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Quarry blasts assessment and their environmental impacts on the nearby oil pipelines, southeast of Helwan City, Egypt

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Abstract Ground vibrations induced by blasting in the cement quarries are one of the fundamental problems in the quarrying industry and may cause severe damage to the nearby utilities and pipelines. Therefore, a vibration control study plays an important role in the minimization of environmental effects of blasting in quarries. The current paper presents the influence of the quarry blasts at the National Cement Company (NCC) on the two oil pipelines of SUMED Company southeast of Helwan City, by measuring the ground vibrations in terms of Peak Particle Velocity (PPV). The seismic refraction for compressional waves deduced from the shallow seismic survey and the shear wave velocity obtained from the Multi channel Analysis of Surface Waves (MASW) technique are used to evaluate the closest site of the two pipelines to the quarry blasts. The results demonstrate that, the closest site of the two pipelines is of class B, according to the National Earthquake Hazard Reduction Program (NEHRP) classification and the safe distance to avoid any environmental effects is 650 m, following the deduced Peak Particle Velocity (PPV) and scaled distance (SD) relationship ($PPV = 700.08 \times SD^{-1.225}$) in mm/s and the Air over Pressure (air blast) formula (air blast $= 170.23 \times SD^{-0.071}$) in dB. In the light of prediction analysis, the maximum allowable charge weight per delay was found to be 591 kg with damage criterion of 12.5 mm/s at the closest site of the SUMED pipelines.

1. Introduction

Egypt experiences an increase in the infrastructure and mineral resource developments. As a result, quarrying activities have increased to supply the required construction materials. The use of explosives to execute blasting activities always leads to concern its effect on the environment. These effects are normally nuisances to the neighboring residence, as they come

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in the form of dusts, toxic gases, noises, fly rocks, air blasts and ground vibrations. In most cases, after blasting activities worldwide, there are usual complaints about damage to residence and pipelines.

The aim of the current research is to identify a vibration level that will not cause damage to the oil pipelines of SUMED Company close to the limestone quarry of the National Cement Company (Fig. 1).

Based on the literature review (Devine, 1966; Muller, 1997; Elseman, 2000; Tripathy and Gupta, 2002; Nicholson, 2005; Khaled et al., 2007a,b, 2008; Hakan et al., 2009; Aldas, 2010), it was revealed that, there are a number of parameters that needed to be considered. These ranges; distance from the two pipelines, geological conditions of the area, quantity and design of blast and the ground vibration threshold according to the various standards.

Fly rocks are considered to be the most undesirable movement of rocks during the blasting activities. Damage by a fly rock can not be refuted; the evidence is usually present and visible. Fly rocks can be a result of overcharge, too small burden, or basic loose rocks on the crest of the bench.

The term Air over Pressure (air blast) is often used to describe the air waves, which are generated by blasting activities. Oriard (2002) simply defines this as the pressure above the atmospheric pressure. Air waves are compressed waves that travel through the air. Under certain weather conditions and poor blast design, air blast can travel considerable distances. Audible air blast is called noise, while air blasts at frequencies below 20 Hz and inaudible to the human ear are called concussions. Over pressure is usually expressed in pounds per square inch (psi) or in decibels (dB) (Bollinger, 1971; Siskind et al., 1980; Konya and Walter, 1985; ABC, 1987).

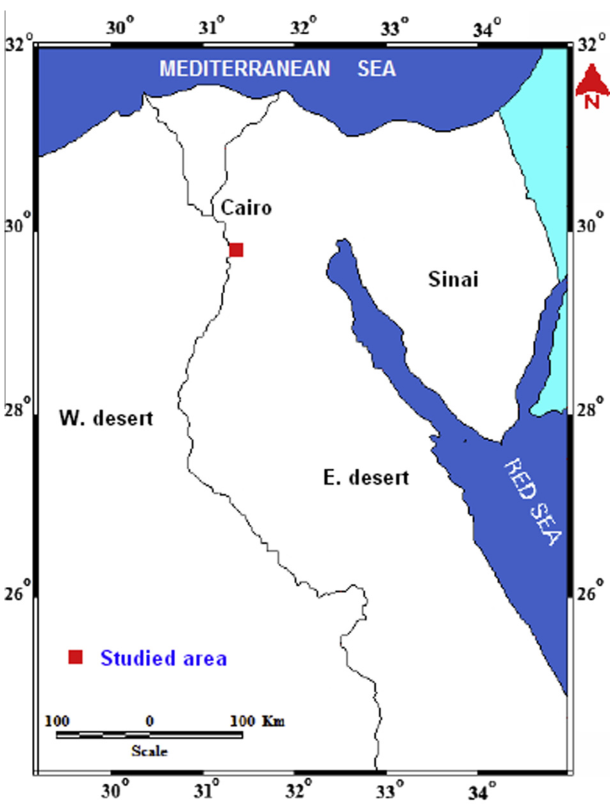

Fig. 1 Location map of the studied area.

As the seismic waves travel through the rock, there are movements of the particles. This is commonly referred to as vibration. The motion of the ground particles (vibration) occurs in 3-dimensions, which are vertical, longitudinal and transverse. When there is a vibration, each particle has a velocity and the maximum velocity is referred to as the Peak Particle Velocity (PPV). This PPV readings are used as the standard for measuring the intensity of the ground vibration in either in/s or mm/s (1 in/s = 25.4 mm/s).

To evaluate the environmental impact of the quarry blasts at NCC, the ground vibrations (PPV and air blast) are monitored for two months at various distances as well as at the two oil pipelines of SUMED Company.

The shallow seismic surveys (for P-waves and Multi channel Analysis of Surface Waves (MASW)) are performed for studying the near surface layers at the closest site. The MASW is based on the inversion of the Rayleigh wave dispersion curves, which are proved to obtain the characterization of the local S-wave velocity profile with a good accuracy. The advantage of this technique is the determination of low velocity layers. The average shear-wave velocity in the uppermost 30 m (Vs_{30}), which is adopted by the National Earthquake Hazard Reduction Program (NEHRP) classification in the USA (Street et al., 2001), is used to evaluate the closet site of the pipelines to the quarry.

2. Geologic setting

Mohamed et al. (2012) investigate the geologic setting of the area in detail. They constructed a geological map (scale 1:20000) which reveals that most of the area consists of deposits of Pliocene, Upper, and Middle Eocene (Fig. 2). The Pliocene deposits are represented by wadi deposits, which are composed of compacted sandstone of medium to coarse grains. The Upper Eocene deposits are represented by Wadi Garawi and Qurn Formations, while the Middle Eocene deposits represented by Observatory Formation. Wadi Garawi Formation consists of marl and marly limestone with clay intercalation at the upper part of the formation and thicknesses ranging from 50 to 80 m. Qurn Formation is composed of five units; the first unit (at the base) consists of massive crystalline limestone inter-bedded with argillaceous limestone as shown in the composite geological section (Fig. 3). The second unit includes argillaceous limestone, marl and shale. The third unit of Qurn Formation is made up mainly of marl and shale. The fourth unit is represented by limestone with claystone bands. The fifth and last unit (at the top) of Qurn Formation consists of limestone. The Observatory Formation of Middle Eocene is characterized by highly fractured limestone and caves. (Farag and Ismail, 1959; Moustafa et al., 1985; Mohamed et al., 2012) investigate the surface structures at the whole area and state that the area has been dissected by sets of normal faults trending NW-SE, E-W, and NE-SW.

