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Numerical Evaluation of Vibration Induced by Explosive Blasting in the Bauxite Mines of Sangarédi, Guinea

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

During rocks blasting by explosives in mines and quarries, Vibration phenomena appear in the surrounding environment, often causing significant damage to neighboring structures such as: buildings, bridges, tunnels and dams. This is why mining companies using the technique of the explosion are often faced with constraints of limiting the vibration level in order to minimize or eliminate potential damage to neighboring structures or reduce neighbor complaints.

This paper presents a new numerical prediction model for vibration level induced by explosive blasting in the Bauxite mines of Sangarédi, Guinea. The dynamic damage law is associated with vibration phenomena analyses to determine numerical value of the particle velocities of different points located at different distances from the explosion hole for the explosion of a single charge hole, in order to compare to the vibration level required by the specifications of the Guinea mining company, which authorizes a vibration level of 10 mm/s in an inhabited area. The prediction of the vibration level gives particle velocities of 11m/s at a distance of 10 m from the explosion hole. Based on the results of the model, one could estimate that this required vibration level would be reached at a distance of 80 m from the blast hole.

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1. INTRODUCTION

The observation of the rock blasted reveals the existence of four fragmentation zones [1]: 1-the crushing zone near the explosive in which the rock material is fragmented by shearing and completely transformed into dust, 2-the radial fracture zone again called a multiple fragmentation zone in which pieces or blocks of rock break off and large cracks appear, 3- the simple fragmentation zone in which some cracks appear and 4-elastic vibration zone in which the rock is not damaged but subject to particle vibrations. An estimate of the extent of this area is made in [2]. Thus, the evaluation vibration level in this zone is real concern for mining companies with regard to compliance with international standards. Therefore, an appropriate explosion technique is necessary to ensure the safety of mine employees and the protection of nearby infrastructure from the effects of vibrations. This vibration problem has been investigated by many scientific researches. The environmental effects of explosive blasting have for example been studied in [3]. The discussion of the parameters used in the empirical expression of the blasting vibration velocity has been made [4].

Others researcher state that to assess explosion safety, considering only particle velocity as the only indicator for measuring the intensity of the explosion does not accurately reflect the destruction that can occur in structures, because the seismic wave frequency, vibration duration and other factors were not taken into account [5]. To take into account all these factors [6] proposed explosion vibration analysis by wavelet energy packet method.

Predicting undue vibration peaks in rocks during blasting is one of the basic problems in explosives design. The vibration intensity due to the explosion in rocks is often described by the peak vibration velocity for a given particle, peak vibration velocity (PVV). This quantity is used as a measurement of vibration intensity and control of degradation parameters.

Empirical formulas have been obtained from in-situ measurements in explosive firing ranges and are widely used throughout the world due to the enormous difficulties associated with the use of numerical or theoretical analyzes of explosion phenomena and processes in the rocks [7,8]. In order to have an accurate prediction the Blasting Vibration Velocity (BVV) several studies use a large number of qualification factors such as: the diameter of the borehole (diameter of the explosive) [Gao et al. [8]], the topography of the terrain [9], the surface of the rock [10] and the nature of the rock mass [11].

Other authors have used more than 11 parameters in addition to those mentioned above in BVV prediction research using the natural network method as in [12]. Obviously, the more parameters make it possible to quantitatively describe the explosion and the observation conditions and the more accurate they are, the closer the predicted value is to that observed in-situ and the degree of correlation becomes better. A large number of analysis, result of the measured data indicates that the BVV can be expressed as a function of the load weight the distance from the rock mass, the properties of the soil along which cross the waves of the explosion and the conditions of the observation point [13,14]. The world-famous particle velocity prediction equation is established in [15]. In addition to the quantity of explosive used and the distance between the location of the explosion and the point observation, its formula takes into account site parameters such as structure, topographical, physical and mechanical properties.

This assessment of the vibration level is often made by direct measurements on site through vibration measuring devices. Proper numerical prediction model for vibration level induced by explosive blasting is still a topic of current research [16,17].

This paper presents a new model for prediction of vibration level induced by explosive blasting in the Bauxite mines of Sangarédi, Guinea.

