ORIGINAL PAPER

Evaluation of seismo-acoustic hazards from cement quarry blasts on the New Administrative Capital, Egypt

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Abstract

Cement industry is one of the strategic sectors in Egypt. In most cases, cement factories are using explosives to obtain the materials needed for the industry. Such activities pose threats to the surrounding environment. The threats are more serious when the quarries are located near to a strategic site. The New Administrative Capital (NAC) is one of the leading development projects in Egypt that happen to occur close to some cement quarries that use explosions to obtain the raw materials. Possible unfavorable effects are expected on the buildings and projects at NAC. To evaluate these effects and to propose measures to ensure the safety of NAC structures, the present work was carried out. Threats expected are due to both ground motion and air over pressure. The methodology adopted in the study was based on monitoring the explosions, ground motions, and air over pressure. The monitoring was conducted using temporary arrays that were deployed in the explosion day. The time period required is almost 2 years. Furthermore, the collected data were processed to reject low quality data. The processed data were modeled in terms of the international standards to determine the threshold level of hazards for both ground motion and air over pressure. The work is finally summarized in terms of model equations in terms of the scaled distances. The choice of the scaled distances was to simplify the model by eliminating the effect of the charge per delay parameter. The final results showed that keeping the charge weight per delay under 45 kg, threats at a distance of 7 km is vanished. The model showed also that the effect of air over pressure is higher with scaled distances than the ground motion. To the best of our knowledge, the present work is the first of its kind in Egypt. Also, it is recommended to study the frequency effect of both parameters and to account for the effects of the site on the ground motion.

Keywords Cement factories · Quarry blasting · New Administrative Capital of Egypt · Peak particle velocity · Air over pressure

Introduction

Cement industry is one of the strategic industries in Egypt because of the huge limestone outcrop and its geographic location. As a result, several cement factories are taking place and are concentrated in lower Egypt (Fig. 1). The study area, i.e., the New Administrative Capital, is in the vicinity of a number of cement factories that are located to the east of Cairo.

The extraction of materials used for cement industry is usually obtained from nearby quarries. Limestone and clay are the major raw materials that are greatly consumed for the cement industry (e.g., Moneim et al. 2013). Limestones are obtained by blasting using explosive technologies to ensure the minimum effects on the surrounding environment. These harmful effects are in the form of flying rocks, ground vibration, air overpressure, noise, and emission of small-sized particles into the air.

The present work is focusing on the effects of ground vibrations and air overpressure on the nearby NAC structures. Several factors are affecting the level of ground vibration level at any site. These factors are the distance to the site, the charge weight per delay, and the method of initiation. Other factors affecting vibration level, such as
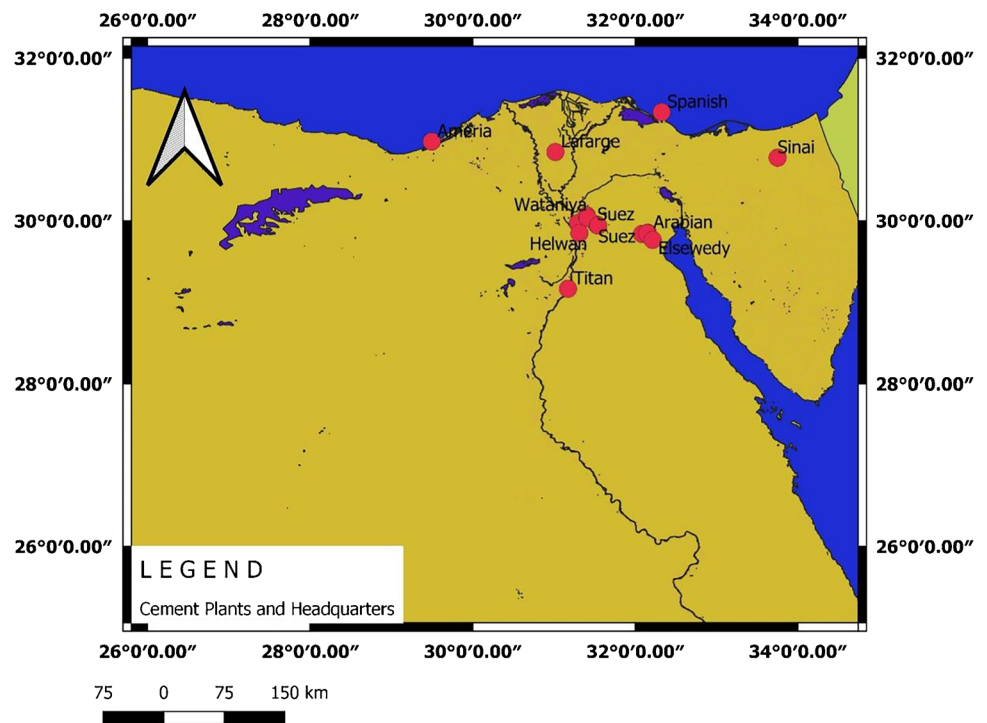
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Fig. 1 Distribution of cement plants in Egypt. Most of the cement factories are located close to Cairo (source: maps. google.com)

geology of the site, type and layering of the rock, slope of layers, nature of the terrain, and water level in the area, are factors beyond control.

Several studies (Birkenhauer 1945; Duvall 1962; Sames and OMeara 1996; Segarra 2010; Hudson et al. 1961; Devine 1962) have been concentrated on the effects of vibrations from quarry blasts on the neighboring urban and administrative areas. Some other studies (Farahani 2015; Allmann et al. 2008; Saad et al. 2019; Hedlin et al. 1990) targeted the discrimination between microearthquakes and quarry blasts.

The impacts of quarry blasts on the environment are not only mechanical vibration; it also includes pollution to the environment as well. Hence, several studies (Toraño et al. 2005; Johnson and Schomer 1975; Siskind and Stagg 1997) were conducted to evaluate other effects on human health. In the present work, the focus will be the effect of both ground vibration and air over pressure.

The cement quarries in the greater Cairo metropolitan are currently monitored by the National Research institute of Astronomy and Geophysics (NRIAG). Accelerometers are deployed in the vicinity of cement quarries to ensure that the level of peak ground acceleration is below a certain value to ensure the safety of nearby buildings and facilities. However, since a new strategic city, i.e., the new administrative capital is underway; special studies are needed to ensure the safety and sustainability of the project. This requires investigations of other form of vibration monitor such as the peak particle velocity (PPV) and air over pressure measurements.

PPV is a widely accepted measurement to evaluate the potential damage from quarry blasts. Several international standards such as the United States Bureau of Mines (USBM) were based on the PPV values. In fact, the PPV records may be representing either the ground shaking from the explosion or the air over pressure. Hence, it may be more reliable than the accelerometer data that is usually ground shaking only.

