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Investigating Sustainable Blasting via Peak Particle Velocity Impact on Evbonogbon Town, Edo State, Nigeria

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Abstract

This research is hinged on the fact that blasting operation, a vital process in the extraction of solid minerals from mines and quarry, with its negative impact on the environment cannot be abandoned. However, with proper ethics and design parameters, the environment can be protected in adherence to the principle of sustainability. Slam stick X accelerometer was deployed to measure the level of vibration for quarry A, B, C and D, expressed as its Peak Particle Velocity (PPV), by comparing the result obtained for each of the quarry with the maximum acceptable threshold for PPV 50 mm/sec, stipulated by the International Organization for Standard (ISO). Sixteen (16) blasts were monitored for ISO compliance. The results from blast revealed that 37.50% of the blast initiated PPV that exceeded the maximum acceptable threshold of 50 mm/s recommended by ISO. This is likely responsible for the cracks in buildings and structural failure witness in the study areas while 62.50 % were below the recommended standard. From this research, houses within the quarries whose blasting operation produces PPV are lower than the 50 mm/s threshold lack visible cracks and the resident have positive perception towards the quarry operations. On the other hand, buildings close to quarry site generating PPV higher than the ISO threshold have several cracks and negative perception towards the presence of the quarry. The finding shows that site C experienced the worst blasting practices, while site B experienced the best blasting practices according to ISO threshold.

Keywords: *Sustainability, blasting, Quarry and Peak-Particle-Velocity*

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1. INTRODUCTION

The focus of this research is on the investigation of blasting operations in Evbonogbon town in Edo State, a town that hosts four quarry companies. This is to help in mitigating environmental and social impacts that are likely in the town, by canvassing for ethics that will improve efficiency, and promoting responsible resource management. This work will also highlight how advancements in blasting technology are being aligned with several United Nation (UN) Sustainable Development Goals (SDGs).

SDGs was birthed and propagated by the United Nations (UN) in the year 2015 (Sianes et al., 2022). SDGs were developed based on the cardinal four Millennium Development Goals (MDGs), categorized into environmental, social, economic and governance with legal components (Smith 2020; and Fauzi et al., 2025). Some of the SDGs that are connected to the fallout of the extractive industry operations are x-rayed, to show how operational procedures can be streamlined to prevent, mitigate and ameliorate negative environmental and socioeconomic impact. Some of these SDGs are:

i. SDG 3: centres on good health and well-being, and aims to reduce health risks. Mining blasts have long been associated with dust and gas emissions that negatively impact the health of mine workers and local communities.
ii. SDG 6: focuses on clean water and sanitation, with the intention of protecting groundwater. By the use of advanced explosive designs and blasting methods research, reduces the risk of groundwater contamination.
iii. SDG 7: centres on affordable, efficient and clean energy. This evaluated how using more powerful explosives in the blasting stage can reduce the energy needed for downstream crushing and grinding (comminution), leading to overall energy savings and reduced CO_2 emissions.
iv. SDG 8: relates to decent work and economic growth. This has the capacity to improve productivity. Innovations like advanced explosives and digital blast design software are improving blast quality and mine productivity, which contributes to economic growth.
v. SDG 15: focuses on life and on land, that is biodiversity and land protection. Blasting is known to cause habitat destruction and land degradation.

1.1 Sustainability

Emmanuel (2021) states that as man interacts with its environment on daily basis, by the process of extraction of important agricultural materials and mineral products needed to satisfy the ever increasing yearnings for the basic necessity of life, food, clothing and shelter; the environment is constantly being modified in ways that may adversely affect the life sustaining potential, of the impacted environment (IPCC, 2021). In order to minimize these challenges and improve environmental sustainability, Environmental Management System (EMS) was developed as a tool for environmental management, administration and control. This buttresses current values and beliefs in the extractive sectors, which is sustainability. This means the process of meeting economic and environmental needs of the present and also facilitating the potential of the forthcoming generations to do same (Emmanuel, 2021).

The concept of sustainability is a dire perception that demands a multifaceted methodology to achieve a balance environment, social and economic dimensions. The framework for the actualization of sustainability globally has been hinged on the SDGs (United Nation Department of Economics and Social Affairs, 2025).

