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The effect of mine blasting on nearby structures, A case of Octea Mining Limited, Sierra Leone

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Abstract

Rock Blasting is an essential and critical tool used in mining operation in which it primary aim is to fragment the rock and expose the desired mineral from the waste rock. Ground vibration stimulated by blasting is a severe environmental issue in Sierra Leone mines. The level at which it can minimize ground vibrations has been studied by varying the ditch depth. Thus, there is a need for such research. This paper presented an integrated program case study operations on the impact of blasting on nearby structures. The computational 3D model using ANSYS LS-DYNA software was employed. In the numerical simulated 3D model, a ditch was created between the blasting hole and the structure, which was strongly anticipated to reduce ground vibration further. The results demonstrated that the reduction percentage largely depends on the ditch depth to blast hole depth ratio. At a ratio between 1.0 and 1.4, which seems practicable, the vibration was drastically reduced by 62-66 percent. The findings will help in formulating and mitigating environmental issues related to blasting.

Keywords: Rock Blasting, Ground Vibration, Ditch, Vibration Reduction/Control, Structures

1. Introduction

The use of explosives in mining and construction activities is nearly every day. Blasting is one of the most effective methods for rock excavation. Recent products and new blast style studies can keep the favorite technique for the next decades(Iramina et al., 2018). Even though the method is dependable and economical, explosives must touch upon some environmental shortcomings. Since many mining sites area unit enclosed by individuals, some of the blasting results, like noise and ground vibration, are also considered annoying or perhaps a threat. This is due to the questions that always emerge about blast vibration impacts and explicitly about whether vibrations can or might have caused damage and other harm in homes and different structures. The suitable response relies mainly upon vibration levels, frequencies and less significantly on location and structure-specific factors. Inhabitants notice and react to vibration at levels much lower than the levels developed as structural damage thresholds(Ak, Iphar, Yavuz, & Konuk, 2009; Kuzu, 2008).

Previous studies have shown that continuous blasting vibration on structures has diminished human resistance to its impact(Gou et al., 2020; Heath, Wilson, & Gad, 2015). To understand how these three factors control the response of a structure and how a house vibrates, one can think more about the continuum-based methods such as mesh-based methods(The Finite difference Method (FDM) and the finite element method (FEM), discrete particle methods (such as the discrete element method (DEM) and hybrid FEM-DEM methods(Heath et al., 2015) (Wang et al., 2007; (Heath et al., 2015)(Gao et al., 2017; Saiang, 2011);). However, continuum-based methods (FEM) often fail to simulate crack, fragmentation, and large deformation of rock mass (Lisjak, Figi, & Grasselli, 2014; Wu, Liang, & Liu, 2015; Zhou et al., 2019).

Therefore, there is a need for improvements in blast vibration impact to contribute and ensure the safety of blasting engineering in structures. In the current study, ground vibrations induced by bench blasting from the Octea Mine site were used as a referenced case to evaluate the damage risk on structures and to find out the site-specific reduction techniques through numerical simulations.ANSYALS-DYNA was employed in the study to simulate a 3D model in which a ditch with varying lengths was created between the blast and the structure.

In West Africa, studies have been investigated the responses of building to blast in several countries. For instance, In Ghana,Bansah(Bansah, Yalley, & Dumakor-Dupey, 2016)studied the main effect of blasting on residents or communities around the blasting areas.Also, Amel et al. (Amel Ezzeldin) carried out studies on the environmental aspects of Mining and Related Industrial Activities.Studies conducted by Niminyi et al.(Niminye et al., 2016) aim to reduce vibration by opening artificial discontinuities such as presplitting, barrier holes, and trenches. Precisely, there is a lack of literature on the response of structural damages during near-field blasting, especially in Sierra Leone, West Africa. There is a need for a novel study to understand the ground vibration impact and structures. Therefore, such research is fundamental and timely in Sierra Leone.

