FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 9 No. 7, July, 2025, pp 222 – 225
DOI: https://doi.org/10.33003/fjs-2025-0907-3787

EVALUATION OF VIBRATION MAGNITUDE FROM STAGGERED DRILLED HOLE PATTERNS IN A LIMESTONE MINE, OKPELLA, EDO STATE, NIGERIA

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ABSTRACT

The evaluation of vibration magnitude created by a staggered drilled holes pattern in a limestone quarry in Okpella, Edo State, Nigeria was investigated. The SLAM STICK X rendered the time spectrum into frequency spectrum which is then converted into velocity to determine the sites constants which are related to the rock geological factor. The generated equation from the site constants is a guide for blasters when using staggered drilled holes pattern in limestone quarry. The study established the specific site constants (k and β) as 721.6 and -1.52 respectively for vibration generated in Okpella limestone mine to predict blast-induced vibration and safe distance. A predictive model developed for the studied quarry based on these constants, gave a safe distance of 102 meter when an explosive weight of 420 kg was exploded. The values generated from the equation generated from the model was compared with the Australian Standards to decide the weight to be used and distance between shot point and observation point to determine the safety of structures.

Keywords: Vibration, Peak particle velocity, Staggered drill holes pattern, Weight of explosives, Square root scale distance

INTRODUCTION

In mining, rock breaking by blasting with explosives is employed because it is efficient, cheap, and convenient and it is able to break the hardest of rocks. However, only a portion of the total energy of the explosives used is effectively expended in breaking the rocks while the rest is dissipated in the form of seismic wave travelling rapidly along and within the ground surface and as air overpressure travelling through the air.

Dayamoy et al. (2022) studied the impact of orientation of blast initiation on ground vibrations. They discovered that induced ground vibrations can be controlled by varying the orientation and location of point of interest from blast site. With the orientation of holes blast on site, identification of peak particle velocity can be made.

Aigbogun & Edo (2020) investigated the effect of vibration from blasting in different rectangular drilled pattern in limestone quarry, Okpella, Edo State, Nigeria. Their investigation reveals that the peak particle velocity recorded when the burden was greater than the spacing is higher than when the spacing was greater than the burden.

Reza (2011) describes vibration induced by blasting near surface and underground concrete structures when constructing upper Gotvand dam. Effects of different rock formations, explosives and different detonators methods were analysed. He detonated 216 shots producing 498 ground motions which were measured by Vibraloc vibration monitors. Peak particle velocity and the scaled distance were recorded and analysed statistically. From the analysis, an empirical relationship between the peak particle velocity and the scale was established.

Svinkin (2007) analysed data from the accumulated results of structural responses and damage produced by ground vibrations from surface mine blasting by the United States Bureau of Mines (USBM). His analysis indicates different vibration effects on structures depending on the dominant frequency and the peak particle velocity (PPV) of ground vibrations. He arranged the accumulated data into three zones depending on closely grouped damage results.

Dhekne (2015) studied the environmental impacts of rock blasting in opencast mines. One of the objectives of the study was to design a blast to limit the ground vibrations and noise within the statutory limits prescribed by Indian regulations. In order to achieve the objective, four blasts using the normal practice were monitored. The ground vibrations and the noise were measured using the Instantel make Seismograph. The result from the normal practice shows that the vibrations generated by blast are very high.

Ranjan et al (2016) studies a total of 1089 published blast data of different researchers who have worked in different rock sites and used the result to propose a generalized empirical model for PPV by considering the effects of rock parameters like rock quality designation (RQD), unit weight, uniaxial compressive strength (UCS) and geological strength index (GSI). They concluded that PPV has a good correlation coefficient and hence can be used directly in blast-induced vibration prediction in rocks. They farther agreed with relationship between PPV and scaled distance (SD) which is written as

$$SD = DW^{-\alpha} \quad (1)$$

Where SD is the scale distance, D is the physical distance between the point of observation and the vibration generation point in meters; W is the weight of explosives used in kg and α is ½.

