

## Effects of Quarry Blasting Towards the Residential Area at Kangkar Pulai, Johor, Malaysia

(Kesan Letupan Kuari kepada Kawasan Perumahan di Kangkar Pulai, Johor, Malaysia)

KARTHIGEYAN A/L AL. RAMANATHAN\* & RINI ASNIDA ABDULLAH

### ABSTRACT

*The drill and blast technique have been widely used recently due to demand for natural building materials like rock aggregates. However, the intensity of blasting effects has been questioned on its validity towards the nearby residential areas. In this study, the blasting effects from Quarry A and B has been assessed based on constant location of the residential areas (Taman Pulai Hijauan and Taman Bandar Baru Kangkar Pulai, respectively) using the empirical formulations only. The blasting effects are highly dependent on the maximum instantaneous charge in blast holes (Q) which are dependent on parameters like number of blast holes, charge per column, Powder Factor and number of blast per delay. This study was able to show that with an increase of the independent variables, the Q value rises significantly. The average Q value from Quarry A (181.07 kg) was slightly higher than Quarry B (180.22 kg). The correlations made for each quarry showed that Quarry A had a better regression line with lower standard error due to the high number of blast data obtained during the monitoring period of about 1 year and 8 months. Meanwhile, the impact assessments showed higher PPV (Peak Particle Velocity) value at higher Q holding blast holes in Quarry A compared to Quarry B and decreases with increasing distance. The similar relationship was observed for the air blast assessments. Yet, all of the blasts produced are relatively within safe limits which are less than 5 mm/s Mineral & Geosciences Department (JMG) and less than 125 dBL United States Bureau of Mining (USBM). Thus, extra precaution can be taken by estimating the suitable Q value such as A (97.66 kg) and B (271.68 to 495.01 kg) to maintain safe blasting operations and prevent damages to the nearby residential areas.*

*Keywords: Air blast; blasting effects; drill and blast; independent variables; peak particle velocity*

### ABSTRAK

*Teknik gerudi dan letupan digunakan secara meluas disebabkan permintaan terhadap bahan binaan semula jadi seperti batu agregat. Walau bagaimanapun, keamatan impak letupan terhadap kawasan perumahan yang berdekatan kurang diteliti sebelum ini. Dalam kajian ini, kesan letupan dari Kuari A dan B telah dinilai berdasarkan lokasi yang tetap daripada kawasan perumahan (Taman Bandar Baru Kangkar Pulai dan Taman Pulai Hijauan) menggunakan kaedah empirik sahaja. Kesan letupan adalah sangat bergantung kepada cas berseketika maksimum (Q) yang bergantung kepada parameter seperti bilangan lubang letupan, cas setiap lubang, faktor serbuk dan bilangan letupan setiap langkah. Kajian ini menunjukkan bahawa dengan peningkatan pemboleh ubah bebas, nilai Q meningkat. Nilai purata Q Kuari A (181.07 kg) adalah lebih tinggi daripada Kuari B (180.22 kg). Korelasi yang dibuat menunjukkan bahawa Kuari A mempunyai garisan regresi yang lebih baik dengan ralat piawai yang lebih rendah kerana jumlah data letupan yang tinggi diperolehi semasa tempoh pemantauan selama 1 tahun dan 8 bulan. Manakala, penilaian impak menunjukkan nilai PPV lebih tinggi apabila nilai Q lebih tinggi dalam Kuari A berbanding Kuari B dan berkurangan dengan peningkatan jarak. Hubungan yang sama telah dilihat dalam penilaian letupan udara. Walau bagaimanapun, semua letupan berada dalam had yang selamat iaitu < 5 mm/s (JMG) dan < 125 dBL (USBM). Oleh itu, langkah berjaga-jaga boleh diambil dengan menganggarkan nilai Q yang sesuai seperti A (97.66 kg) dan B (271.68 - 495.01 kg) untuk memastikan operasi letupan yang selamat dan mengelakkan kerosakan pada kawasan perumahan yang berhampiran.*

*Kata kunci: Gerudi dan letupan; impak letupan; letupan udara; pemboleh ubah bebas; PPV*

### INTRODUCTION

Malaysia has been facing a boom in demand recently for resources such as land space and building materials to cater to the country's increasing population. These require the clearance or leveling of hilly area through the surface excavation process (Yilmaz et al. 2016). However, not all the ground material can be normally excavated using

a backhoe. Many contractors have spent heavy coins on alternative method like drill and blast technique due to the high strength and volume of rock.

Blasting contractors should try to minimize the impact of quarry blasting on surrounding environment and the public. This is due to the effect of blasting that induces strong ground motions, flyrock and air blast

pressure that may lead to major accidents (Sharma 2017). At present, the current limited land space forces the placement of blasting quarries to be nearer to residential area. Thus, local councils, enforcers, Mineral and Geoscience Department (JMG) and Department of Environment (DOE) need to be more attentive during blasting activities. This is to ensure blasting is done accordingly to the approved safe guidelines, especially by controlling the blast design parameters.

