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Effects of Blast Design to the Environment in Limestone Quarry

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Abstract

The demand for construction materials produced by quarry rises in tandem with urbanization. The enormous number of complaints, however, has put the quarry owner under constant pressure to ensure safe blasting operations and minimal blasting effect on the environment. Due to the fact that limestone naturally dissolves in water and creates numerous weak spots in rock masses, it has always been thought that limestone quarry operations are more risky than common granite quarry operations. The goal of the study was to identify the rock mass properties of limestone and how they related to the consequences of blasting operations. For a systematic study, the quarry face was divided into four (4) Sections i.e., Section A, Section B, Section C, and Section D. The preliminary study was involved site investigation for quarry face evaluation and data collection as well as results from blast monitoring program for two months in a row was also recorded. The analysis was started with calculation of Blastability Index (BI) of the study area based on rock mass properties data and Blastability Quality System (BQS). The new predicted site constant (rock mass properties), κ and β were calculated based on two globally recognized empirical equations i.e., USBM and Langefors-Kihlstrom and the results was employed as indicator for future blasting operations. The SPSS Regression Model analysis graphs shown USBM predictor was inversely proportional to the PPV, while, the Langefors-Kihlstrom predictor graph was proportional to the PPV. The calculated K and β values for USBM predictor was 40 and 1.0 respectively. Based on the analysis, the rock mass properties at this limestone quarry have high influence to blasting effects and the effect can be aggravated at certain study sections. From all sections, Section A was deemed the most sensitive area or has the highest risk of generating excessive environmental effect with the lowest BI value (higher rock strength) at 49.18%, located closest to sensitive public buildings and recorded the most joint sets. It is can be concluded that the blasting activities in this quarry although at maximum charge per delay (Wmax) was being carried out safely with very minimal effects to the surrounding areas and in accordance to the limits set by the relevant authorities i.e., JMG and DOE Malaysia.

Keywords: *Blast Design, Environment, Limestone Quarry, Local Geology*

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1.0 Introduction

Nowadays, continuing population growth, social, industrial, and economic developments that necessitate more construction materials are just a few of the reasons why the older quarry is still in operation, despite increasing complaints from the surrounding residents. To protect the public from potential impacts posed by quarry activities, stricter regulations have been imposed in order to control and minimize the consequences.

In general, limestone quarries in Malaysia are concentrated in Perak, with a few others in Selangor and Pahang. The majority of these quarries are part of an integrated cement production plant, so the structures are usually located next to each other. Some of the quarries has been developed since decades ago and had once been the area's leading economy. However, over time many new developments have been constructed around the limestone quarry area and some of them even located very close or next to quarry's boundaries. Of late, the quarry new neighbours have begun to feel uncomfortable with quarry routine blasting operations and started sending complaints to authorities. Therefore, it is critical to investigate the factors that may result in generating excessive blast effects to environment. This research will focus on identifying rock mass properties factor in affecting the blast design and its effects on the surrounding environment. To facilitate the study, a number of site investigations and laboratory tests were conducted. Two empirical models were also used to predict the environmental impact before final analysis and discussion were made. A limestone quarry in Selangor was chosen as the case study location. Blasting is a common technique used in quarrying, mining, and some civil engineering construction. Blasting is the controlled use of explosive materials to break up rock mass for excavation purposes, and the end result is commonly referred to as a rock-cut.

Environmental effects may occur at nearby settlements or other building structures, such as schools, houses, dams, or tunnels. The most visible environmental effects of quarry blasting operations are fly rock, ground vibration (PPV), and Airblast Overpressure (AOp) (Kuzu, 2008). The design of a blasting operation is critical in the fragmentation of rock for quarrying, mining, and civil engineering projects. When a blasting operation is carried out, the ground absorbs more than 85% of the released energy in the form of negative effects such as PPV, AOp, and flyrock (Khandelwal & Singh, 2009; Armaghani *et al*., 2016). The geological conditions in the blasted bench have a significant impact on the blasting operation's success and can cause flyrock to surrounding areas (Sastry *et al*., 2015). Bedding planes in non-homogeneous rock layers can cause a variety of problems, including rock overhangs, unexpected muck pile height, toe problems, back breakage, and fragmentation differences, which can lead to excessive PPV, AOp, and Flyrock to surrounding areas if not properly controlled (Sastry *et al*., 2015).