2. VIBRATION PREDICTION INDUCED BY EXPLOSIVE BLASTING MODELING IN THE BAUXITE MINES OF SANGAREDI, GUINEA

The purpose of this paragraph is the prediction of the vibration peak induced by explosive blasting on the Guinean bauxite mining sites. The indicator of the degree of vibration induced by explosive blasting is the particle velocity (PPV) peak particle velocity. In this section we will first numerically determine the particle velocities of different points located at different distances from the explosion hole for the explosion of a single charge hole, in order to compare to the vibration level required by the specifications of the Guinea mining company, which authorizes a vibration level of 10 mm/s in an inhabited area. Next, we will plot the curve of the variation of the PPV as a function of the distance scale (D/W). D the distance between the center of explosion and the measurement point (m).

For this purpose, we use the recent dynamic damage model accounting for inertial effects deduced from a two-scale framework analysis developed by [18]. The model implemented in a finite element code had been used to simulate explosive blasting. In this work we associate the vibration component to this dynamic damage model under to evaluate the vibration level induced by explosive blasting in the Bauxite mines of Sangarédi, Guinea.

2.1 Dynamic Damage Model

In [18,19],the dynamic Eq.s of the damage model were established. Based on the asymptotic homogenization schemes and damage evolution from energy release rate analysis the following set of dynamic Eq.s was found
The momentum balance Eq. is:

$$\frac{\partial \Sigma_{ij}^{(0)}}{\partial x_j} = \langle \rho \rangle \frac{\partial^2 u_1^{(0)}}{\partial t^2} \qquad (1)$$

The macroscopic stress expression is

$$\Sigma_{ij}^{(0)} = C_{ij11}(d)\, e_{x11}(u^{(0)}) \qquad (2)$$

Where $C_{ij11(d)}$ is the damaged stiffness tensor defined as:

$$C_{ij11}(d) = \frac{1}{|Y|}\int_{Y_S} \left(a_{ijkl} + a_{ijmn} e_{ymn}(\xi^{kl})\right) dy \qquad (3)$$