The safety of surrounding environment is the utmost important aspect to be considered when an engineer designs the blast parameters required for blasting. Here, the help of instrumentation system located at strategic places in the surrounding environment allows only a mere prediction of frequency, air pressure and vibration models induced by the blast. A general hypothesis that can be made is that the effects of quarry blasting are much higher if the instrumentations are located nearer to the blast surface. This hypothesis caused Malaysia to brand the quarry activities as heavy industry and has set a minimum buffer zone limit of 500 metres from the intended blasting area to the nearest residential or industrial area (Environmental Requirements: A Guide for Investors 2010).

However, this limit has been on the stake when a tragic blast caused a flyrock incident to occur on the 19th of July 2013 at Masai quarry near Seri Alam, Johor, Malaysia. Flyrock are rocks ejected from the blast surface at high speed that may cause injuries and damages to surrounding environment, people, buildings and vehicles. This massive explosion caused rocks and boulders to rain down on the nearest industrial park located at Jalan Bukit 2 which is 700 metres from the site. It was a fatal accident in which a factory worker was killed, 10 people were injured, 18 cars and 14 factories were damaged (Mohamad et al. 2013).

It is stated that one of the main reasons that this incident occurred was the inappropriate design of blast geometry. At the Masai quarry, blasted granitic rocks generally tend to have high rock strength. Therefore, in order to blast these rocks, a greater weight of explosive cover is needed to increase blast efficiency (Sazid & Singh 2012). If the burden provided by the blast surface is insufficient, then greater energy will be released to the surrounding environment via rock fragments causing flyrock issue to occur. The lack of understanding in this blast design parameters by the explosive engineers will definitely harm the surrounding environment.

Blast design parameters are controllable parameters that allow explosive engineers to perform efficient and safe blasting in a quarry. The parameters involved are blast surface burden, spacing, bench height, explosive weight, powder column geometry and maximum charge per delay (Blasting Training Module 2004). With the aid of this blast design, blasting activities can be carried out and analyzed in terms of fragmentation, blast surface stability and environmental safety.

From the previous case history by Mohamad et al. (2013), the problem statement of this study can be justified to prevent the occurrence of flyrock accidents, extreme ground vibration and air blasts at the studied quarry sites. The granitic rock behavior, blast design parameters used and literally short distanced location of residential area from the quarry site might have some chances of mismatches to occur (Dick et al. 1987). Hence, a detailed study must be done based on blast design parameters by analyzing and assessing the after-effect of the blasting industry with the help of instrumentations installed at the residential areas (Aloui et al. 2016). This will crucially help to understand the effects of quarry blasting towards the safety of the residential areas studied.

The aim of this project was to investigate the effects of quarry blasting from Quarry A and B towards the nearby residential area. This outcome may contribute to the knowledge of rock blast management by enriching the parameters selection for future blast design refurbishment. The previously stated project aim can be solved by tackling these specific objectives stated which is to identify the blast design parameters that will affect the surrounding environment. Another objective was to assess the effects of blasting quantitatively based on the blast design parameters obtained. The last aim was to compare the safety of affected nearby residential areas from the impact of quarry blasting.

## MATERIALS AND METHODS

The methods used to achieve these objectives in a given specific time period is done with the help of an operational framework which is stated in Figure 1. The nearest distance from Quarry A (AQ) to Taman Pulau Hijauan (TPH) is 533 metres while the Quarry B North Face (BQNF) and South Face (BQSF) to Taman Bandar Baru Kangkar Pulau (TBBKP) is about 1585 and 889 metres, respectively. The coordinates of these locations are AQ (1° 33' 40" N, 103° 33' 49" E), TPH (1° 33' 21" N, 103° 34' 00" E), BQNF (1° 35' 09" N, 103° 34' 37" E), BQSF (1° 34' 54" N, 103° 34' 40" E) and TBBKP (1° 34' 22" N, 103° 34' 56" E). There are no vibrometers installed at the residential areas and all results are based on mere empirical formulations that will be discussed further in this section.