MATERIALS AND METHODS

Geological Setting

Okpella lies between latitude 7.2721 and longitude 6.3465 and shares common boundary with Kogi State. Limestone is a sedimentary rock composed largely of the mineral calcite ($CaCO_3$), formed by either organic or inorganic processes Serra, (2006). Limestone is formed either by direct crystallization from water (usually seawater) or by accumulation of shell and shell fragments. All limestone are formed from the precipitation of calcium carbonate from water. Calcium carbonate leaves solutions in many ways and each way produces a different kind of limestone. All the different ways can be classified into two major groups: either with or without the aid of a living organism (that is, either by organic or inorganic processes).The principal component of limestone is the mineral calcite, but limestone frequently also contains the minerals dolomite [$CaMg(CO_3)_2$] and aragonite ($CaCO_3$). Pure calcite, dolomite, and aragonite are clear or white.

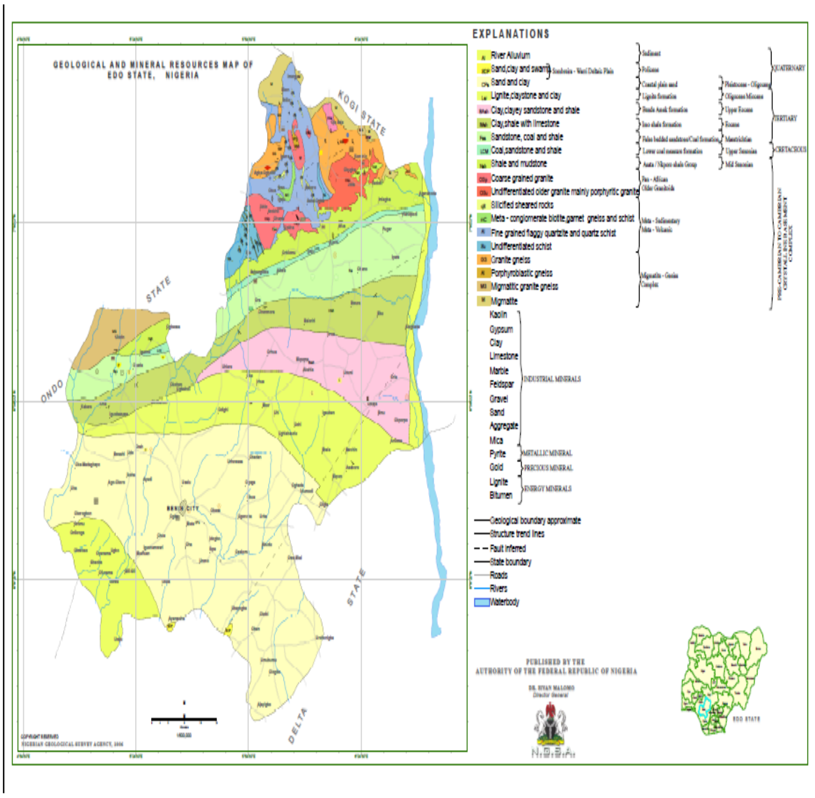

Figure 1: Geological map of Edo showing mineral deposit

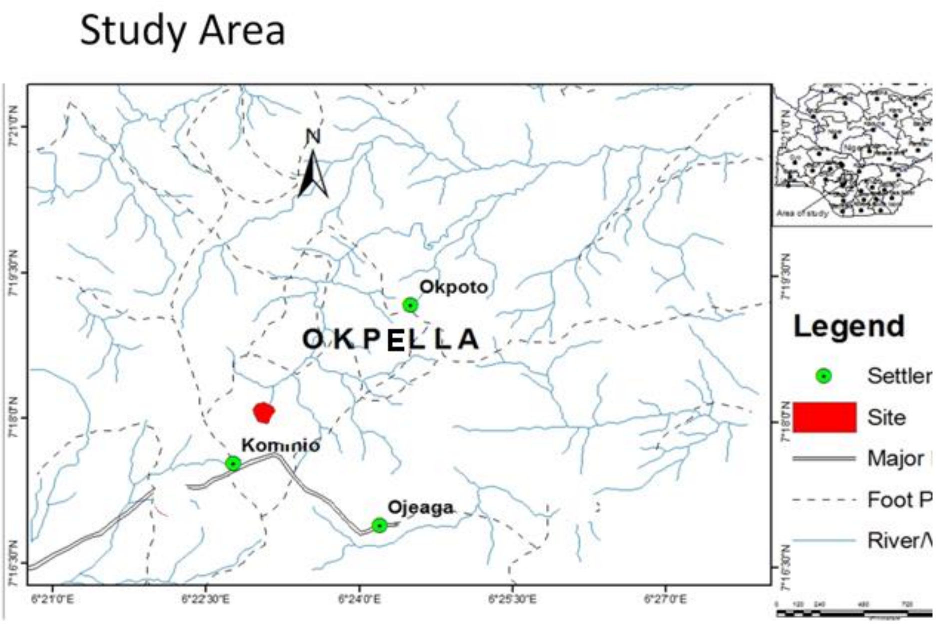

Figure 2: Project site location

An accelerometer, SLAM STICK X (a tri-axial wireless vibration data logging instrument) was used in recording the acceleration and its associated software, midé, render the recorded time spectrum into frequency spectrum using the Fast Fourier Transform (FFT). The wheel tape measures the distance between the blast point and observation point. Steel tape was