The major challenge for the present study is to deduce a relation between the charge weight of an explosion and ground vibration level at a certain distance to the site. This relation will help to predict the vibration level, and following the standards, it will be possible to evaluate whether these charge weights are safe or need to be reviewed. The relation should take into consideration factors such as wave propagation, site characteristics, and structure response. To reach our target, a monitoring system for the wave propagation beside determination of attenuation parameters of the area is essential. The work conducted here is the first of its kind to model the possible characteristics of both ground vibration, PPV, and air overpressure (AOP). The regression analysis conducted using recorded real data may enable future studies to model the possible response of certain engineering structures both under direct or cyclic loads.

Study area

New Administrative Capital is an ambitious strategic project located to the east of Cairo to be the home of all electronic activities controlling the governmental tasks

(Fig. 2). NAC is located 35 km east of Cairo of a total area of 170,000 feddan. The city lies between the regional ring road, the Cairo-Suez Road, and Cairo-El Ain El Sokhna road. Moreover, the area is considered as part of the so-called Cairo-Suez District that exhibits earthquake activities with magnitudes of less than 5. In fact, the earthquake activities there are attributed to the junction between the stable and unstable shelf of Egypt.

Six cement factories are located near the outskirt of NAC. The nearest one is the Qattameya cement factory that is located at about 11 km from NAC and is considered as the highest risk potential. Three factories are located closely spaced at an average distance of 37 km. These factories are Suez, Al Arabia, and El Sewedy cement factories. LaFarge and Helwan cement factories are located at distances of 22 km and 32 km, respectively. These factories are established there because of the huge outcrop of high-grade limestones.

Because of the conditions at the Cairo Suez District (CSD), several researchers (El-Sorogy et al. 2005; El-Sorogy et al. 2017; Mowafi 2006; Serougy 2015) have studied the depositional environments and stratigraphic sequence there. Other researchers (Hagag and Obermeyer 2016; Attwa and Henaish 2018; Khalaf et al. 2016) have concentrated on the structural environment of the region. Figure 3 represents the surface structural patterns with the rose diagrams to show the main trends. The major trend for the whole area is NW–SE which is parallel to the Gulf of Suez. Another trend is the E-W trend that coincides with the orientation of CSD. Seismological records indicated that several earthquakes with body wave magnitude of less than 5 have been recorded there. No damages have been recorded from these earthquakes, hence their possible effects on NAC may be considered as minimal. The main rock units that are exposed at the surface of the study region after Hewaidy et al. (2018) is shown in Fig. 4. It is evident that a huge limestone exposure took place to the south of NAC, where most of the cement quarries are located. At the area itself, we have both Gebel Ahmar and Hagul formations. Hewaidy et al. (2018) mentioned that Gebel Ahmar is composed of sand and gravels. Hagul formation, on the other hand, is composed of Upper Miocene Clastic/limestone sequence of about 22 m thick measured at the entrance of Wadi Hagul (Seleem and Aboulela 2011).

Material and methodology

For evaluating the effect of cement quarry blasts on NAC, two phases were adopted. Phase 1 was primarily a recording and monitoring of both ground motion and air over pressure from some selected blasts. Phase 2 was entirely an analysis and establishing prediction equations for both ground vibration in PPV units and AOP in DB. The predicted values are then compared against world standards to determine the potential of damages from the cement quarries. Unfortunately, no local standards for Egypt to evaluate the safety level for both PPV and AOP. Henceforth, some of the standards are adopted for the final recommendations about the safe maximum charge per unit delay that would not cause any threat to the buildings and facilities of NAC.

Fig. 2 The location of the New Administrative Capital with cement factories used in the present study
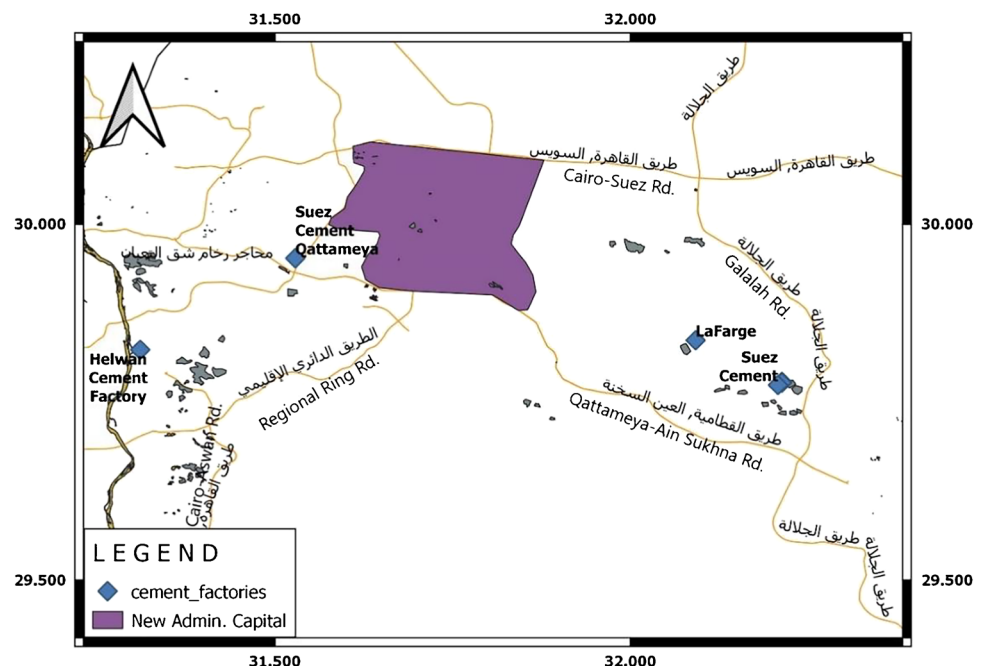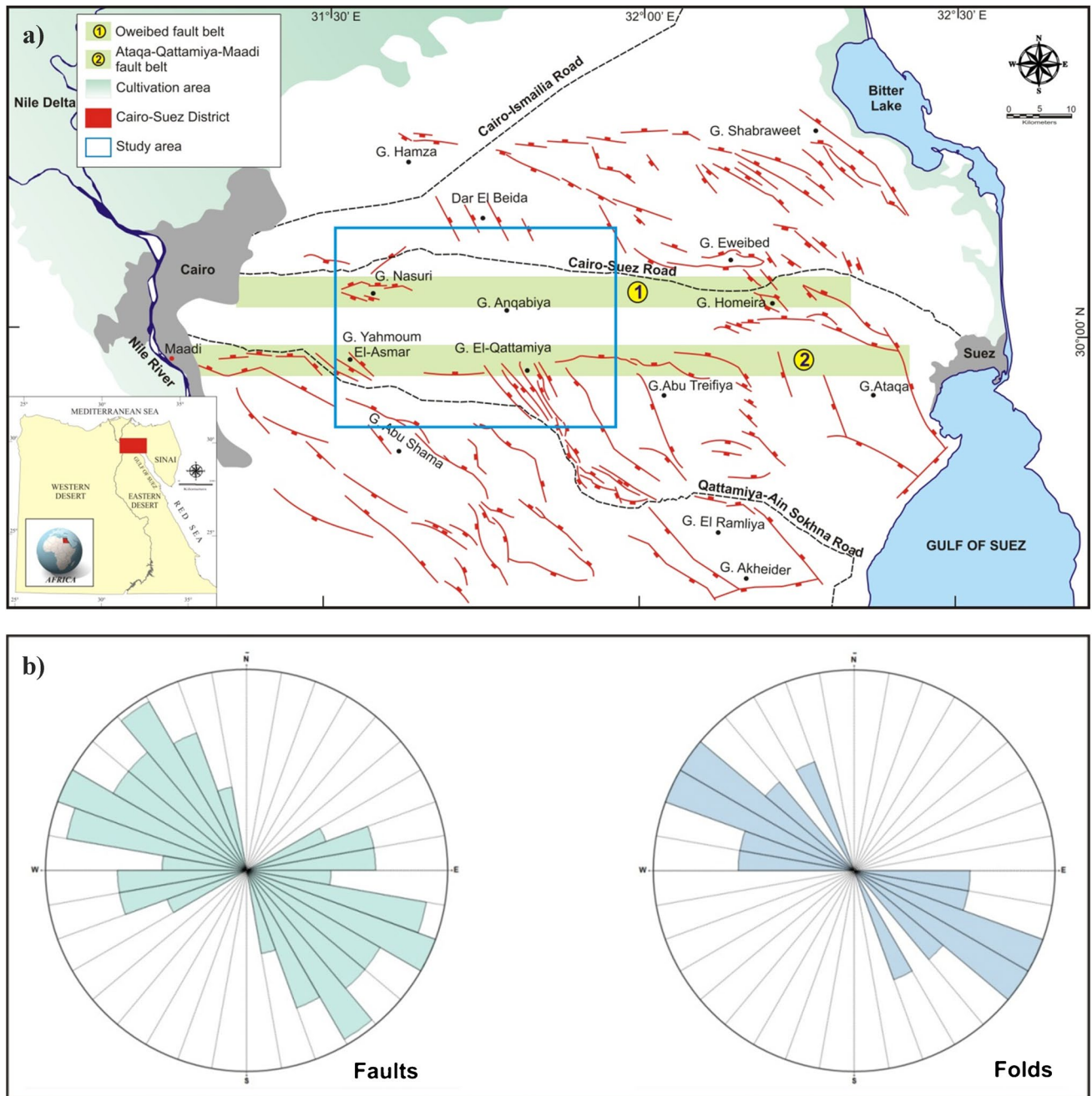
Fig. 3 (**a**) The surface structures of CSD and (**b**) the rose diagram that shows the main structural trends