1.2 Component of Sustainability

The three components of sustainability, often referred to as the Triple Bottom Line (TBL) or the 3 pillars of sustainability are; social, environmental and economic sustainability. These three components are interconnected and mutually reinforcing, and are often depicted as a tripod or a triple helix to illustrate their interdependence (Nica, et al. 2025; and Das et al 2025). The basic features of these components are as outline below:

2 Social sustainability focuses on the wellbeing of human and their habitats, including aspects like social justice, equity, and human rights;
3 Environmental sustainability relates to the conservation and management of natural resources, including aspects like climate change, biodiversity, and pollution.
4 Economic sustainability applies to the economic viability and resilience of systems, including aspects like financial stability, resource allocation, and economic growth.

1.3 Sustainable Blastıng

Sustainable blasting practices in mining involves using advanced technologies to minimize environmental impact (Ajaka & Adesida, 2014), while maximizing efficiency, the cardinal aims of sustainable blasting practices are to reduce environmental impact, improve safety, increase efficiency and to support sustainable mining practices (Bulushi et al, 2025). The approach to achieve sustainable blasting practices comes under different categories, such as:

i. Digital blast Design and simulation software that optimize blast patterns, reduces vibration, and minimizes fly rock.
ii. Wireless electronic detonators and remote initiation. This enhances safety and precision.
iii. Real time environmental monitoring that tracks vibration, dust, and air quality.

iv. Artificial Intelligence (AI) powered predictive analytics. This optimizes blast design and reduces risks.
v. Eco-friendly explosives that reduce ecological footprint.

Mining and quarrying significantly impact groundwater, leading to contamination, depletion, and altered hydrology. Here are some of the key effects of mining and quarrying operations on groundwater:

i. Groundwater contamination during mining operations releases toxic substances like heavy metals, acids, and chemicals into groundwater, triggering grave medical conditions to nearby inhabitant and animals.
ii. Acid Mine Drainage (AMD), are Sulphide minerals in rocks that react with air and water, forming tetraoxosulphate IV acid, which contaminates groundwater and harms aquatic life.
iii. Heavy metal contamination may be experienced during mining. This exposes heavy metals like arsenic, lead, and mercury, which leaches into groundwater, affecting human health and ecosystems;
iv. Groundwater depletion during mining activities diminishes the aquifer, altering essential components of the biosphere, and affecting nearby ecosystems.
v. Altered hydrology is one of the major fall out of mining. This changes the natural water flow patterns, in some instances it increases the surface runoff, erosion, and sedimentation, which can smother aquatic habitats.

To mitigate these impacts, responsible mining practices, which involves controlled blasting, modern technologies, and effective regulations are crucial.

1.4 Controlled Blasting

Controlled blasting is a technique used in mining, quarrying and construction to break rock or soil using explosives in a predictable and safe manner. It involves carefully planning and executing the blast to achieve specific goals, such as fragmenting rock to a desired size or minimizing damage to surrounding structures (Obosu & Frimpong 2025; and Bulushi et al, 2025).

Quarry refers to any excavation on the earth surface on which valuable rocks are being mined essentially for construction purpose. There are two main subdivisions of the quarries, namely the dimension-stone and *comminuted*-aggregate quarrying. The first consist of large piece of rocks, such as marble, are mined in diverse dimension for several industrial purpose and domestic usage. In the second class of quarry called *comminuted*-aggregate quarry, different classes of rocks are broken majorly for the purpose of domestic and industrial engineering applications. According to the Department of Planning and Environment (2016), a third class of quarry is the sand quarry, which is a source of vital resource, especially to the building and construction sector.

Mining and quarry activities are known as nonpoint sources of pollution that contribute to water pollution by adding dissolved solid, suspended solid and toxic heavy metals to hydrologic cycle, (Emmanuel & Edo, 2020). All the various forms of quarry and quarry operations leave a negative footprint on the environment of operations. So adequate care needs to be taken, to comply with existing national environmental regulations and international best practices, considering the fact that some of these mining and quarry sites are close to residential houses, (Ongen *et al,* 2018, and Ongen, *et al*, 2020).

