Investigating Vibration Effect from Blasting Using Delay Initiation and Square Drill Pattern in Limestone Quarry in Okpella, Edo State, Nigeria

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ABSTRACT

In recent times Okpella has experienced an increase in limestone mining activities to meet the increasing need of cement for constructions. Blasting has been the most efficient, economic and convenient method of breaking in-situ hard rocks. Only a portion of the energy dissipated by the explosives used in blasting is consumed in breaking the rocks while greater percentage of the remaining energy is released as vibration in the form of seismic waves traveling very rapidly within the subsurface. Peak particle velocity (PPV) measurement using slam stick X was compared for an undefined drilled borehole arrangement and drilled boreholes arranged in square pattern with 500 ms delayed in blasting initiation. PPV was plotted against the scaled distance and the result shows that the vibration generated when blasting with square borehole drilled pattern and at 500 ms delay blasting initiation was lower by up to 42.01 % when compared with blasting in an undefined borehole arrangement.

Keyword: Peak Particle Vibration; blasting; delay initiation; square drilled hole pattern

1.0 INTRODUCTION

With increasing mining and construction activities in areas close to human settlements, ground vibration has become a critical environmental issue as it causes human annoyance and structural damage, Singh, T.N. and V. Singh, (2005), Ozer, U (2007), Khandelwal M. and Singh T.N., (2007).

Investigation on ground motion and airblast over pressure measurements around open pit mine near Metlaoui village (south-western Tunisia) was done. The empirical relation proposed by USBM to calculate the sites constant was used, Aloui M (2016). The site parameters obtained provide the reseaachers the propagation equation of the blast induced seismic waves in the study site. Also, an overview of frequency for the study area revealed the dominance of low frequencies (>40 Hz). They concluded that such values can cause damage to the nearby structures when a specific PPV value is reached by blasting

LS-DYNA was used to simulate the effect of adjacent empty hole. Influences of key parameters of adjacent empty hole in rock blasting, pitch of holes, empty hole diameter, and uncoupled medium were investigated. This numerical simulation results shows that the stress on an adjacent empty hole wall gradually decrease with increase in the pitch of holes, the stress concentration weakens as the empty hole diameter incresses and the blasting efficiency of the water-medium uncoupled charging is the highest, and the rock-breaking effect is the best, which is suitable for cut hole blasting, Yuezong Yang (2018)

An orthotropic dynamic damage constitutive model of structural material was proposed to improve the overly simple dynamic damage models of previous studies. In the study a dynamic increase factor was used to assess the strain rate effect, and the dynamic damage stiffness matrix of the unit body was determined using the Sidoroff energy equivalence principle. The Mazars damage evolution model was used to calculate damage variables in the principal axis directions, and the Hoffman yield failure criterion for orthotropic materials was applied. The orthotropic dynamic damage constitutive model is input into dynamic finite element program LS-DYNA as the user subroutine to simulate the dynamic responses of typical masonry structures according to different blasting vibration excitations. The effects of varying particle peak velocity, principal frequency, and duration of blasting vibration on structural dynamic responses and damage were analyzed. The results shows that maximal equivalent stress and strain increase positively with the particle peak velocity, structures have a danger frequency band, and structural damage increases with duration, Shihai Chen and Zihua Zhang (2016).

Studies on the failure and damage of structures under blasting vibration are very few. A design of a three-dimensional continuum damage constitutive model, which considered the orthotropic elastic properties, strength envelope, and damage threshold for brick that analyzed the dynamic responses and damage of typical masonry structures under blasting vibration was investigated. The results revealed that damage to first-story columns was more substantial than that to second-story columns, whereas damage to beams was similar for both floors, Wu C, Hao H and Lu Y (2005), Hao H and Wu C (2005), Hao H, Ma GW and Lu Y (2002), Ma G, Hao H, Lu Y, (2002).

The level of ground excitation and structure vibrations depends on blasting technology, weight and type of, delay timing, parameters of waves at a site, site geology, scaled distance, susceptibility ratings of adjacent and remote structures, and other factors. In estimating ground vibrations, a common practice is to use PPVs to predict structural responses and human tolerance to ground vibrations by using various empirical ground motion predictors, Ak H (2009). PPV is given as a function of site conditions (i.e., geological and technological conditions) and scaled distance, Mesec J, Kovac I, Soldo B, (2010).