Phase 1

Some the selected quarry blasts were monitored using both accelerometers and "MINIMATE-PRO" instrument of INSTANTEL that was used to record both PPV and AOP. The blasts monitored were selected with the bilateral communications with the quarry units of the cement factories investigated in the present work. The units provided exact timing and locations of the blasts in addition to the charge weight per delay used.

Special interests were given to the Qattameya cement factory, since it is the closest threat to the site of interest. Recordings were also conducted for other quarries show a negligible threat to NAC. Henceforth, the data used for phase II belongs to recordings at Qattameya cement quarry.

Ground vibrations are usually recorded with three component instruments. This common practice is adopted to fully characterize the particle vibration in the vicinity of the recorder. Since the location of the blast is known, the
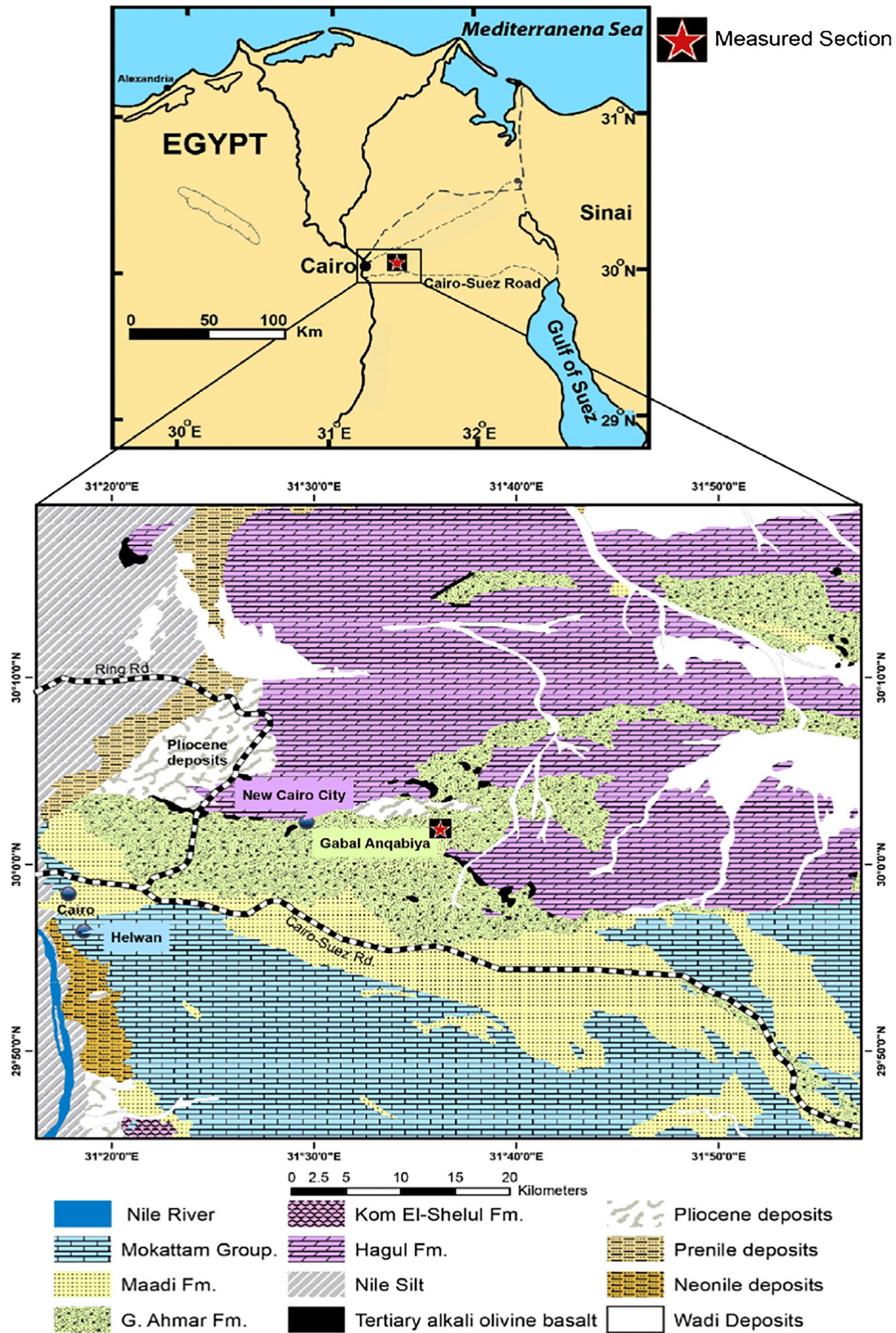
Fig. 4 Surface Geologic formations at the study area (after Hewaidy et. al, 2018)