1.5 Blast Management

Blast management should be in accordance with the project approval and Environmental Protection Agency (EPA) Standards. Explosive storage and transport use are expected to be strictly in accordance with established status and internationally best practices. Potential impacts of blasting can be kept within the project approval, and Mine Lease conditions and guidelines, provided the maximum instantaneous charge (MIC) is kept below 60 kg when blasting at 700 m from residences. Singh *et al* (2002), reveals that it is only about 20-30% of the energy of explosive that is used for disintegration and dislodgment of broken rocks. With this understanding, the uncontrolled usage of excessive mass of explosive during blasting is uneconomical and can be catastrophic due to ground vibration (Hammed, 2018).

Particle velocity at a specific location is the common means of measuring ground vibrations. The commonly recognized only parameter of ground vibration accepted as fundamentally detrimental is Peak Particle Velocity (PPV), (Singh & Singh, 2005). Singh and Singh (2005) further states that blast determinative constraints are essentially connected to explosive features and shot hole design factors, with potentials of being altered by the quarry managers in response to economics and safety. There are other fixed and unalterable constraints which are connected to geological settings, and rock quality. Blasting during quarry operations also impact either positively or negatively on both surface and subsurface hydrology, by the damage or interruption of aquifer drift pattern.

1.6 Research Gap and Objective

The motivation behind this investigation is to foster the technique and culture of sustainable blasting practice, that will yield PPV regarded as safe for residents and properties. This can be achieved by the deployment of devices that can measure the level of vibration and shock waves associated with blasting. The following, seismograph or an accelerometer will be effective for this study.

2. MATERIALS AND METHOD

2.1 *Location of Study Area*

Research location is the quarry town of Evbonogbon along Benin-Ore express road. Evbonogbon town is located in Ovia South West Local Government Area of Edo State, and hosts four large quarries, namely Georgoi Rock, Harvey Quarry Limited, Reynold Construction Company (RCC), and Zhong Tai Quarry. These quarries basically produce granite aggregates suitable for all construction purposes. The predominant rock type in the area being studied is fine grained biotite granite. The Geological map of Edo State is shown in Figure 1.