3. Ground vibration damage criteria

When an explosive charge is detonated in a rock, the charge is converted into hot gas and intense pressure. This pressure nor-

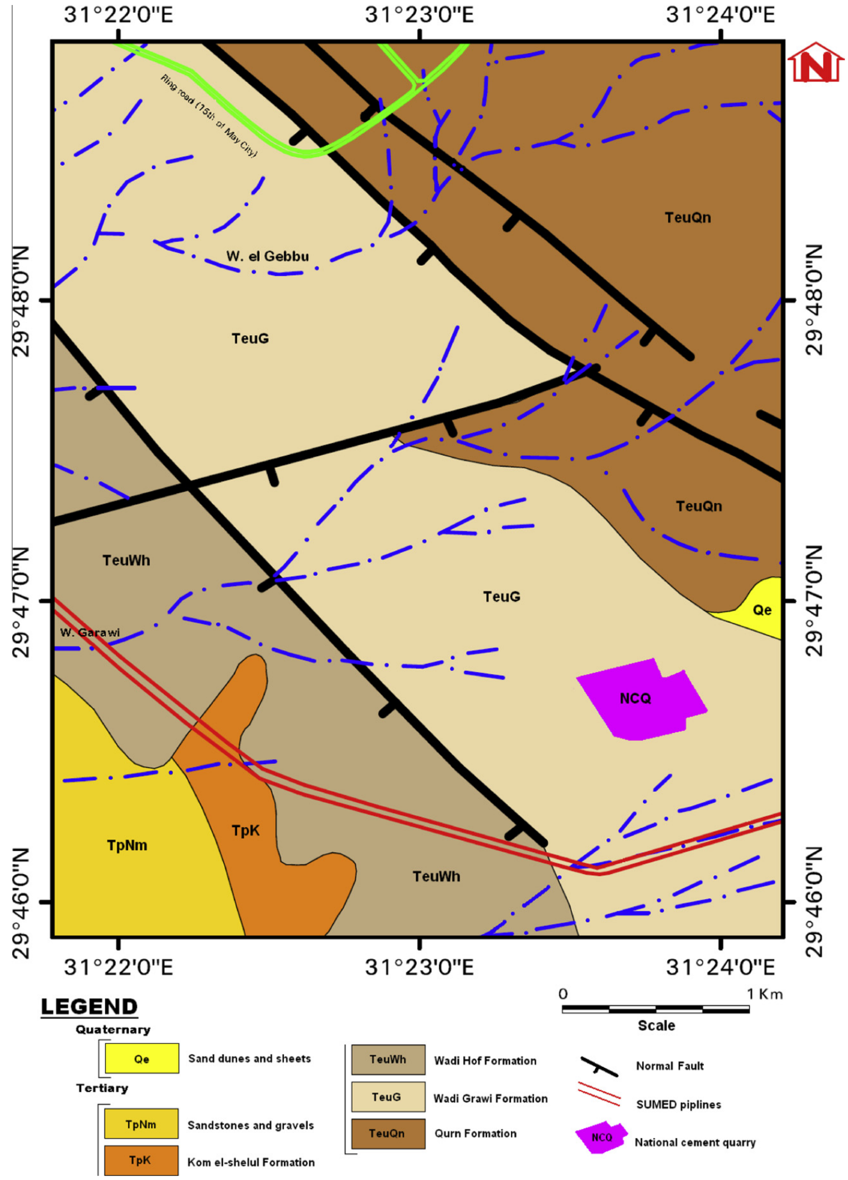

Fig. 2 Geologic map of the interested area (After Mohamed et al., 2012).

mally melts and crushes the rock around the blast hole to a certain point, almost two times the diameter of the confined area. This is highly dependent on the type of rock, as in some cases the cavity formed around the whole, yields more than four times the volume (Bauer, 1980).

Since the energy from the detonation is insufficient to crush further than four times the diameter of the confined hole, beyond that point radial cracks are formed and extended across the cavity. This energy continues to work on the rock by expanding theses cracks. All crushing and cracking of the in situ materials take place within the inelastic zone. Beyond the inelastic zone, there is the elastic zone, where no further permanent damage from the explosion energy takes place. Oriard (2002) refers to the activities within the elastic zone as elastic waves; these may stretch and bend, but will never break.

All structures or facilities surrounding a blast site will respond, with the vibration intensities dependent on physical variables such as; distance from blasting to position of interest, explosive charge weight per delay, and the frequency of vibration.

In most countries there are regulations and guidelines that are used to ensure that all vibration levels are kept within a specific limit. The United States have used the Office of Surface Mining Reclamation and Enforcement (OSMRE, 1987) and the United States Bureau Mines USBM (Duvall and Fogelson, 1962) code and regulations to protect buildings and buried pipes that are considered as damage criteria in the current study. They use the threshold values as: PPV = 12.5 mm/s, air blast = 122 dB for superstructures and PPV = 50 mm/s for buried pipes. The geology of Egypt and nature of constructions are much different so, those criteria might not give the expected results. In such a case it is necessary to use the USBM criteria for reference to set conservative limits that will be most applicable for the interested area. The conservative levels criteria are set at threshold ground vibration (PPV) of 12.5 mm/s and air blast of 120 dB.

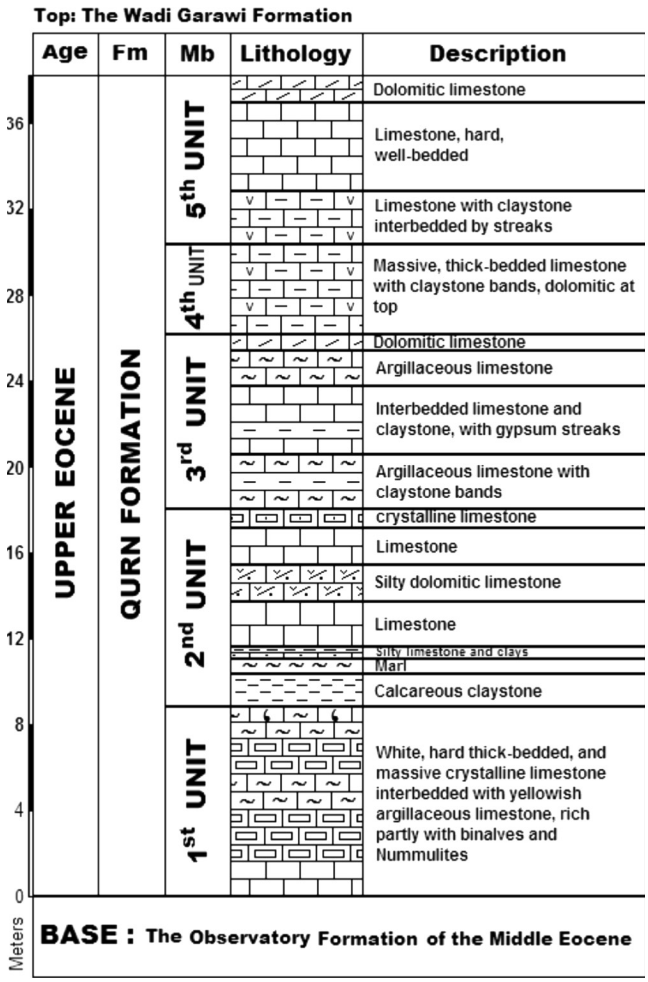

Fig. 3 The composite geological section at the area of interest (After Mohamed et al., 2012).

4. The concept of scaled distance

Scaled distance (SD) is a dimensionless parameter for distance. It is derived as a combination of distance and charge weight influencing the generation of seismic and air blast energy. Scientists, through research of the propagation law (Konya, 2003), have developed a method to estimate and compare ground vibrations from a blast during the planning and design stage to stay within the prescribed vibration limits. The amplitude of ground vibrations is established by the quantity of energy present to create the vibration and the distance through which the vibrations have propagated. The square root scaled distance formula relates ground vibration amplitude to the explosive charge weight per delay and the distance from the blast. The typical way of combining distance and explosive energy is to divide the true distance by the square root of the maximum explosive charge weight per delay to obtain a normalized or scaled distance (ISEE, 1998) as follows:

$$SD = d/\sqrt[2]{W} \quad (1)$$

where: SD is the scaled distance (in $m/kg^{0.5}$); d is the true distance from shot to specific location and W is the maximum explosive charge weight per delay.