## SITE OBSERVATION

As stated previously, blasting occurs in an igneous origin geological background which is the granites. Both quarries are situated in Kangkar Pulau near Iskandar Puteri, Johor, Malaysia. The mentioned quarries are at the vicinity of the granitic Gunung Pulau and produces granite aggregates for various construction uses in a large scale. Most of aggregates will be supplied in house and also to Singapore with an average of 3.5 tons of production daily. While, the monitoring points are at Taman Pulau Hijauan (TPH) for Quarry A (QA) and Taman Bandar Baru Kangkar Pulau (TBBKP) for the Quarry B (BQNF &

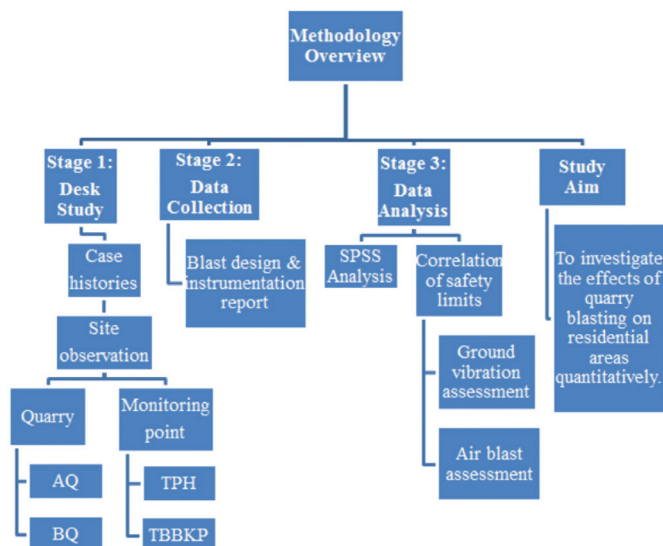


FIGURE 1. Flowchart of operational framework that will be used in this study

BQSF). The location of the quarries and the studied high potential risk residential areas are shown in Figure 2. The residential areas of the monitoring point are considered as modern type of buildings.

These study areas are majorly underlain by granites that were emplaced during the igneous intrusive activities from Early Triassic to Late Cretaceous (Hutchinson 1997). Previously, geochemists like Sia and Rozi (2002) proved that the compositions of these rocks are majorly made up  $\text{SiO}_2$  (more than 70%).  $\text{SiO}_2$  is a colourless compound found mainly as quartz which possesses high resistance to weathering and deformability. Thus, this issue creates problem during blasting due to the need of large amount of explosive charges that may cause major vibration to the surroundings.

#### DATA COLLECTION OF QUARRY'S BLAST DESIGN PARAMETERS

Data collection is done by referring to the blast design parameters in the blast design report of each quarry. These reports were merely based on a total of 94 data which comprises of 60 blasts (Quarry A) and 34 blasts (Quarry B). The monitoring period was about 1 year and 8 months starting 11th January 2017 to 6th September 2018. Both of the quarries studied carries out about 2 to 6 blasts per month. In addition to that, comparisons of blast parameter used in each of these quarries are collected and shown in Table 1. These parameters will play a major role in assessing the effects of blast in this study.

#### DATA ANALYSIS

Several correlation of safety limits have been carried out to ensure that the objectives of this study can be interpreted in the data analyzing stage. In this stage, three further sub stages that involve the assessments of blast design parameters and effect of quarry blasting were carried out.

There were Statistical Package of Social Science (SPSS) analysis, ground vibration and air blast assessments: Using the empirical methods based on regulations set by JMG and United States Bureau of Mining (USBM).

In the SPSS analysis, the multiple regression line method was used to perform manipulation and analysis with simple instruction for highly complex data sheet (IBM SPSS Data Collection Divestiture 2016). The final product of analysis was in the form of coefficients and constants that were able to quantitatively express the suitable equation to relate the blast design parameters for each quarry, respectively. However, there were slight variances from the actual output value via the standard estimate error due to the  $R^2$  value of regression lines not being exactly 1.00 (0.996 for Quarry A and 0.894 for Quarry B). Hence, the study's objective to identify the influential blast design parameters on the blasting effects still can be proven using this correlation from the SPSS analysis due to the accepted high average percentage of 94.5%.

Besides that, the other sub stages highlight the assessments are on ground vibrations by using the theory of Peak Particle Velocity (PPV). This PPV value was obtained using (1) with Malaysian site constants to increase data reliability that suits site conditions (Hashim & Khider 2017; Juna & Syed 2013). In (2), the air blast values can be obtained using the similar parameters from (1). The (1) and (2) are as follows:

$$\text{PPV} = K (D/Q^{1/2})B \quad (1)$$

where  $K$  and  $B$  is the site constants (37 and - 0.63, respectively),  $D$  is the distance from quarry to residential area (monitoring point) in metres and  $Q$  is the maximum instantaneous charge (kg).

$$A = 165 - [24 \log (D/Q^{1/3})] \quad (2)$$

where  $A$  is the air blast noise level (dBL).