This research work is i) to develop and design a 3D model using ANSYS LS-DYNA software package to help tackle or minimize blasting vibration impacts on structures situated nearby mining sites. (2) to suggest measures for the effective control of ground vibrations due to blasting at Octea mining Limited, and (3) to highlight possible recommendations to vibration reduction on structural damage.

2. Materials and Methods

2.1 Description of Study Area

Koidu Holdings is a mining company that is focused on diamond explorations. The company mining operation rested on the kimberlite project situated in the historically productive diamond fields of Eastern Sierra Leone, a country found in West Africa.

The Koidu Kimberlite project is located within the Tankoro Chiefdom of the Kono District in the Eastern Province of Sierra Leone. It is approximately 2km south of the district capital, Koidu, and about 330 Km East of Freetown, the capital city. The study area general overview Map is shown in figure 1.

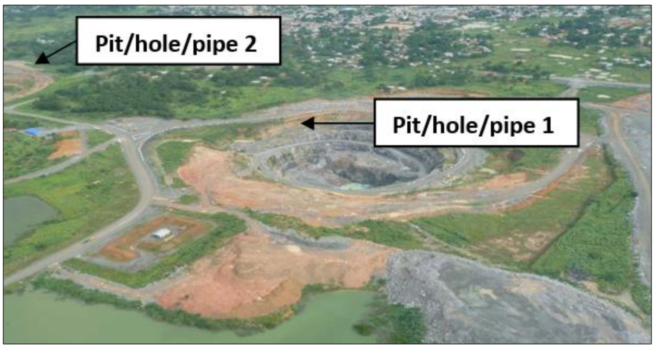

Fig 1: General View of The Koidu No.1 Pipe/Hole Vertical Pit

2.2 Methodology

The simulation was carried out with real circumstances of an open-pit mine. A computational 3D model of dimensions 320m x 40m x 50m in size was used. A free face was created with a bench height of 7 m. The hole diameter was 115mm with a distance of 4 m (burden) from the free face was also considered. The stemming length is 3m, bearing in mind that explosive detonation commonly spreads in the rock mass as seismic waves. Few Other parameters were distorted to save computing time and improve the accuracy of the numerical results. Specific simulation points were selected at a particular distance away from the blasting hole.Vibrations were measured at diverse points at a spacing of 6.0 m between the points. The bottom, top, and side of the model were set as the non-reflection boundary.

The parameters used in this model are those proposed from the full-scale single hole blast that was carried out at the Koidu Limited Mine site. Once the fundamental geometry was created, the subsequent procedure was to apply the blasting load on the blast hole walls.

The standardized model was employed to study the level of reduction in ground vibration due to varying ditch depth. Figure1 shows the edge line 3D Model with all the proposed parameters (i.e., blast hole, ditch, structure, and rock).

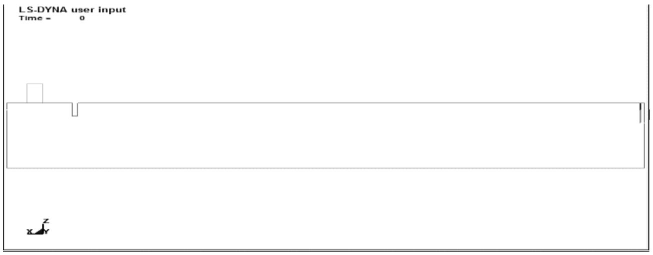

Fig 2: The edge line 3D Model

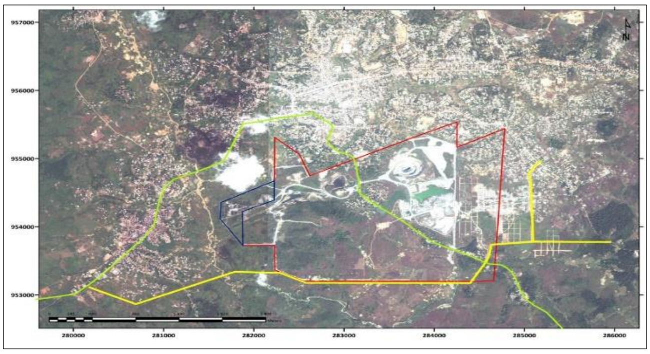

Fig 3: Quick Bird Satellite Image Illustrating the Closeness of Koidu Town to the Koidu Mining Lease Area.No.1 Pipe and No.2 Pipe is connected with Dyke Zones A And B,Bothof which are Evident along Strike that is Resulted to the Remains of Small Scale Work

