SAFETY EVALUATION OF GROUND VIBRATIONS INDUCED BY BENCH BLASTING AT CEMEX LIMESTONE QUARRY, ASSIUT, EGYPT

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Abstract

This paper presents the analysis and measurements of ground vibrations induced by bench blasting operations in limestone quarry at Assiut Cement Company (CEMEX), in Egypt. The object of this study is to predict peak particle velocity and to determine the safe distance for this site. For this purpose, blasts have been recorded using five seismographs to record ground vibrations events. Buildings and constructions close the quarry area have been given the first priority in these measurements, and the ground vibration components were measured for each event. After carrying out statistical analysis, the site-specific parameters were determined to predict the peak particle velocity. In this analysis, the prediction curves of maximum charge weight per delay versus distance for different damage criteria was drawn to be able to perform controlled blasting in order not to damage to the nearby structures, especially to the plant buildings and structures. The particle velocities and frequency values of all blast events were evaluated according to German DIN 4150 in order to determine the damage risks of the nearby structures.

1. Introduction

Drilling and blasting combined still an economical and viable method for rock excavation and displacement in mining works. The ill effects of blasting, i.e. ground vibrations, air blasts, fly rocks, noises, etc. are unavoidable and cannot be completely eliminated but certainly minimize up to permissible level to avoid damage to the surrounding environment with the existing structures [1,2]. Among all the ill effects, ground vibration is major concern to the planners, designers and environmentalists [3]. Ground vibrations resulting from rock blasting is troublesome problem for mining, construction, quarry, and pipeline industries. Researchers around the world are working hard to provide damage criteria and continue to improve it to increase its reliability [4].

Ground vibration is directly related to the quantity of explosive used and distance between blast face to monitoring point as well as geological and geotechnical conditions of the rock units in excavation area [5]. Depending on the level of the stresses produced from wave motion, they can cause damage to buildings structures in the nearby residential properties by causing dynamic stresses that exceed the strength of building material or rock material. Thus the level of the ground vibrations induced by blasting on building structures and human beings need to be predicted, monitored and controlled [6].

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The prediction of ground vibration components plays an important role in the minimization of the environmental complaints. In recent years, one of the problems encountered by technical personnel who are responsible for the excavation with blasting is true or false complaints of people or organizations in the neighborhood [7, 8].

The best approach to the problem of how to estimate the amount of charge so that safe vibration level limits will not be exceeded at a given distance is to use instrumentation on blasts to determine within a site what the specific constants are in the actual blasting conditions. For the analysis of vibration-related problems, it is necessary to consider the combined effect of several factors such as site characteristics, propagation of surface and body waves in the ground, and response of structures. In order to effectively control vibration-related problems, the development of are liable vibration monitoring system and the proper assessment of attenuation characteristics of various vibrations are essential [9].

These efforts go back to Rockwell's Energy Formula of 1934. Some of these criteria used energy, energy ratio, displacement, velocity, or acceleration of ground motion. By the late fifties, it was generally agreed that the particle velocity of ground motion near the structure was the best damage criterion. It was claimed that if the peak particle velocity (PPV) is less than 2 in/sec (50 mm /sec), the probability of damage to residential structures would be low. Higher PPV would increase the probability of damage. This damage criterion was assumed independent of the frequency in the range from 1 to 500 cps and independent of the component of the PPV if it was longitudinal, transverse, or vertical [10-13].

2. Site-specific Criterion

In the predictions of ground vibration, although a lot of empirical relationships have been established and used by different researchers in the past, the site-specific technique is still implemented for each different site. The most reliable relationships are those that accept the scaled distance and particle velocity as a basis. The scaled distance is defined by equation below:

$$S.D. = R/Q^{1/2}$$

where S.D. is the scaled distance and D is the absolute distance between the shot and the station (m), and Q is the maximum charge per delay (kg).

The peak particle velocity (PPV) is determined from the following formula:

$$PPV\ (mm/sec) = K \times (SD)^{-b}$$

which has extensively been used in practice, and where K is the ground transmition coefficient and b is a specific geological constant.

In order to establish a best fit relationship between the peak particle velocity and the scaled distance, multiple regression analysis has to be performed using the obtained recorded data.

3. Test Site [14]

Assiut Cement Company (CEMEX) plant is located about 15 km North-West of Assiut city. The limestone quarry lies west of the cement plant. Limestones cropping out in Assiut are uniform in macrolithology, fairly rich in organisms, and accordingly of different microfacies. They belong to Lower Eocene. The quarry limestones have a density of 2.2 g/ cm^3 and a total porosity of 7.81%.

The average mechanical properties of the quarry limestones are as follow:

- Compressive strength = 24.4 ± 6.98 MPa.
- Tensile strength = 6.6 ±1.78 MPa.
- Shear strength = 11.0 ± 3.87 MPa.
- Cohesion = 6 MPa.
- Angle of internal friction = 31.6°.

The quarry is divided into upper, middle and lower bench fig. 1. The height of the upper bench is 26 m, the height of the middle bench is 30 m and the height of the lower bench is 35 m. The middle, lower bench consists of two different limestone layers the first is an extension to the upper bench layer and it forms about 50.5 m from the top of the lower bench while, the remaining is from another limestone layer. Although, the second layer is small if it is compared to the first layer, it contains high percent of calcium carbonates and low silicon dioxide so, it is very important to add this layer to the first one to obtain a suitable mixture for cement manufacture.