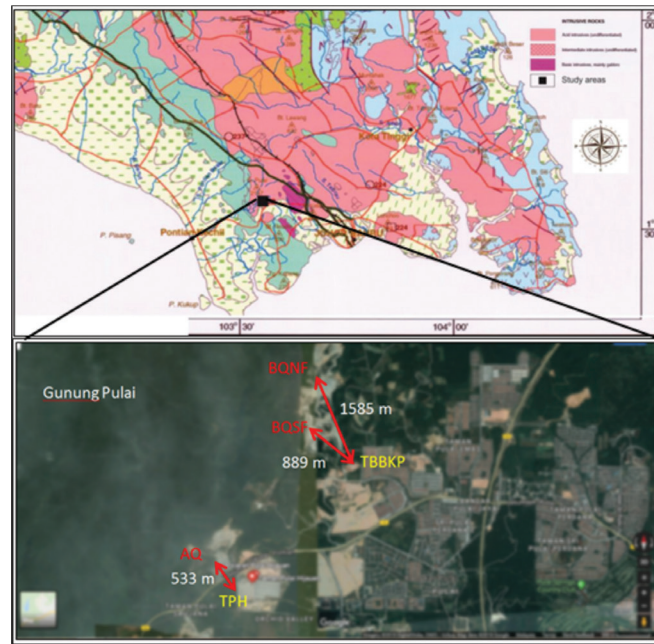


FIGURE 2. Location of study area via geological (JMG 2004) and Google maps (image softened due to restriction)

TABLE 1. Comparison of used parameters for blasting works in respective quarries

Parameters	Quarry A	Quarry B
Hole diameter	89 mm	
Burden	3.35 m	2.70 m
Spacing	3.35 m	3.90 m
Subdrill	0.91 - 1.00 m	0.90 m
Hole length	8.53 - 16.76 m	9.70 - 14.1 m
Type of explosives	Ammonium Nitrate Fuel Oil (ANFO emulsions) and boosters	
Density of explosives	1.2 kg/m <sup>3</sup>	
Charge weight per metre	7.47 kg/m <sup>3</sup>	
Stemming length	1.82 - 2.13 m	2.10 - 2.40 m
Explosive column length	7.61 - 16.31 m	8.2 - 13.7 m
Powder factor	0.45 - 0.59 kg/m <sup>3</sup>	0.53 - 0.77 kg/m <sup>3</sup>
Detonation	Non Electric (NONEL) delay system	
Distance from monitoring point	533 m	889 - 1585 m

In addition, according to JMG (2004), the safe blasting criterion that is advised to ensure that the PPV and air blast values should not exceed 5 mm/s and 125 dBL. If exceeded, structural damages and nuisance to public will occur with varying scales. If the effects of blasting show a caution level of damage on the residential areas, then immediate measures must be taken into review the blast design used in order to maintain the safety of the surroundings in study area. Thus, the correlation between these parameters on the effects of blasting will help to prove and validate the current safety issues of the studied areas in Kangkar Pulai.

## RESULTS AND DISCUSSION

Results obtained from blast data's that were provided from two different quarries namely Quarry A and B are presented herein.

### RELATIONSHIP BETWEEN DESIGN PARAMETERS AND EFFECTS OF BLASTING

There are only few parameters are directly related to these effects as introduced briefly via the pathway of blasting and formulation method. This formulation method is able to provide the weight of the maximum instantaneous

charge ( $Q$ ) value in kilograms. According to New South Wales (NWS) Mineral Council (2009),  $Q$  is the maximum amount of explosive detonated per delay. This  $Q$  value is highly dependent on parameters such as number of blast hole, charge per column, Powder Factor (PF) and number of blast per delay. Generally, any increase of those stated parameters will have a significant rise in the  $Q$  value (Niklasson et al. 2014). Hence, this will eventually cause the rise of the severity of blasting effects towards the surrounding areas as shown in Figure 3.

From Figure 3, it can be observed that the  $Q$  value increases with the blast design parameters, thus justifying the hypothesis stated previously. However, in Figure 3(a), the highest  $Q$  values were found more in lowly numbered blast holes as shown in Table 2. This could be due to the large volume of rock that was needed to blast during the operation works. Since the diameter of all the blast holes remained constant at 89 mm, the  $Q$  value was highly dependent on the volume of rock designed to blast. Blasting engineers designed as so in order to regulate the desired fragmentation level of a particular blast. Even though the number of blast holes was lesser than the usual trend, the  $Q$  value must be set at a maximum to provide sufficient energy to break the rock mass into smaller fragments. This rock mass may have less or no discontinuities where there is absence of weakness planes especially in rock Grade I and II. If this was not performed, then the blast could not provide desired fragmentation and also would be classified as uneconomical in terms of cost, time and energy (Singh et al. 2016). Nevertheless, providing a large amount of  $Q$  value into blast holes will cause an excessive outbreak of energy via ground vibration and air pressure.

While, from Figure 3(b), longer explosive column has the ability to contain more explosive charge in the blast hole. When these heavily charged holes are blasted, ideally it releases energy together with heat, pressure and sound from the rock mass into the surrounding environment.

Yet, only one third of the total chemical energy from the explosive material is released by the detonation (Karlous & Solomos 2013). The other forms of energy mentioned are released at a slower rate via the combustion process between burning explosive product and the air.