In 2013, a tragic quarry blasting incident in Masai (located in Seri Alam near Pasir Gudang, Johor) had once made national headlines. The massive explosion rained down rocks and boulders on the nearest industrial park, which was located 700 metres away from the blasting site. It was a fatal incident in which a factory worker died, ten people were seriously injured, 18 cars and 14 factories were damaged (Edy Tonnizam *et al*., 2013).

In view of effects to the surrounding environment due to blasting especially quarries located very close to public buildings, the writer was chosen an urban limestone quarry as a case study. Although the terrible blasting incident was occurred in a granite quarry but it still can be a good reference for a limestone quarry as both quarries shared many similarities in terms of rock physical characteristic.

2.0 Methodology

To achieve the research objectives in an appropriate manner is one of the most important aspects of this thesis. Several field investigations, data collection, and laboratory test programs will be carried out. Geological structures at the study site will be investigated and recorded while rock samples will be collected from quarry face in various zones to determine the rock's physical properties i.e., point load strength index, and other parameters. Many researchers agree that the environmental effects of blasting operations are strongly related to the properties of the rock mass. A number of previous studies conducted on various sites and in laboratories backed up this claim. The main goal of this research study is to determine the rock mass properties of a limestone quarry and to investigate its effects on blasting operations and the environment. To achieve the research objective, the research methodology was reviewed. The research design was divided into three (3) phases in order to achieve all of the research objectives for this study, as shown in Table 1.

3.0 The Site

The research site is a limestone quarry located in the heart of Rawang town in Selangor, Malaysia. The site is part of an integrated cement plant, and its presence is considered very important for the people living in the surrounding areas, particularly for their socioeconomic development. However, despite having been in operation for many years, the effects of blasting operations in this area have yet to be formally studied. The position of studied site is shown in geological map as shown in Figure 1.

The topography of the study area is relatively flat land, with contour levels ranging from 25 to 30 meters above mean sea level. The average ground level in the area where the crusher is located is about RL 30 m. The northern portion of the project site is undulating and has a gentler slope. Sungai Rawangflows from southeast to northwest located next to the study site.

3.1 Local Geology

Geologically, the site is located in the centre of Peninsular Malaysia's Western Belt. The Kuala Lumpur area's regional geology (including the studied site) is underlain by middle-upper Silurian metamorphic and metasedimentary rock sequences. The Kuala Lumpur Limestone formation (studied site) sits uncomfortably on top of the older metamorphic rocks i.e., HS and DS (Gobbett & Hutchison, 1973). The site location is within the Kuala Lumpur Limestone Region (Northern). It's made of hard, strong light grey to dark grey limestone and marble. They are commonly found as the bedrock to unconsolidated alluvial deposits in Kuala Lumpur's low-lying areas. The Batu Caves hill is one of the most spectacular examples of exposed Kuala Lumpur Limestone bedrock