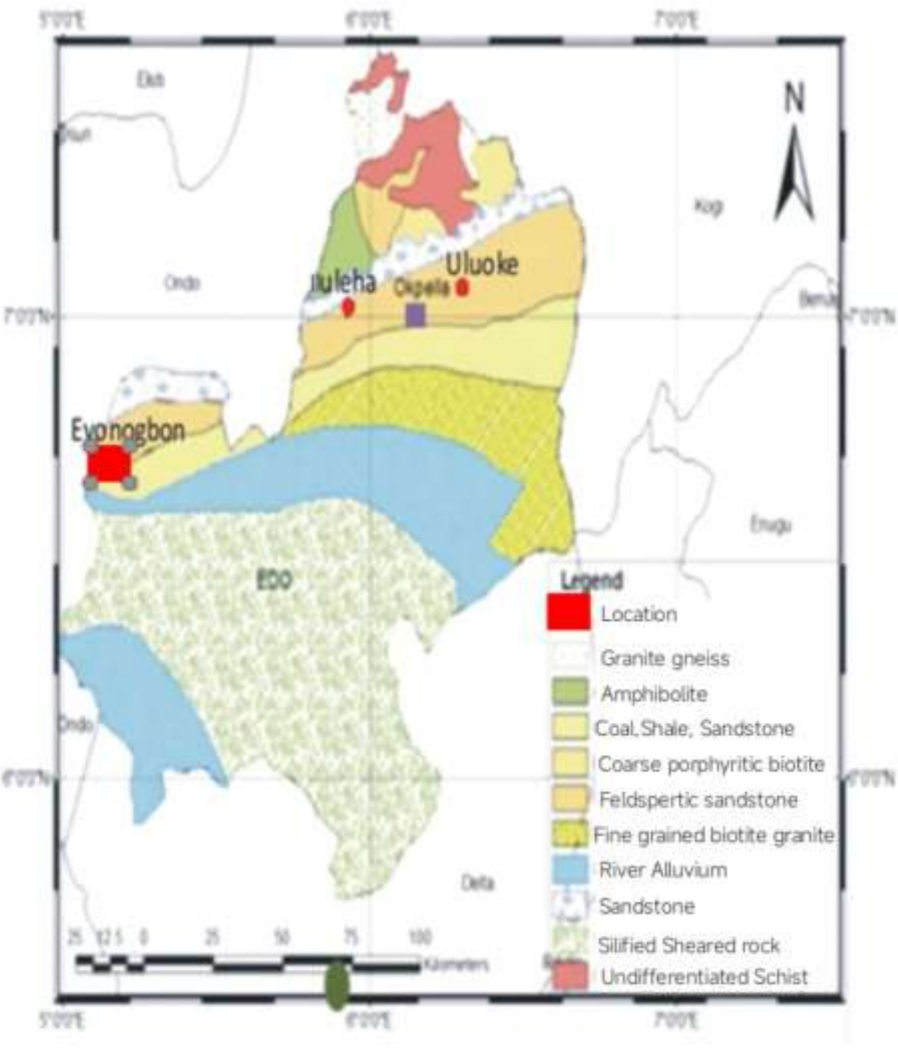

Figure 1: *Geological map of Edo State, indicating the area being studied.*

2.2 *Blast and Vibration Data*

Ground vibrations produced by blasting in quarries in the area being studied is measured using *Slam stick X (SSX)* accelerometer positioned at various locations within the quarries. *Slam stick X* accelerometer, a tri-axial transducer for vibration measurement. The SSX accelerometer is manufactured as a cordless (wireless) vibration data logging structure. The SSX accelerometer allows the user to acquire vibration data without alteration to the vibrating structure. The SSX is a tri-axial vibration data logger, with the capacity for determining and recording accelerations at a rapid sampling rate. In this study, total of sixteen (16) blast operation was studied taking note of the drill pattern, diameter of shot hole and depth.

3. RESULT AND DISCUSSION

3.1 Vibration Data

Ground vibrations produced by blasting in quarries in Edo State were monitored by accelerometer model (Slam Stick X/500 g) positioned at various locations. The accelerometer deployed for monitoring purposes was the Slam Stick X. It is a tri-axial transducer for vibration measurement.

Configuring, charging, and transferring the information from the SSX to a Portable Computer (PC) or order output devices was accomplished via the usage of a micro USB connection and the SSX laboratory software. This software allows the operator to program the data capturing process for diverse sample rates or activating modes, and export acquired data to CSV presentation, applicable with other software.

3.2 Peak Particles Velocity (PPV) Equations

The Midé software converts the recorded section into Fast Fourier Transform (FFT). FFT presents a graph of acceleration and frequency. The frequency and acceleration values are converted to velocity using equations 1, 3 and 4, respectively, for specific conditions.

$$v = \frac{1000a}{2\pi f} mm/s \text{ (m/s)} \quad (1)$$

where a is acceleration (m/s2) and f is frequency in Hz.

Then,

$$1000a \text{ (m/s}^2) = 1 \text{ mm/s}^2 \quad (2)$$

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

If acceleration (a) is in g, then

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

The Slam Stick X (SSX) may be set up to acquire data instantaneously, once an operator initiates given time delay, at a precise time, or in response to some activation parameters (temperature, pressure, or g-level range). The SSX is intended to have limited dimension and mass to enable it to be firmly attached via the application of double-sided tape on practically any vibrating surface. The Midé software converts the recorded section into Fast Fourier Transform (FFT). FFT presents a graph of acceleration and frequency as shown in the result and discussion section.

3.3 Vibration Data from Quarry Site

A total of 16 blasting were monitored and their peak particle velocities (PPV) recorded. In the entire quarry sites monitored, there was no particular firing pattern and the watergel type of explosive was used. Borehole diameter for sites A to D was 100 mm with depth of 10 m. Holes were stemmed with rock cuttings. Blast data and Peak Particle Velocity (PPV) of the four quarry sites are shown as indicated in Table 1.