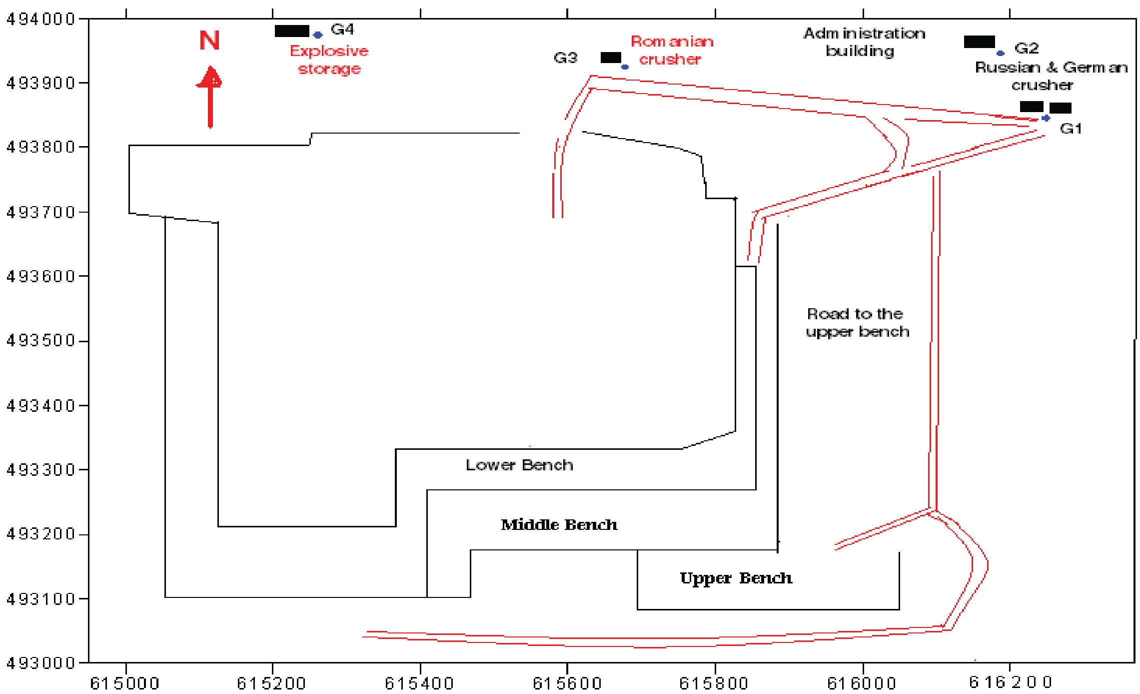


Fig. 1. *Map of the quarry*

4. Field procedure

Ground vibration components induced by blasting in the quarry were monitored to estimate the damage risk and site-specific attenuation for the quarry by using SSU-2000 DK seismograph system. The parameters of charge quantity per delay and the distance between the source and the station were recorded. The distances between shot points and seismographs were determined by surveying.

The blasting pattern, drilling pattern and explosive charges for each shot were designed by blaster engineer of the company. For each blast, the vibrations have been measured simultaneously on the surface and for these shots, only necessary quantitative measurements and observations have been performed.

The horizontal distance between each seismograph location and the blast has been measured using a total station. About 30 minutes before the blast is fired, the seismographs are switched on and about 30 minutes after the blast firing the seismographs are switched off, uninstalled, cleaned and carried out to the office. Then, printouts of the events and disk copies has been made and data has been calculated and /or tabulated for statistical analysis.

5. Results and Discussion

The data obtained from blast operations performed at the quarry were recorded along five structures with two firing methods: 1. Electric firing + Detonating cord down lines, 2. NONEL firing method. An example of the results of ground vibration measurements and data are given in table 1.

Table 1. ***Some of the results of ground vibration measurements***

No.	Q, kg	R, m	S.D., m/kg$^{1/2}$	PPV, mm/sec	Frequency, Hz		
					L	T	V
1	1070	621	18.71	3.4	6.4	6.4	11.1
2	1215	502	14.4	2.9	8	6.6	8.6
3	820	595	20.78	2.3	9.8	4.9	8
4	830	529	18.36	3.4	16.6	7.4	11.9
5	1525	587	15.03	3.8	5.3	7.2	9
6	1115	500	14.97	3.3	6	8.4	4.8
7	910	687	22.77	2.0	7.5	6.1	7.6
8	870	602	20.41	2.5	8.3	5.7	8.7
9	1265	501	14.09	3.3	7.2	11.1	8.7
10	1155	559	16.45	2.2	8	4.2	8.6
11	830	965	33.5	1.6	6	1	8.4
12	1550	770	19.56	2.3	3.6	4	7.1
13	1060	623	19.14	3.3	8.1	5.5	6.6
14	1050	507	15.65	2.9	10	8	10.6
15	890	758	25.41	1.7	5.8	7.3	5.4
16	1010	822.3	25.87	2.0	5.8	5.7	5.2
17	770	529.8	19.09	2.4	5.9	4.4	7.8
18	1090	718.5	21.76	1.7	5	1.7	6.4

where R = the absolute distance between the shot and the station (m)
Q = the maximum explosive charge per delay (kg)
S.D. = the scaled distance (m/kg$^{1/2}$)
PPV = vector sum particle velocity

6. Statistical analysis of the results

When statistical analysis techniques are applied to blast vibration data, peak particle velocity and scaled distance give a site-specific velocity attenuation equation. It should be stated that in these data tables, PPV is the peak particle velocity (mm/s), Q the maximum charge per delay (kg), R the distance between blast location to vibration monitoring point (m), and K and b the site constants, which can be determined by multiple regression analysis.