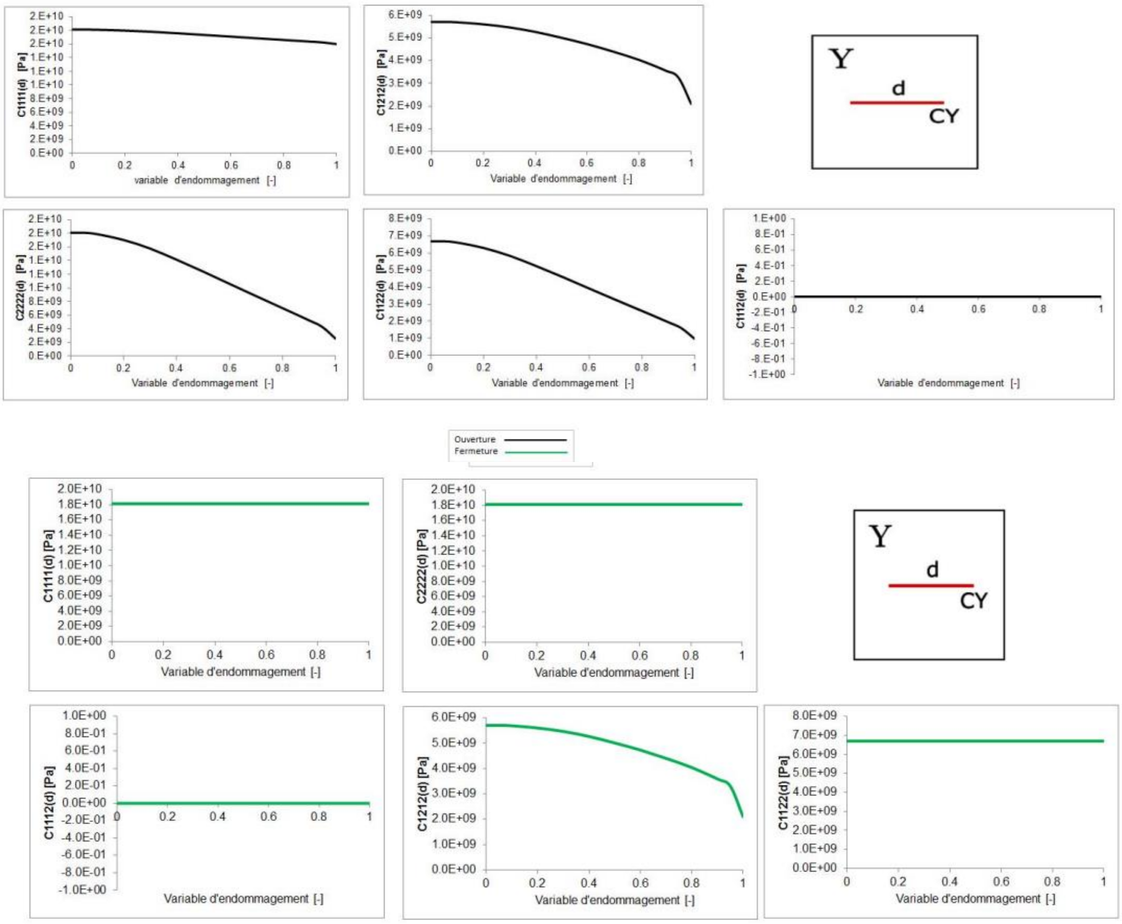

Fig. 1. Homogenized coefficients of bauxite

are the homogenized coefficients, in which ξ^{kl} represents the unit cell mode deformation [20]. From the above Eq.s, the dynamic damage evolution law for vertical and horizontal micro-cracks orientation is:

$$\frac{dd}{dt} = \frac{2C_R}{\varepsilon}\left(\frac{\mathcal{G}_c}{\varepsilon\frac{\partial C_{ijkl(d)}}{\partial d}e_{xkl}(\boldsymbol{u}^{(0)})e_{xij}(\boldsymbol{u}^{(0)})} + \frac{1}{2}\right) \tag{4}$$

2.2 Study of Vibration Movements of a Dissipative System

The dynamic equation which governs the vibratory movements of a system is written as following

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F\} \tag{5}$$

Where $\{u(t)\} = \begin{pmatrix} u_1(t) \\ u_2(t) \end{pmatrix}$ is the degree of freedom of the system, [M] the mass matrix, [C] the damping matrix, [K] the stiffness matrix and {F} the nodal force. In the case of our study, the nodal force vector is random load, because the wave pressure coming from the explosion is a temporal signal. We can also look for the frequency content of this signal using the Fourier transforms. We considered Rayleigh proportional damping in our case. Rayleigh proposes the damping matrix [C] as a linear combination of the mass matrix [M] and the stiffness matrix [K].

$$[C] = \alpha[M] + \beta[K] \tag{6}$$

The constants α and β are determined experimentally. α, dampens the low frequencies and β the high frequencies. The values used in our case are α = 6.30 and β = 0.01([21]). I recall the vibration induced by the explosion is studied in elasticity. This because, we adopted the hypothesis of [22,23] according to which the rock is damaged only in the immediate vicinity of the blast holes. A few meters further the wave generated by the explosion has not sufficient energy to fragment the rock. Its long transmissibility is similar to an elastic wave.

3. BLASTING DAMAGE AND VIBRATION SIMULATION

3.1 Blast Load

The following explosion pressure time history has been considered:

$$P = P_d\left(\frac{d_c}{d_h}\right)^3 \frac{t}{t_r} e^{\left(1-\frac{t}{t_r}\right)} \tag{7}$$

Where d_c , and d_h are the diameters of the explosive and blasthole (mm), respectively. P_d is the detonation pressure ~~(Pa)~~ which is the pressure exerted by the expansion of gases from the explosion. It can be calculated from the following Eq., as suggested by the National Highway Institute (Konya and Walter 1991):

$$P_d = \frac{449.93 \times SG_e \times VOD^2}{1+0.08SSG_e} \tag{8}$$

Where, SG_e is the density of the explosive (g/cm3), VOD is the detonation velocity of the explosive (m/s), t is the elapsed time, and tr (= 0.0003361 s) is the time to reach peak pressure. The value of P_d , d_c and d_h are determined according to the type of explosive. In this study we consider the explosive Emulstar 3000 UG (see Table.2). Fig. 2 shows the pressure time history corresponding to Eq.8.

The numerical parameters used in the simulation are in Table 2.