The diamond field in the study area comprises the undulating coastal plains and the dissected margins of the inland plateau, which are delimited by the broad valleys of the most important rivers. In the studied area, approximately 0.36km^2 of the mining rent is covered by a famous hill called Monkey Hill.

There are three villages close to the work area, and production direction is towards them. Blast-induced vibrations cause environmental problems. It aimed to observe the efficiency of numerical simulation by varying ditches/trenches, yielding results used to reduce basting vibration on structures.The mechanical properties of therocks are given in Table 1.The open-pit mining method with bench blasting is employed for both the ore and the waste rocks using theexcavator–truck system. The pre-split usually is conducted to improve the bench stability.

Table 1: Joint Rock characteristics

Joint set	Dip Direction	Dip Angle (^{0})
1	308	80
2	081	87
3	200	88
4	282	83

3. Result and Analysis

Numerous structures were closed to the Koidu Limited Mine site, two of which were identified for damages studies. Surface structures that are located nearby the mine site were chosen by the geological and survey department to investigate the study of the damage. The selected designs are RC Primary School and the New Sembehun Association (NSA) that were constructed several years ago. The blasting faces at the mine were progressing towards the structure.

The first structure encompasses a small room and a hall with a height of 3.1m. The structure had metal steel (Aluminum), a pyramid roofing design with a 250mm thick brick wall. The second structure also consisted of a small room with dimensions (2.20m by 2.0m) and a hall measured (3.8m by 3.85m) with a height of 3m. The roof of the wall has a tile concrete clay sheet. The wall thickness was 300 mm, made of bricks, plastered with cement and sand mixture.

The blasts were carried out at different benches, and pre-split blasting was employed. The borehole diameter, hole depth, burden, spacing, number of holes detonated, explosive quantity, and delay interval were some of the investigated studied parameters. The blast holes were initiated by detonating cords. Extensive seismic arrays were used to mark out the vibrationcharacteristics at near-field and far-fields. The different types of parameters investigated in the studies are shown in table 2 below.

Table 2: A summarize blast design parameters of the experimental site

Blasting parameters	Koidu Limited site
Burden (m)	4.0
Hole Diameter (mm) Bench Height (m)	115 7.0
Spacing (m) Spacing: Burden Ratio Sub Drill (m) Stemming length (m) Column Length (m) Blast Hole Length (m)	6.0 1.20 0.5 3.0 4.5 8.0
Hole inclination Explosive Type	Vertical R100GEmulsion
Initiation system	Detonating fuse
Charge mass per hole(kg)	28.7
Explosive density	0.72-0.8g /cm^3
Detonation sequence	Hole-by –hole
Initiation pattern	Staggered (square V)
U117E charging unit capacity	1,500kg
Primer (Booster)	400g

During the simulation processes, changes to the model can be made, making it much easier to solve problems. Fractions of the modified area of the model can be added and removed during the simulation processes. The solution can be obtained from that point, which makes it productive in getting accurate results. The dispersed and shared memory solver offers brief spin periods on desktop computers and clusters operations using windows programs. In obtainable results from the ANSYS solver for both pre and post-processing, LS-DYNA typically comes with the LS-PrePost tool. The LS-PrePost can be utilized to generate inputs and visualize numerical results. The software package can simulate blast wave propagations using the Jones-Wilkins –Lee (JWL) equation of state (EOS) found in the LS-PrePost.

The basic assumption in this model is that particle shapes are arbitrary, any particle may interact with any other particle, and there are no limits placed on particle displacements or rotations.