The cube scaling (SD^* in $m/kg^{0.33}$) was used in establishing the air vibration (air blast) decay characteristics as given in the following relationship:

$$SD^* = d/\sqrt[3]{W} \quad (2)$$

Ground vibrations generally decay with distance from the shot. Specifically, ground vibrations from blasting in most geologic settings decay or attenuate to approximately one third of their former value for each doubling of distance (ISEE, 1998). To predict ground vibrations in Peak Particle Velocity, scientists have developed the following equation (Oriard, 2002; Konya, 2003; ISEE, 1998; Dowding, 2000; Wyllie and Mah, 2004):

$$PPV = K(SD)^{-\alpha} \quad (3)$$

where PPV is the Peak Particle Velocity in mm/s, K is the site factor (particle velocity at scaled distance = 1 and is defined as a measure of how much vibration energy is transferred to the ground near the explosive charge) and α is the curve slope (decay exponent – always negative and is defined as how fast the energy attenuates with distance).

The air blast level (in dB) decay is given by the following relation (m and a are defined as site constants as K and α in Eq. (3)):

$$\text{Air blast} = m(SD^*)^{-a} \quad (4)$$

5. Data collection

5.1. Ground vibration and air blast

Due to the sensitivity of the National Cement Quarry (NCQ) location (Southeast of Helwan City Fig. 4) with respect to the adjacent SUMED oil pipelines; all blasting activities must be monitored for vibration levels. The purpose is to help to prevent property damage as a result of ground vibrations and air blasts from blasting activities. To collect all these data, five seismographs were used at different times and distances. At times when the conditions were considered to be serve, at least three to four seismographs (Minimate Blaster) were used simultaneously. The Minimate Blaster seismographs (Fig. 5) are of Instantel origin. They are all fitted with four channels, three channels for tri-axial transducers for monitoring vibrations in the Longitudinally, Transverse and Vertical directions and one channel to monitor the air blast.

The data were collected for two months (four times per week). Sixty events are recorded at various distances. Forty of them are recorded, where the instruments are located at the ground surface above the two pipelines, the recorded events are listed in Table 1.

5.2. P-wave shallow seismic survey

In order to classify the shallow foundation section into soil and bedrock and to define the competence scales and geotechnical characteristics at the closest area of SUMED pipelines to the NCQ, the shallow seismic refraction survey was carried out through applying the forward, mid-point and reverse acquisition system (vertically) to create the compressional (P) waves and perform the Multi channel Analysis of Surface Waves (MASW) technique and invert the phase velocity into shear

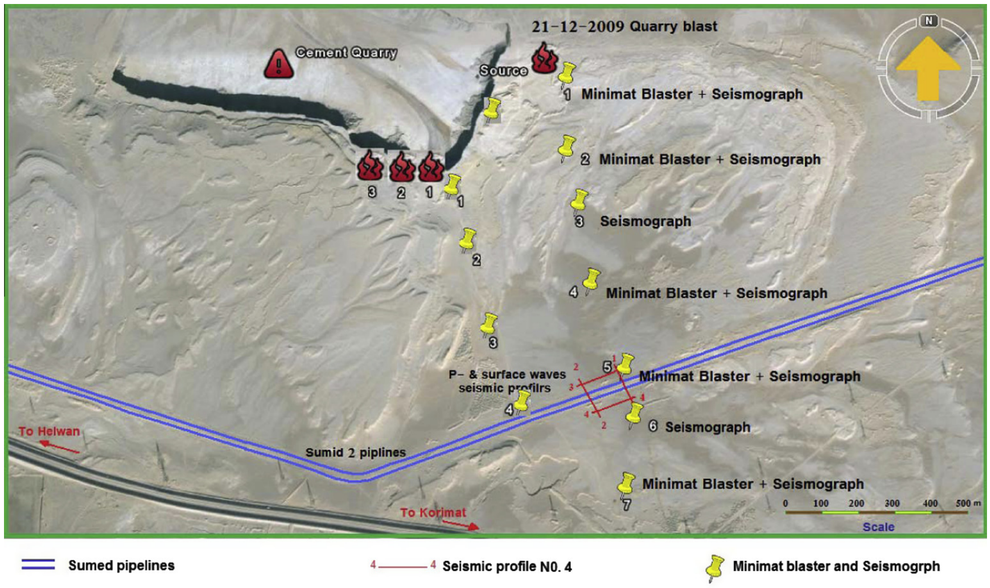

Fig. 4 The location map of the seismic profiles and vibration record sites at the National Cement Quarry.

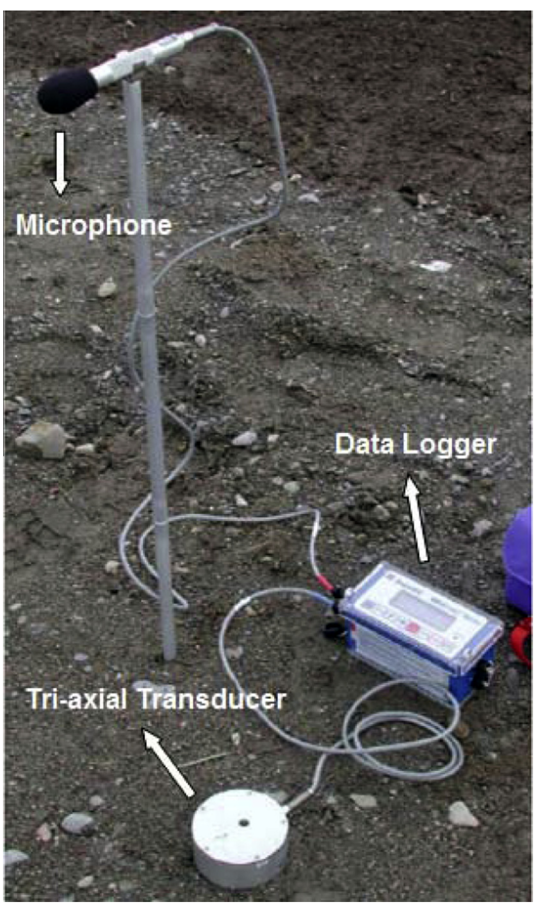

Fig. 5 The Instantel Minimate Plaster instrument, which is used to record the vibrations of the National Cement Company Quarry Blasts.

waves (S) velocity. The object of such P-waves and S-waves generation is to conclude the variations of velocities (compressional, Vp and shear, Vs,) with depth and correlate them with the subsurface geologic information. The P-wave seismic refraction field work executed at SUMED site is consisted of four seismic profiles distributed regularly around the two pipelines (Fig. 4). Accordingly, for each seismic site, two seismic refraction profiles are acquired, one for the compressional waves and one for the surface waves, using the MASW technique.

The P-waves are acquired by generating seismic energy using energy source, sending the created seismic waves inside the earth. The direct (head) and refracted (diving) waves are detected through geophones, which are motion sensitive transducers, that convert the mechanical ground motion into electrical signals, whose voltage amplitude is proportional to the received energy. Four profiles have 94 meter long spread, the total spread length should be three to five times the maximum depth anticipated (Redpath, 1973). The geophone spacing was fixed and equal to 2 m. The geophones must be firmly coupled to the ground. The technique is to shot the profile (5 shots) 5 meters far from both ends, also from its mid-point, in addition to 2 shots (between G12-G13 and G36-G37). Fig. 6, shows a representative example of the recorded P-wave seismograms at the seismic profiles P1.

5.3. MASW survey

Another technique to determine the shear wave velocity is used. This is the most common type of MASW (Multi channel Analysis of Surface Waves) survey that can produce 1-D and 2-D Vs profile (Park et al., 1999). The overall setup is illustrated in Fig. 7a. The maximum depth of investigation (Z_{max}) that can be achieved is usually in 10–30 m range, but this can be varied with sites and types of active sources used. A fairly heavy sledge hammer was used as a source of active MASW. Vertical stacking with multiple impacts can suppress ambient noises significantly and is therefore always recommended, especially if the survey takes place in an urban area. Low-frequency of 4.5 Hz geophones is used. Length of the receiver

Table 1 The parameters of the recorded events due to quarry blasting at the NCC quarry.