In order to find the site constants, namely K and b, the graph between the recorded PPV values and S.D. were plotted and these graphs with 95% prediction interval and 95% confidence interval are given as in fig. 2.

The site constants for this quarry and equations obtained from the regression analyses are summarized in table 2.

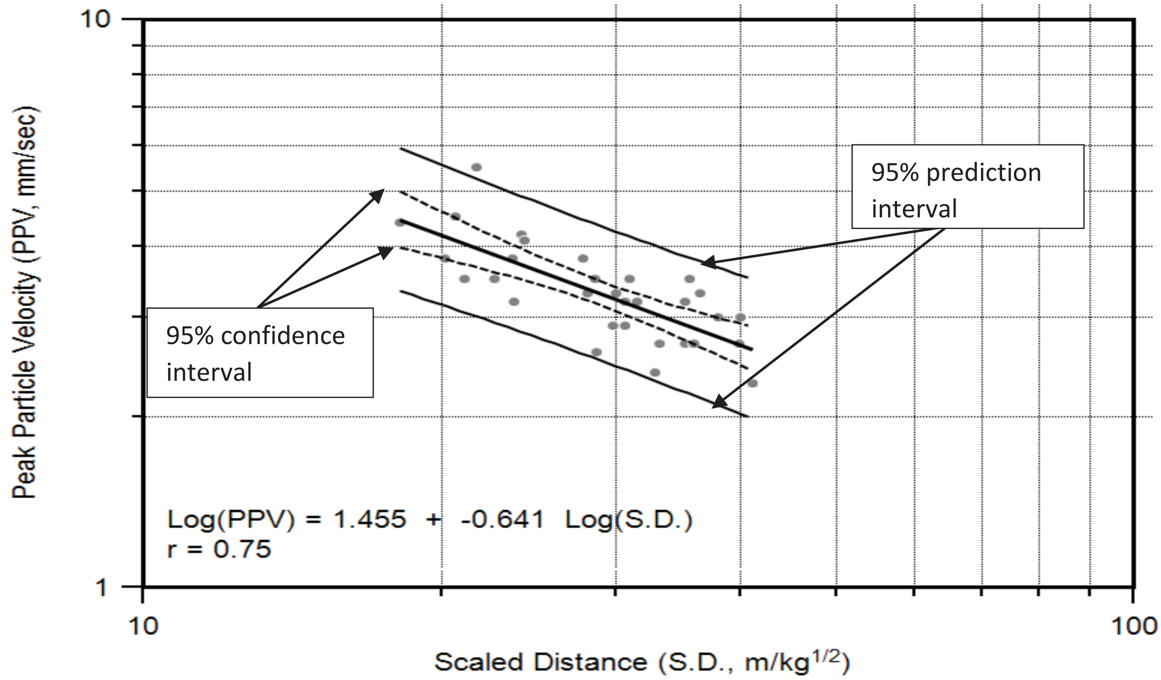


Fig. 2 ***Relationship between peak particle velocity and scaled distance***

This graph illustrates 50% and 95% confidence interval in addition to 95% prediction interval.
where: confidence interval expected about 95% of those intervals to include the true value of the PPV mean, and prediction interval expect next value to lie within that prediction interval in 95% of the points.

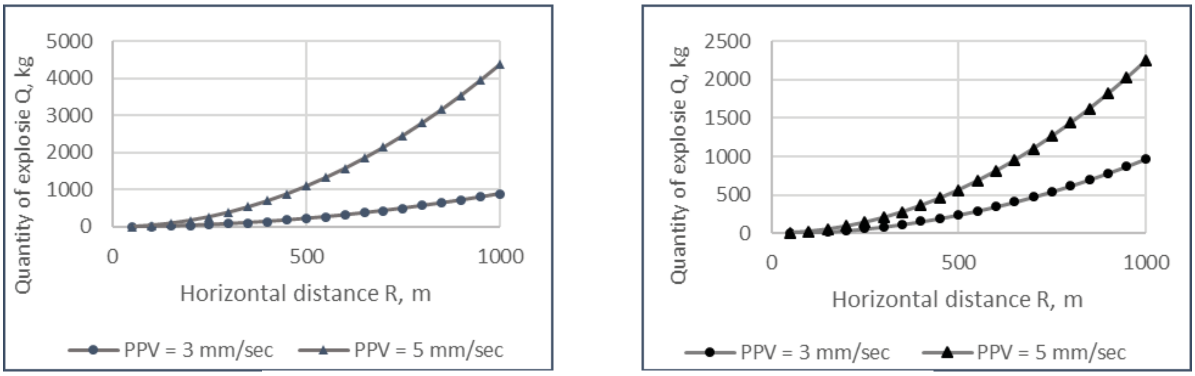
Table 2. ***The site constants and prediction equations***