Various parameters usually are employed or consider in the model creation. For this particular section, the materials in the model need to be defined. The materials used in the simulation process are described in table 3 as follows

Table 3: Defined Parameters used in the model

Part	Model	Material
1	Clogged hole	Plastic kinematic
2	Explosive hole	High explosive Burn
3	Rock	Plastic kinematic
4	Structure	Plastic kinematic

3.1 Mechanical Properties of the Rock Mass

The rock mass properties usually are presiding over by the properties of intact rock materials and the discontinuities of the rock. Suppose the conditions of the rock influence the rock mass are subjected to, principally the in situ stress and groundwater. As the case may be, the noticeable rock assemblages in the studied area are: Granite, Granodiorite, Gneiss, Quartzite, and dolerite sill were all unspecified to have elastic properties for this purpose. *MAT-PLASTIC KINEMATIC and MAT-HIGH-EXPLOSIVE BURN* seen in table 3 were chosen as the material model for the blasting simulation. The kinematic theorems for elastic-plastic from the materials model are usually for nonlinear kinematic hardening solids. The materials model comprises the following; tensile stress and strain curves in which the density, strength, and modulus of elasticity were all considered and summarized in Table 4 below.

Table 4: Rock mass properties

Rock Type	Matrix Density (g/cm3)	Compressive strength /Mpa	Flexural Strength (Mpa)	Tensile strength /Mpa	Abrasion Strength (cm^3/50cm^2)	Young's Modulus static (Gpa)	Porosity
Granite	2.62	183.7	19.7	10.6	4.7	28.0	0.59
Granodiorite	2.8	222.0	21.0	12.8	7.1	30.6	0.25
Dolerite Sill	2.99	358.1	49.72	17.87	2.55	27.1	0.05
Gneiss	2.67	194.6	19.1	10.9	4.5	29.2	0.16
Quartzite	2.69	174.5	28.3	13.8	8.4	28.5	0.18

3.2 Explosive modular properties

The emulsion explosive was the proposed explosive used; this is comparatively due to its high detonation parameters and its excellent safety characteristics. The Jones-Wilkins – Lee (JWL) equation of state parameters for emulsion-type explosives has been obtained from cylinder test expansion measurement. A realistic approach to the numerical modeling of an emulsion explosive and its interactions with, for instance, rock is to record the equation of state parameters sets for an adequately acceptable range of densities, diameters, and detonation velocities. Because these features are generally recognized for a specified blasting application (for example, the detonation velocity is simply calculated on-site for the actual diameter, density, and nearby rock), the final design can be attained by choosing a parameter set of the same composition, with features and test characteristics as close as likely to the ones for the explosive in the application of interest.

3.3 JWL Calculation Parameters

The JWL equation of state is usually used in explosive modeling to define the pressure-volume –energy connection of the detonation pressure products; it is an empirical character, with several parameters that permit flexible calibration from experimental data initial and large extensions.

The JWL expression is:

$$P \;= A\left(1-\frac{\omega}{R_1 V}\right)e^{-R_1}V \;\; + B\left(1-\frac{\omega}{R_2 V}\right)e^{-R_2}V \; + \frac{\omega E}{V}(1)$$

From the expression above, E is the Energy, V denotes the volume, and A, B, R_1, R_2 and $\omega$are explosive constant to be resolute. The above equation is obtained from the pressure-volume expression for the detonation products of isentrope and Gruneisen –type expansion.

Table 5: The JWL equation of state parameters for Emulsion Explosive (BME) Calculations

Density	**Velocity**	**Pressure**	**JWL-equation of state parameters**					
ρ0 [kg/m ^{3}]	[m.s^{-1}]	Gpa	A [GPa]	B [GPa]	R $_1$	R $_2$	ω	E 0 [GPa]
1250	3600	8.127	849.560	16.679	6.849	1.660	0.42	3.377

3.4 Structural Modular Properties

Many factors influence the properties of concrete structures. This is principally due to the mixed proportion of cement, sand, aggregate, and water. The ratios of these materials usually impact the life of the structure and influence the blasting vibration. The proposed model structures consider the following presumptions as to the structural properties.