3.2 Blast Zone Modeling

We have considered a bench blast model in 2D. To obtain a detonation wave pressure and more precise explosion, the geometric model requires a very fine mesh near the blast hole.

Table 1. The characteristic of EMULSTAR 3000 UG

SG_e (kg/m3)	VOD (m/s)	P_d (GPa)	d_c (mm)	d_h (mm)	tr(s)
1.25	5600	9.9	80	165	0.0003361

Table 2. Numerical parameters used in the simulation

$E[Pa]$	$\nu[-]$	$\varepsilon[m]$	$\mathcal{G}c[jm^{-2}]$	$\rho[kg/m^3]$	d_0	θ
$14.5* 10^9$	0.27	$2* 10^{-9}$	107.49	1912	0.2	0

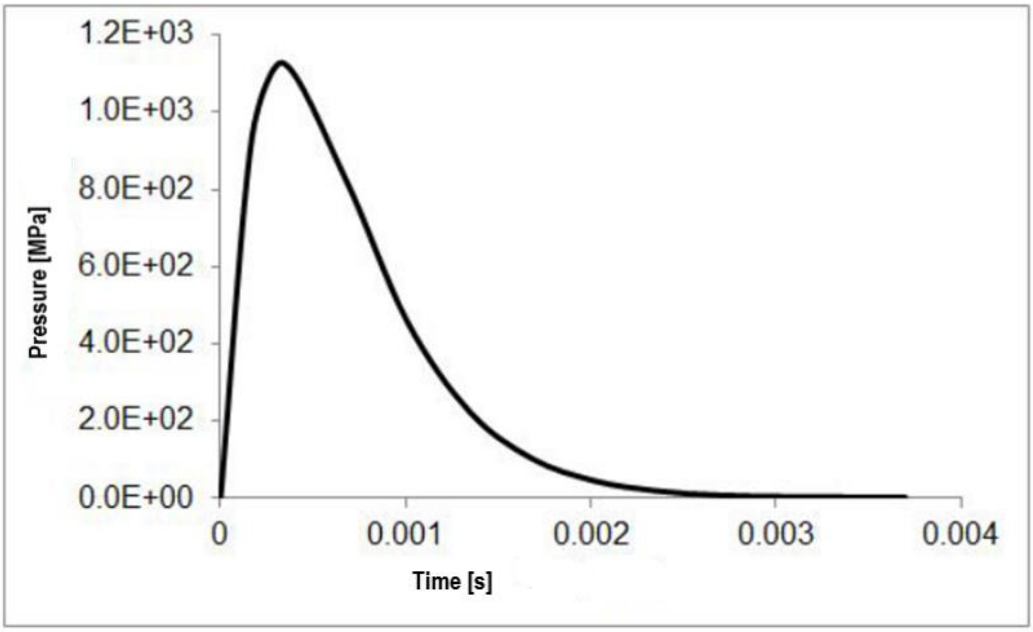

Fig. 2. Blast pressure time history used in the simulations

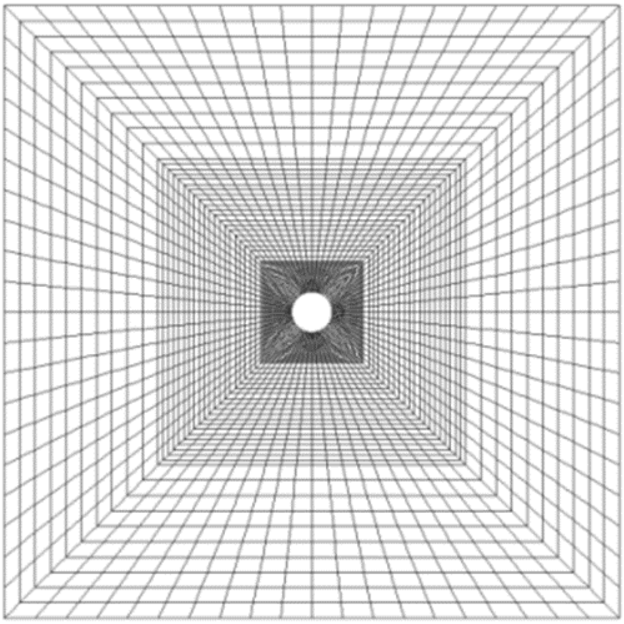

Fig. 3. Blast zone model

4. RESULTS AND DISCUSSION

4.1 Numerical Results

We first show the damage distribution around the blasthole for different explosion times (Fig. 4). We can notice that the first damage appears after t = $2.28*10^{-5}$ seconds. From t =$1.42*10^{-4}$ seconds, the damaged zone becomes more important. We also can notice the damage zone is larger in the horizontal direction than in the vertical direction, this because that the orientation of the cracks is 0 as shown in Table 2. This orientation is favorable to the propagation of mode I tensile stresses because the orthoradial tensile stresses are perpendicular in this orientation.