Another issue to address here in this data analysis is the different values of  $Q$  obtained at similar amount of charge weight per column blast hole. For example,  $Q$  values of 130.15 kg and 260.31 kg were obtained in two different blast holes that each contained 130.15 kg of charge weight per column in Quarry A. This was due to the influence of number of blast per delay which in this case was about the factor of 2. Nonetheless, increased  $Q$  values will generate extra heave and shock energy that eventually triggers excessive ground vibration towards the surrounding environment (Shirani Faradonbeh et al. 2016). Thus, extra precaution must be taken by blast designers to set a suitable length of explosive column so that the charge per column does not provide an immoderate  $Q$  value which will influence the occurrence of mismatch to occur.

Besides that, from Figure 3(c), the variation of PF used from 0.47 to 0.80 kg/m<sup>3</sup> during blasting operation shows that the rock breakage difficulties at studied quarries are from high to very high (Table 3). In addition, most of the Quarry B blasting works were observed to engage a higher degree of PF (0.54 - 0.80 kg/m<sup>3</sup>) value compared to Quarry A blasts (0.45 - 0.59 kg/m<sup>3</sup>). This could be due to the size and characteristics of the burden (rock mass) that was needed to blast. Nevertheless, this was not the actual case because it was identified from the blast design that a lower burden size was used for higher PF value at Quarry B (2.70 m) compared to Quarry A (3.35 m). Thus, the main influencer of usage of higher PF value in Quarry B might be due to the characteristics of rock mass being more massive and lower number of discontinuities. The burden with massive rock type that has few existing planes of weakness requires a higher powder factor compared

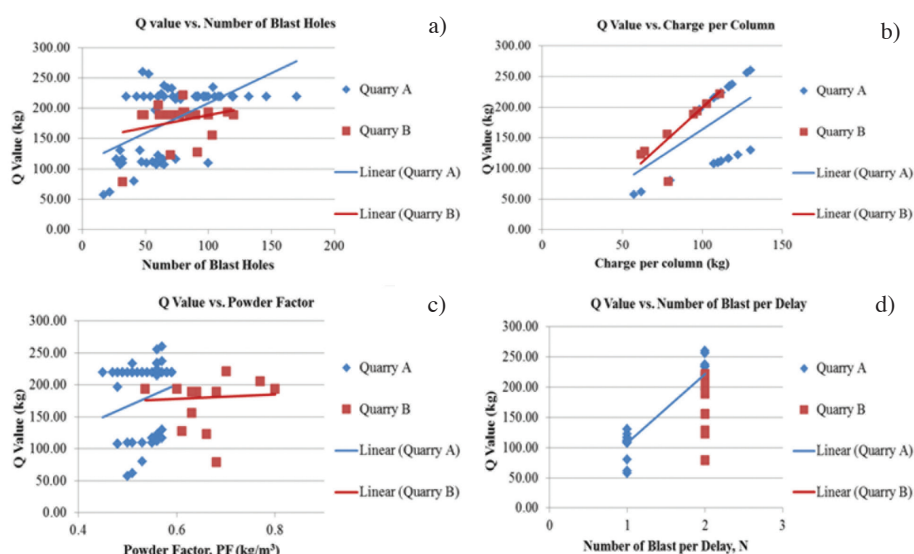


FIGURE 3. The relationship between selected blast design parameters on  $Q$  of both quarries

TABLE 2. Data comparison of number of blast holes with volume of rock and  $Q$ 

Quarry	A			B		
	Min	-	Max	Min	-	Max
Number of blast hole	17	48	170	32	80	120
Volume of rock ( $m^3$ )	1627.4	9852.5	32060.9	4012.4	13374.7	18954.0
$Q$ (kg)	57.25	260.31	219.52	78.84	221.91	189.04

TABLE 3. Classification of rock breakage difficulty at studied quarries (Dick et al. 1987)

Difficulty	Low	Medium	High	Very High
PF ( $kg/m^3$ )	0.10 - 0.18	0.18 - 0.34	0.34 - 0.57	0.57 - 1.14

to a heavily jointed rock mass (Lamotte 1978). Hence, if detailed rock mass classification, mapping and lab test are done based on the rock mass, then a better correlation of these parameters can be established.

Lastly, from Figure 3(d), the entire  $N$  designed during the blasting operation at each of the quarries was less than or equal to 2. If  $N$ 's value was 0, then there was an absence of detonation and time delay in the blast holes, thus no blasting activities takes place. However, in this study, all the blasts used the NONEL delay system which allows the usage of blast time delay ranging up to 60 milliseconds (ms). The maximum  $N$  obtained was 2 which mean that there was more than a blast hole blasted at the same delay time. Apart from that, the charge per column with number of blast per delay has the similar effect on the  $Q$  value. It can be concluded that a lower time delay causes the rise of  $N$  which eventually increases the charge per column and finally the  $Q$  value. Yet, careful attention needed to be practiced when selecting time delays as it can lead to the increase of air blast and ground vibration effects to the surrounding environment as well as building structures (Kopp & Siskind 1986).