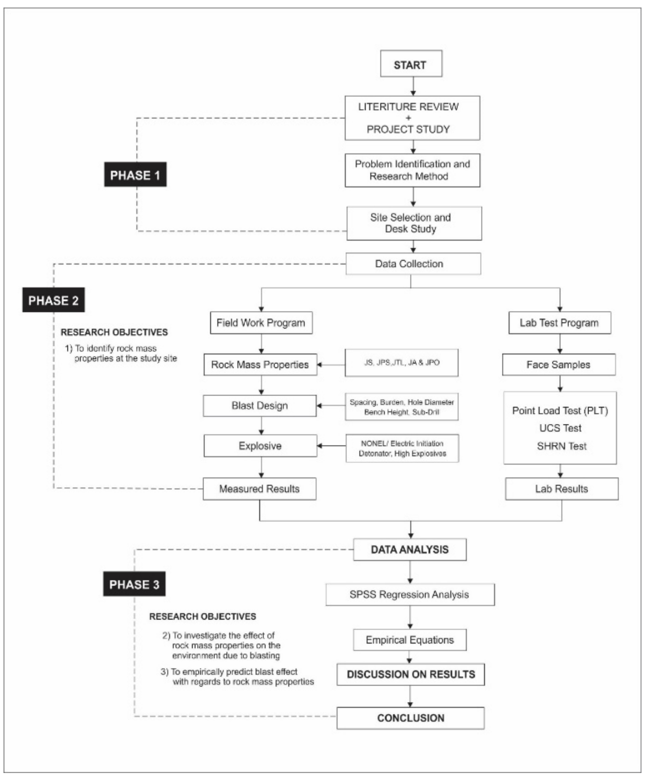


Table 1. Flow Chart of the Study

3.2 Adjacent Interest

The quarry site in the general neighbourhood is well developed. The study site is surrounded by many sensitive areas i.e., residential areas, schools, temples and many others. The distances of all sensitive buildings to the study site in 600m radius is shown in Figure 2. The distance is ranged from 245m to 490m with Temple A and residential area B are the nearest buildings with 245m and 275m respectively. For a systematic study, the quarry face was divided into four (4) contiguous study sections with each section at 100m interval between them. as shown in Figure 2. The segment that covered the majority of the active blasting area was classified as Section A (SA), Section B (SB), Section C (SC), and Section D (SD).

4.0 Results and Discussion

To obtain a systematic result, the rock face was divided into four (4) sections, with each section counting joint sets and recording joint conditions. Several laboratory and field tests were carried out to identify rock physical properties. For a period of two months, blasts in each

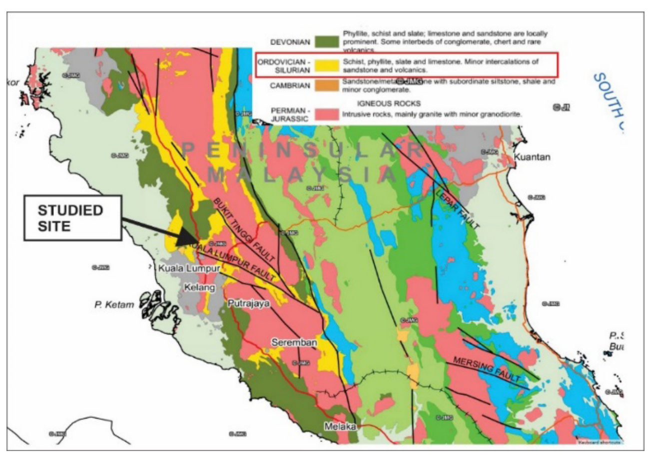


Figure 1. Geological Map (JMG Malaysia, 2012).