Table 1: *Blast Data and Peak Particle Velocity (PPV) of the Site*

Site	Distance	Mass of Explosive	Velocities at the Axis			Scale Distances		Frequency	PPV
	(m)	(kg)	X	Y	Z	S. R. ($m/kg^{1/2}$)	C. R. ($m/kg^{1/3}$)	(Hz)	(mm/sec)
A1	600.000	980.000	24.140	30.120	50.000	19.170	60.410	58.000	50.000
A2	560.000	940.000	21.210	26.870	52.320	18.270	57.170	45.000	52.320*
A3	800.000	1200.000	19.140	24.400	40.000	23.090	75.280	65.000	40.000
A4	770.000	1400.000	16.440	21.210	46.000	20.580	68.830	60.000	46.000
A5	144.700	440.000	27.580	37.120	75.300	6.900	19.020	30.000	75.300*
B1	317.000	400.000	20.150	24.920	40.830	15.850	43.020	50.000	40.830
B2	361.000	300.000	14.460	18.800	33.260	20.840	53.930	54.000	33.260
B3	722.000	800.000	14.210	20.640	27.920	25.530	77.780	100.000	27.920
B4	443.400	840.000	19.840	25.570	41.760	15.300	46.990	70.000	41.760
C1	367.200	900.000	18.380	20.040	48.950	12.240	38.030	65.000	48.790
C2	115.000	400.000	39.770	47.730	86.360	5.750	15.610	26.000	86.360*
C3	175.100	600.000	32.880	42.420	73.180	7.150	20.760	30.000	73.180*
C4	190.000	600.000	31.820	36.360	68.180	7.760	22.530	35.000	68.180*
D1	207.000	600.000	26.700	34.820	64.080	8.450	24.540	58.000	64.080*
D2	177.200	420.000	24.690	32.920	63.090	8.650	23.660	58.000	63.090*
D3	467.400	460.000	16.320	19.990	31.000	22.210	60.550	78.000	31.000
ISO									50.000

*PPV that exceeds the maximum of 50 mm/sec. as recommended by the ISO

The vibration data gathered from the four quarry sites were imported into the Slam Stick X software for analysis, and sections of their Fast Fourier Transform (FFT) at the point of maximum vibrations are shown in Figures 2 to Figure 5 for each of the quarry sites.

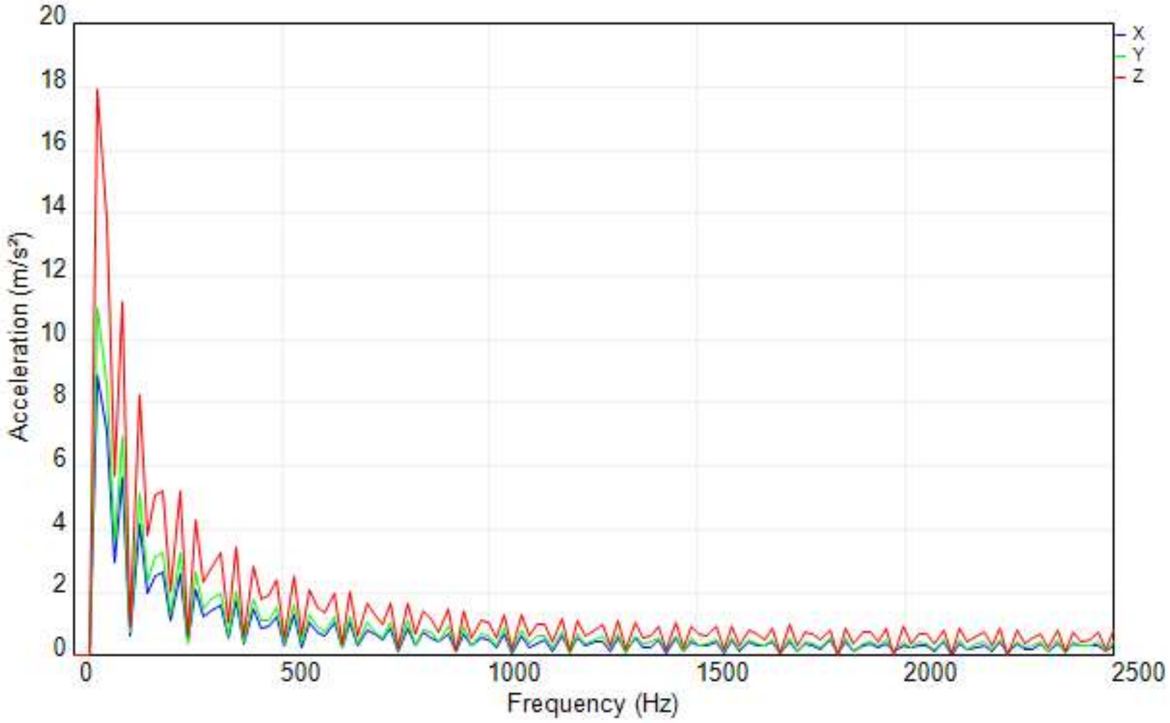

Figure 2: *Acceleration versus frequency from section of FFT for Shot 1 in Site A*