Structure	Firing method	k	b	Equation	r
Administration building	NONEL	200	1.21	$PPV = 200 \times \left[\frac{R}{\sqrt{W_d}}\right]^{-1.21}$	0.84
	Electric + D.C.	28.51	0.641	$PPV = 28.51 \times \left[\frac{R}{\sqrt{W_d}}\right]^{-0.641}$	0.75
Explosive magazine	NONEL	29.65	0.777	$PPV = 29.65 \times \left[\frac{R}{\sqrt{W_d}}\right]^{-0.777}$	0.73
	Electric + D.C.	18.37	0.613	$PPV = 18.37 \times \left[\frac{R}{\sqrt{W_d}}\right]^{-0.613}$	0.64
Russian crusher	NONEL	83.18	1.009	$PPV = 83.18 \times \left[\frac{R}{\sqrt{W_d}}\right]^{-1.009}$	0.78
	Electric + D.C.	109.9	1.098	$PPV = 109.9 \times \left[\frac{R}{\sqrt{W_d}}\right]^{-1.098}$	0.71
Romanian crusher	NONEL	52	0.963	$PPV = 52.00 \times \left[\frac{R}{\sqrt{W_d}}\right]^{-0.963}$	0.72
	Electric + D.C.	33.88	0.881	$PPV = 33.88 \times \left[\frac{R}{\sqrt{W_d}}\right]^{-0.881}$	0.77
German crusher	NONEL	73.96	1.018	$PPV = 73.96 \times \left[\frac{R}{\sqrt{W_d}}\right]^{-1.018}$	0.85
	Electric + D.C.	144.54	1.267	$PPV = 144.54 \times \left[\frac{R}{\sqrt{W_d}}\right]^{-1.267}$	0.79

** r is the correlation factor
k, b : the site constants
Electric + D.C.: Electric trunklines + detonating cord down lines

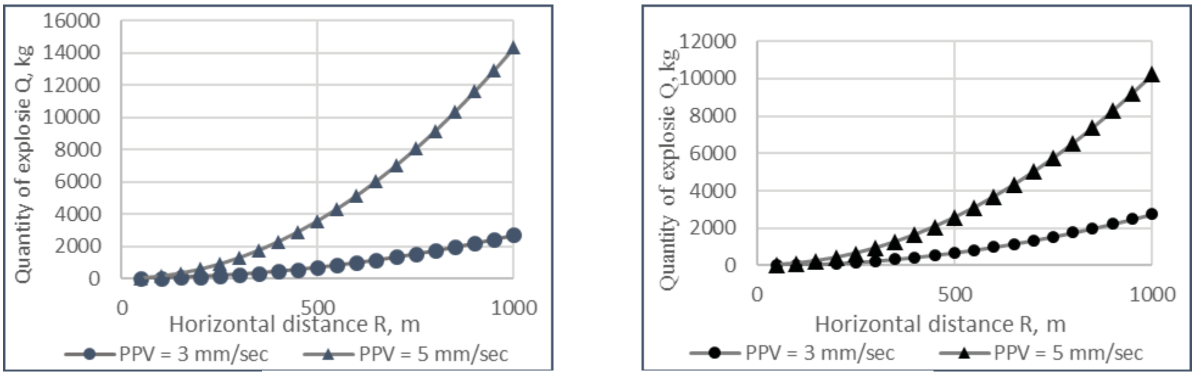
7. Practical blasting chart

By using the attenuation equations obtained from the statistical analysis for the studied structures, practical blasting charts have been worked out. This provides efficient and time-saving design of future blasting operations to the blast engineers. These charts have been prepared using the prediction of permissible maximum charge per delay considering different structures. In the construction of these practical blasting charts, the relations between the maximum charge weight per delay and the distance were obtained from Table 2. The maximum permissible PPV values described in the damage criteria have been fulfilled. The maximum permissible PPV values are 3 mm/s for ‘‘industrial buildings’’, 5 mm/s for ‘‘residential buildings’’ in DIN 4150 criterion. The permissible charge per delay for a specified distance according to this criterion can be graphically determined from the figures below.



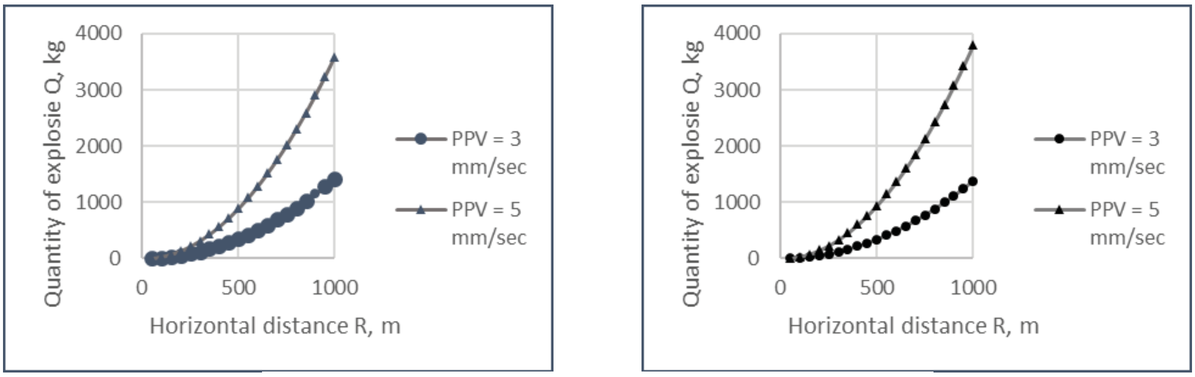
(a) (b)

Fig. 3 ***Practical blasting chart for administration building:***
(a) Electric trunklines + detonating cord down lines, (b) NONEL