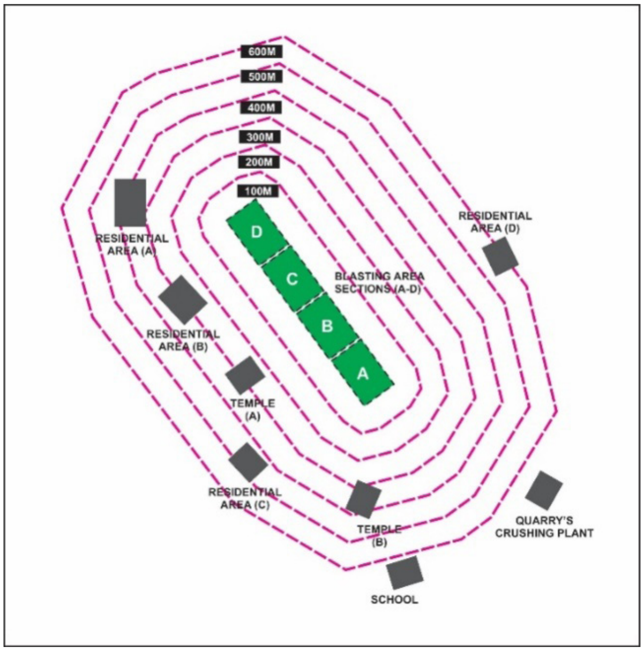


Figure 2. The sensitive buildings within 600m radius.

section were monitored with reputable seismograph machine at the nearest sensitive buildings.

4.1 Field Investigation

Under tropical climate, the limestone deposit in the current study area has varying degrees of weathering. Limestone is a porous rock that contains voids at all depths. Because of the carbonaceous nature of the rock, water plays an important role in dissolving carbonate in limestone, and weathering solution acts not only on the surface but also at depth (Tugrul & Zarif, 2000). The site photograph depicts well-developed benches with varying degrees of weathering. According to field observations, the rock profile in the study area is classified into three classes, as shown in Table 2, fractured (completely and highly weathered), blocky (moderately weathered), and massive (fresh) limestone. There are two layers above the limestone: top soil and boulders embedded in soil, which are insignificant because blasting is not or is only rarely done. However, the study focuses only on the massive limestone class, which is located at depths ranging from 20m to 60m below ground level. The massive limestone level was divided into four study sections, each of which was classified based on field observations of rock mass properties such as Joint Set (JS), Joint Plane Spacing (JPS), Joint Trace Length (JTL), Joint Aperture (JA) and Joint Plane Orientation (JPO).

The site mapping results for Section A is tabulated in Table 3 has the highest number of JS and JPS length with 31 nos. and 559.8 mm respectively as compared to other sections. Meanwhile, JTL at this section is among the lowest at 2.7 m. JA is gap or void of two block rock mass has strong relationship with flyrock occurrence as per many researcher studies. JA also can be seen within this section as the length gap is the highest among others with 28.5 mm.

Therefore, this section is considered as the weakest area and blast impact like fly rock is most likely to happen if the blasting operation is not properly controlled. In view of the lower number of JS and JPS in Sections B, C, and D as shown in Table 3 the like lihood of flyrock during blasting is lower than in Section A. Section D, on the other hand, may have the second highest tendency to produce flyrock after section A due to its higher number of JA.

Based on the results of the above analysis, it is possible to conclude that the presence of more JS and longer JPS lengths in the study section increases the likelihood of flyrock formation. Because of the cavities and crevices, the explosives were accidentally filled in greater quantity during charging for the given amount of burden. As a result, the flyrock protrudes more than anticipated (Mishra *et al*., 2011). In addition, the larger the gap of JA the further flyrock can be projected to surrounding areas as excessive explosive could be stored into void within the blast hole accidentally and normally the shotfirer is unaware of this phenomenon. In this study, Section A has a higher likelihood of having flyrock than the other sections in terms of rock mass discontinuities.

4.2 Blastability Index

Many researchers agree that geological discontinuities on rock mass influenced blasting to certain extend. Blastability refers to the degree of difficulty in fragmenting rock mass by blasting. The Blastability Index (BI) developed by Lilly, (1986) was determined to be the most appropriate index for this study as collected data from site investigation stage (geological discontinuities) can be translated into BI for further analysis. The BI for every studied section was calculated using empirical equation developed by Lilly, (1986).