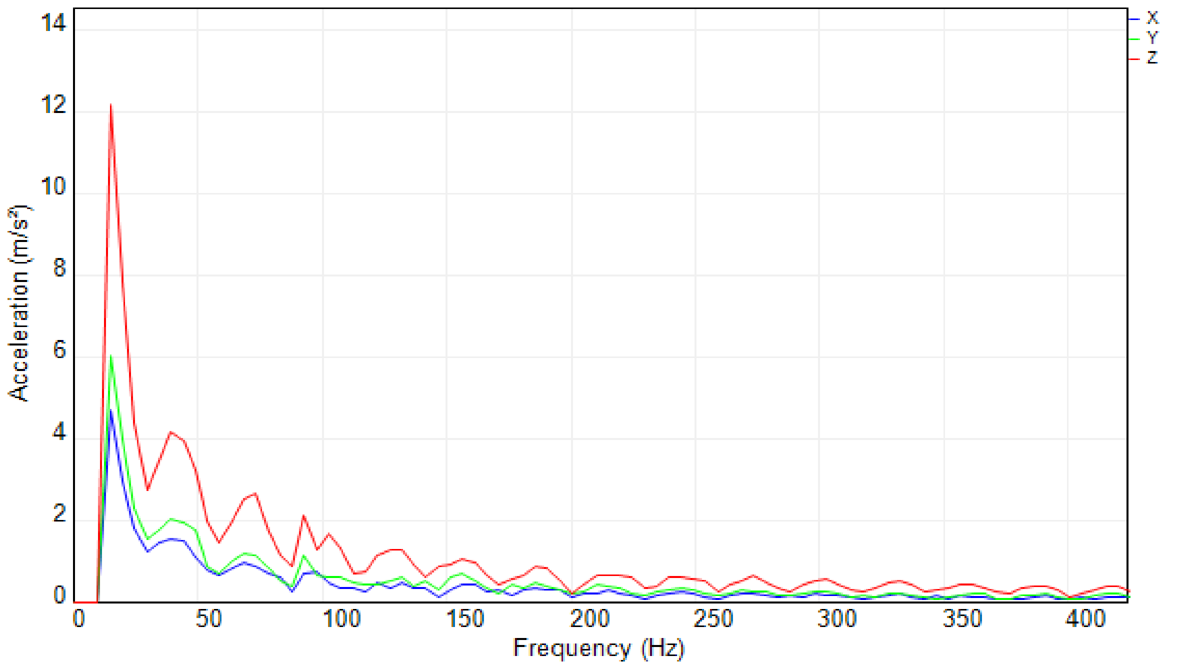

Figure 3: *Acceleration versus Frequency from Section of FFT for shot 1 in Site B*