Table 1 Various parameters recorded in the present study

No	D	DPPV	PPV of each component							AOP			Date
			Trans		Ver		LONG		PPV	DMC	F*	dB	
			PPV	F*	PPV	F*	PPV	F*					
1	90	7.1	25.3	45.8	31	12.4	28.3	15.6	49.0	16.6	2.25	148	25_dec_2019
2	274	21.7	9.29	11	11.2	13.5	16.9	17.1	17.2	50.5	2.38	135	25_dec_2019
3	335	26.5	9.64	13.1	8.94	11	16.6	37.4	17.9	61.7	4	134	25_dec_2019
4	335	26.5	4.98	17.4	4.79	13.1	6.1	12.4	7.2	61.7	2.5	135	25_dec_2019
5	453	35.8	6.41	12.6	4.76	9.88	3.9	13.1	7.9	83.4	3.38	136	25_dec_2019
6	431	34.1	4.1	21.3	4.1	10.5	5.3	94.5	6.1	79.4	2	129	01_jan_2020
7	586	46.3	2.24	19.3	1.41	8.75	2.4	9	2.1	107.9	2.5	125	01_jan_2020
8	680	53.8	1.59	9.75	1.75	10.3	1.78	13.3	2.4	125.3	2	121	01_jan_2020
9	791	62.5	1.41	38.8	1.08	9.25	1.02	13.5	1.6	145.7	4	122	01_jan_2020
10	913	72.2	1.19	21.5	0.81	10	0.937	19.8	1.2	168.2	2	120	01_jan_2020
11	100	7.9	29.3	31.5	27.3	80.3	31.8	31.8	51.1	18.4	2.25	125	22_jan_2020
12	170	13.4	15.6	33.4	7.57	15.4	18.7	33.8	20.4	31.3	2.63	119	22_jan_2020
13	300	23.7	12	32.8	4.03	11.3	9.29	32.5	14.1	55.3	3.5	115	22_jan_2020
14	400	31.6	4.32	34	2.67	11.5	3.05	11	4.5	73.7	2.25	111	22_jan_2020
15	500	39.5	2.48	17.8	3.41	11.8	3.11	21	3.6	92.1	2.25	108	22_jan_2020
16	170	13.4	27.7	33	9.83	34	21.4	34	32.2	31.3	2.25	123	29_jan_2020
17	194	15.3	13.7	33.5	6.49	34.3	15.1	33.5	15.6	35.7	2.25	119	29_jan_2020
18	350	27.7	7.84	30.8	3.92	34.8	9.06	33.3	9.5	64.5	2	116	29_jan_2020
19	425	33.6	8.4	66	2.98	9	8.14	32.6	9.1	78.3	3.25	116	29_jan_2020
20	525	41.5	3.65	33	1.67	8.75	3.84	33.6	4.9	96.7	2.13	114	29_jan_2020
21	480	35.8	5.52	41.5	2.62	15.3	7.06	81.5	8.0	88.4	2.5	127.3	12_FEB_2020
21	480	27.7	14.3	15.1	4.16	13.5	11.8	29.1	15.2	88.4	2.25	129	12_FEB_2020
22	580	33.5	3.1	27.3	2.1	13.8	3.84	27	4.87	106.8	2	131	12_FEB_2020
23	725	41.9	6.51	13.3	2.81	15	4.46	106	6.8	133.5	4	124	12_FEB_2020
24	865	49.9	1.78	6.88	1.3	14.1	1.0	8.3	1.81	159.3	6.6	123	12_FEB_2020
25	1190	68.7	1.19	8	1.1	8.25	0.83	5.75	1.3	219.2	2	121	12_FEB_2020
26	625	49.4	1.6	38.3	1.1	36.8	1.3	38.3	1.8	115.1	2.5	127	19_FEB_2020
27	730	57.7	1.06	38.3	0.81	13	1.3	40.3	1.54	134.5	2.25	126	19_FEB_2020
28	885	70.0	0.667	32.5	0.714	38.5	0.7	10.3	0.861	163.0	4	123	19_FEB_2020
29	1017	80.4	0.921	38.5	0.429	10.5	0.58	16.8	0.966	187.3	5.5	123	19_FEB_2020
30	1110	87.8	1.11	38	0.81	15.8	0.94	38.8	1.34	204.5	2	121	8_FEB_2020
31	342	27.0	4.29	101	4.02	15.6	3.79	15.4	5.53	63.0	2.25	129.9	8_july_2020
32	433	34.2	2.48	17.4	2.06	15.6	1.65	15.3	2.59	79.8	2.25	128	8_july_2020
33	571	45.1	1.64	27.5	1.76	8.5	1.06	40.5	1.94	105.2	2.25	126	8_july_2020
34	665	52.6	1.87	59.9	1.05	8.0	1.08	15.9	2	122.5	2.25	124	8_july_2020
35	786	62.1	1.4	16.4	1.37	26.6	1.11	15	1.65	144.8	2.25	123	8_july_2020

instrument is oriented to measure the vertical, longitudinal, and transverse components. Vertical and longitudinal components are measuring a mix of P and SV phase energy. The transverse component, on the other hand, is recording the SH phase energy. The latter is considered as a maximum threat to buildings from the Earthquake Hazards' point of view.

Since most of the international standards rely on the PPV data rather acceleration, the analysis conducted here is based on the PPV data. Thirty-five blasts were successfully recorded and analyzed. Some other last recordings were failed because of technical problems with the setting of the instruments. The data from the successful recordings are presented in Table 1. The recordings were conducted in the distance range from 90 to 1190 m, i.e., the measurements spanned 1100 m. Besides, the PPV values range from 35 at close distance to almost 1 mm/s at the farthest distance (Fig. 5). The dominant frequencies of the PPV are less than 40 Hz (Fig. 6). It is evident from the figures and the table