From the various graphs shown Figure 3, it can be clearly observed that the  $Q$  value used in both quarries is highly dependent on several blast design parameters explained previously. Therefore, the Statistical Package for Social Science (SPSS) analysis used here is in terms of multiple linear regression method which requires several data parameters helps to establish a suitable formulated equation. The data can be divided into dependent and independent variable where correlations were computed for both the quarries (Table 4). Both equations shows good correlation because of the  $R^2$  values obtained are approaching 1.00. However, the computed equations have some estimated standard area which may cause some difference from the actual output ( $Q$ ) value. According to Evans (2002), a lower  $R^2$  value will increase the standard estimated error which might be because of the lack data number which was justified via the lower number of data obtained from Quarry B. If the monitoring period was much longer for Quarry B, then the standard error can be reduced and (c) value approaches positive. Therefore,

blasting engineers for respective quarry can use these equations as a guideline to estimate the suitable  $Q$  values which will be easier to assess future blasting effects.

#### ASSESSMENTS ON EFFECTS OF QUARRY BLASTING

This part of the assessments is divided into two parts namely the ground vibration and air blast. From Figure 4(a), the PPV value increases with  $Q$  value due to fast expansion of blast hole (Kumar et al. 2016). With this rate of expansion, a fairly large amount of explosive energy will be transferred to the rock mass rather than losing it to the surrounding environment via heat or sound energy. When this energy travels through the rock mass especially in its rock matrix, rocks will start to fail due to crack propagation together with the blast induced shock waves. The stated shock waves are considered as ground vibration which will be represented in terms of Peak Particle Velocity (PPV) with units of velocity (mm/s). Thus, it can be summarized that the  $Q$  value influences the intensity of ground vibrations. Besides that, ground vibrations have the tendency to decay or reduce its energy when the distance increases (Figure 4(b)). The distance here indicates the distance between blast face (quarry location) and their residential areas. A general hypothesis can be made which shows that the location of Quarry B from the monitoring point (TBBKP) is much safer compared to location of Quarry A to TPH. Although being within safe limits, Quarry A still shows a greater range of vibration intensity (PPV) which will have a higher probability of soil or basement instability (Baxter 2001). However, there was no evidence of foundation instability at the residential areas nearby the quarries since the PPV values are still tolerable and relatively within safe limits. Instability problem arises when the PPV values exceeds 5 mm/s according to DOE (2007).

Following the statement that emphasizes the importance to prevent structural damages, many parties especially the USBM has set some limitations on the PPV values based on the age of the buildings (Table 5). In this study, both the residential areas are classified as new houses with the age of less than 10 years. It was also observed that the type of frequency resulted from blast influences the PPV details. A higher frequency value shows a higher allowable

TABLE 4. Type of variables and data used to obtain equations from the SPSS analysis

Dependent variable		Independent variable		
Output data		Input data		
Max. instantaneous charge (Q)	Number of hole (a)	Charge per column (b)	Powder factor (c)	Number of blast per delay (d)
Quarry		Computed equations		
A	$Q = -0.039a + 1.125b + 11.868c + 111.982d - 129.856$ $R^2 = 0.996$ ; Std. error estimate = 3.88644			
B	$Q = 0.346a + 2.322b - 28.058c + 10428.772d - 20900.167$ $R^2 = 0.894$ ; Std. error estimate = 15.31536			

TABLE 5. Frequency and PPV values based on the age of buildings (USBM 1980)

Frequency details			PPV details	
			New house	Old house
Audible	Acoustic	> 40 Hz	< 50 mm/s	< 50 mm/s
Resonance	Infrasound	< 40 Hz	< 18.75 mm/s	< 12.5 mm/s

range of PPV values compared to a lower frequency type. The relationship between these two aspects based on the blast data information obtained from both quarries is shown in Figure 4(c). This graphical method is basically an evaluation of damage risk from the blast shots according to USBM criterion.

From Figure 4(c), it can be observed that a majority of blast data could not be plotted on the graph. This is because of the monitoring microphones could not detect any frequency value or it is more than 100 Hz. The following situation occurred vastly in Quarry B where a total of 94% (82% + 12%) of the blast data could not be graphically plotted for the x-axis (frequency). While, Quarry A only scored 87% (87% + 0%) of non-plotted data for the similar axis (Table 6). From these figures, most of the ground vibration has an audible frequency level. This frequency level has lesser consequences towards the surrounding environment compared to resonance frequencies lower than 40 Hz (Siskind et al. 1980). Thus, the correlation between PPV and frequency values enables to ensure the safety of blasting.