Table 6: Structure properties

Typical composition by volume	**Percentage strength**
Cement	7-15%
Water	14-21%
Aggregate	60-80%

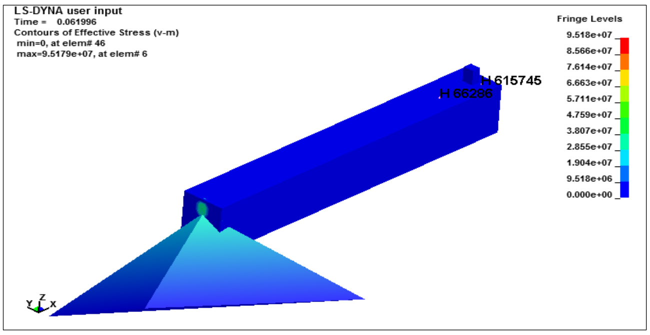

Fig 4: 3D model with 0m

The visualization of a 3D model with 0m Trench depth was clearly demonstrated in figure 4 above. The wave propagation spread out from the source at a faster rate to the building. Therefore, the varying depth of trenches is necessary for the effective control of ground vibration erupted from surface mine blasting.

3.5 Computation of Vibration for Different Ditch Conditions

To ascertain or establish the extent of reduction in ground vibration due to ditch techniques,model studies were conducted for four different 3D blocks in which the first model was created without a ditch, and the other three models have ditch with depths of varying length, i.e., 10m,16m and 22m respectively. The Ditch depth values are designated as (T), and the blast hole depth is also chosen (H). In the first establishment, a 0m ditch with a diameter of 115mm and structure was created in the calibrated model at a random distance of 300m behind the blast hole that was several meters away from the monitoring points, as shown in figure 1. And subsequently, the other models were also developed by keeping the blasting hole constant and then varying the ditch depth.

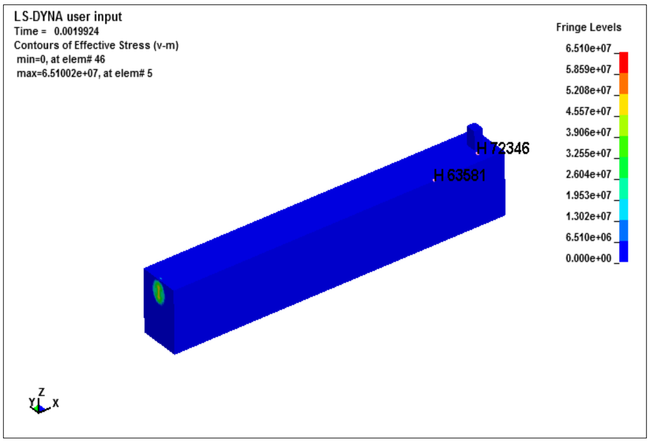

Fig 5: t =19924 we wave propagation at 0m Ditch depth

Figure 5 shows a conceptualized 3D model in which the ditch/Trench depth was put at 0m, and the other parameters were kept constants. The 0m ditch depth does not show any significant impact in the ground vibration reduction measured analysis.

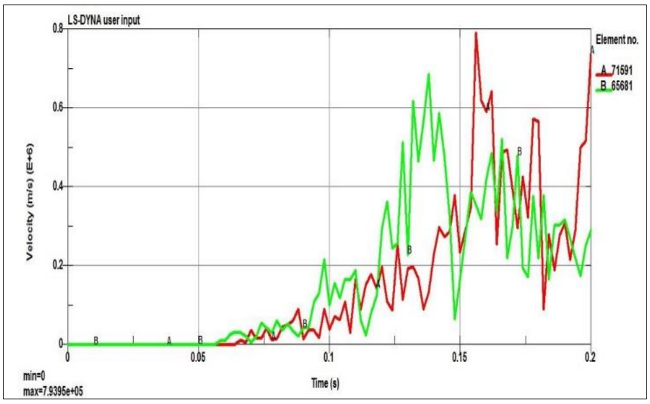

Fig 6: Generated vibration histories at two locations with a 0m ditch depth

The graph of the velocity (m/s) against time (s) for the 0m ditch is shown in Figures6 above. The generated vibration histories indicated two waveforms, A and B. As seen from the figure, point A is represented by the red curve line, and The green curve line depicts b. The simulation points are obtained from the 0m ditch depth wave propagation. The recorded minimum and maximum points are 0m/s and 7.9395m/s, respectively. The maximum velocity was used for the vibration reduction calculation.