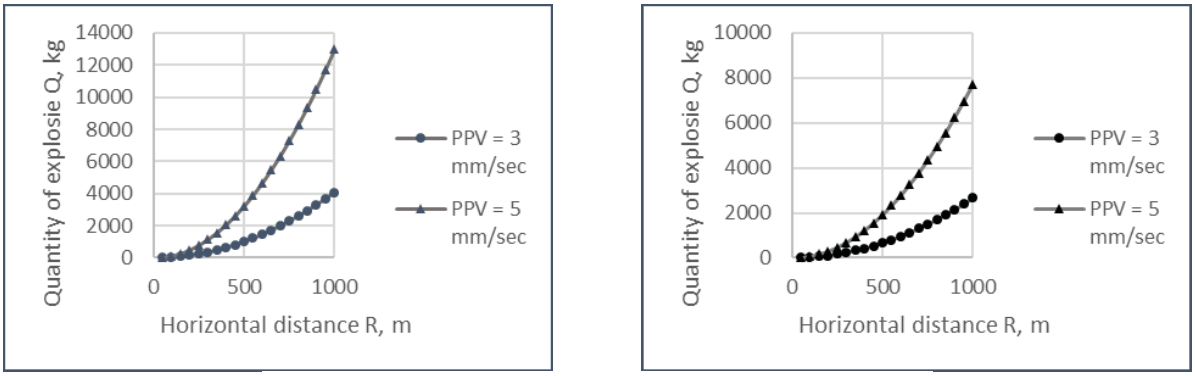
(a) (b)

Fig. 4 ***Practical blasting chart for explosive magazine:***
(a) Electric trunklines + detonating cord down lines, (b) NONEL



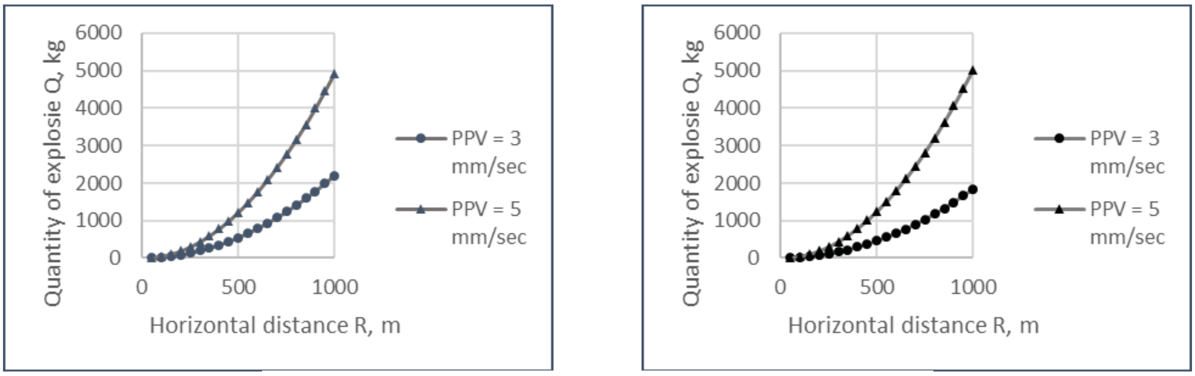
(a) (b)

Fig. 5 ***Practical blasting chart for Russian crusher:***
(a) Electric trunklines + detonating cord down lines, (b) NONEL



(a) (b)

Fig. 6 ***Practical blasting chart for Romanian crusher:***
(a) Electric trunklines + detonating cord down lines, (b) NONEL



(a) (b)

Fig. 7 ***Practical blasting chart for German crusher:***
(a) Electric trunklines + detonating cord down lines, (b) NONEL

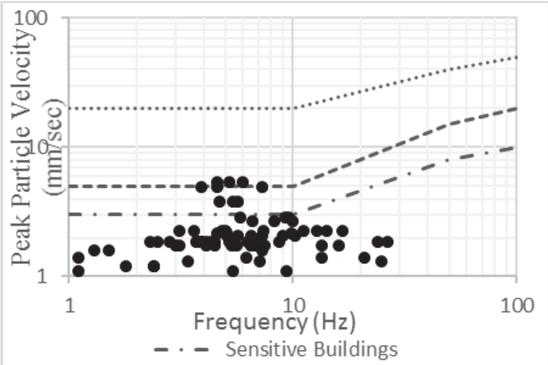
These charts relates the maximum charge amount per delay, the peak particle velocity and distance (R), it should be noted that the values of PPV lines is based on the threshold damage limits of the DIN 4150 criterion. It is possible to use these charts in a practical way of determining either the maximum charge per delay or distance to prevent damaging of any specified structure from future blasting.

8. Frequency analysis and evaluation of damage risk in blasting operations

The frequencies associated with the ground motions are very important in determining the possibility of damage to structure. The frequency of the greatest amplitude pulse is usually considered the frequency of excitation. Most available guidelines are based on frequency–velocity control bounds. Frequency plays a large role in vibration-related structural damage. Peak particle velocity (PPV) data versus frequency are plotted in Figures below. Frequencies given in Figure are the peak frequencies for peaks of radial, vertical, and transverse components.

9. Evaluation of damage risk in blasting operations

The particle velocities and frequency values of all blast events were evaluated according to the German DIN 4150 criterion in order to determine the damage risks of the nearest buildings and structures. This criterion states are 3 mm/s for ‘‘sensitive buildings’’, 5 mm/s for ‘‘residential buildings’’. The graphic of measured peak particle velocity versus frequency values of all events according to DIN 4150 are given in Fig. 8 (a, b, c, d, e) and Fig. 9 (a, b, c, d, e).