Figure 4(d) also shows the range of actual PPV value obtained from the blast data of each quarry. For Quarry A, the PPV of 2.535 mm/s and 3.568 mm/s was the lowest and highest value. Apart from that, Quarry B scored the lowest value of 0.220 mm/s and highest value of 3.060 mm/s. This shows us that the residential area located at a shorter distance to Quarry A may feel a slightly unpleasant condition from the surrounding environment. According to Krehl (2008), this condition is due to the vibration initiated from blasted holes at the quarry that might cause some surface instability via travelling shock waves.

A way identified to prevent these instabilities is by carefully observing the threshold value which was shown previously in Figure 4(d). Once the threshold limit with

the respective PPV values was considered, none of them exceeded the limit set by JMG of 5 mm/s. Nevertheless, a total of 93% and 3% of blast exceeded the (conservative) 3 mm/s level at Quarry A and Quarry B, respectively. In general, both the quarries produced ground vibrations induced by blasting activities that are considerably safe and not unpleasant to the surrounding environments and structures.

The overpressure values decrease with increasing distance which can be observed from Figure 5(a). This relationship also correlates well with the general hypothesis made previously during the ground vibration analysis. Nevertheless, blast hole with higher Q value will provide high energy that causes ground vibration and air overpressure to nearer monitoring points (residential areas) compared to the further ones. Following this statement, the range of air blast recorded in Quarry B is at safer limits if compared to Quarry A but both are within the specified safe limits. From Figure 5(b), of these values are below the limit set by USBM which requires the air blast value to be lower than the 125 dBL. This threshold value stated only confirms the prevention of damaging structures, yet there will still be occasional banging sound heard during blasting activities.

#### SAFETY OF AFFECTED RESIDENTIAL AREAS FROM QUARRY BLASTING

From the overall results obtained previously, simple indicators can be established to be employed in the blast design in the respective quarries by the blast engineers. This is done by using the empirical formulas stated previously. For example, Quarry A (AQ) which is located 533 m from the residential area (TPH) only allows to take a maximum of 97.66 kg per blast hole which would produce a safe ground vibration of 3 mm/s. The limiting value of 3 mm/s is chosen to have a more conservative approach towards the blasting activities. If the Q value used in Quarry

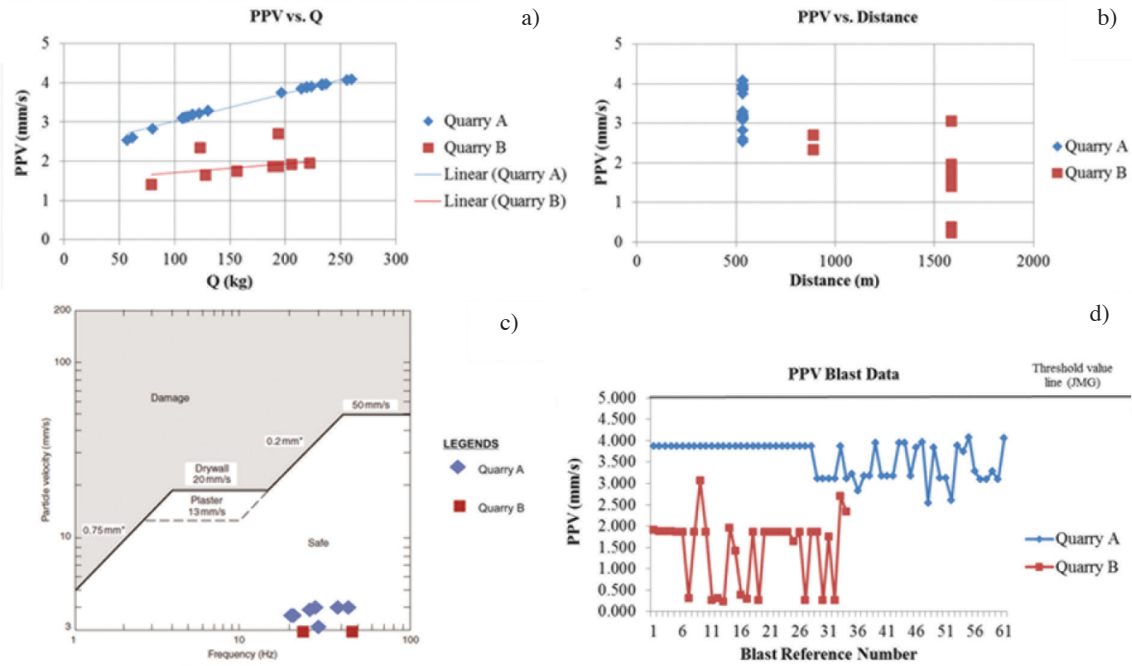


FIGURE 4. The relationship between PPV, Q, distance of monitoring points and frequency

TABLE 6. The distribution of the frequency from Quarry A and B blasting operation