Fig. 5 The distribution of PPV values with distances. The charge weight per delay is ignored for the plot
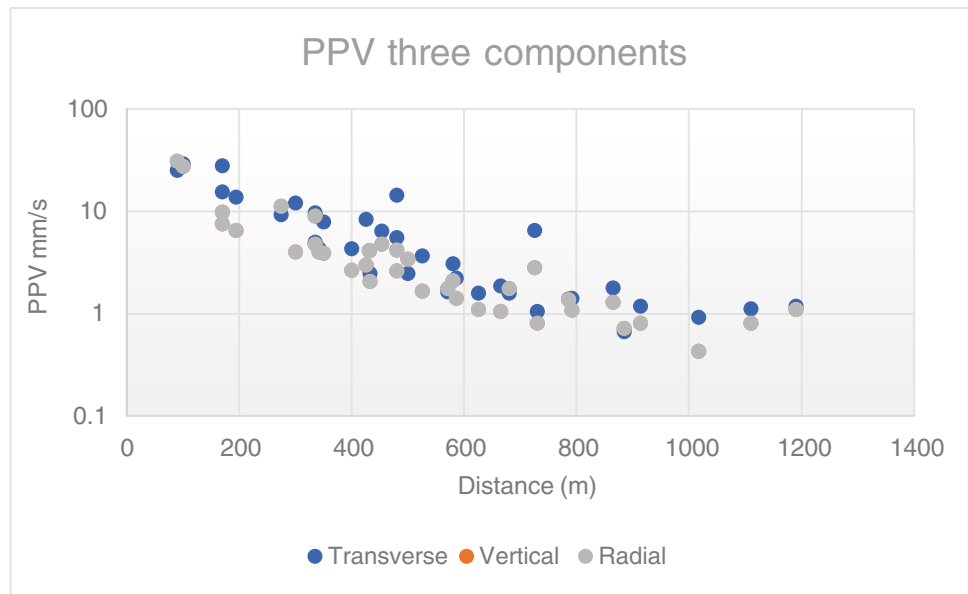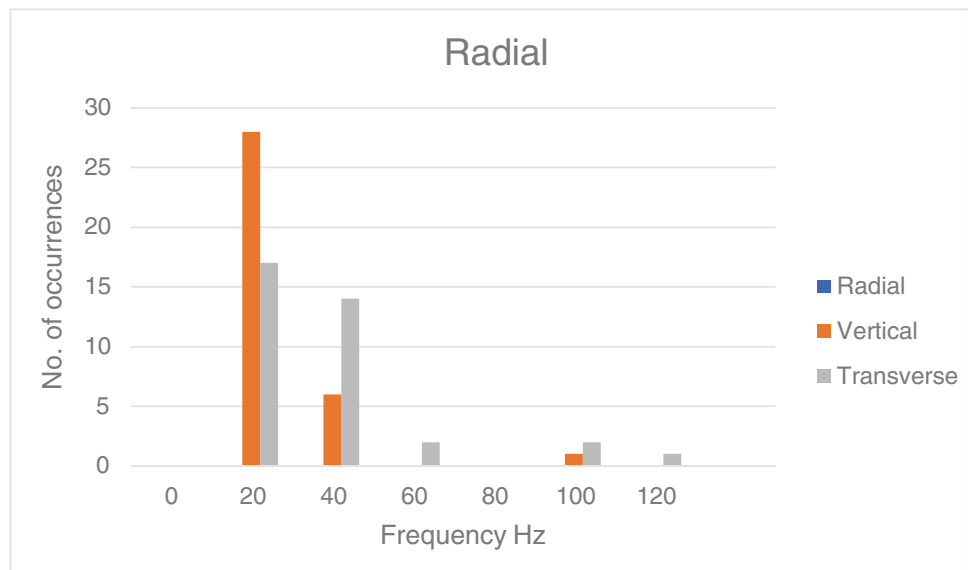

Fig. 6 The frequency recurrence plot of the recorded PPV. The majority of the recoded PPV has frequencies below ≤ 40 Hz


that the effect of the blasting diminishes at the end of the distance window for the present study. The frequency distribution of the PPV shows also that most of the vertical data belongs to frequencies less than 20 Hz.

AOP data, on the other hand, shows a different behavior than the PPV measurements (Fig. 7). The plot of the AOP data tells that the attenuation is slower than the PPV. The attenuation may be represented as a straight line. The frequencies of the AOP measurements were generally small with a dominant frequency of 2.25 Hz. The maximum frequency reported is 6.6 Hz reported once at 865-m distance. Hence, the recorded AOP lies in the infrasound range.

One important quantity, i.e., the charge weight per delay was not considered in the data plots. The charge weight seems more pronounced at the shorter distances; as the distance increases, both PPV and AOP seem not affected.

The recordings were conducted at close distances to the blast locations, since this close range usually carries more information about the blast delay and charge weight. Some of the recordings were conducted at farther distances to have an idea about the attenuation characteristics of the blasts. Besides, some recordings of the Egyptian National Seismological Network were obtained and analyzed. The latter is used to have an idea about blasting parameters at large distances.

Fig. 7 The AOP plot against distances. The charge weight per delay is ignored. The attenuation is much less than PPV
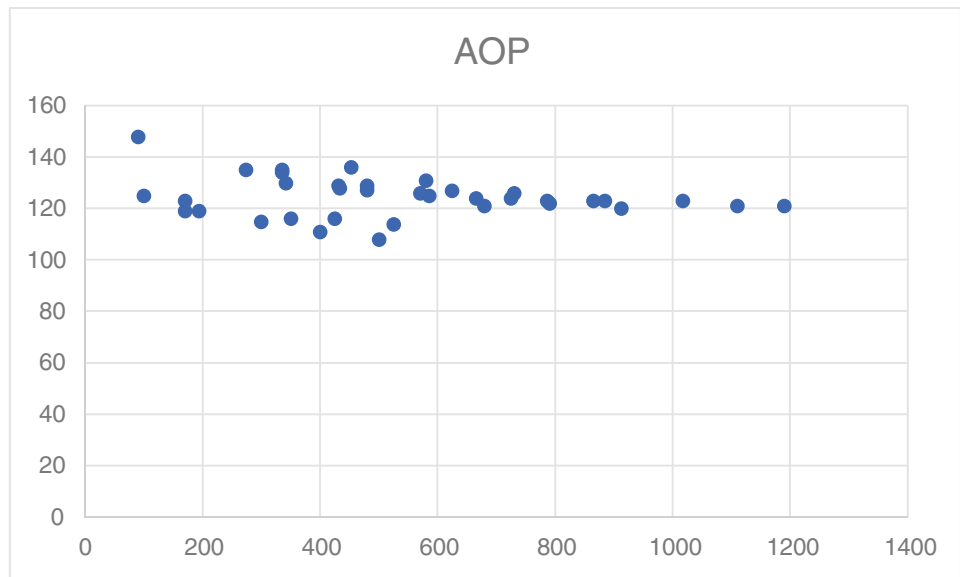
Phase 2

The data collected from phase 1 is subjected to data review and analysis to isolate and remove bad data. Besides, a relation between the PPV and the scaled distance is deduced to predict blast effects at various distances in the light of some selected worldwide standards. The useful data is further prepared for establishing the prediction equations for PPV and AOP over distances.

Several researchers (German DIN Standard (1983), Indian CMRI standards (1993) and Kahriman 2001) have carried out various studies for this purpose. Empirical and conventional models for predicting PPV are essentially based on two important variables, the so-called maximum charge per delay and the distance from the blasting site. Usually, the charges of blasting are not fired at once. The charge is distributed on certain holes that are fired with certain delays to reduce the unwanted effects of the blast. A charge per delay is the charge at each hole. All models considered were based on a scaled distance (SD) (Fig. 8). The scaled distance is the hybrid variant of maximum charge per delay D, and distance from blast site W. This allows only simple graphical presentation of the data.