No	Date	Distance (m)	Total charge (kg)	Charge/delay (kg)	Scaled distance, SD (m/kg$^{0.5}$)
1	21/12/2009	90	1850	400	4.5
2	21/12/2009	270	1850	400	13.5
3	21/12/2009	660	1850	400	33.0
4	21/12/2009	910	1850	400	45.5
5	21/12/2009	1250	1850	400	62.5
6	17/02/2010	40	1060	400	2.0
7	27/01/2010	50	960	400	2.5
8	27/01/2010	200	960	400	10.0
9	27/01/2010	450	960	400	22.5
10	27/01/2010	630	960	400	31.5
11	27/01/2010	750	960	400	37.5
12	27/01/2010	60	960	400	3.0
13	27/01/2010	220	960	400	11.0
14	27/01/2010	470	960	400	23.5
15	27/01/2010	650	960	400	32.5
16	27/01/2010	770	960	400	38.5
17	17/02/2010	80	1060	400	4.0
18	17/02/2010	130	1060	400	6.5
19	17/02/2010	160	1060	400	8.0
20	17/02/2010	160*	1060	400	8.0
21	17/02/2010	170*	1060	400	8.5
22	17/02/2010	180*	1060	400	9.0
23	17/02/2010	300	1060	400	15.0
24	17/02/2010	370	1060	400	18.5
25	17/02/2010	550	1060	400	27.5
26	17/02/2010	560	1060	400	28.0
27	11/03/2010	140	1060	400	7.0
28	11/03/2010	380	1060	400	19.0
29	11/03/2010	780	1060	400	39.0
30	11/03/2010	110	960	400	5.5
31	11/03/2010	360	960	400	18.0
32	14/03/2010	390	1060	400	19.5
33	14/03/2010	790	1060	400	39.5
34	14/03/2010	140	1060	400	7.0
35	14/03/2010	380	1060	400	19.0
36	14/03/2010	110	1060	400	5.5
37	14/03/2010	210	1060	400	10.5
38	14/03/2010	430	1060	400	21.5
39	17/03/2010	980	1850	400	49.0
40	17/03/2010	970	1850	400	48.5
41	21/03/2010	1820	3000	400	91.0
42	22/03/2010	570	1000	400	28.5
43	22/03/2010	690	1000	400	34.5
44	22/03/2010	620	1000	400	31.0
45	24/03/2010	1730	3900	400	86.5
46	29/03/2010	1340	3355	400	67.0
47	31/03/2010	1760	3355	400	88.0
48	04/04/2010	1800	3355	400	90.0
49	07/04/2010	1650	3355	400	82.5
50	08/04/2010	760	955	400	38.0
51	08/04/2010	830	955	400	41.5
52	11/04/2010	1710	3355	400	85.5
53	15/04/2010	1380	2985	400	69.0
54	18/04/2010	1320	2985	400	66.0
55	21/04/2010	1300	2985	400	65.0
56	22/04/2010	1350	2985	400	67.5
57	29/04/2010	1200	2985	400	60.0
58	02/05/2010	1310	2985	400	65.5
59	03/05/2010	1110	2985	400	55.5
60	05/05/2010	1310	2985	400	65.5

* Distance to the opposite direction, where a channel was found between the blasting and record sites.

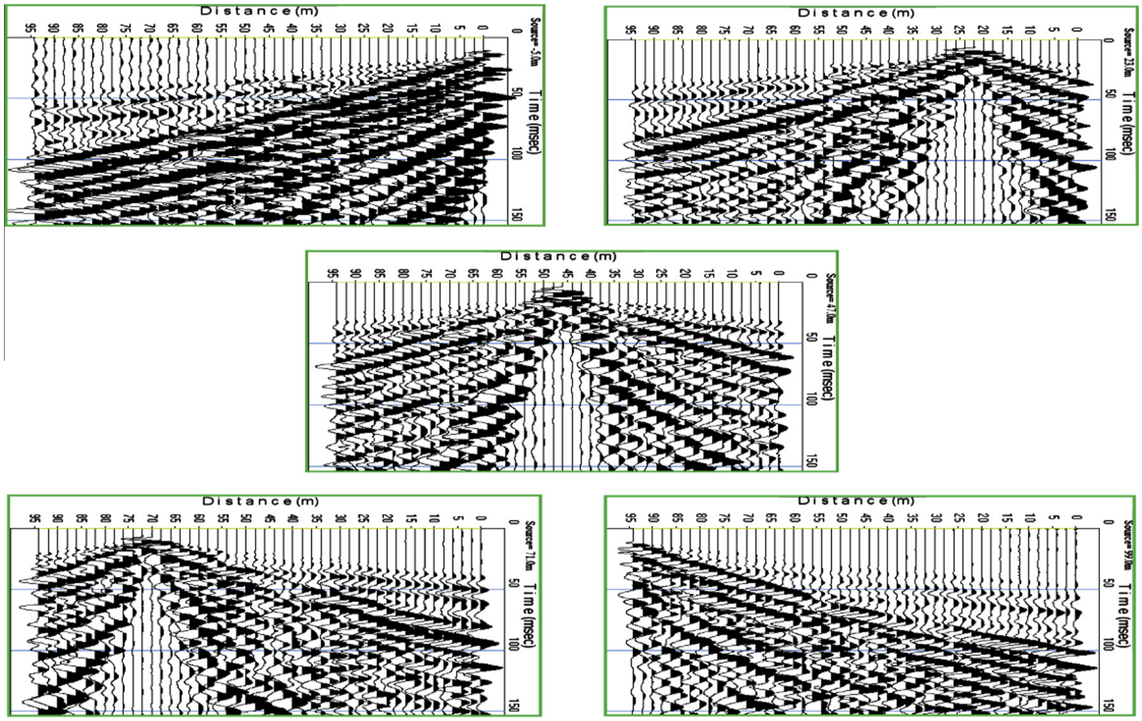

Fig. 6 The P-wave seismograms records at the seismic profile P1.

spread (D) (Fig. 7a) is directly related to the longest wavelength (λ), that can be analyzed, which in turn determines the maximum depth of investigation (Z_{max}). On the other hand, (minimum if uneven) receiver spacing (dx) is related to the shortest wavelength (λ) and therefore the shallowest resolvable depth of investigation (Zmin). A 1 ms of sampling interval is most common with a 2 s total recording time (T = 2 s). Fig. 7b, shows an example of the MASW profile P1.

6. Seismic data processing and interpretation

It was pointed out that, the true refractor velocities can not be determined by shooting at only one end of a seismic line, but such velocities can be determined if the arrival times are recorded from both ends. Further, a depth computed from an intercept time actually represents the depth of the refracting surface projected back to the shot point. The reversed profile, however, offers a significant advantage in that, the true velocities and thicknesses of layers can be computed beneath each geophone to allow the mapping of irregular and dipping boundaries by using several methods. The delay time method was discussed by many authors, as: (Gardner, 1939; Barthelmes, 1946; Slontick, 1950; Tarrant, 1956; Wyrobek, 1956; Parry, 1977) The Wave Front method was elaborated by (Thornburgh, 1930; Gardner, 1974; Baumgarte, 1955; Hales, 1958; Rockwell, 1967; Schenck, 1967). Hagiwara's method was explained by (Masuda, 1975). The Plus-Minus method was discussed by (Hagedoorn, 1959) and the Generalized Reciprocal Method (GRM) was introduced by (Palmer, 1980).

On the basis of the first arrival P-waves picking up, the wave forms are analyzed by picking the first breaks and determining the travel time-distance (T–D) curves and depth models using SeisRefa software package (Seisrefa, 1991), which is a complete seismic refraction processing and modeling software. It is based on its processing on the delay time and ray tracing methods.