Frequency details		Quarry (Percentage distribution, %)		
		A	B	
Resonance	Infrasound	< 40 Hz	10	3
Audible	Acoustic	41 - 100 Hz	3	3
		> 100 Hz	0	82
		Not detected	87	12

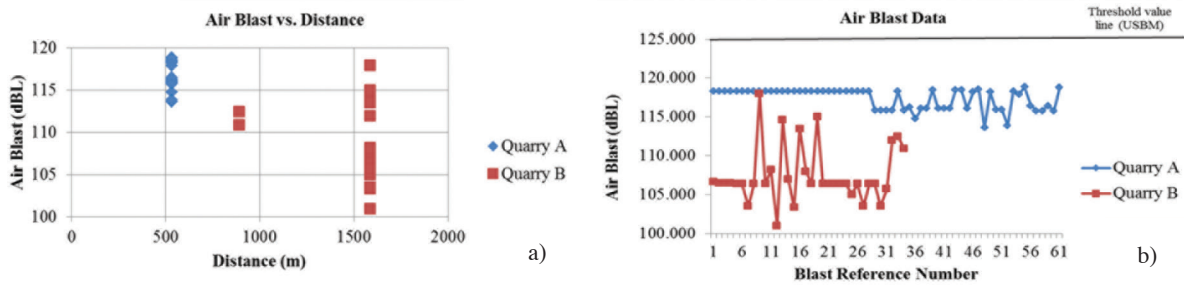


FIGURE 5. a) The relationship between PPV and distance and b) USBM safe limits

A exceeded this limit, there will be a higher probability of damage to the buildings and environment. Meanwhile, a greater buffer zone in terms of distance between Quarry B (BQSF and BQNF) allows a higher maximum  $Q$  value to be carried in a blast hole ranging between 271.68 kg - 495.01 kg (Figure 6(a)).

Similarly, the same required charge mass used to induce 3 mm/s was applied to simply predict the expected air blast over distance. The effect on air blast and  $Q$  value over distance were calculated (Figure 6(b)). It is clear

that at distances as low as 200 m from the charged blast hole, air blast levels are already below 125 dB(L) which is safe and a conservative approach to be employed in each quarries. Thus, this helps to reduce nuisance in terms of noise pollution to the surrounding environment.

### CONCLUSION

The final conclusions that can be drawn according to the study objectives to are as follows: Number of blast holes,



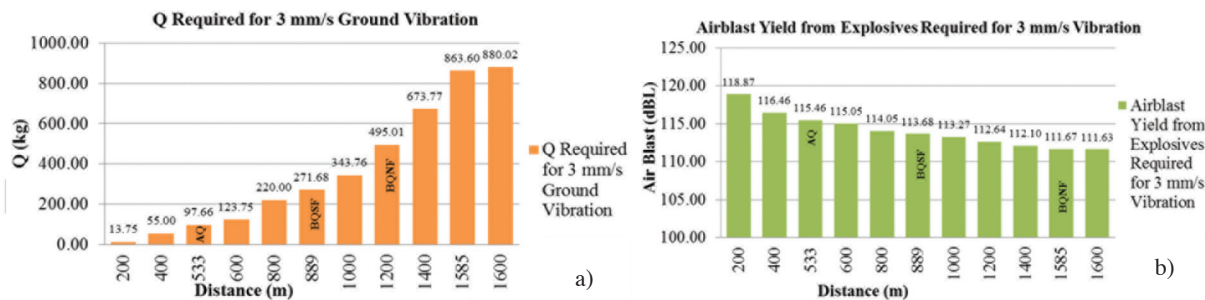


FIGURE 6. a) The  $Q$  value required to induce 3 mm/s ground vibrations, and b) The air blast values expected from the 3 mm/s blast induced ground vibrations

charge per column, PF and number of blast per delay highly influences the  $Q$  value. Average means of  $Q$  for Quarry A (181.07 kg) is slightly higher than B (180.22 kg). The parametric correlation shows that Quarry A has better  $R^2$  line (0.996) and lower standard estimated error (3.88644) than B. The PPV and air blast level drops with increasing distance. Based on the empirical formula, higher  $Q$  value in Quarry A causes the rise of resonance effects (< 40 Hz) and also the PPV value. Yet, there were no visible damages or nuisance to the residential areas. Quarry B governs a safer blast design and operations compared to Quarry A. However, both quarries' blasting effects are within the safe limits set by JMG and USBM. Suitable  $Q$  values proposed to prevent exceeding conservative limits (3 mm/s & 125 dB(L)) are 97.66 kg (A) and 271.68 - 495.01 kg (B). This provides an important database for blasting engineers and operation team in the future for both the quarries.

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School of Civil Engineering  
Faculty of Engineering  
Universiti Teknologi Malaysia  
81310 UTM Skudai, Johor Darul Takzim  
Malaysia

\*Corresponding author; email: karthigeyan-1994@graduate.utm.my

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