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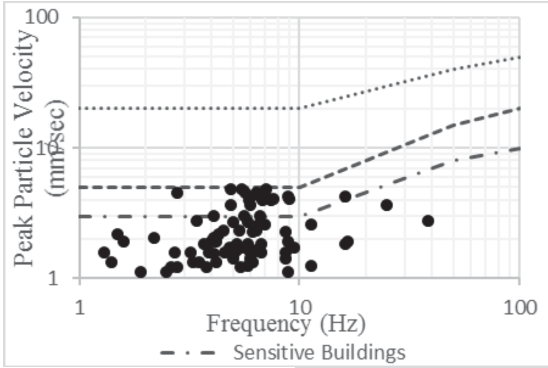

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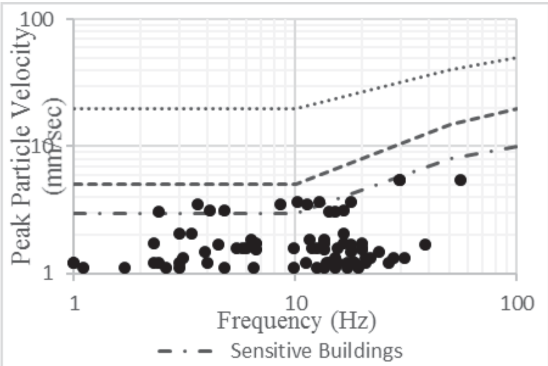

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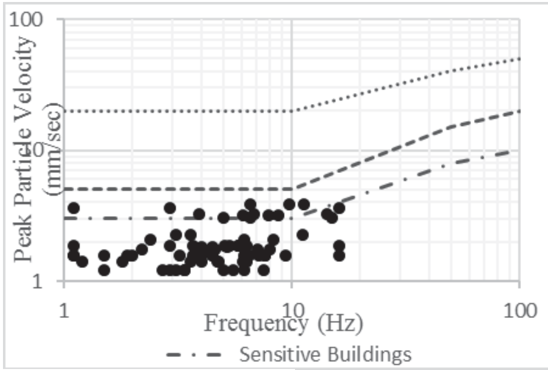

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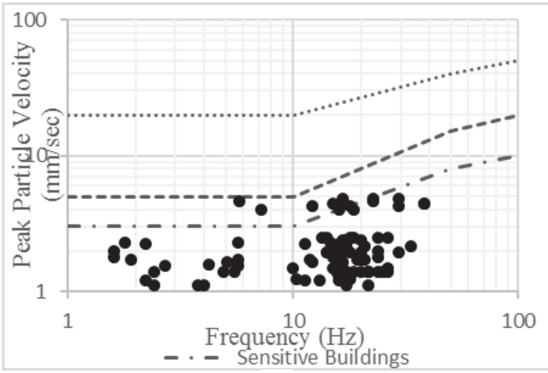
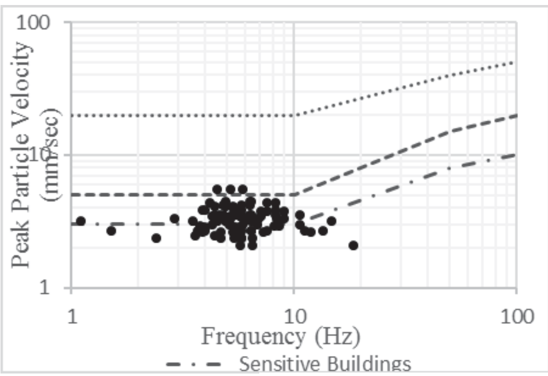
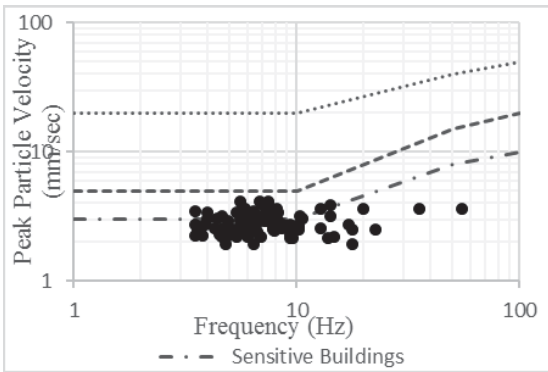


(e)

Fig. 8 ***Evaluation of damage risk of the shots according to DIN 4150 criterion with NONEL firing method: (a) Administration building. (b) Explosive magazine. (c) German crusher. (d) Romanian crusher. (e) Russian crusher.***



(a)



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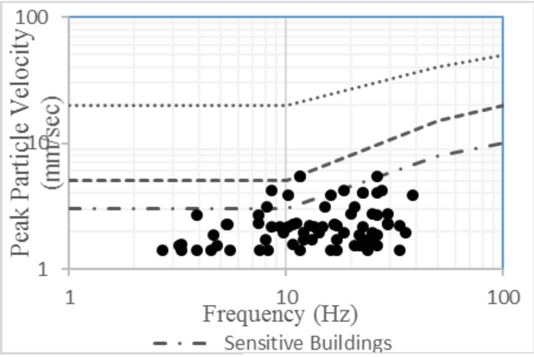