According to the first arrival P-waves, the wave forms are analyzed. The deduced time-distance curves and the corresponding 2-D depth model at each profile are obtained in order to interpret the subsurface features. Fig. 8, illustrates the 2-D depth model for one seismic profile (P1).

By applying the MASW technique, we obtain the dispersion curves (phase velocity versus frequencies). The shear wave velocity profiles are obtained through an inversion process for the dispersion curve of the Raleigh-type surface waves on a multi channel record. This inversion process requires an initial shear-wave velocity profile, which is obtained using the P-wave shallow seismic refraction data and a constant Poisson's ratio of 0.3 at each of the 4 sites. The dispersion and inversion processing steps are carried out using the SurfSeis software package (SurfSeis, 2010). Fig. 9a, shows the dispersion curve of profile P1, where the fundamental mode is quite obvious. Applying inversion analysis to the dispersion curves, we obtain the shear wave velocity model. Fig. 9b, shows the shear wave velocity model of profile P1.

7. Results

7.1. Ground vibration and air blast

The variations in the PPV and air blast values are attributed to the amount of explosives detonated per delay and the distance from the blast facing the set up of monitoring instrument on a particular day. The Peak Particle Velocity (PPV) of the sixty

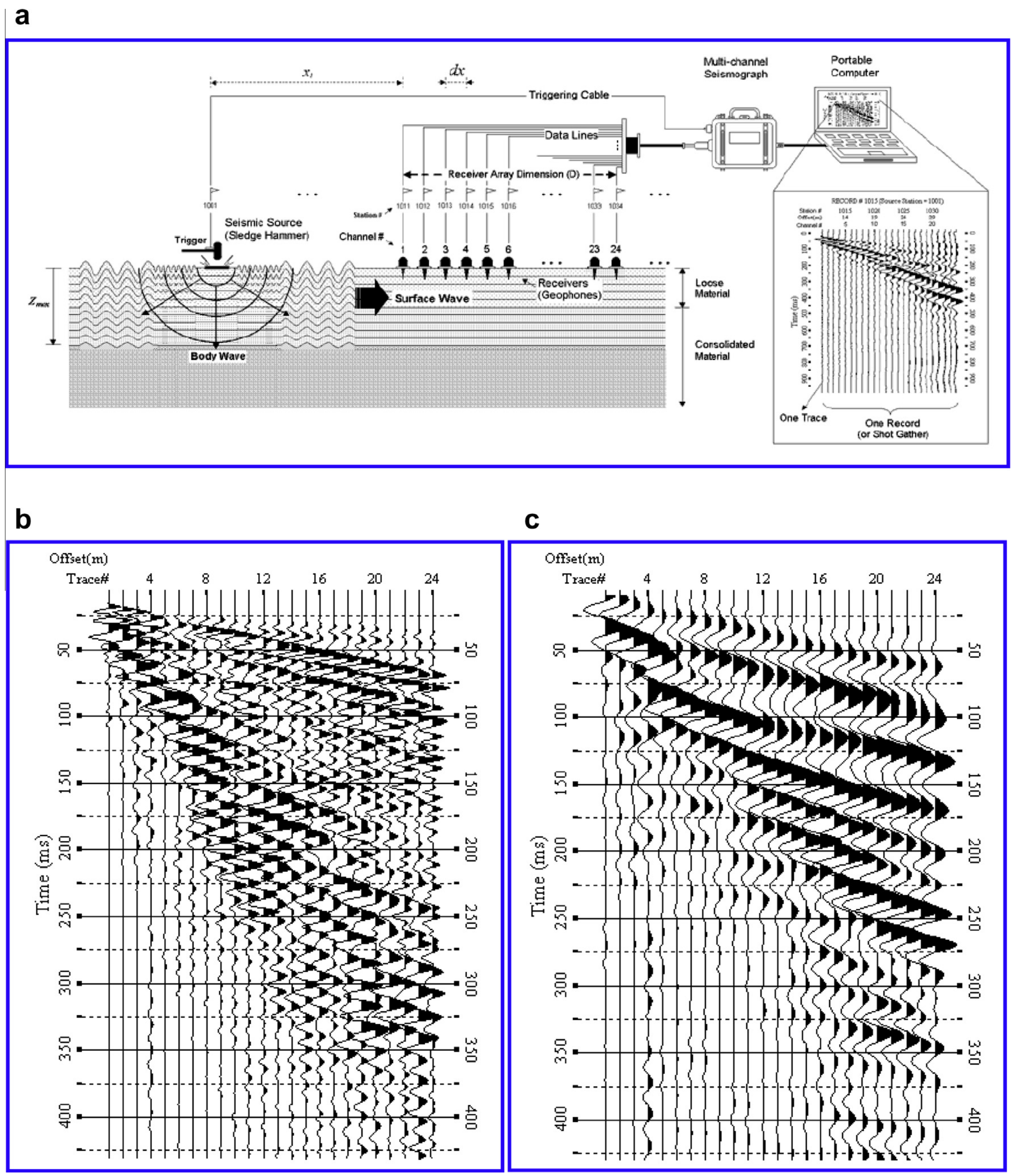

Fig. 7 (a) The Multi channel Analysis of Surface Wave (MASW) data acquisition configuration for determining the 1-D and 2-D shear wave velocities; (b) The surface-wave seismogram records at the seismic profile P1; and (c) The surface-wave seismogram records after applying frequency filtering of the seismic profile P1.

blasting activities (Table 1) ranges from a low value of 0.5 mm/s at a distance of 1310 m to a high value of 253 mm/s at a distance of 40 m. The Peak Ground Acceleration (PGA) in *g* and the Peak Ground Displacement in mm due to the blasting were observed and are listed in Table 2. The sound level or Air over Pressure (air blast) from the sixty monitored blasts exhibits levels above 120 dB twenty times.

The two events number 19 and 20 (Tables 1 and 2) are recorded by two instruments located at the same distance (160 m) and suffered from the same explosive charge (1060 kg), the first in the direction of the SUMED pipelines, while the second at the opposite direction. The recorded PPV at the first instrument is 41.5 mm/s while at the second instrument is 19.7 mm/s. This lower value is due to the energy dispersion at the free face to the opposite direction.

7.2. Seismic

The results of the P-waves and MASW seismic survey reveal that, the obtained near-surface section consists of four layers in the four seismic profiles up to a depth of 20 m (Table 3). The first layer with a thickness of 0–1 m is characterized by less

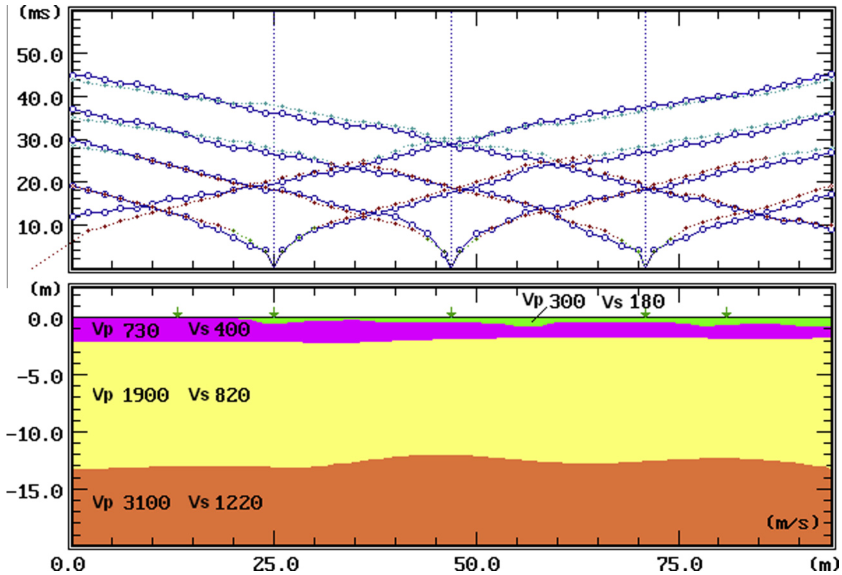

Fig. 8 The T–D curves of the five P-wave shootings (upper panel) and the 2-D depth model which consists of four layers with the corresponding P-wave velocities at the seismic profile P1 (lower panel).