The BI empirical equation developed by Lilly, (1986) is as follows:

BI = 0.5 x (RMD + JPS + JPO + SGI + H) (1)

Where,

RMD: Rock Mass Description

JPS: Joint Plane Spacing

JPO: Joint Plane Orientation

SGI: Specific Gravity Influence

H: Mho's Scale Hardness

The BI calculations result in Figure 3 shows that Section C has the highest BI of the study area with 59.26 and Section A has the lowest BI with 49.18. According to the bar

chart, all studied sections have exceeded the red line, indicating that the rock mass in the study area is considered soft or very easy to be blasted according to Blastability Quality System (BQS).

In this study, the Blastability Quality System (BQS) prepared by Christaras and Chatziangelou's (2014) was also used as main reference. According to Table 4, BI values ranged from 49.18 to 59.26 for all study sections are above 40 as per BQS indicates that the rock category for the study site is soft and very easy to be blasted. In general, the higher BI values, the lower risk of getting excessive environmental effect to surrounding areas due to less amount of explosive involved to break soft rock. The

	1 to 3 m		Top soil	Blasting not required
	3 to 5 m		Boulders with top soil	Boulders are broken by hydraulic hammer
FRACTURED LIMESTONE	Completely weathered (WC) 3 to 5 m		Sheared zone limestone	JPS 200 to 800 m , JA 4 to 15 m , JTL 0.4 to 1.2 m RQD 5 to 15 % GSI 8 to 15 % Average SHRN 8
	Highly weathered (WM) 5 to 10 m		Thin bedded limestone	
BLOCKY LIMESTONE	Moderately weathered (WM) 8 to 12 m		Blocky limestone	JPS 300 to 1200 m , JA 2 to 8 m , JTL 0.6 to 2.0 m RQD 17 to 78 % GSI 42 to 37 % Average SHRN 12
MASSIVE LIMESTONE	Fresh (F) 20 to 60 m		Thick limestone	JPS 600 to 1500 m , JA 3 to 35 m , JTL 0.8 to 2.5 m RQD 67 to 90 % GSI 55 to 83 % Average SHRN 43
			Cavity 0.2 to 0.5 m	
			Thick limestone	

Table 2. Weathering rock profile at limestone quarry (Ramesh, 2020)

low PPV results ranged from 0.28 to 0.83 mm/s recorded during blast monitoring activities has proven the BQS rating. It can be concluded that, out of all sections, the study section A is deemed the most sensitive area or has the highest risk of generating excessive environmental effect with the lowest BI value (higher rock strength) at 49.18 and among the shortest distance at only about 380m away from the blast site. However, low amount of explosive per delay (W) used during blasting in section A has resulted in low PPV monitoring result and yet a well-controlled blast design (PF: 0.59 kg/m^3) employed also play a very significant role in ensuring safe and optimal blasting operation.

4.3 Blast Effect Prediction Techniques

The prediction exercise was focusing only on ground vibration effect as it is deemed the most significant effect to the surrounding areas since the past 10-15 years as informed by the quarry manager. The calculation was based on 25 blast events recorded during the study stage. Two empirical prediction techniques which currently being used globally and also tested on limestone quarries had been chosen. The scaled distance derived from a combination of distance and explosive charge weight is usually used in blasting prediction techniques. There are two widely used empirical formulas as given in Equation (2) and Equation (3) contain site constants, K and β which considering the influence of local rock mass characteristics as shown in Table 5. (Morhard, 1987)

4.3.1 κ and β Values

Twenty-five (25) blast events were taken to determine the value of predicted site constant κ and β based on the geologic condition of the rock mass as shown in Figure 4. A scaled distance is an imperative dimensionless parameter that can be inversely proportional or proportional to the PPV depending on type of predictor being used. The regression model analysis graph as per Figure 4(a) shows USBM predictor is inversely proportional to the PPV or in other term the higher the PPV, the shorter the scaled distance. Meanwhile, the LK predictor graph as shown in Figure 4(b) is proportional to the PPV which indicates the higher the PPV, the higher the scaled distance. However, the utmost aim for generating the graphs was to determine the value of predicted site constant κ and β for both USBM and LK predictors.