used to measure the spacing and burden and the diameter of the holes. The water gel type of explosive and the delay initiating cables were used for the explosion. The accelerometer was attached to a nearby structure. The distance between the structure and the blasting point was measured using the wheel tape. The SLAMSTIC X records the ground motion (ground acceleration) in m/s^2. The SLAMSTICK with its associated software render the recorded time spectrum into frequency spectrum using the Fast Fourier Transform from the frequency at every point is obtained. The ground motion which is in acceleration is converted to velocity using equation (1)

$$PPV = \frac{1000a}{2\pi f} \qquad (2)$$

Where PPV is the peak particle velocity;
a in equation (2) is the recorded ground motion (acceleration) and f is the frequency associated with the maximum acceleration.
The square root distance is calculated using equation (1)

And finally, the site constants were obtained using equation (3)

$$\text{PPV} = K(SD)^{\beta} \qquad (3)$$

Where k and β are site constants which are related to rock geologic factor.The Standards Association of Australia recommended (-1.6) for β, and suggested criteria for selecting k values to be: for under confined conditions - hard or highly structured rock, k = 500; for free-face average (normal confinement), k = 1140 and for heavily (over) confined, k = 5000.

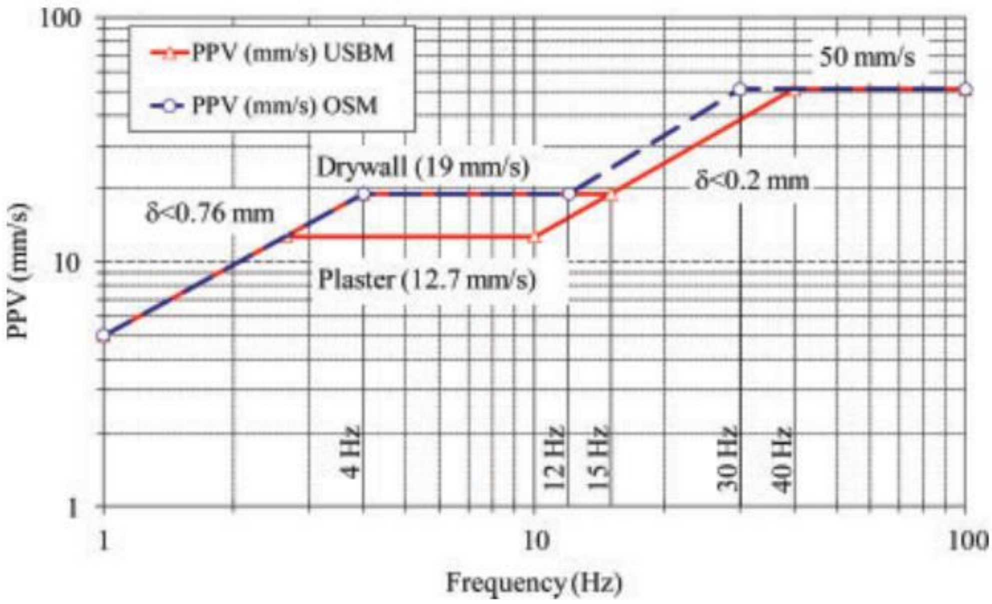

Figure 3: USBM and OSM safe limit criteria against ground vibrations due to subsurface blasting

