *Geology of Peninsular Malaysia*, University of Malaya/Geological Society of Malaysia: Kuala Lumpur.

Winzer, S. R., Anderson, D. A., & Ritter, A. P. (1983), Rock Fragmentation by explosives, In Proceedings of the First International Symposium on Rock Fragmentation by Blasting, pp. 225-249, Lulea, Sweden.