A predictive model based on gene expression programming for estimating ground vibration produced by blasting operations was conducted in a granite quarry, Malaysia. The results demonstrated that the proposed model is able to predict blast-induced ground vibration more accurately than other developed technique, R Shirani Faradonbeh, (2016)

Airblast and ground vibration levels and its potential impact on neighboring communities was evaluated using two calibrated seismographs to monitor the blast at Chimiwungo Pit in nearby township of Manyama, Kabwe, E. and Wang, Y.M. (2016). The mass per delay simulated and calculated ranged between 1568 kg/delay to 2352 kg/delay. The readings indicates that there would be no negative impact on any potential neighboring communities, outside the mine boundary, as Manyama Township was at about 2000 m away from the blast, and the peak particle velocity was predicted at 2.46 mm/s.

Nigeria has no definite legislature on vibration and vibration control. There is also no regulation or acceptable peak particle velocity (PPV) limit. Some mining operators adapt specific drill pattern for charged holes. The aim of the research work is to therefore study the vibration generated when different drilled patterns (square drill pattern and no specific pattern) are employed. Comparison between instantaneous initiation in an undefined drill hole pattern and drilled holes arranged in square patterns is made to know which generated least vibration. The SLAM STICK X a tri-axial accelerometer is the equipment used in collecting vibration data.

When an explosive is detonated in borehole, energy is transferred into the surrounding rock as a result of the generated shock and gas pressures. Initially the pressure of the shock wave is higher than the compressive strength of the rock and the rock around the borehole is crushed. 20 % of this total energy dissipated by the explosives used in blasting is consumed in breaking the rocks while the rest is released as vibration in the form of seismic waves travelling very rapidly within the subsurface, air overpressure, light and sound, Dhekne P. Y. (2015). The shock wave decays quickly below the compressive strength of the rock. At this point, the shock wave travels inside the rock without breaking it. Farther away from the borehole (shot point), the waves attenuate into elastic waves. The elastic waves travel within the rock material and later, part of the wave is refracted to the surface of the rock and propagate as surface wave. This surface wave is capable f causing damage to structures if its magnitude is high. The weight of explosives and the distance from the point of initiation to measuring point determine the value of the measured vibrations. To be able to excavate large volume of the in-situ mineral deposit without endangering nearby structures, mitigation methods have to be applied. The square drilled pattern of holes configuration was adopted in site B in a mine in Okpella, Edo State Nigeria while in site A, the traditionally undefined pattern was investigated.

In the square pattern, the spacing and the burden are of equal length of 2m with the holes in the second row directly behind the holes at the front row. This drilling pattern can be easily explained to labors.

The frequency/acceleration value was converted to velocity using the equation

$$\boldsymbol{v} = \frac{\boldsymbol{a}}{\boldsymbol{2\pi f}} \qquad (1)$$

Where a is acceleration (m/s^2)

and f is frequency in Hz.

Then,

a*1000 (m/s^2) = 1 mm/s^2 (2)

$$\therefore v = \frac{1000*a}{2*\pi*f} mm/s \qquad (3)$$

If acceleration (a) is in g, then

$$v \approx \frac{9807*a}{2\pi f} \text{mm/s} \qquad (4)$$

The square root scaled distance S.R as

$$\text{S. R.} = \frac{D}{W^{1/2}} \qquad (5)$$

2.0 GEOLOGY OF THE STUDY AREA:

Limestone is a sedimentary rock composed largely of the mineral calcite ($CaCO_3$), formed by either organic or inorganic processes, Serra, R. (2006). Nigeria is endowed with large deposits of limestone located in all parts of the country. Limestone is the principal raw material for cement manufacturing. It is white and greyish in colour when relatively pure. They contain variable amounts of Mica, Calcilicates and sometimes, small inclusions of Gneiss, Pegmatite and Quartz.

Okpella is situated in latitude 7.2721 and longitude 6.3465. Okpella shares a common boundary with Kogi State. Okpella limestone deposit falls into the Precambrian limestone. It is confined within the schist belts of the western half of western Nigeria. It is pure calcium carbonate in the basement complex.

3.0 MATERIALS AND METHODS

An accelerometer, SLAM STICK "X" was used in recording the acceleration and the associated software, midè, render the recorded time spectrum into frequency spectrum using the Fast Fourier Transform (FFT). The wheel tape measures the distance between point of blasting and the observation point. Steel tape was used to measure hole diameter, burden and the spacing. The watergel type of explosive (SuperPower 90) figure 1 and delay initiating cables were used.