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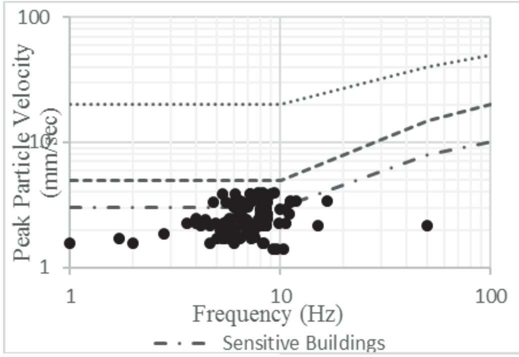

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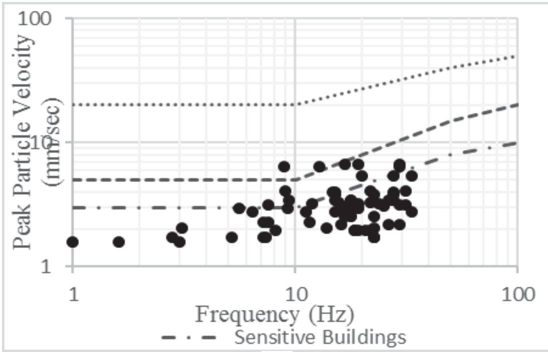
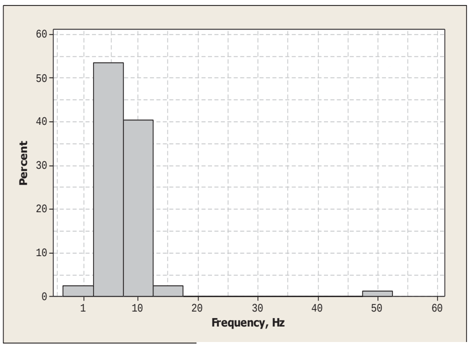


(e)

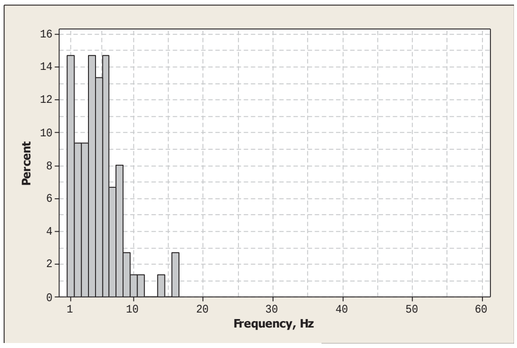
Fig. 9 ***Evaluation of damage risk of the shots according to DIN 4150 criterion with Electric firing method: (a) Administration building. (b) Explosive magazine. (c) German crusher. (d) Romanian crusher. (e) Russian crusher.***

10. Ground motion frequencies

The distributions of frequency values for all vibration components are shown in figures.

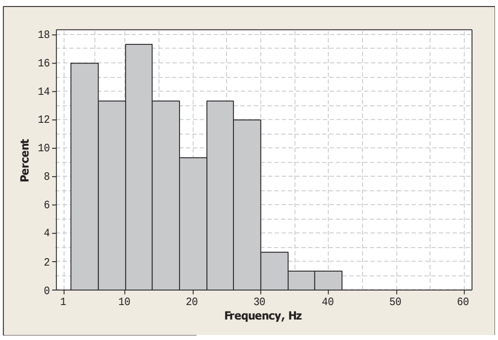


(a)

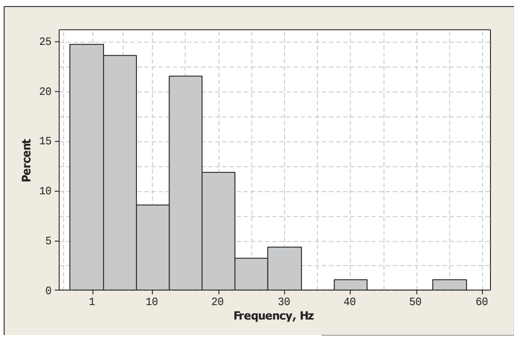


(b)

Fig. 10 ***Frequency distributions of blast-induced vibrations at Romanian crusher: (a) Electric trunklines + detonating cord down lines, (b) NONEL***

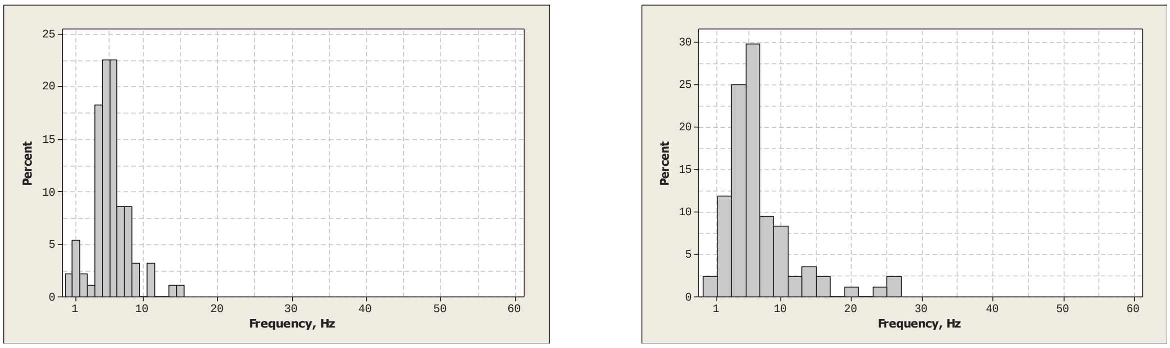


(a)