Fig. 8 Prediction model for PPV with scaled distance for the blasts from Qattameya quarry
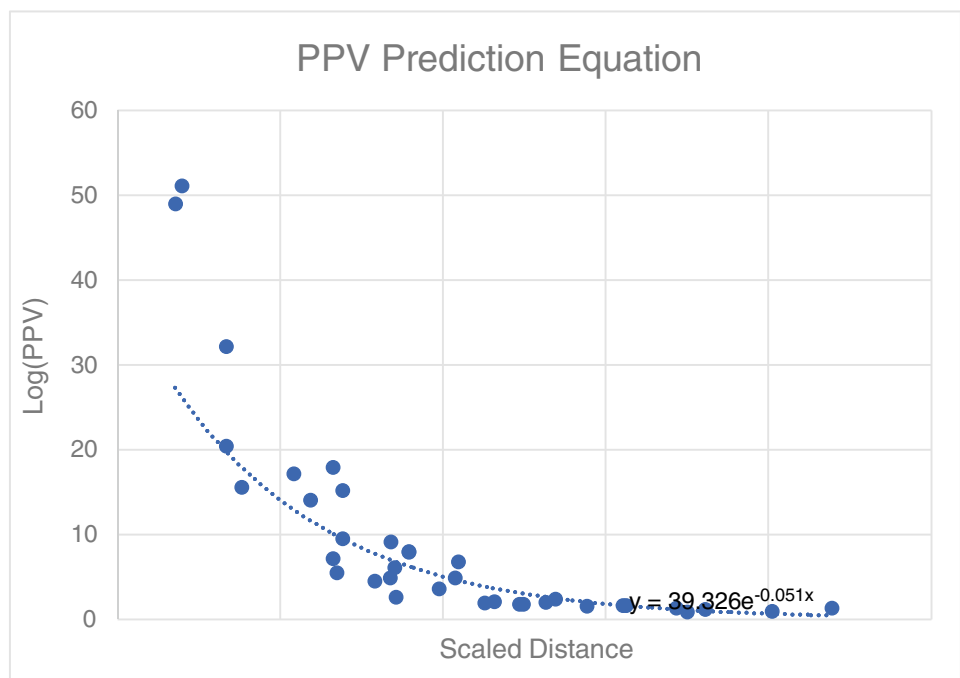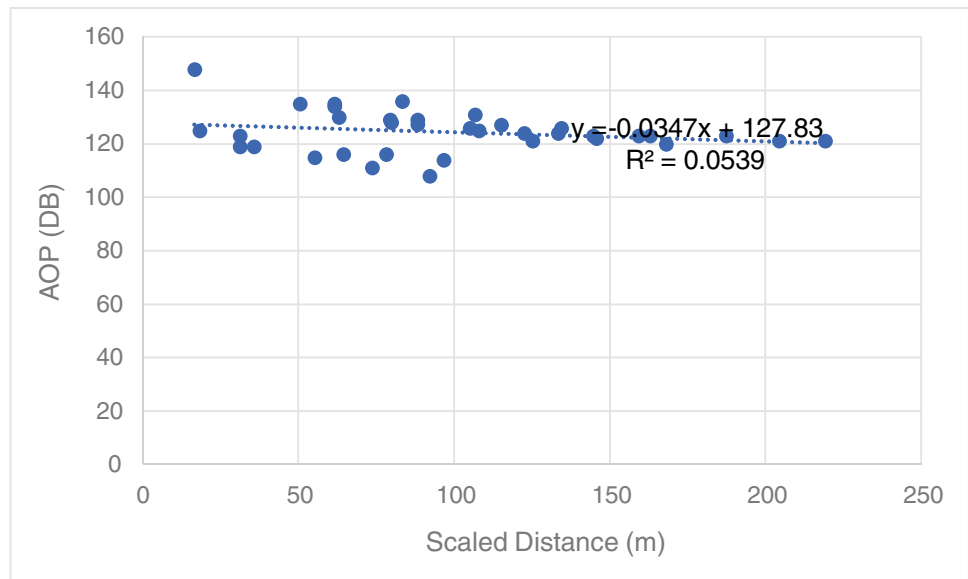

$$y = 39.326e^{-0.051x}$$

Fig. 9 Prediction model for AOP with scaled distances

Another parameter of importance is the AOP. What makes this parameter vital is the low attenuation properties. This implies that AOP effect can reach farther distances compared to PPV. Hence, a prediction equation of AOP is sought to predict the value in DB at distances that can reach NAC. From the data plot in Fig. 7, it is observable that this parameter follows a linear relation with the scaled distance. A straight-line fitting is presented in Fig. 9 below.

The model equation shown in Fig. 9 suffers from low R^2 index (~ 0.05); this is most likely because of the slow attenuation of the AOP. Besides, the charge weight per delay is slightly changeable, since the quarry explosions are already under monitoring, and a safe limit is set.

Results and discussion

Vibration-induced damage thresholds are usually expressed in terms of peak particle displacement, velocity, or acceleration and sometimes include a

frequency dependent factor. Harmonic vibrations may be described by frequency and any of the following: peak particle displacement, peak particle velocity, or peak particle acceleration. Although PPV is widely used to quantify the damaging potential of a vibration, it must be recognized that velocity itself, cannot induce damaging forces. Such forces are generated in structures by both:

a) differential displacements which give rise to distortion as the structure follows movement of the ground upon which it is founded or
b) change in the ground particle velocity vector (magnitude or direction) which produces inertial forces upon the structure.

In practice, the structure will be subjected to both "distortion" and "inertial" mechanisms at the same time that will be superimposed upon pre-existing stresses and strains from other causes. Hence, damage will occur when the combined effects exceed the tolerance of the structure. Vibration can also give rise to longer term ground movements (e.g., by

Table 2 Risk of damage in ordinary dwelling houses (Langefors and Kihlstrom 1978)

	Sand, shingle, clay under groundwater level	Moraine, slate, soft limestone	Hard limestone, quartz sandstone, gneiss, granite, diabase	Type of damage
P-wave velocity m/s	300–1500	2000–3000	4500–6000	
Vibration velocity mm/s	4–18	35	70	No noticeable cracks
	6–30	55	110	Insignificant cracking (threshold value
	8–40	80	160	cracking
	12–60	115	230	Major cracks

compaction) which may also contribute materially to structural distress. The dependence of distortion induced in structures on wave propagation velocity has been recognized by Langefors and Kihlstrom (1978), who gave risk of damage thresholds which are closely proportional to the wave propagation velocity of the ground upon which the structures are founded (Table 2).

Several worldwide standards are suggested to reduce the expected effects of quarry blasts on both human and engineering structures. From Table 2, it is evident that the effects depend on the charge weight, distances, and velocities of surface layer. The surface layer in the study area belongs to the first category, i.e., velocity ranges from 300 to 1500 m/s. Henceforth, the level of PPV capable of producing damage ranges from 8 to 40 mm/s. This level indeed is dependent on both distances and charge weight. The use of scaled distance accounts for both the charge weight and distance. As a result, the parameters required to estimate the expected risk are reduced to only the PPV. The present work adopted a number of worldwide standards to evaluate the risk at the buildings of NAC.