Table 3. Site mapping results for Section A to D

Joint Properties	Particular	Results Section A	Results Section B	Results Section C	Results Section D
Joint set (JS)	Number of Joints	31	17	26	16
Joint plane spacing (JPS)	Minimum	250	150	120	110
(mm)	Maximum	900	580	750	480
	Average	559.8	258.5	339.7	264.7
Joint trace length (JTL)	Minimum	0.7	0.6	0.7	1.5
(m)	Maximum	5.8	5.2	5.8	6.2
	Average	2.7	2.4	2.8	3.3
Joint aperture (JA)	Minimum	3	5	5	4
(mm)	Maximum	35	30	36	54
	Average	28.5	15.4	14.8	21.9
Joint plane orientation (JPO)	Rating	30	20	30	40

Table 4. Relationship of BI and Blast Design

	Study sections			
	A	B	C	D
Rock mass parameters (ave.)				
BI	49.18	54.33	59.26	54.17
Blasting parameters (ave.)				
D (m)	380	422.5	328.7	355
W (kg)	35.5	40.5	38.3	34.3
PF (kg/m^3)	0.59	0.6	0.61	0.58
Monitoring results (ave.)				
PPV (mm/s)	0.28	0.57	0.83	0.74

Based on Figure 4 (a), the equation obtained is as follows:

$$y = -1*x + 1.6 \quad (4)$$

Meanwhile, based on Figure 4 (b), the Equation obtained is as follows:

$$y = 1.07*x + 0.83 \quad (5)$$

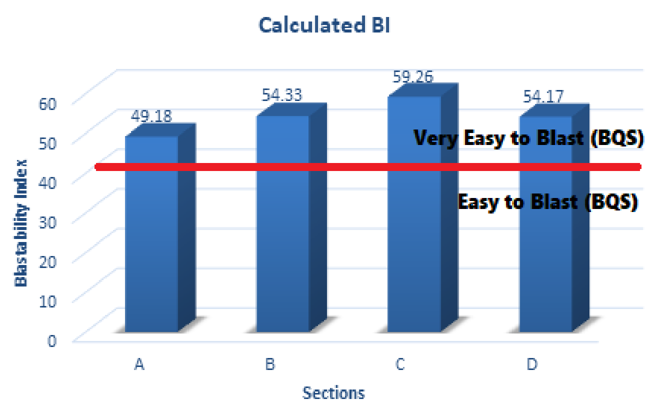


Figure 3. Comparison BI and BQS.

In order to calculate the value of site constant K and β, Equation 4.5 is used by taking the substitution of Equation 4.3 and 4.4:

$$\log v = -\beta\,[\log (D/\sqrt{W})] + \log \kappa \quad (6)$$

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

$$y = mx + c \quad (7)$$

where, calculated β and κ are shown in Figure 4 (a), below:

The calculated results presented in Table 6 shows the κ values derived for the study site is way lower as compared to recommended κ values proposed by both USBM and LK at 152.75 and 44.43 respectively. It is worth noting that, the results differ very much may be due to many factors i.e., different of study site, type of rock, climate and number of data sets. However, the derived κ value for the study site is much closer to recommended κ:37 value proposed by local researchers i.e., Hashim and Khider, (2017); Juna and Syed, (2013). As per hypothesis made by Olofsson, (1988), the lower calculated κ values indicates rock mass at the study site consists of low rate of homogeneity, weathered and fractured rocks as well as higher presence of faults, joints and cracks. The statement this well suited with the present rock mass condition at the study site.

