Modelling of Blast-Induced Vibration at Lafarge Quarry, Gunung Kanthan, Perak Malaysia

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Received: 13-OCT-2024; Reviewed: 27-DEC-2024; Accepted: 29-DEC-2024
https://dx.doi.org/10.4314/fuoyejet.v9i4.21

ORIGINAL RESEARCH

Abstract— Blasting is the predominant technique employed for various applications and purposes for hard rock excavation. Blast energy from explosives cannot be fully utilized for rock fragmentation. The unused energy generated has adverse environmental impacts that may lead to human discomfort and damage to structures. Such unused or surplus blast energy may cause ground vibration, flyrock and airblast. Effective blasting plans should anticipate and reduce potential adverse impacts by estimating the expected vibration level. Factors like the geological condition of the site, the type and amount of explosives used, and the blast pattern play a significant role in determining these harmful effects. This study aims to establish the specific site constants (k, β) for Lafarge Quarry in Kanthan to predict blast-induced vibration and safe distance. The study estimates the site constants and applies them to assess vibration levels for a given distance and maximum instantaneous charge (Q). Ten different and independent blast events were investigated, with each blast's maximum charge per delay evaluated. Peak Particle Velocity (PPV) readings were taken using an Instatel MiniMate Plus, located 600 meters from the blasting area, and the scaled distance (SD) was calculated for each event. Regression analysis evaluated the site-specific constants (k and β) as -1.66 and 2,262, respectively, demonstrating that fixed numerical constants cannot universally predict blast-induced vibration due to varying global geological conditions. A predictive model was developed for the studied quarry based on these constants, and the model provides vibration predictions that are more accurate and closer to the actual measurements than those produced by the Australian Standards. This work confirms the previous works that blast constants are site-specific and depend on the geological conditions of the studied area..

Keywords— Airblast, Flyrock, Ground vibration, Peak particle velocity, Scaled distance.

1 INTRODUCTION

Mining and quarrying of minerals and rocks are associated with environmental discomforts (Adigun & Kayode, 2019; Melodi, 2017). Most economic mineral deposits occur within a massive hard rock, and the rock masses need to be fragmented to achieve production. Blasting is still the most common, cheapest, and most efficient excavation technique for driving home this objective. Proper adoption of the blast design and good selection of explosives and initiators might contribute significantly towards the productivity, profitability and safety of the mines and their environs (Fernández et al., 2022).

An improper blast design and a weak geological factor of rock may lead to environmental issues like ground vibration, airblast, flyrocks and back break due to the dissipated energy from explosives (Hosseini, et al., 2023). Predicting the level of this unavoidable damage and putting measures in place to reduce it to the barest allowable minimum is a hallmark of the sustainable exploitation of minerals and rocks (Roy et al., 2016). The most common parameter to evaluate these effects is the peak particle velocity, PPV (Hosseini, et al., 2023; Kumar et al., 2016).

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Section E- CIVIL ENGINEEERING AND RELATED SCIENCES
Can be cited as:
Shehu, S. A. and Hashim, M. H. M. (2024). Modelling of Blast-Induced Vibration at Lafarge Quarry, Gunung Kanthan, Perak Malaysia. FUOYE Journal of Engineering and Technology (FUOYEJET), 9(4), **706-710.**
https://dx.doi.org/10.4314/fuoyejet.v9i4.21

Using the square root scaled distance equation, quarry operators predict ground vibration with site constants of k = 1140 and β = -1.6, based on adaptations from Australian Standards (Standards Australia, 2006). The Standard Association of Australia designed a Scaled Distance approach to anticipate blast-induced vibrations when blasting occurs against a free face under normal conditions. This method is adopted due to the absence of relevant local standards for ground vibration estimation, as (Rodríguez et al., 2022) reported. The current study assesses the site constants (k, β) for Lafarge Quarry in Kanthan, Perak, Malaysia, and employs them to predict vibration levels based on distance and maximum instantaneous charge (Q).