An illustration of this can be found in Fig. 10. The values of PPV expected at NAC are very small. In Fig. 10, the study assumed the quarry explosions are located close to NAC. All the values are located below the safety standards adopted by USBM. Only two PPVs exceed the standards at frequencies between 10 and 20 Hz and PPV of almost 30 mm/s. Siskind (2000) summarized the ground vibration effects from quarry blasts (Table 3). It is evident from Table 3 that the lowest limit from USBM measure at low frequencies is 12.7 mm/s. However, the measure at high frequencies reaches about 51 mm/s. Comparing this with measures in Table 2, it is evident that the USBM measure is taking more conservative measures than Langefors and Kihlstrom (1978). Oriard (2002) agreed on 50 mm/s as a safety limit to keep houses safe during a quarry blast. The present study adopted such measure as a safety limit in the neighborhood of NAC.

Effects of ground vibration are not only dependent on amplitudes but also on frequencies as well. A graph chart representing the standards set by USBM is shown in Fig. 10. The observed PPV from the present study is plotted on the

Fig. 10 A chart summarizes the standards of USBM. The building standards are plotted as solid lines. Recorded PPV and AOP obtained from the present work were plotted assuming stations located inside NAC. The distance is dropped to present the worst scenario from the current blasting regulations
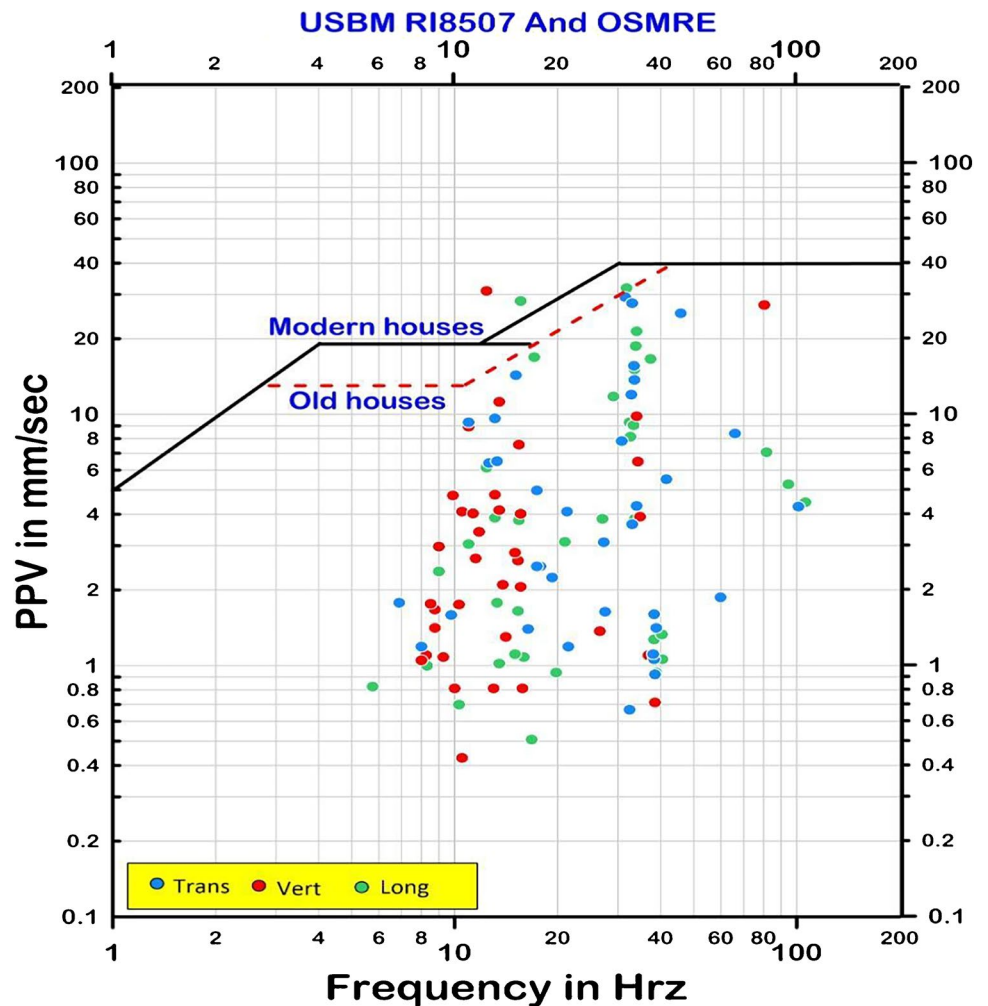
Table 3 Some reported effects of ground vibration on building and facilities (after Siskind 2000)

PPV (in/s)	PPV (mm/s)	Vibration effects
0.001	0.0254	Quiet background
0.01	0.254	Threshold of human perception for steady-state vibration (physical)
0.03	0.762	Traffic at 50 ft (16 m)
0.03	0.762	Noticeable houses rattling and response from vibration
0.06	1.524	Threshold of human perception for transient vibration (physical)
0.10	2.54	Truck traffic on bumpy road at 50 ft (16 m)
0.18–0.32	4.572–8.128	Train at 20 ft
0.30	7.62	Pavement breaker at 30 ft
0.50	12.70	Lowest threshold for plaster creak extension in house
0.50	12.70	Lowest USBM safe vibration criteria (USBM RI-8507, for low frequencies)
0.50	12.70	Typical household environment from inside activities and natural forces of wind, temperature, and humidity
0.70	17.78	ANSI limit for human comfort: steady state vibration (S-3.18–1979)
0.75	19.05	Strictest federal to protect homes from cosmetic cracking from surface coal mine blasts (OSM, for distances > 5000 ft)
0.79	20.066	Lowest level for an observed crack extension in wallboard (RI8507)
1.00	25.40	Federal limit to protect homes from cosmetic cracking from surface coal mine blasts (OMS, for distances of 301 to 5000 ft)
1.20	30.48	Response of house superstructure from 62-mph wind (BOCA code, 10 psf)
1.25	31.75	Federal limit to protect homes from cosmetic cracking from surface coal mine blasts (OMS, for distance < 300 ft)
2.00	50.80	USBM recommendation for safe blasting from 1962 and 1971 (RI 5968 and B 656)
2.00	50.80	Most states limit for protecting homes from blasting
2.00	50.80	Safe-level criteria for cosmetic cracking in homes from high-frequency blasts, such as construction (USBM RI 8507)
2.00	50.80	ANSI limit for human health: Steady state vibration (S-3.18–1979)
2.00	50.80	Highest vibrations generated inside homes by walking, jumping, slamming doors, etc
4.00	101.6	ANSI limit for human health: steady-state vibration (S-3. 18)