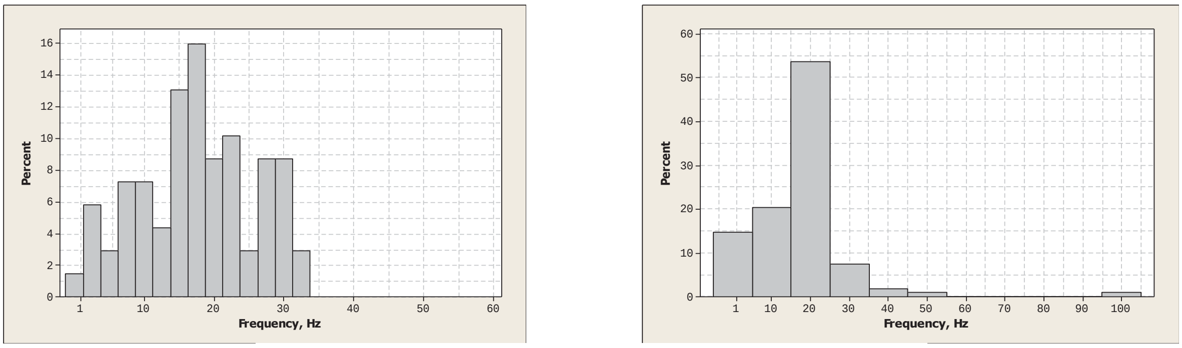
(b)

Fig. 11 ***Frequency distributions of blast-induced vibrations at German crusher: (a) Electric trunklines + detonating cord down lines, (b) NONEL***



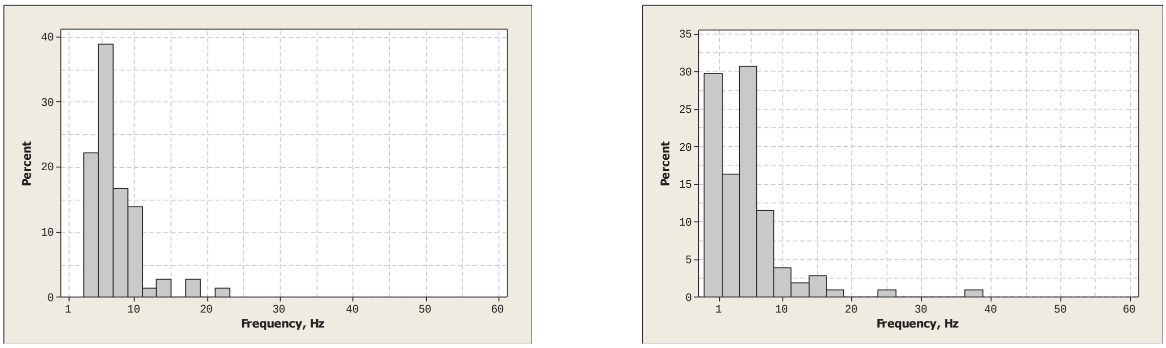
(a) (b)

Fig. 12 ***Frequency distributions of blast-induced vibrations at administration building: (a) Electric trunklines + detonating cord down lines, (b) NONEL***



(a) (b)

Fig. 13 ***Frequency distributions of blast-induced vibrations at Russian crusher: (a) Electric trunklines + detonating cord down lines, (b) NONEL***



(a) (b)

Fig. 14 ***Frequency distributions of blast-induced vibrations at explosive magazine: (a) Electric trunklines + detonating cord down lines, (b) NONEL***

These results show that the measured frequency values at this site are quite low. It is known that low-frequency vibrations have a greater potential for damage than high-frequency vibrations. Since the self-structural frequencies of buildings range between 4-12 Hz for the superstructure and 10-20 Hz for the wall in general, and then the damage risk can be quite high if the amplitude of vibration is greater than 12.70 mm/sec when the frequency of the exciting ground wave is in the range of 3-10 Hz [15]. This most probably results in cosmetic cracking. Moreover, if the measured frequency of the exciting ground wave is equal to or greater than the natural frequency of the building, and even if the amplitude of vibration, measured at the ground outside the building, is lower than 12.70 mm/sec, the building will resonate. The resonation, therefore, will increase the vibration amplitude due to the amplification, which means cosmetic cracking can also occur. Consequently, the low-frequency values determined show that it is important for the blaster and mine authority to record and evaluate all blast events.

11. Conclusions and Recommendations

The ground vibration data obtained from blast operations performed at the quarry, which were recorded along five structures. From these data, the following conclusions obtained:

1. PPV prediction equations by scaled distance were established to evaluate the potential damage of the blasting operations on the nearby structures which are Administration building, explosive magazine, Romanian crusher, Russian crusher and Germany crusher.
2. The German vibration standard (DIN 4150) intended to protect building is considered in this study. Based on this established damage criteria, the ground vibration measurements and frequency data recorded at the quarry nearby structures were below the threshold values for a safe condition.
3. Frequency of the different ground vibration components has analyzed. The majority values were below 50 Hz, which is acceptable as low frequency according to the international standards. These results will increase the risk of induced resonance of the structures of which have a natural frequency of 5-10 Hz. Also, it was thought that such low frequencies can lead to human response at this site. Therefore, it was concluded that the concerning measurements would be helpful for minimizing the annoyance of the employees.
4. For the controlled blasting operations which prevent damaging of any structure, a modified practical blasting chart was prepared by considering DIN 4150 damage criteria and structure types. As a result of the study, the mine management was recommended to implement a modified practical blasting chart prior to blasting. Finally, it is thought that these charts can be used as a practical guide for blasting operations in the future at these tunnels.

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