Various countries and institutions have set permissible levels for the peak particle velocity. The minimum vibration that a human being can trigger is in a range of 0.254 to 0.838 mm/s (Siskind et al., 1981), while the International Society of Explosive Engineers (ISEE, 2024) states that most people will feel the vibration of 0.51 mm/s. To minimize these harmful effects of blasting, the controllable blast parameters must be designed to accommodate the uncontrollable ones.

The quantity of explosive charge and distance between blast points to the monitoring point are significant factors controlling the emission of ground vibration. It is challenging to achieve higher productivity while still maintaining a greener environment. There is no right or best answer to develop a method that can fulfil all requirements, but safety must always be given priority (Wyllie & Mah, 2017).

Damage to structures is proportional to ground particle velocity (Rodríguez et al., 2022; Siskind et al., 1981; Zong et al., 2024). While this is universally accepted, the constants k and β usually taken as 1140 and 1.6, respectively, as developed by the United States Bureau of Mines, USBM (Siskind et al., 1981) and adopted by Australian Standards (Standards Australia, 2006) cannot be globally correct due to difference in geological conditions even within a geographical terrain. The constants are site specifics. Various researchers have predicted ground vibration by expressing the PPV in terms of scaled distance and maximum amount of explosives per delay. However, the predictor proposed by Siskind *et al.* (1980) for the United States Bureau of Mines (USBM) is universally used by most researchers and mine/ quarry operators

2 OBJECTIVES OF THE STUDY

1. To establish the specific site constants for Lafarge Quarry in Kanthan using the concept of Peak Particle Velocity (PPV).
2. To generate a predictive model for evaluating blast-induced vibration.
3. To evaluate permissible charge weight per delay for possible improvement of fragmentation.
4. To determine safe distance based on the quarry's current blast practices.

3 METHODOLOGY

Blast data were collected for ten events. The Instatel MiniMate Plus was stationed at 600 m from the blasting site to measure the peak particle velocity (PPV) to indicate ground vibration level. The Instatel MiniMate Plus was connected to Instatel Blastware to analyze the ground vibration in three axes – vertical, horizontal and longitudinal. The highest of the three values was taken as the peak particle velocity. A Garmin GPSmap 62S tracker was used to determine the distance from each blast site to its respective monitoring station. The maximum instantaneous charge per delay (Q) was evaluated for each of the ten blast events. Scaled distance (SD) was also assessed for each blast event. Regression analysis was then carried out between the peak particle velocity and the scaled distance to determine the site constants k and β for predicting the vibration level in the studied quarry.

Peak particle velocity of vibration has been reliably predicted using the concept of scaled distance (SD) (Aladejare et al., 2022; Choi & Lee, 2021; Hosseini et al., 2023). The most reliable relationship between blast geometry and ground vibration is relating particle velocity to scaled distance (Bui et al., 2019; Hosseini et al., 2023; Lizarazo-Marriaga et al., 2018). The square root scaled distance (SD) was calculated using Equation 1 (Siskind et al., 1981):

$$SD = \frac{R}{\sqrt{Q}} \quad (1)$$

where:

Q = The maximum mass of explosive detonated per delay (kg); and

R = The radial distance from the detonation point to the observation point = 600m in this study for all the blast events.

The peak particle velocity measured (PPV) was then related to scaled distance (SD) as shown in Equation 2:

$$PPV = k(SD)^{\beta} = k\left(\frac{R}{\sqrt{Q}}\right)^{\beta} \quad (2)$$

Where:

PPV = Peak particle velocity (mm/s);

k, β = Site constants which are related to rock geologic factors.