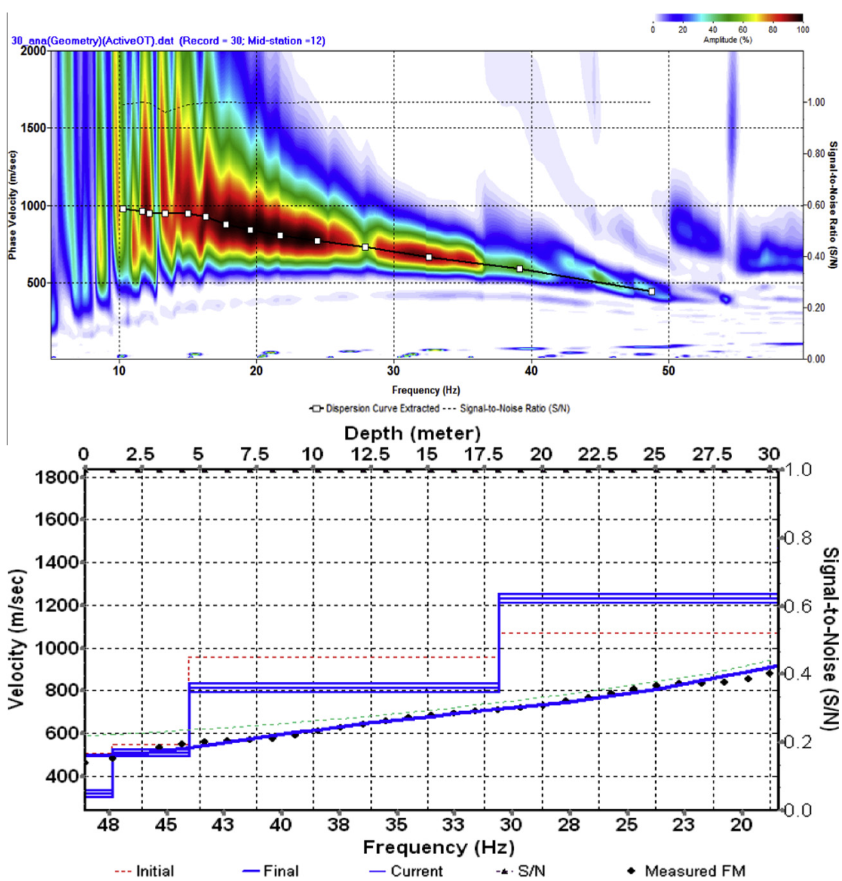

Fig. 9 The dispersion curve (phase velocity versus frequency) deduced from the surface wave records at profile P1. The fundamental mode is quite clear (upper panel). The 1-D shear wave velocities deduced from the inversion technique of the dispersion curve are illustrated in the lower panel (profile P1).

physical properties (P-wave velocity 300–310 m/s and S-wave velocity 180–190 m/s). The second layer with a thickness of 1–2.5 m summarizes medium physical properties (P-wave velocity ranges between 720 and 750 m/s and S-wave velocity 430–450 m/s). The third layer with a thickness of 10–12 m demonstrates high physical properties (P-wave velocity ranges

Table 2 The parameters of the recorded events due to quarry blasting and the ground vibration and air blast results at the NCC quarry.

No.	SD	Peak Particle Velocity, PPV (mm/s)						PGA	PGD	Air blast	
		L	f	T	f	V	*f*	*g*	mm	dB	*f*
1	4.5	44.3	20.1	34.9	2.00	62.7	43.5	0.915	0.3630	131.4	2.00
2	13.5	21.9	16.2	18.3	50.0	22.7	33.2	1.140	0.1230	127.5	3.25
3	33.0	6.21	8.00	5.71	52.6	4.44	11.1	0.239	0.0286	122.4	4.75
4	45.5	4.44	41.1	5.33	31.6	2.29	33.0	0.159	0.0187	113.5	3.25
5	62.5	3.30	25.1	3.56	29.8	2.16	51.5	0.106	0.0183	109.9	2.14
6	2.0	145	2.00	91.7	15.4	253	2.10	11.19	1.8300	135.0	2.75
7	2.5	46.7	6.90	103	12.3	116	32.8	8.660	1.3100	132.2	3.00
8	10.0	14.6	78.8	25.4	79.3	11.2	5.50	0.703	0.0610	117.8	2.13
9	22.5	11.04	23.0	5.59	23.9	3.56	5.75	0.186	0.0540	108.8	3.63
10	31.5	5.84	23.0	5.59	23.9	3.56	5.75	0.170	0.0443	105.5	2.88
11	37.5	5.59	22.5	5.17	23.0	4.99	32.8	0.210	0.0640	109.5	4.63
12	3.0	80.4	2.00	64.9	20.0	107	42.3	6.060	1.2300	132.2	3.25
13	11.0	20.3	83.6	15.7	33.6	10.3	5.25	0.716	0.0730	117.5	2.25
14	23.5	5.08	22.5	10.8	23.0	4.32	32.8	0.240	0.0730	109.5	3.25
15	32.5	5.59	34.9	5.46	40.0	2.41	5.25	0.210	0.0440	107.5	2.88
16	38.5	5.46	40.4	5.59	44.4	4.57	6.38	0.210	0.0700	110.9	3.25
17	4.0	66.4	15.8	57.1	50.1	51.8	2.00	2.860	0.5830	130.1	2.75
18	6.5	67.6	45.6	50.0	44.5	48.0	44.0	2.620	0.2010	123.7	2.75
19	8.0	41.5	30.9	22.9	32.1	26.7	36.5	1.670	0.2090	122.8	2.75
20	8.0	19.7	8.38	17.5	7.88	8.13	7.88	0.239	0.3040	136.5	2.75
21	8.5	24.4	6.13	9.78	11.9	8.00	13.4	0.239	0.5950	135.8	2.75
22	9.0	13.7	6.00	4.06	9.38	8.00	14.0	0.199	0.2610	135.5	2.38
23	15.0	15.1	50.0	19.2	47.4	14.4	50.8	0.680	0.0776	118.1	2.63
24	18.5	11.4	74.4	7.37	64.8	10.5	69.8	0.860	0.0311	113.1	3.50
25	27.5	6.73	40.3	7.37	43.5	8.00	79.8	0.358	0.0307	111.5	2.63
26	28.0	5.97	46.8	6.22	46.3	6.60	79.8	0.370	0.0231	110.6	3.38
27	7.0	9.02	59.4	8.51	55.9	8.89	32.1	0.358	0.0322	123.0	2.75
28	19.0	7.87	43.4	12.1	38.1	4.70	41.0	0.305	0.5260	126.6	2.38
29	39.0	2.54	31.8	3.68	32.5	1.14	36.6	0.093	0.0210	109.2	2.50
30	5.5	12.3	40.3	17.1	49.1	10.2	51.6	0.517	0.0638	120.5	2.00
31	18.0	11.4	31.9	13.1	35.1	3.56	34.5	0.292	0.0641	113.3	2.00
32	19.5	6.22	49.1	7.37	28.0	4.95	8.75	0.292	0.0433	115.6	2.25
33	39.5	3.68	39.1	5.08	21.6	3.30	38.1	0.119	0.0331	107.0	2.38
34	7.0	33.5	26.6	16.0	8.00	50.8	58.8	3.420	0.2820	126.3	2.00
35	19.0	8.00	37.9	9.78	44.8	4.44	9.00	0.345	0.0427	115.0	2.25
36	5.5	37.2	18.0	44.6	16.0	56.8	27.1	3.550	0.3650	124.1	2.25
37	10.5	11.7	15.8	15.7	77.3	9.65	26.8	0.437	0.1040	119.2	2.38
38	21.5	6.73	91.8	10.0	92.0	3.94	16.8	0.424	0.0314	112.8	2.50
39	49.0	2.54	28.5	3.94	29.9	2.41	33.8	0.093	0.0190	116.4	3.38
40	48.5	2.79	28.5	3.56	29.9	2.29	33.8	0.198	0.0198	117.2	2.25
41	91.0	1.90	26.3	2.41	27.4	1.27	37.5	0.053	0.0128	113.8	4.13
42	28.5	6.60	40.3	6.86	24.9	3.05	44.8	0.265	0.0499	122.8	2.25
43	34.5	3.43	37.6	2.92	45.5	3.05	59.1	0.119	0.0213	116.9	2.38
44	31.0	5.97	38.9	3.05	38.8	3.05	39.3	0.159	0.0233	127.5	2.50
45	86.5	1.65	34.5	1.65	34.8	0.76	56.6	0.039	0.0091	118.2	3.00
46	67.0	1.14	28.0	1.65	32.6	1.27	33.4	0.039	0.0097	109.2	2.25
47	88.0	1.27	23.1	1.78	34.5	0.64	37.3	0.053	0.0080	114.0	2.00
48	90.0	1.65	33.0	1.02	32.0	0.64	21.5	0.039	0.0079	111.2	3.38
49	82.5	1.52	26.6	1.65	27.5	1.02	50.8	0.039	0.0077	112.0	2.50
50	38.0	3.43	7.25	5.08	27.5	3.30	38.3	0.133	0.0580	111.5	2.38
51	41.5	3.43	25.9	7.24	27.5	2.79	33.1	0.172	0.0510	111.8	2.38
52	85.5	0.89	24.0	1.40	21.8	0.64	5.50	0.039	0.0070	122.7	3.13
53	69.0	1.02	41.1	1.40	5.50	0.64	6.75	0.027	0.0309	115.9	2.13
54	66.0	1.02	39.1	1.78	6.25	0.76	6.88	0.039	0.0218	115.2	2.50
55	65.0	3.68	50.4	6.48	34.3	2.29	52.1	0.172	0.0326	117.2	2.13
56	67.5	1.20	40.1	1.20	2.00	1.20	38.0	0.027	0.0161	115.0	2.38
57	60.0	2.03	45.9	1.90	43.1	0.76	8.25	0.053	0.0113	117.4	3.25
58	65.5	1.78	42.6	1.78	2.50	1.40	32.4	0.053	0.0109	114.0	2.38
59	55.5	1.27	40.3	2.16	2.38	1.52	39.8	0.053	0.0294	117.8	2.13
60	65.5	1.02	5.00	1.14	5.00	0.51	5.38	0.027	0.0294	116.6	2.50