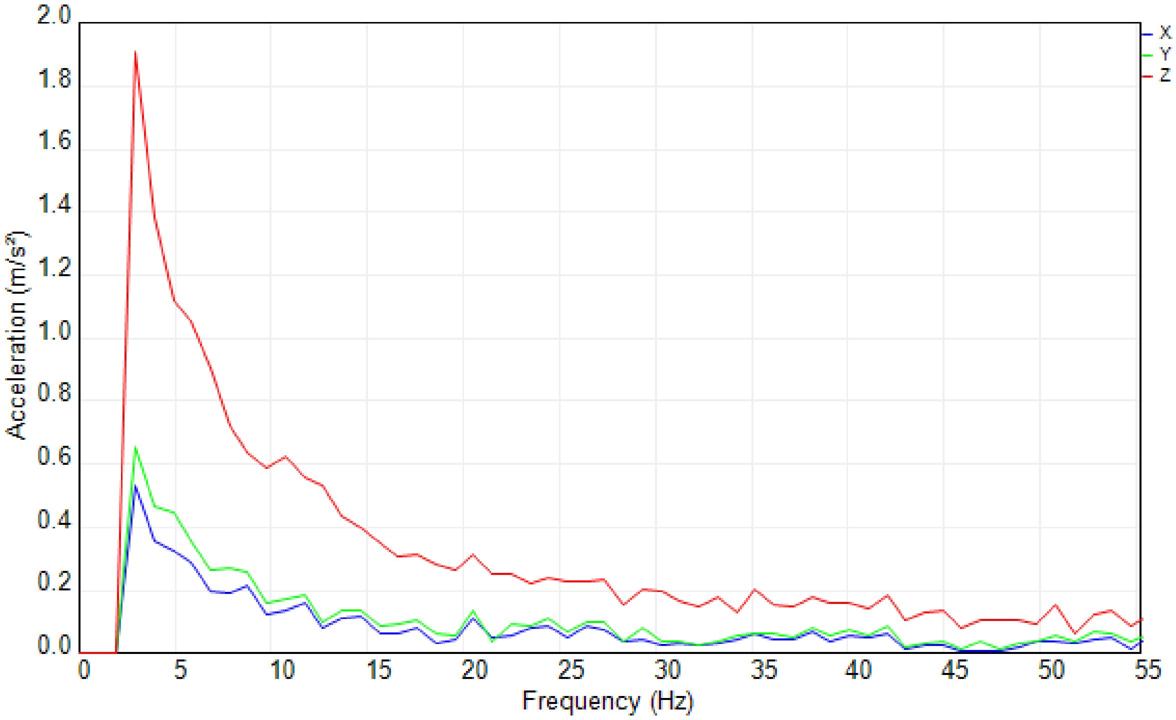

Figure 4: *Acceleration versus Frequency from Section of FFT for Shot 1 in Site C.*

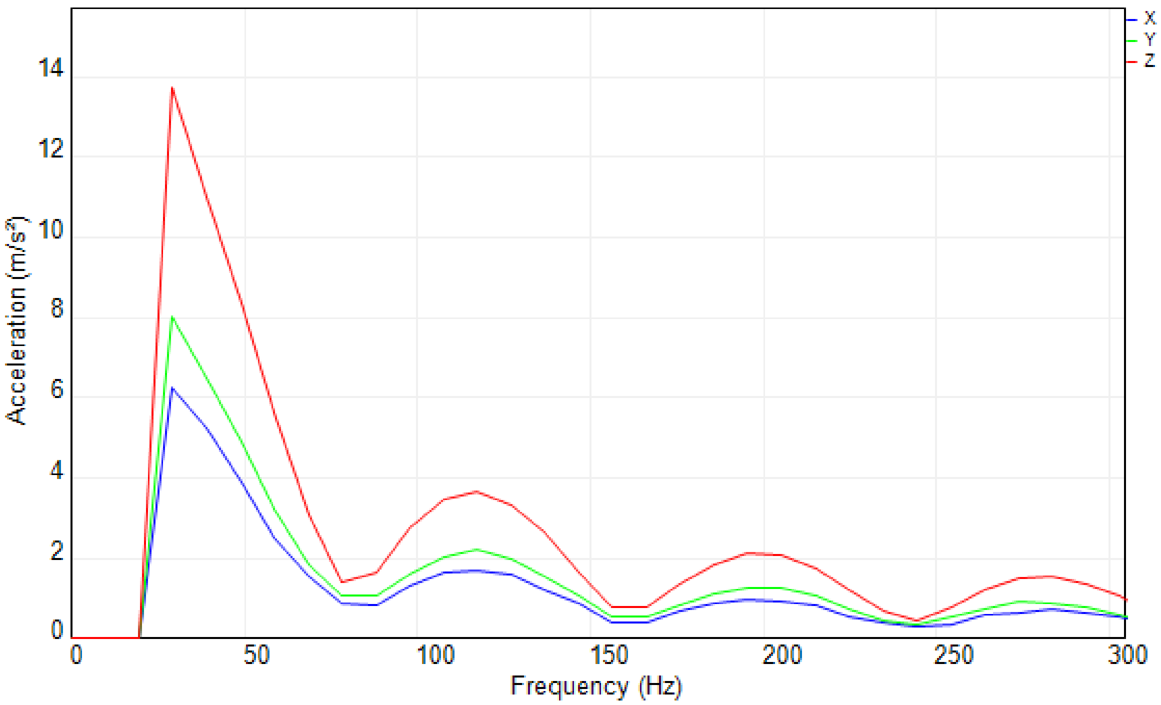

Figure 5: *Acceleration versus Frequency from Section of FFT for Shot 2 in site D*