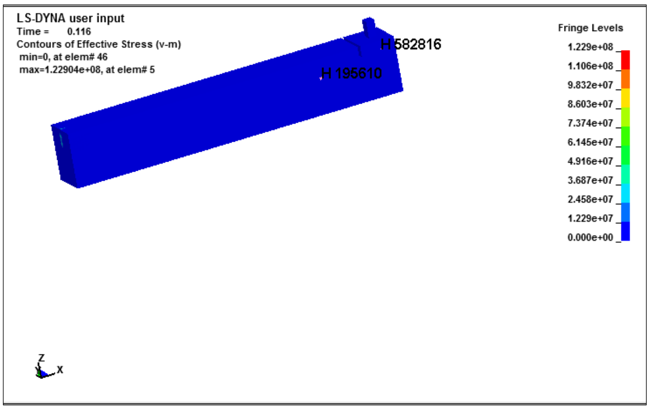

Fig 7: t =166us wave propagation at 10m Ditch depth

A theorized 3D model in which the ditch/Trench depth was put at 10m is shown in Figure7, and the other parameters were unchanged. The 10m ditch depth based on the measured, calculated data impacted the ground vibration reduction measured analysis.

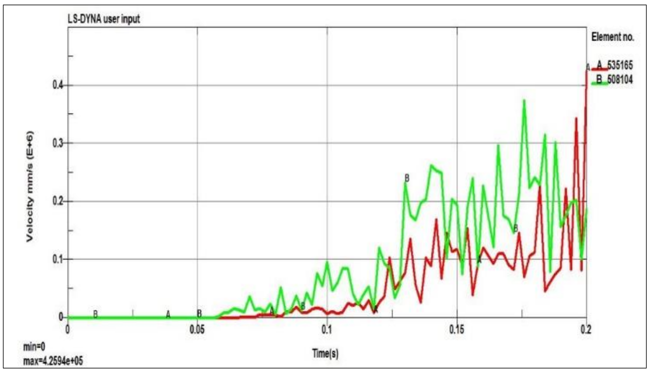

Fig 8: Generated vibration histories at two locations with a 10m ditch depth

The plot of the velocity (m/s) against time (s) for the 10m ditch is presented in Figure8 above. The vibration generated histories specified two waveforms, A and B. As realized from the figure, points A and B are represented by red curve lines and green curves lines. These points were obtained from the 10m ditch depth wave propagation. The observed minimum and maximum points were 0m/s and 4.2594m/s, respectively. The maximum velocity was used for the vibration reduction calculation.

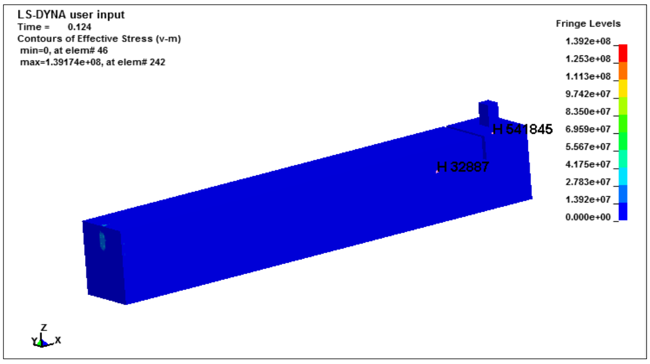

Fig 9: t =124 wave propagation at 16m Ditch depth

The hypothesized 3D model in which the ditch/Trench depth was put at 16m is shown in Figure 9, and the other parameters were unmodified. The 16m ditch depth demonstrated a more significant influence in the ground vibration reduction calculations.