Table 3 The Obtained elastic moduli and geotechnical parameters at SUMED area.

Layers	Profile	Vp m/s	Vs m/s	Vp/Vs	Density (gm/cm^3)	Poisson's ratio (σ)	Rigidity modulus (dyn/cm^2)	Young's modulus (dyn/cm^2)	Bulk's modulus (dyn/cm^2)	*N*-Value	U. bearing capacity (kg/cm^2)
Layer 1	1	300	180	1.67	1.29	0.22	4.18E+08	1.02E+09	6.03E+08	7.7	0.23
	2	310	190	1.63	1.30	0.20	4.7E+08	1.13E+09	6.23E+08	9.0	0.27
	3	305	185	1.65	1.30	0.21	4.43E+08	1.07E+09	6.13E+08	8.3	0.25
	4	310	190	1.63	1.30	0.20	4.7E+08	1.13E+09	6.23E+08	9.0	0.27
Layer 2	1	730	440	1.66	1.61	0.21	3.12E+09	7.58E+09	4.42E+09	> 50	3.16
	2	720	430	1.67	1.61	0.22	2.97E+09	7.26E+09	4.36E+09	> 50	2.95
	3	750	450	1.67	1.62	0.22	3.29E+09	8.01E+09	4.74E+09	> 50	3.37
	4	730	430	1.70	1.61	0.23	2.98E+09	7.36E+09	4.61E+09	> 50	2.95
Layer 3	1	1900	820	2.32	2.02	0.37	1.36E+10	3.72E+10	4.73E+10	> 50	19.58
	2	1800	800	2.25	2.05	0.39	1.31E+10	3.65E+10	5.64E+10	> 50	18.22
	3	1400	800	1.75	1.90	0.26	1.21E+10	3.05E+10	2.1E+10	> 50	18.22
	4	1500	820	1.83	1.93	0.29	1.3E+10	3.34E+10	2.61E+10	> 50	19.58
Layer 4	1	3100	1220	2.54	2.31	0.41	3.44E+10	9.70E+10	1.76E+11	> 50	62.78
	2	3100	1310	2.37	2.31	0.39	3.97E+10	1.10E+11	1.69E+11	> 50	77.35
	3	2900	1220	2.38	2.27	0.39	3.39E+10	9.43E+10	1.46E+11	> 50	62.78
	4	2700	1300	2.08	2.19	0.31	3.7E+10	9.74E+10	8.75E+10	> 50	75.63

Table 4 Vs_{30} and site class according to the IBC at closest site of SUMED pipelines.

Profile	Vs_{30} (m/s)	Site class
1	800	B
2	920	B
3	880	B
4	1010	B

between 1400 and 1900 m/s and S-wave velocity 800–820 m/s). The P-wave velocity of the fourth layer reflects values of 2700–3100 m/s and S-wave velocities of 1220–1310 m/s.

The average shear wave velocity up to 30 m depth is obtained, in addition to the geotechnical parameters, as listed in Table 3. The results demonstrate that, the closest site of the SUMED pipelines is classified according to the NEHRP classification (Street et al., 2001) to the class B (Table 4).

From the obtained depth models deduced from the P- and S-waves up to 30 m depth at the SUMED site, there are no near-surface structures, caves and less competent layers than the overlain.

8. Discussion

The relationship between the monitored vibrations in terms of PPV and the distance from the quarry blasts to the monitoring instruments (D in m) using the measurements of the sixty blasting activities is deduced and summarized according to (OSMRE, 1987) as follows (Fig. 10a):

$$\mathrm{PPV(mm/s)} = 26569 \times \mathrm{D}^{-1.307} \quad (5)$$

The correlation coefficient R^2 is equal to 0.9868. The charge weight per delay was fixed to 400 kg as listed in Table 1. The empirical relation (Eq. (5)) indicates that the ground vibrations from the quarry blasts attenuate to one third of their former value for each doubling of distance.

The PPV-SD (square root scaled distance in m/kg$^{0.5}$) relationship, when introducing the concept of the scaled distance using the measurements of the sixty blasting activities, is deduced and summarized according to Tripathy and Gupta, 2002 (Fig. 10b), which is considered as a prediction formula as follows:

$$\mathrm{PPV(mm/s)} = 440.64 \times \mathrm{SD}^{-1.225} \quad (6)$$

The correlation coefficient R^2 is equal to 0.9809.

The prediction relationship (Eq. (6)) is modified to the maximum (worst case) which represents a 95% confidence level to be:

$$\mathrm{PPV(mm/s)} = 700.08 \times \mathrm{SD}^{-1.225} \quad (7)$$

From the last relationship (Eq. (7)), the maximum allowable charge per delay without any environmental effect is 591 kg for a safe distance of 650 m (the minimum distance between the quarry blasts and the two pipelines) at a damage criterion of PPV = 12.5 mm/s (USBM).