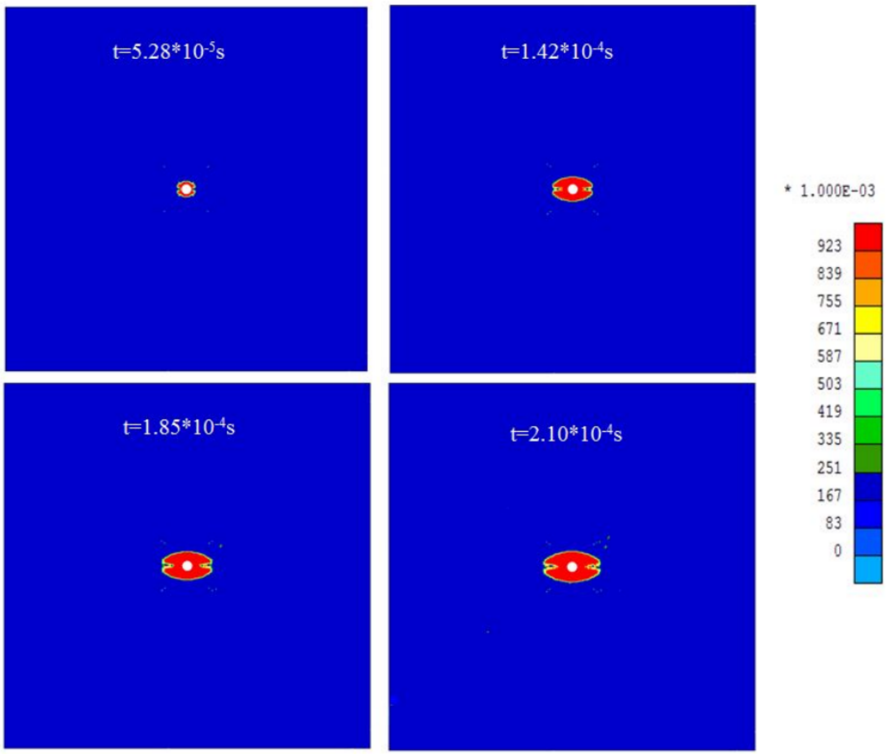

Fig. 4. Damage distribution at different times around the blast holes

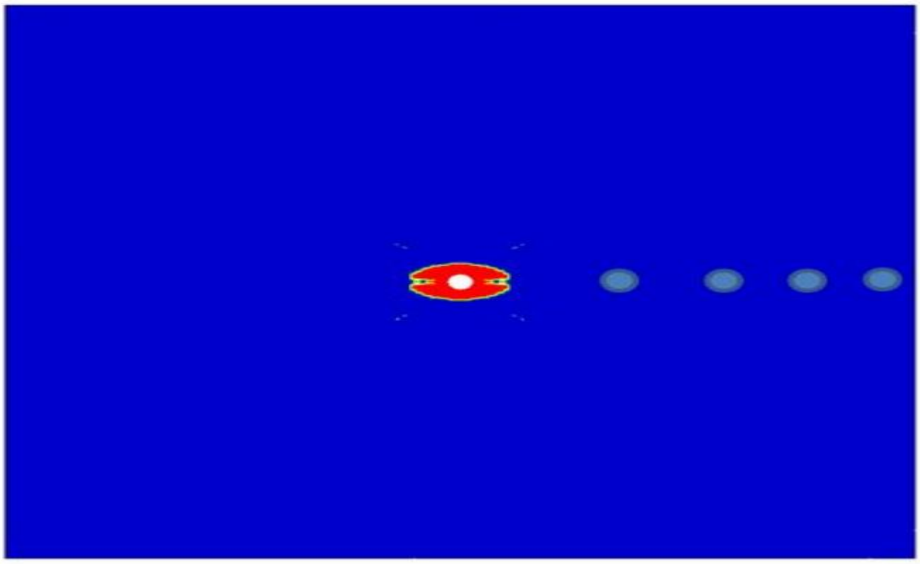

Fig. 5. Particle velocities calculation points

Secondly, we extracted the particle velocities from different points located at different distances from the blast holes. These points are considered parallel to the blast front. Figure (Fig. 5) shows the different calculation points in the explosion zone and the figure (Fig. 6) represents the corresponding particle velocities in the horizontal direction. These particle velocities are represented up to an instant greater than the instant corresponds to the peak of the explosion pressure $t = 3.36 * 10-4$ s), this in order to consider the maximum speed. It is obvious that the closer we are to the explosion center, the greater the particle velocities (for the first wave front), in other words the vibrations are important.

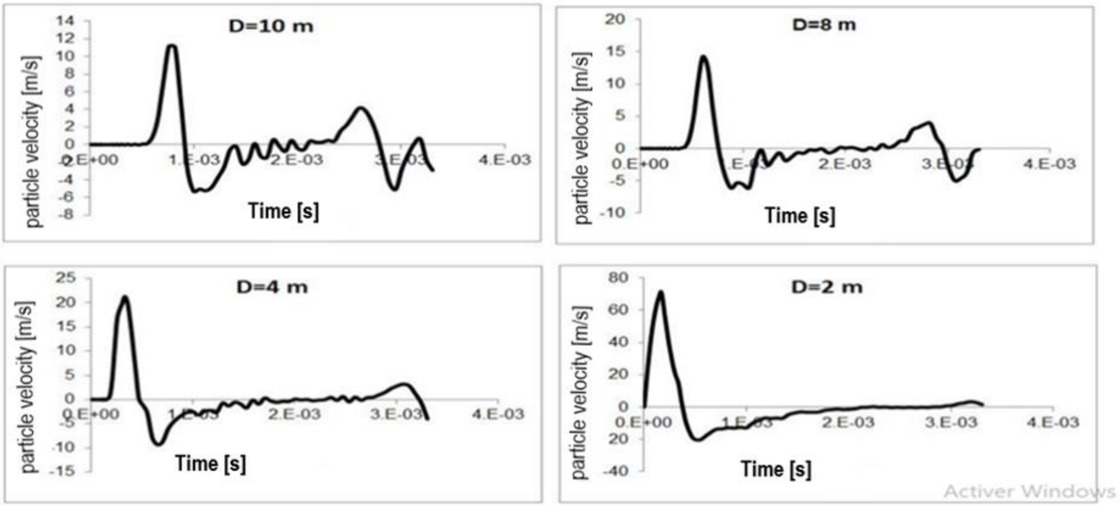

Fig. 6. Particle velocities at different distances from the explosion center

This could be explained by the fact that the surface crossed by the wave front widens as we move away from the explosion center, thus causing a loss of wave speed. On the other hand, the term of damping also helps slow down the wavefront.

In our simulations, the prediction of the vibration level gives particle velocities of 11m/s at a distance of 10 m from the explosion hole. The vibration level required by the specifications for mining sites in Guinea is 10 mm/s in a populated area. Based on the results of the model (Fig. 6), one could estimate that this required vibration level would be reached at a distance of 80 m from the blast hole.

5. CONCLUSION

This research allowed, using a new dynamic damage model, to predict the vibration level induced by explosive blasts in the Sangarédi bauxite mines in Guinea. The damage distribution map at different times of the explosion was first shown. After we extracted the particle velocities from different points located at different distances from the blast holes. These particle velocities are represented up to an instant greater than the instant corresponds to the peak of the explosion pressure t = $3.36 * 10^{-4}$ s), this in order to consider the maximum speed. In our simulations, the prediction of the vibration level gives particle velocities of 11m/s at a distance of 10 m from the explosion hole. The vibration level required by the specifications for mining sites in Guinea is 10 mm/s in a populated area. Based on the results of the model one could estimate that this required vibration level would be reached at a distance of 80 m from the blast hole.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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