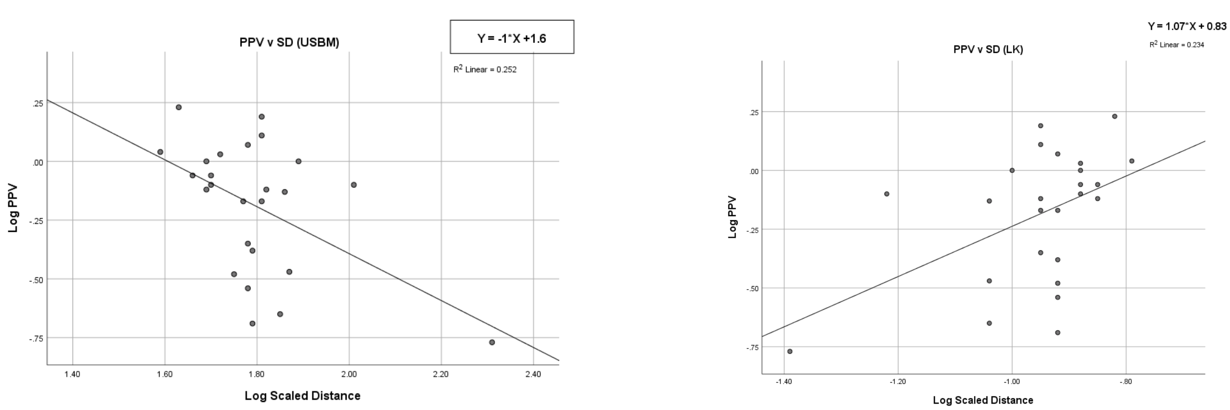
Meanwhile, based on Table 6 as well, the β value is related to geometrical spreading and inelastic attenuation. The calculated β values for the study site are closer to the recommended β values proposed by both USBM and LK at 1.16 and 1.17 respectively but a little bit higher as compared to β:0.63 value proposed by local researchers i.e., Hashim and Khider, (2017); Juna and Syed, (2013). The higher β value indicates a less competent rock mass at the study site that will attenuates vibration energy more quickly (Scott, 2009). Hence, it is can be concluded that the derived site constants κ and β values for the study site are highly reliable and comparable in Malaysia's perspective. It is important for this site to use the right κ and β in order to have a better prediction for future blasting and eventually reduce complaints from nearby residents.

According to Table 7, both PPV predictors shows very high accuracy in predicting the PPV. The PPV prediction results using USBM predictor shows better results as compared to LK predictor in term of PPV value close to measured results. The USBM predictor accounted higher number or 16 predictions while LK predictor accounted only 9 predictions closer to the measured PPV monitoring results from the total 25 blast events. In general, majority of the prediction results (study Section A to D) for both USBM and LK predictors are slightly higher than measured PPV monitoring results with slim different ranged between 0.01 mm/s to 0.88 mm/s. Nevertheless, those values are still within the maximum permissible limit of 5 mm/s set out by blasting regulator i.e., JMG Malaysia.

Since both constants β and K used in the prediction 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),

Table 5. The used prediction equations

Author	Equation
USBM (Duvall and Fogelson, 1962)	$\upsilon = K\,[\,D/\sqrt{W}\,]^{-\beta}$ (2) $\upsilon = K\,[\text{Scaled Distance}]^{-\beta}$
Langefors-Kihlstrom, (1963)	$\upsilon = K\,[\sqrt{\,[\,W/D^{2/3}]^{\beta}}]$ (3) $\upsilon = K\,[\text{Scaled Distance}^{\beta}]$



(a) (b)

Figure 4. Regression SPSS Analysis for log (PPV) against log (Scaled Distance) using equations from **(a)** USBM and **(b)** Langefors-Kihlstrom, (1963).