The Air over Pressure–SD* relationship, when introducing the concept of the cube root scaled distance (SD* in m/kg$^{0.33}$) using the measurements of the sixty blasting activities, is deduced and summarized as follows (Fig. 11), which can be used as an air blast prediction formula:

$$\mathrm{Air\ blast(dB)} = 152.87 \times \mathrm{SD}^{*-0.071} \quad (8)$$

The correlation coefficient R^2 is equal to 0.8536. The prediction relationship (Eq. (8)) is modified to the maximum (worst case) which represents a 95% confidence level to be (Fig. 11):

$$\mathrm{Air\ blast(dB)} = 170.23 \times \mathrm{SD}^{*-0.071} \quad (9)$$

The obtained Peak Ground Acceleration (PGA in *g*) and the Peak Ground Displacement (PGD in mm) values in relation to the square root scaled distance using the measurements of the sixty blasting activities are deduced and summarized as follows (Fig. 12a, b):

$$\mathrm{PGA}(g) = 32.35 \times \mathrm{SD}^{*-1.445} \quad (10)$$

The correlation coefficient R^2 is equal to 0.9519.

$$\mathrm{PGD(mm)} = 2.89 \times \mathrm{SD}^{*-1.273} \quad (11)$$

The correlation coefficient R^2 is equal to 0.9252.

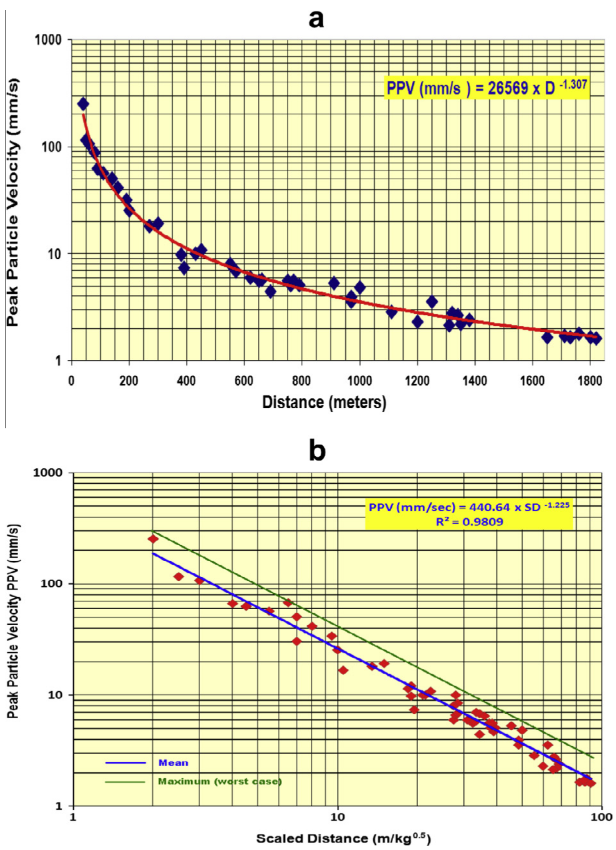

Fig. 10 (a): The PPV versus distance to the monitoring instrument relationship obtained from the sixty blasting activities at the two pipelines of SUMED Company, which are located very close to the National Cement Quarry; (b) The PPV–scaled distance relationship was obtained from the sixty blasting activities at the two pipelines of SUMED Company which are located very close to the National Cement quarry.

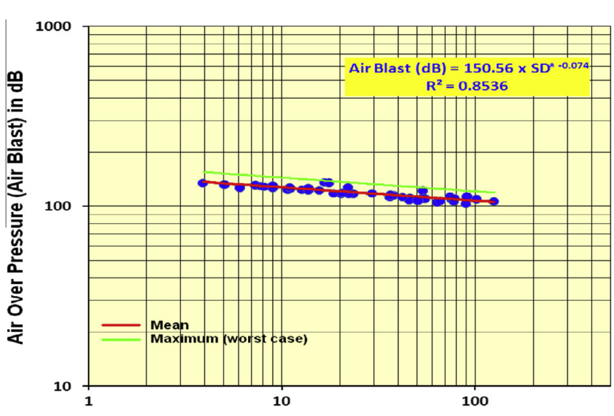

Fig. 11 The Air over Pressure versus the cube root scaled distance, obtained from the sixty blasting activities at the two pipelines of SUMED Company which are located very close to the National Cement quarry.

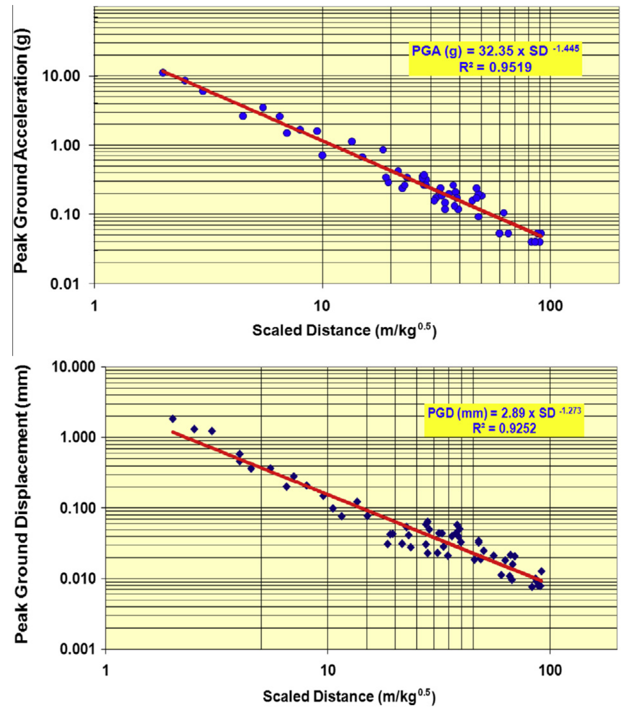

Fig. 12 a: The relationship between the Peak Ground Acceleration (PGA) values of the recorded quarry blasts and the scaled distances to the two pipelines of SUMED Company; b: The relationship between the Peak Ground Displacement (PGD) values of the recorded quarry blasts and the scaled distances to the two pipelines of SUMED Company.

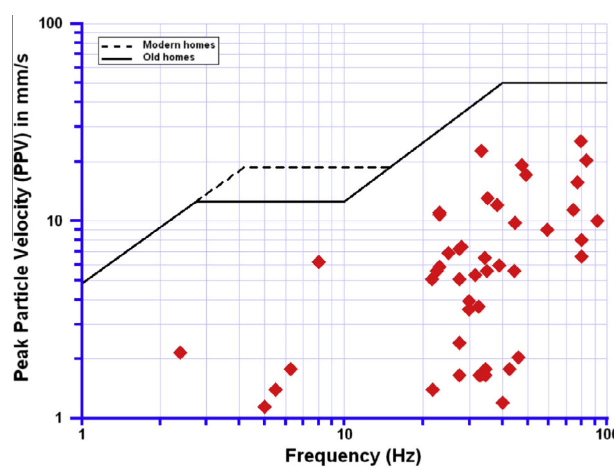

Fig. 13 Evaluation of damage risk of the recorded NCC quarry blasts according to the USBM criterion taking into consideration the PPV and its corresponding frequency.

The measured magnitudes of PPV and the corresponding frequencies of the quarry blasts were evaluated taking into consideration several established damage criteria (USBM) used in mining and geotechnical/structure engineering as shown in Fig. 13.

9. Conclusions

In undertaking the task of doing this research, it has been revealed that, most practicing blasters rarely follow guidelines. It is the duty of the authority in charge or the regulatory body in charge to provide the necessary conditions and limitations to be adhered to. These limitations should not only be prepared, but should also be enforced. The current research is a trial to start to develop a standard for the conditions and limitations in order to mitigate the effects of the blasting activities on the environment. From the shallow seismic survey for the P-waves and MASW, it is obvious that, the closest area of the two pipelines of SUMED Company near the National Cement Quarry is not affected by shallow structures, caves or low velocity layers. The geotechnical parameters also demonstrate that, the SUMED pipelines area is belonging to class B, according to the NEHRP code.

From the vibration records in terms of PPV, air blast and SD at the SUMED area due to the blasting activities at the National Cement Quarry, the maximum allowable charge per delay without any environmental effect is 591 kg for a safe distance of 650 m (the minimum distance between the quarry blasts and the two pipelines). Those values are obtained according to the deduced prediction formulae as in Eqs. (7) and (9).

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