The researchers divided the research area into two labeled A and B figiure 2.

Site A

Ten blasting were monitored and recorded in this site (table 1). The site was not clear of trees and overburden. No particular arrangement of drilled hole pattern was adopted and blasting was instantaneous (no delay).

Site B

In site B, the drilled holes were arranged in square pattern with the spacing and burden of 2m. Eleven blasting were monitored recorded in this site (table 2), and the delayed initiation time was 500ms.

Figure 1: Watergel Explosives

Study Area

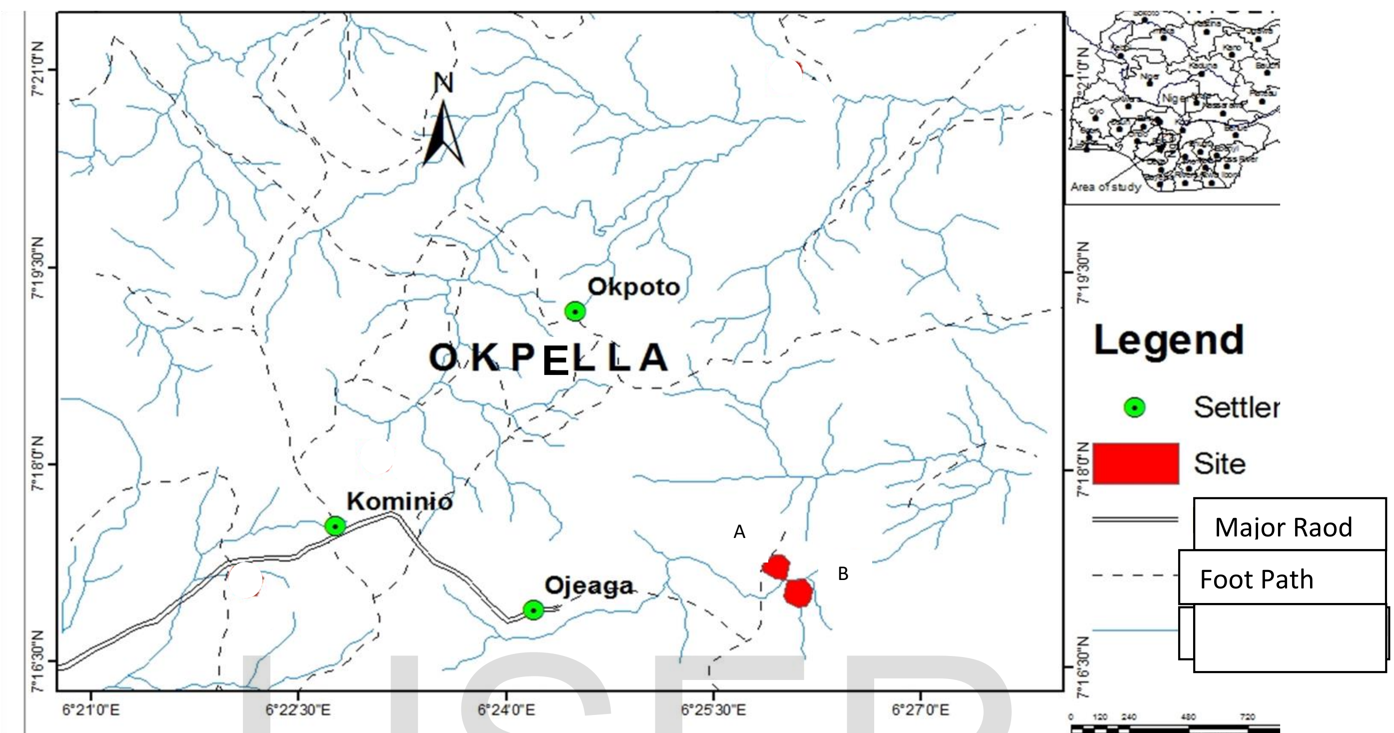

Figure. 2: Map of study Area

4.0 RESULT

Table 1: Date from site A

SHOT	DISTANCE (m)	WEIGHT OF EXPLOSIVES (kg)	AXIS			SCALE DISTANCE ($m/kg^{1/2}$)	FREQUENCY (Hz)	PPV (mm/s)
			X	Y	Z			
1	600	980	24.14	30.12	50.00	19.17	58	50.00
2	560	940	21.21	26.87	52.32	18.27	45	52.32
3	800	1200	19.14	24.30	40.00	23.09	65	40.00
4	770	1400	16.44	21.21	46.00	20.58	60	46.00
5	700	1300	21.04	26.69	49.27	19.41	62	49.27
6	480	1400	24.14	30.17	56.72	12.83	58	63.79
7	560	920	21.04	26.69	49.27	18.46	62	49.27
8	600	1500	24.90	31.13	56.72	15.49	42	56.72
9	660	100	19.10	23.86	46.93	20.87	60	46.93
10	720	1200	18.48	21.55	47.21	20.78	62	47.21

Table 2: Data from Site B

SHOT	DISTANCE (m)	WEIGHT OF EXPLOSIVES (kg)	AXIS			SCALE DISTANCE (m/kg$^{1/2}$)	FREQUENCY (Hz)	PPV (mm/s)
			X	Y	Z			
1	207.0	600	26.7	34.82	64.08	8.45	58	64.08
2	177.2	420	24.69	32.92	63.09	8.65	58	63.09
3	467.4	460	16.32	19.99	31.00	22.21	78	31.00
4	295.0	560	22.73	28.41	48.30	12.47	60	48.30
5	126.6	540	45.28	56.29	88.07	5.45	26	88.07
6	184.3	620	27.27	33.64	72.73	7.40	30	72.73
7	200.0	680	30.93	39.77	70.70	7.70	36	70.70
8	192.5	720	32.88	42.42	73.18	7.17	30	73.18
9	320.0	800	23.86	27.53	50.17	11.31	52	50.17
10	410.0	1000	15.91	20.15	45.61	12.97	60	45.61
11	430.0	1000	22.03	27.53	45.89	13.60	60	45.89