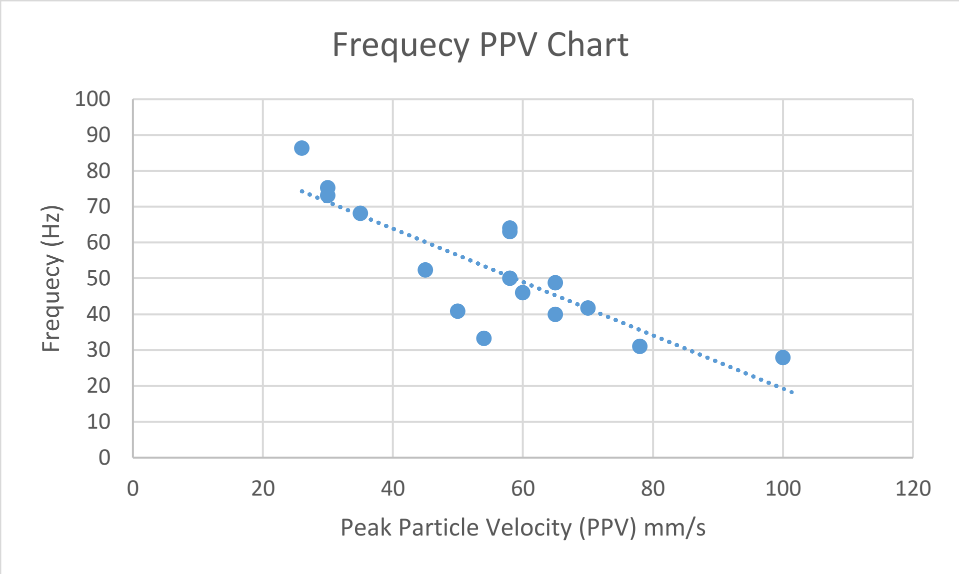

Figure 6: *Plot of PPV against frequency*

3.5 Discussion

The vibrations in the four quarry sites designated A to D were monitored and sections of their Fast Fourier Transform (FFT) at the point of maximum vibration were generated, from which the PPV and the frequency of each blast was deduced. The results from blast reveal that 37.50% of the blast initiated PPV that exceeded the maximum acceptable threshold of 50 mm/s recommended by the International Organization for Standard (ISO). This is likely responsible for the cracks in buildings and structural failure witnessed in the study areas while 62.50 % were below the recommended standard. From Table 3, it can be deduced that site C experienced the worst blasting practices, while site B experienced the best blasting practices when compared to ISO threshold. Table 1 shows that the maximum displacement of particles was along the Z axis for all of the blasts monitored, while the least displacement was along the X axis. This is also corroborated by Figures 2 - 5. Figure 6 shows a plot of PPV against frequency, indicating an inverse trend between both parameters. Table 2 shows the various deductions from Figures 2 – 5.

Table 2: *Features and Inferences from FFT Accelerometer Results*

Stations	Frequency range	Maximum acceleration	Inferences
Station A	0-2500 Hz	18.4 m/s^2	Minor reverberation
Station B	0-400 Hz	12.1 m/s^2	Increased geological damping.
Station C	0-55 Hz	1.95 m/s^2	Competent rock and optimal blast design parameters.
Station D	0-300 Hz	13.35 m/s^2	Persistent measurable amplitude, indicating either reduced overburden thickness at site D or higher energy release rate.

4. CONCLUSION

The adverse impact associated with unregulated blasting operations can be ameliorated by ensuring strict adherence to appropriate blast design principles. This is essential to preventing the numerous negative consequences commonly linked to quarry blasting activities. The mine Inspectorate (MI) and the Mines Environment and Compliance (MEC) Directorates of the Ministry of Solid Mineral Development (MSMD should be adequately equipped to assess peak particle velocity (PPV) and air quality during both routine and unscheduled site inspections. Implementing these measures will promote environmental sustainability and operational safety. Furthermore, blast hole parameters should be carefully designed and optimized to minimize blast induced vibrations. Near field records are dominated by low frequency, resulting in high amplitude motion. Progressive distance increase results in exponential reduction of amplitude and severe suppression of frequencies within the range of 50-100 Hz. Blast design and local surface condition can significantly alter the high frequency content. The empirical PPV frequency relationship constitute a robust site specific calibration dataset that can be directly incorporated into vibration prediction models, damage criteria assessment and regulatory compliance evaluations.

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CONFLICT OF INTEREST

No conflict of interest was declared by the author.

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