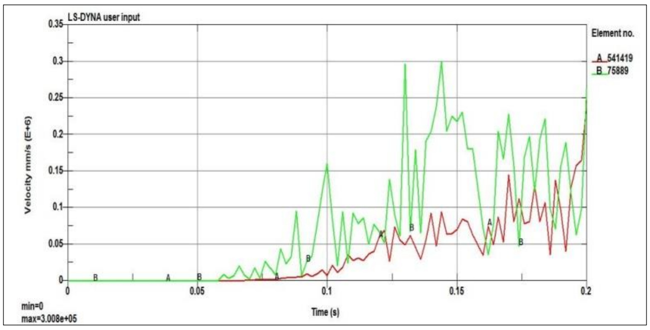

Fig 10: Generated vibration histories at two locations with a 16m ditch depth

Figure 10 shows the velocity (m/s) plot against time (s) for the 16m ditch. The vibration generated two waveforms, A and B stated histories. As apprehended from the figure, points A and B are represented by the red curve and green curve lines. These points were obtained from the 10m ditch depth wave propagation. The observed minimum and maximum points were 0m/s and 3.008m/s, respectively. The obtained maximum velocity was used for the vibration reduction computations.

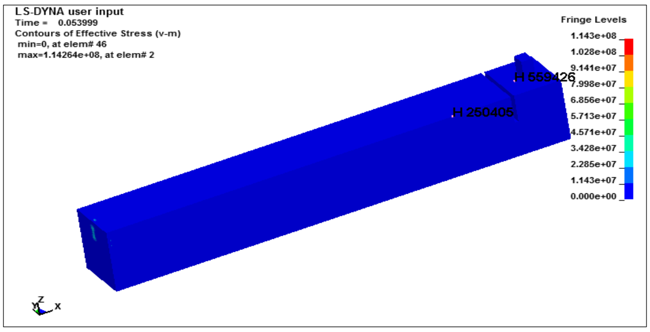

Fig 11: t = 53999wave propagation at 22m Ditch depth

The postulated 3D model in which the ditch/Trench depth was put at 22m is shown in figure 11, and the other parameters were kept constants. The 22m ditch depth demonstrated a greater influence in the ground vibration reduction measured analysis and it was best fitted for this research findings.

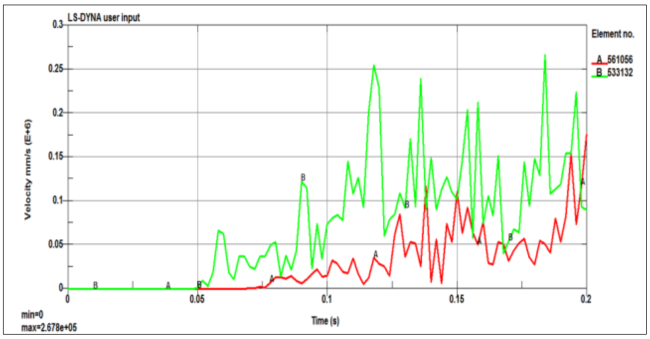

Fig 12: Generated vibration histories at two locations with a 22 m ditch depth

A plot of the velocity (m/s) against time (s) for the 22m ditch depth is shown in figure 12. Two waveforms, A and B, indicated the generated vibration histories. As captured from the figure, points A and B are represented by red curves lines and green curve lines. These points were obtained from the 22m ditch depth wave propagation. The experiential minimum and maximum points were 0m/s and 2.678 m/s, respectively. The maximum velocity got was used for the vibration reduction calculations.