Fig. 11 Estimated PPV at the nearest distance to NAC (~7000 m) using the prediction equation developed in the present work
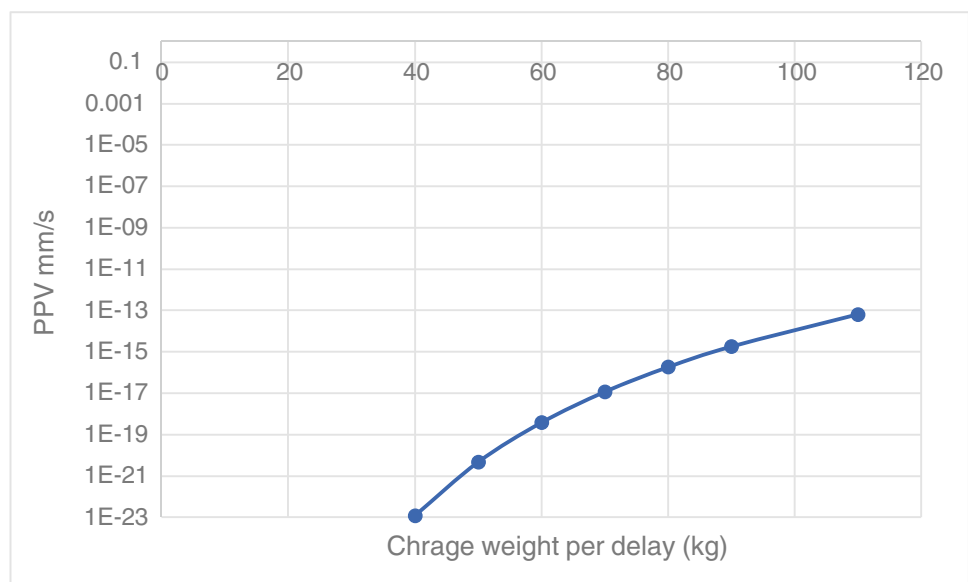
graph to get an idea about the expected effects if the values recorded were at the sites of interest. From the figure, it is evident that only two of the recorded values have possible damage to buildings at NAC.

The actual PPV values expected at the closest scaled distances of NAC can be obtained using the prediction equation model for PPV. Figure 11 shows the expected PPV values at 7 km with various charge weights per delay. Up to 110 kg charge weight, the estimated PPV is negligible.

Table 4 AOP criteria after Oriard ([2002](#))

1.0 psi (171 dB)	General window breakage
0.1 psi (151 dB)	Occasional window breakage
0.029 psi (140 dB)	Long-term history of application for as a safe project specifications
0.0145 psi (134 dB)	Bureau of mines recommendation following a study of large-scale surface mine blasting

Table 5 Overpressure limit recommended by USBM for surface mining (RI 8485)

134 dB	0.1 Hz high pass measuring system
133 dB	2.0 Hz high pass measuring system
129 dB	6.0 Hz high pass measuring system
105 dB	C-slow weighting scale on a sound level meter
(Events less than or equal to 2-s duration)	

The AOP, on the other hand, may have some unpleasant effect on residents of NAC. An air-blast with a peak AOP of 130 dB can be mildly unpleasant, whereas exposure to jet aircraft noise at a level of 130 dB would be painful and deafening (https://www.agg-net.com). For more safety, the present study adopts 120 dB as a safety limit for residents at NAC. This limit is confirmed with parameters indicated in Tables [4](#) and [5](#). Oriard ([2002](#)) indicated that 171 dB could cause general window breakage. Table [5](#) relates the limits assigned by USBM to frequency.

The use of the prediction equation for AOP predicted here indicated that for a charge weight per delay of less than 45 kg, the expected AOP is approximately 113 dB. Taking into consideration that the dominant frequency from observations is 2.25 Hz, it is recommended to keep the maximum charge weight below 45 kg.

Conclusion

Normally most of the habitation who lives near a source for blasting (i.e., cement plants) suffered from fearing of the effect of the blast vibrations and AOP noise on their homes. This effect will not be limited to the people's buildings but will extend also to the plant building and structure as well. A clear mitigation strategy is needed locally to determine the regulations for blast-induced process in different industries. This strategy is proposed to minimize the effects of ground vibration and air overpressure on the nearby NAC structures. Universally, the relation between peak particle velocity and scaled distances is accepted as the formula determined potential damage for buildings. The United States Bureau Mines (USBM) guidelines and

German vibration (DIN 4150) standards intended to protect buildings are adopted in this study. Using the regulation limit of the above standards, all the monitored ground vibration paired with the frequencies are below any damaged limit. When the recorded PPV values from the blasting inside Qattameya plant (the nearest plant of the New Cairo City) were over 19 mm/s with a low frequency band (< 40 Hz), a damage to the nearby structures is expected. Therefore, it was concluded that the mitigation measurements would be helpful for minimizing the annoyance of the people who live in the quarry area and surroundings. International regulations are used in parallel for the evaluation of the monitored and recorded ground vibrations from the structural damage potential point of view. The permitted ground vibration limit in international regulation is 19 mm/s for seismic waves, having frequencies ranging from 4 to 10 Hz. The permitted levels in international standards are valid for the structures which are engineered and constructed, in accordance with construction regulation. It is concluded that the conditions of structures in NAC cannot tolerate 19 mm/s vibration velocity. The results and the conclusions drawn from the investigation, together with the technical and administrative precautions to be taken are determined and given below.

1. The recorded vibration velocities are lower than 0.6 mm/s within 900 m to NAC, 4 mm/s within 290 m and 51 mm/s within 100 m. Thus, no damage has been occurred in structures at surrounding settlements in the past and at present.

2. The maximum charge amount detonated per delay in production blasts at present is 160 kg. There will be no damage risk at all, in the future also, if the maximum charge amount per delay is kept below 190 kg or more preferably less than 155 kg.

3. The permitted ground vibration limit is given as 6.35 mm/s by American National Standards Institute (ANSI, S2.[47-1990](#)) for eliminating intolerable levels of vibration for humans in buildings up to 12 blast events per day. However, this limit is found to be high from the structural damage point of view, taking the conditions of buildings into account, and the vibration limit

to be allowed in the ground at settlements is accepted as 3 mm/s to remain at the safe side.

4. A 3 mm/s vibration limit is taken as a basis for the evaluation of human response and disturbance as well. The lowest vibration level that can be perceived by the most sensitive occupants in settlements is 1.2 mm/s by taking the frequency range of seismic waves into account; however, the highest vibration levels arriving at neighboring settlements are less than 1 mm/s. Thus, it is concluded that the occupants are not disturbed by the direct effect of vibrations.

5. Scaled distance values of more than 65 are found to be safe both the from structural damage and human disturbance points of view. It can be declared hereby that the ground vibration levels recorded during this study and analyzed from the past records comply with international regulations.

6. Continuous monitoring of ground vibrations is recommended to follow up any cause for damage in structures in the inhabited areas surprisingly, which may arise from unexpected geological features. If an anomaly is observed in the records during continuous monitoring, necessary measures can be taken accordingly. The maximum vertical peak particle velocity of 1.5 mm/s was recorded near the foundation of the nearest house. All the blasts recorded fall well below the safe limit. There is also a similar situation for the AOP as the highest value of 125 dB was within a tolerable range. Using the Nonel initiation system is likely to reduce AOP if compared with the conventional detonating cord, although all the AOP records fall below the adopted safe limit. The quantity of explosive per delay should not exceed 45 kg per delay which should result in a vibration peak particle velocity of 18.6 mm/s. The frequencies should not fall below 10 Hz as low frequencies tend to result in possible longer vibration periods. These levels can be considered very conservative due to the sensitive nature of the inhabitants in the vicinity of the quarry.

Declarations

Conflict of interest The authors declare no competing interests.

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