Table 6. Calculated β and κ values

Author	κ	β
USBM (Duvall & Fogelson, 1962)	40	1.0
Langefors-Kihlstrom, (1963)	6.8	1.07

Table 7. Calculated PPV prediction and measured results

Data Set	Section	PPV Prediction results		PPV Measured results
		B=1.0, K=40	B=1.07, K=6.8	
		USBM (mm/s)	**LK** (mm/s)	(mm/s)
1	A	0.65	0.70	0.21
2	A	0.56	0.57	0.22
3	A	0.65	0.70	0.42
4	B	0.52	0.59	ND
5	B	0.62	0.67	1.30
6	B	0.62	0.67	0.68
7	B	0.67	0.71	0.29
8	C	1.04	0.97	1.10
9	C	0.95	0.92	1.69
10	C	0.81	0.82	ND
11	C	0.69	0.73	0.68
12	C	0.54	0.55	0.34
13	C	0.88	0.86	0.86
14	C	0.62	0.67	1.55
15	C	0.67	0.68	0.44
16	D	0.39	0.36	0.79
17	D	0.80	0.81	0.79
18	D	0.80	0.81	0.88
19	D	0.77	0.79	1.08
20	D	0.67	0.71	1.17
21	D	0.82	0.84	0.76
22	D	0.55	0.56	0.74
23	D	0.71	0.74	0.33
24	D	0.20	0.21	0.17
25	D	0.61	0.66	0.76

Table 8. Predictions and allowable limits

	Predictions		**Allowable Limit**	
	USBM (mm/s)	**LK** (mm/s)	**DOE** (mm/s)	**JMG** (mm/s)
W max :42.5 kg	0.72	0.76	3	5
W min :4.5 kg	0.24	0.22	3	5

the calculated PPV results shows in Table 4 are more reflecting to the actual site conditions. The slightly different between prediction and measured results indicates the PPV predictions in this study is significant.

The comparison between PPV predictions and allowable limits set out by JMG and DOE Malaysia is tabulated in Table 8. The average blast distance from the studied section A to D and monitoring area is about 360.4 m with maximum charge per delay (Wmax) is 42.5 kg and minimum charge per delay (Wmin) is 4.5 kg. According to Table 4 the calculated PPV prediction results based on Wmax and Wmin for both USBM and LK predictors are well below the DOE and JMG Malaysia allowable limits at 3 mm/s and 5 mm/s respectively. It is can be concluded that the blasting activities in this quarry although at maximum charge per delay (Wmax) was being carried out safely with very minimal effects to the surrounding areas and in accordance to the limits set by the authorities.

5.0 Conclusions

The final conclusion, the analysis of rock face geological mapping concluded that section A is the weakest rock face area and blast effect like fly rock is most likely to happen if the blasting operation is not properly controlled. The BI results shows that section C has the highest BI of the study area with 59.26 and section A has the lowest BI with 49.18. According to the bar chart of BI results, all studied sections have exceeded 40, indicates that the rock mass in the study area is considered soft or very easy to be blasted according to BQS. From all sections, section A is deemed the most sensitive area or has the highest risk of generating excessive environmental effect with the lowest BI value (higher rock strength) at 49.18 and among the shortest distance at only about 380m away from the blast site. However, low amount of explosive per delay (W) used during blasting in section A has resulted in low PPV monitoring result and yet a well-controlled blast design (PF: 0.59 kg/m^3) employed also play a very significant role in ensuring safe and optimal blasting operation.

Blasting effect prediction i.e., ground vibration (PPV) was chosen to be computed using empirical equations developed by USBM and LK. Hence, the derived new site constants κ and β values for the study site are highly reliable and comparable in Malaysia's perspective. It is important for this site to use the right κ and β in order to have a better prediction for future blasting and eventually reduce complaints from nearby residents. USBM predictor shows slightly better results as compared to LK predictor in term of PPV value close to measured results. The calculated PPV prediction results based on Wmax and Wmin for both USBM and LK predictors are well below the DOE and JMG Malaysia allowable limits at 3 mm/s and 5 mm/s respectively. It is can be concluded that the blasting activities in this quarry although at maximum charge per delay (Wmax) was being carried out safely with very minimal effects to the surrounding areas.

6.0 Acknowledgement

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