4. Numerical Results and Discussions

The model studies supported that ditches do reduce the vibration impact on strictures. Table 7 elucidates the results from the model studies. It can be concluded that the reduction in vibration level is strongly connected to the depth of the ditch, and concerning this, the maximum efficiency of a ditch usually is the T/H ratio which lies between 1.0 and 1.4. The T/H ratio of 1.0 is approximately 66%. It is worthy to note that digging a parallel trench instead of deepening it to twice the blast hole depth is much better and profitable.

Table 7: Summarized results from the studied model

Depth of Ditch T (m)	Hole Depth H (m)	Ratio T/H	3D model Maximum velocity (mm/s)	Percentage reduction %
0	15	0.0	7.9396	-
10	15	0.6	4.2590	46
16	15	1.0	3.0080	62
22	15	1.4	2.6780	66

From the summarized table 7 shown above, Percentage reduction can be calculated as thus:

$$Percentage\ reduction\ (PR) = \frac{Initial\ velocity\ max. - Final\ velocity\ max.}{Initial\ velocity\ max.} \times 100 \quad (2)$$

For Ditch Depth of 10m
From Table 7
Initial velocity maximum =7.9396
Final velocity maximum = 4.259
Therefore, the percentage reduction for Ditch 10m is expressed as thus;

$$Percentage\ reduction\ (PR) = \frac{Initial\ velocity\ max. - Final\ velocity\ max.}{Initial\ velocity\ max.} \times 100 \quad (2)$$

$$PR = \frac{7.9396 - 4.259}{7.9396} \times 100 = 46\%$$

For Ditch Depth of 16m
From Table 7
Initial velocity maximum =7.9396
Final velocity maximum = 3.008
Therefore, the percentage reduction for ditch 16m is expressed as thus;

$$Percentage\ reduction\ (PR) = \frac{Initial\ velocity\ max. - Final\ velocity\ max.}{Initial\ velocity\ max.} \times 100 \quad (2)$$

$$PR = \frac{7.9396 - 3.008}{7.9396} \times 100 = 62\%$$

For Ditch Depth of 22m
From Table 7
Initial velocity max =7.9396
Final velocity maximum = 2.678
Therefore, the percentage reduction for ditch 22m is expressed as thus;

$$Percentage\ reduction\ (PR) = \frac{Initial\ velocity\ max. - Final\ velocity\ max.}{Initial\ velocity\ max.} \times 100 \quad (2)$$

$$PR = \frac{7.9396 - 2.678}{7.9396} \times 100 = 66\%$$

Note: The initial velocity values were kept constant while the final velocity varied. The values for both initial maximum and final maximum velocity were obtained from the velocity-time graph of each ditch depth.

From the above calculations, it was observed that the percentage reduction increases as the depth of the ditch were increased. Numerous researchers have employed this technique in their studies, and the conclusion drawn from their findings was that the reduction in vibration intensity increases as the ditch depth was increased (Champion Reefs, September 2005), (A.J.Prakash, 2009).

In summation, therefore, the results from the model studies are at per with the field experiments and hence prove to be a reliable and cost-effective tool to resolve the vibration reduction problems.

5. Conclusion

Problems. We have found out the effect of blasting on nearby structures in Koidu city, Sierra Leone. Numerical analysis using ANSYS LS-DYNA software was employed to carry out such studies.A ditch with varying lengths was created between the blast and the monitoring location (residence or structures) based on the research. The percentage reduction of blasting vibration increases as the ditch hole was increased from the results and analysis. And this concept of varying the length of ditches may significantly reduce ground vibration.

The ditch depth (T) to blast hole depth (H) ratio was vital for the percentage of vibration reduction.

The above results and the conclusions drawn from these investigations are safe to be made following the literature reviewed. The results of the model studies were similar to those of field studies. They are also found to be consistent with what other researchers have previously studied. In summation, the set objectives of this paper were accomplished.

6. Recommendations

The mine administration must monitor ground vibration for all blasts that are carried out close to surface structures and ensure that vibrations are within the permissible levels. The vibration will not cause any damage to inhabited structures. And local bye-laws on mining must be fully implemented.

7. Acknowledgments

Researchers acknowledged Koidu Holdings Limited for their support during the site visitation

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