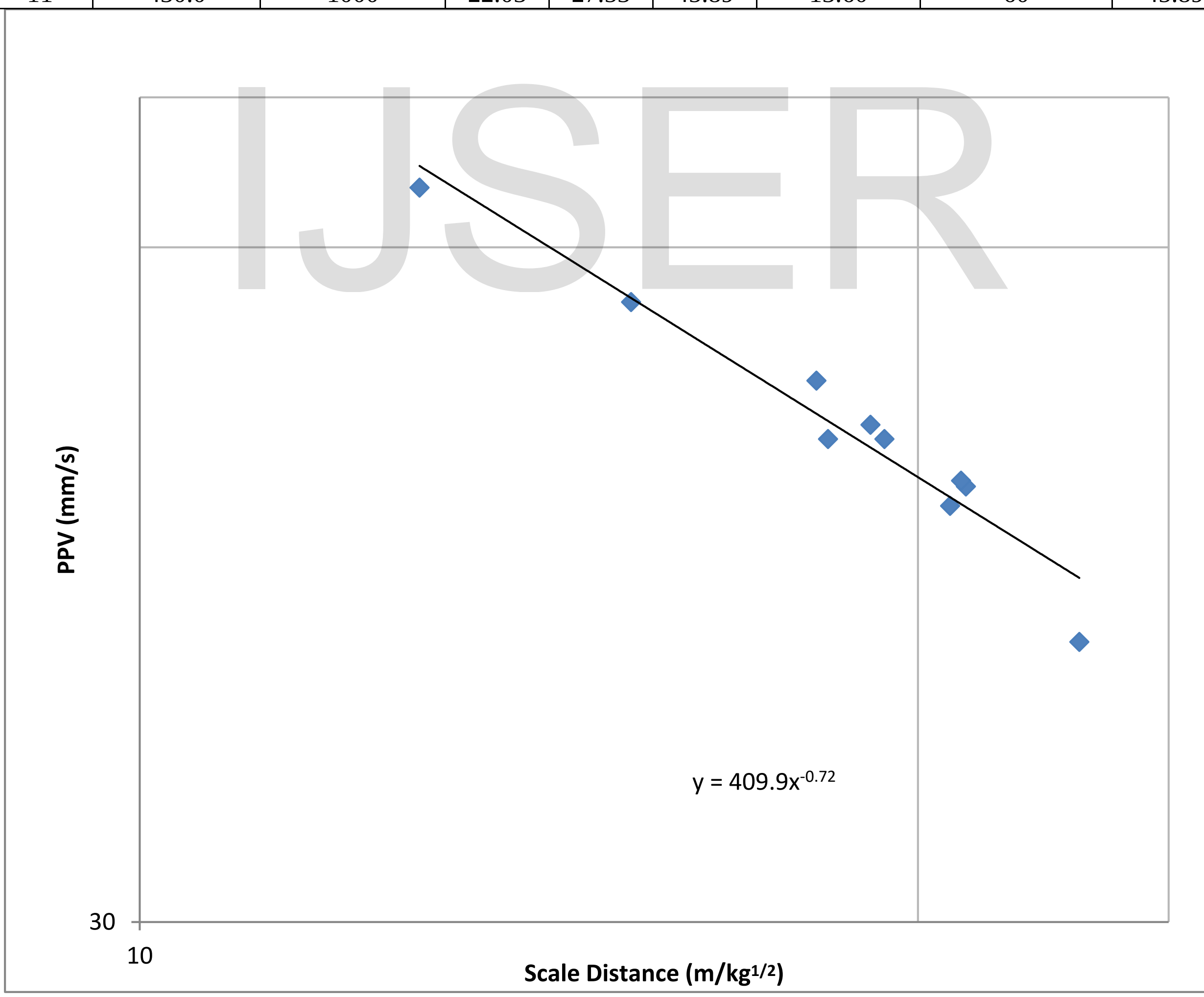

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Figure 3: log – log of PPV versus square root scaled distance for site A according to Table 1