RESULTS AND DISCUSSION

Table 1: PPV generated for the investigated site

SHOT	Distance (m)	Weight of explosives (Kg)	Maximum Acceleration (m/s^2)	Frequency (Hz)	Square Root Distance	Peak Particle Velocity (mm/s)
1	207.0	600	6.40	58	8.45	17.55
2	177.2	420	6.30	58	8.65	17.28
3	467.4	460	.3.00	78	21.79	6.12
4	295.0	560	4.83	60	12.48	12.81
5	126.6	540	8.80	26	5.45	53.85
6	184.3	620	7.27	30	7.40	38.55
7	200.0	680	7.07	36	7.66	31.24
8	192.5	720	7.31	30	7.17	38.76
9	320.0	800	5.0.1	52	11.31	15.33
10	410.0	1000	4.56	60	12.97	13.95
11	430.0	1000	4.58	60	13.60	12.14

Table 1 above shows the peak particle velocity calculated using the square root scale distance and the weight of explosive used in each blast and the distance from the blasting point to the point of observation.
From table 1, the least peak particle velocity (PPV) is 6.12 mm/s at a distance of 467.4 m when an explosive weight of 460 kg which generated a frequency of 78 Hz at the point of observation while the maximum peak particle velocity recorded was 53.85 at a frequency of 26 Hz at a distance of 126.6 m when an explosive weight of 540 kg was detonated.
The generated equation of the model is of the form

$$\text{PPV} = 721.6(SD)^{-1.57} \qquad (4)$$

Where
PPV is peak particle velocity and SD is the square root scale distance.
Equation 4 is a guide to blaster when mining limestone using staggered drilled hole pattern.

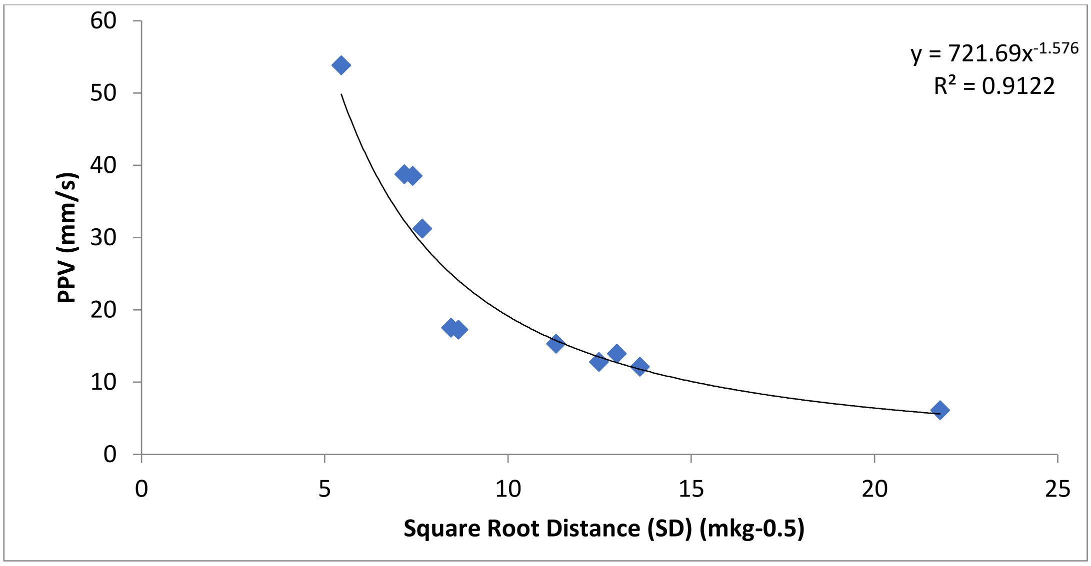

Figure 4: Graph of PPV against square root distance according to equation 3

CONCLUSION

With a maximum explosives of 1000 kg and at a distance of 410 m, the peak particle velocity (PPV) recorded was 13.95 with a frequency of 12.97 Hz which is safe for the structures within that perimeter when compared with the United State for Bureau of Mine (USBM) and OSM criteria which stipulates a safe limit of PPV of 50 mm/s. When explosive weight of 540 kg was exploded and recording done at a distance of 126.6 m the peak particle velocity was 53.85 mm/s at a frequency of 26 Hz which is higher than the recommended safe limit for structures. Using equation 4 as a guide, when an explosive weight of 1000 kg is to be used, the nearest structure should not be in a distance less than 180 m from the blasting point for the safety of the structures.

The model variables (peak particle velocity and scale distance) are highly correlated with R^2 equal to 0.915

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