The commonly adopted values of k (Siskind et al., 1981; Standards Australia, 2006) defined as amplitude constant are:

- 500 for free face - hard or highly structured rock;
- 1140 for free face average rock; and
- 5000 for Heavily confined

The constant β is defined as the decay rate of ground vibration with distance. Similarly, commonly adopted values for β by the researchers are:

- 1.4 for slower decay;
- 1.6 for moderate decay (default value) and
- 2.0 for rapid decay

However, this study established the site constants k and β as peculiar to the studied site by taking the log of both sides of Equation 3 (Ajaka et al., 2014; Nateghi, 2011; White et al., 2003):

$$\log_{10} PPV = \beta \times \log_{10} SD + \log_{10} k \quad (3)$$

This converts the relationship into the generally accepted straight-line Equation (4).

$$y = mx + c \quad (4)$$

Where m stands for the slope and c is the intercept.

A graph of log scaled distance was plotted against log peak particle velocity. The value of k was taken as the PPV intercept at a scaled distance of unity, while β was taken as the slope of the graph as represented in Equation 3 (White et al., 2003; Wyllie & Mah, 2017). The determined constants were further used to predict the ground vibration level.

4 RESULTS AND DISCUSSION

Table 1 shows the maximum charge per delay (Q), the scaled distance (SD) and the peak particle velocity (PPV) for each of the ten blasting events studied. All the measured peak particle velocities are less than the maximum vibration level of 5 mm/s, as fixed by the Malaysian Department of Mineral and Geoscience for all mining and quarrying operations. Thus, the blasting practices of the quarry are environmentally friendly.

Figure 1 displays the regression analysis between the scaled distance log and the peak particle velocity log. Both logs were taken to base 10 for easier interpretations.

http://dx.doi.org/10.46792/fuoyejet.v9i4.21 engineering.fuoye.edu.ng/journal

Table 1: Evaluated vibration parameters

Blast Events	Distance from Measuring station (m)	Maximum charge per delay (kg)	Scaled distance (m/kg$^{1/2}$)	Measured PPV (mm/s)
1	600	82.5	66.06	2.144
2	600	67.5	73.03	1.738
3	600	54.3	81.42	1.596
4	600	45.0	89.44	1.243
5	600	84.7	65.19	2.225
6	600	74.0	69.75	1.895
7	600	59.4	77.85	1.657
8	600	85.6	64.85	2.155
9	600	93.1	62.18	2.412
10	600	55.2	80.76	1.564

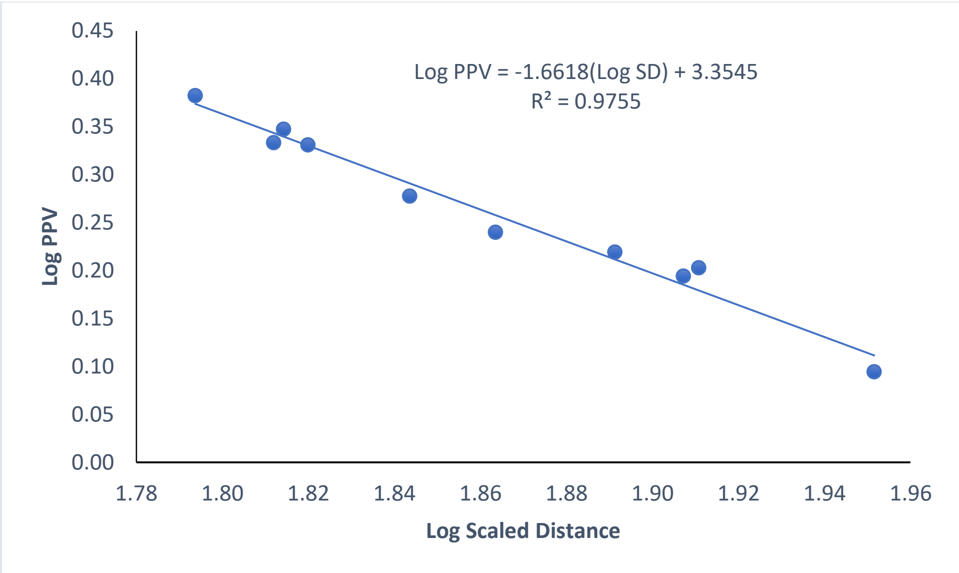

Fig. 1: Regression analysis between scaled distance and peak particle velocity

The dependence of peak particle velocity (PPV) on scaled distance (SD) was established with a very strong correlation coefficient of 0.98, as shown in Equation 5.