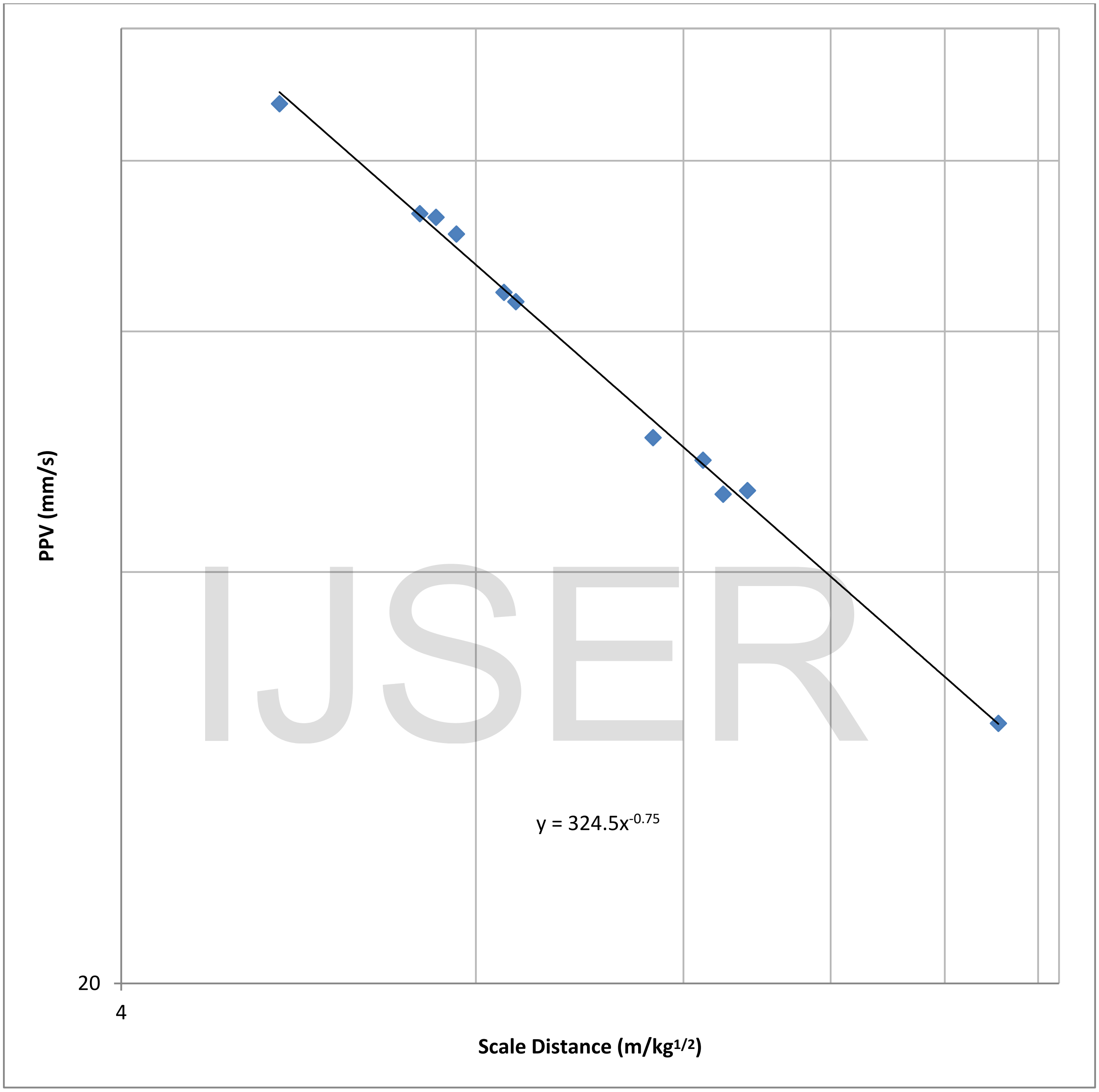

Figure 4: log – log of PPV versus square root scaled distance for site B according to table 2

From figures 3 and 4, for sites A and B respectively, the equations for the figures with the best correlation are:

$y = 409.9x^{-0.72}$; for site A and $y = 324.59x^{-0.75}$ for site B (6)

Where y is the peak particle velocity (PPV) and x the square root scale distance (SD).

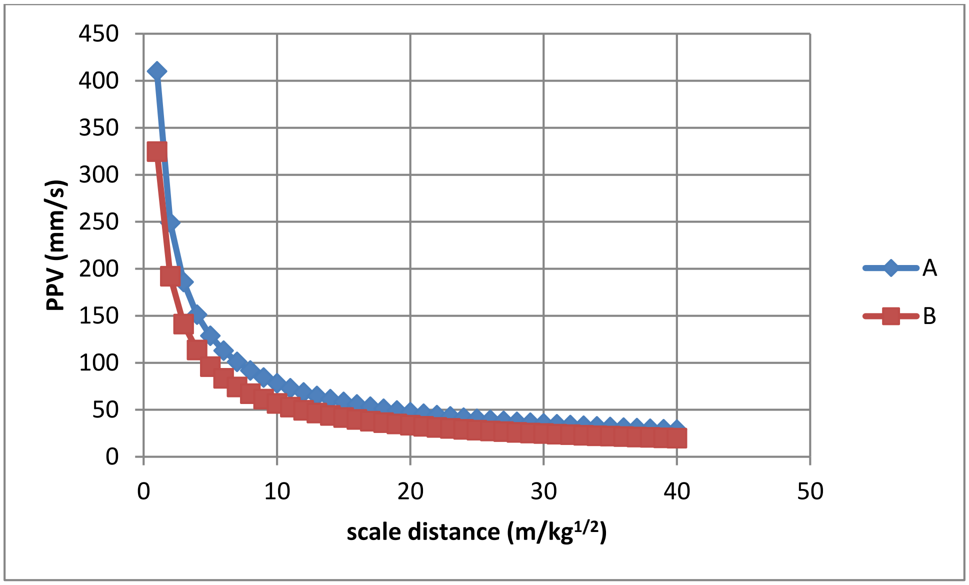

Figure 5: Comparing PPV for sites A and B

4.0 DISCUSSION OF RESULT

In tables 1 and 2, the first column represents the shot number. Column 2 is the distance from the shot point to the point of observation and column 3 is the total weight of explosives used for that shot. Column 7 is obtained using equation 4 and column 9 is obtained using equation 5.

Figure 5 compares the values of maximum vibration generated in sites A and B using equations 6 and 7

The PPV generated for site A was higher than that generated in site B by between 34.4 and 38.16% for scale distance of between 8 and 20 $m/kg^{1/2}$. The PPV in site A was also higher than that generated in site B by between 38.36 and 39.84 % for scale distance of between 21 and 30 $m/kg^{1/2}$. The Peak Particle Velocity generated in site A was higher than that generated in site B by between 39.99% to 41.06% for scale distance of between 31 and 40 $m/kg^{1/2,}$ and finally, for the compared range, the PPV in site A was higher than that generated in site B by between 41.16% and 42.01% for a scale distance of between 41 and 50 $m/kg^{1/2}$

5.0 CONCLUSION

The PPV generated by blasting in a limestone quarry in Okpella, Edo State, Nigeria, where there is no defined drill pattern and with an instantaneous initiation shows an increase of between 34.4 % and 42.01% for scale distances of between 8and 40 $m/kg^{1/2}$ to blasting in an environment where the holes are drilled in square pattern and the initiation was delayed by 500ms. This shows vibration generated by blasting with an undefined drilled pattern increases when compared with blasting in an environment where the bore holes are arranged in square pattern.