$$\log_{10} PPV = -1.6618 \log_{10} SD + 3.3545 \quad (5)$$

Equation 5 puts the value of constant β as -1.6618 while constant k is $10^{3.3545}$ which equals 2262. These values proved that no numerical fixed constants can be universally correct to quantify blast-induced ground vibration owing to varying geological factors across the globe. The results of this study also confirms previous work that blast constants are site-specific and depend on the geological conditions of the studied area(Fissha et al., 2023; Khandelwal & Singh, 2007; Kumar et al., 2016)

The values of constants β and k can now be replaced in Equation 2 to obtain the vibration prediction equation for the studied quarry, as shown in Equation 6.

$$PPV = 2262(SD)^{-1.6618} = 2262\left(\frac{R}{\sqrt{Q}}\right)^{-1.6618} \quad (6)$$

Thus, Equation 6 is a model for predicting ground vibration level due to blasting at Lafarge Quarry in Kathan, Ipoh. The model will help evaluate blast designs before field implementation.

The maximum instantaneous charges per delay (Q) at a fixed peak particle velocity of 4mm/s and various distances (R) have been further established for the quarry using this predictor Equation (6), as shown in Table 2. The 4mm/s was chosen instead of the maximum permissible level of 5mm/s by the Mineral and Geoscience Department of Malaysia (JMG) for maximum safety.

Table 2 shows that a maximum weight per delay of 175.27 kg is allowed at 600 m. However, the current average weight charge per delay used by the quarry at the same distance of 600 m is 70.1 kg. Thus, the charge weight can be increased to a maximum of 175.27 at the

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same current distance of 600 m for better fragmentation without exceeding the permissible vibration limit of 5 mm/s. Better fragmentation will increase the efficiency of downstream processes.

Based on the current practices of the quarry, the maximum charge weight per delay is 93.1 kg, while the average stands at 70.1 kg. Table 3 outlines the peak particle velocities at various distances and 100 kg as the maximum detonated charge per delay. The 100 kg benchmark used instead of the maximum recorded value of 93.1 kg or the average of 70.1 kg is also for safety reasons.

Table 2: Permissible weight of charge per delay at 4mm/s

R (m)	100	200	300	400	500	600	700	800	900	1000
Q (kg)	4.87	19.47	43.82	77.9	121.72	175.27	238.56	311.59	394.36	486.86

Table 3: Peak particle velocities (PPVs) at 100kg maximum instantaneous charge

R (m)	100	200	300	400	500	600	700	800	900	1000
PPV (mm/s)	49.28	15.58	7.94	4.92	3.40	2.51	1.94	1.56	1.28	1.07

Adeniyi et al. (2016) reported the neural and behavioural changes in male periadolescent mice …. When citing a section in a book, please give the relevant page numbers.

5 CONCLUSION

The site constants (β, k) for assessment of blast-induced vibration at Lafarge Kanthan Quarry have been established as -1.6618 and 2262, respectively. There are noticeable differences between these values and those of the Australian Standards (AS 2187.2 -1993) due to variations in geological conditions. The prediction equation for ground vibration established for the quarry will be of immense benefit for the preliminary assessment of blast design before field implementation.

There is an opportunity to improve the fragmentation by increasing the maximum charge per delay to 175.27 kg at the current safe distance of 600 m with only a maximum peak particle velocity of 4mm/s. However, a distance of 400 m is still considerably safe based on the current blast practices of the quarry if fragmentation is not to be improved.

Correct prediction of blast vibration is essential for safer operations, better fragmentation management and ensures higher productivity and overall sustainable operations.

ACKNOWLEDGEMENT

The monetary support provided by the Universiti Sains Malaysia (USM) through grant number 1001/PBAHAN/8014043 is sincerely acknowledged and appreciated.

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