REFERENCES

Ak H, Iphar M, Yavuz M, Konuk A (2009) Evaluation of ground vibration effect of blasting operations in a magnesite mine. *Soil Dynamics Earthquake Eng 29(4):669–676*

Aloui M, Bleuzen Y, Essefi E, Abbes C (2016) Ground Vibrations and Air Blast Effects Induced by Blasting in Open Pit Mines: Case of Metlaoui Mining Basin, Southwestern Tunisia. *J Geol Geophys 5: 247. doi:10.4172/2381-8719.1000247*

Dhekne P. Y. (2015) Environmental Impacts of Rock Blasting and Their Mitigation *International Journal of Chemical, Environmental & Biological Sciences (IJCEBS) Volume 3, Issue 1 ISSN 2320–4087 (Online)*

Hao H, Ma GW and Lu Y (2002). Damage assessment of masonry infilled RC frames subjected to blasting induced ground excitations .*Engineering Struct; 24: 799–809*.

Hao H and Wu C (2005). Numerical study of characteristics of underground blast induced surface ground motion and their effect on above-ground structures Part II. Effects on structural responses. *Soil Dynamics EarthquakeEng; 25: 39–53.*

Kabwe, E. and Wang, Y.M. (2016) Airblast and Ground Vibration Monitoring at Chimiwungo Pit. *Geomaterials, 6, 28-38. http://dx.doi.org/10.4236/gm.2016.61003*

Khandelwal M. and Singh T.N., (2007). Evaluation of blast-induced ground vibration predictors *Soil Dynamics Eng. 27 (2007) pp 116–125.*

Ma G, Hao H, Lu Y, (2002). Distributed structural damage generated by high-frequency ground motion. *J Structural Eng: ASCE 2002; 128: 390–399*

Mesec J, Kovac I, Soldo B (2010) Estimation of particle velocity based on blast event measurements at different rock units. *Soil Dynamics Earthquake Eng 30(10):1004–1009.*

Ozer, U, Kahriman, A, Adiguzel, D, Aksoy, M, Karadogan, A, (2007), The Investigation of Ground Vibrations Induced by Bench Blasting at Different Quarries at Çatalca District in Turkey,*The Thirty-Three Annual Conference on Explosives and Blasting Technique, January 28 -31, 2007 Nashville, Tennessee, USA. Volume I. pp 241-253.*

R Shirani Faradonbeh, D JahedArmaghani, M. Z. AbdMajid, M. MD Tahir, B. Ramesh Murlidhar, M. Monjezi and H. M. Wong *(2016):*Prediction of ground vibration due to quarry blasting based on gene expression programming: a new model for peak particle velocity predictionInt. *J. Environ. Sci. Technol. 13:1453–1464 DOI 10.1007/s13762-016-0979-2*

Serra, R. (2006). Dictionary of Geology. *Academic (India) Publishers, New Delhi – 110008*.

Shihai Chen and Zihua Zhang (2016). Masonry Structural Damage and Failure under Blasting Vibration.*Advances in Mechanical Engineering. Vol. 8(2)-10 Doi: 10.1177/1687814016633412 aime.sagepub.com.*

Singh, T.N. and V. Singh, (2005). An intelligent approach to prediction and control ground vibration in mines. *Geotech. Geologic. Eng., 23: 249-262. DOI: 10.1007/s10706-004-7068-x*

Wu C, Hao H and Lu Y (2005). Dynamic response and damage analysis of masonry structures and masonry infilled RC frames to blast ground motion. *Engineering Struct; 27: 323–333*.

Yuezong Yang, Zhushan Shao, Junfeng Mi, and Xiaofeng Xiong: (2018), Effect of Adjacent Hole on the Blast-Induced Stress Concentration in Rock Blasting, *Advances in Civil Engineering, vol. 2018, Article ID 5172878, 13 pages, 2018. https://doi.org/10.1155/2018/5172878*

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CONFLICT OF INTEREST

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