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MEASUREMENT AND ANALYSIS OF THE EFFECT OF GROUND VIBRATIONS INDUCED BY BLASTING AT THE LIMESTONE QUARRIES OF THE EGYPTIAN CEMENT COMPANY

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ABSTRACT- Ground vibrations and airblasts are part of the output of the blasting operations. which have an impact on the environment. When their levels are high, they can cause human annoyance, discomfort, and even cause damage to nearby structures. Hence, measuerment of ground vibrations and airblast levels and use of published damage criteria are necessary to judge the design of the blasting operations if it complies with the safe regulated levels or it does not.

The Egyptian Cement Company (ECC) plant is located about 3 km north of km 93 Elmaadi-Elsukhfla road (about 70 km South West of Suez). The objective ofthis paper is the measurement and evaluation of the level of groundvibrations and airblast over pressures induced by blasting at the limestonequarries of the ECC. This objective has been attained through extensive plan of measurements. Fifteen blasts covering all the working faces, have been monitored using nine modem seismographs. Measurements have included the maximum magnitudes of the three mutually perpendicular components of the peak particle velocities, airblast over pressure levels as well as recording complete wave traces of vibrations. Also, effect of the explosive initiation method on ground vibrations and airblasts has been investigated. The ivestigation has been carned out for different charge weights at various distances. These measurements and records have been analized to provide propagation laws for ground vibrations and airblasts. These propagation laws are important for the quarry manager and engineer to predict the level of ground vibration and airblast before carrying out the blast.

INTRODUCTION

The Egyptian Cement Company (ECC) plant is located 3 km north of km 93 Elmaadi-Elsukhna road (about 70 km South West of Suez). The limestone quarry is about 3 km North to the cement plant. On the other hand, the silty clay deposit is located at about 7 kin South of km 43 Elinaadi- Elsukhna road i.e. about 50 km west of the cement plant. ECC has begun production with one production line in February, 1999 and the second production line started in August, 1999. Each production line is of clinker-capacity 8600 tlday (1.4 million ~year). The third and fourth production lines are under construction and planned to start production by October 2000 to achieve 5 million tons/year [1,2]

Limestone Deposit and Quarry [1]

The deposit is 1.7 km long and 1.5 kin wide forming a plateau dipping gently (6 deg.) toward South SouthEast. The top of the plateau culminates at about-304- rn (a.s.l.) or about lOOm above the plant ground level 200-m (a.s.l.). The deposit consists of high-grade limestone, pale yellow, gray to buff medium hard, porous, containing dolornitic limestone and dolomite as well as some flint lenses. Minor faults with a displacement of 1 to 5 m, offset the deposit. The limestone deposit belongs to Mokkatam Formation (Middle Eocene). It is bioclastic limestone with a texture range from Packstone to Wakestone in Dunham classification. The limestone does not has well-developed bedding except on the western part of the deposit, where a 5m thick limestone shows a well-defined lamination. Some sedimentary structures can nevertheless be noticed, such as cross-stratification structure. The physical properties of the limestone are summarized as follows: Compressive strength in kg/cm2 (< 200 = 69.68%, > 200 and <400= 400 < ,%17.64and <1274 = 12.49%); the average density = 1.8 t/m3 ; average moisture content 0.6%(its max. value rises to 5%), and porosity ranges from 20-30%.

Overburden: the overburden consists of limestone fragments with calcareous sand, yellow - brown in color. The thickness of the overburden amounts to 0.6 in. This o. b. constitutes a physical weathering of the underlain limestone. It is characterized by a relatively high content of S03 and Cl.

Ground vibrations and airblast over pressure are part of the output of the rock blasting operations. When their levels are high, they can cause human annoyance and even cause damage to nearby structures. These structures may be owned by the mining company or they may be owned by neighbors for residential, commercial, and industrial purposes. Hence, measurement of ground vibrations and airblast levels and use of published damage criteria are necessary to judge the design of the blasting operations if it complies with the safe regulated levels or it does not. The objective of the present paper is the measurement and evaluation of the ground vibration and airblast levels under the current blasting practices at the limestone quarries of the ECC. In addition, the effect of explosive initiation method on the level of ground vibrations and airblast is investigated. This objective has been attained through measurement of the maximum magnitudes of the three mutually perpendicular components of the particle velocity and recording of complete traces of vibrations. Also full traces for air blast over pressure have been recorded and maximum overpressures have been measured. These measurements have been carried out for different explosive charge weights at various distances. These measurements and records have been statistically analyzed to provide propagation laws for these components.

Gamma Matrix (G. M.) building contains sensitive radiation instruments for continuos Chemical analysis of the crushed limestone on the belt conveyors before reaching the raw mix unit. The Gamma Matrix building is not only containing sensitive instruments providing vital chemical information but also it is one of the nearest buildings to the quarry. Hence, it has been given a major attention and about half the measurements has been taken around it to assure its safety.

GROUND VIBRATIONS DAMAGE CRITERIA

Ground vibrations and air blasts resulting from rock blasting are troublesome problems 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 [3-21].

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 t~hat 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 [3-6].

Concept of the Scaled Distance [4,6-9]

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 airblast energy. If the charge shape is cylindrical (charge length to diameter ratio greater than 6), the propagating wave front will be cylindrical. Scaled distance, $d/w^{1/2}$ combines the effects of total charge weight per delay, W, on the level of the ground motion with increasing distance, d, from the blast. The formula below is obtained empirically.

$$PPV=K(dIW^{1/2})^{-m} \qquad (1)$$

Where:

PPV = peak particle velocity (in/sec),

d = distance between the shot and the nearest dwelling (ft),

W = total weight of explosive per a minimum of 8-rnsec delay (lb),

K, m = site factors,

$d/W^{1/2}$ = square root scaled distance for a cylindrical charge ($fl/lb^{1/2}$)

Constants K and m are called site factors. K is the line intercept of the relation at SD=1 on the log-log graph. It represents the initial energy transferred from the explosive to the surrounding rock. Attenuation rate of the PPV due to geometric spreading and influence of rock characteristics are included in the slope factor, m.

If the charge length to the diameter ratio is less than 6 orthe distance from the shot is so far that the charge can be point source (or spherical) [6] the equation would be:

$$PPV=K(dIW^{1/3})^{-m} \qquad (2)$$

Where:

$dW^{1/3}$ cube root scaled distance ($fl/lb^{1/3}$).

Ground motion dissipation in rock is attributed to three mechanisms: viscous damping of ground vibrations, solid friction absorption of energy, and scattering of the ground motion wave due to reflections at discontinuities and strata inhomogeneities in the rock. The presence of joints, fractures, faults, and shear zones in the path of a ground motion wave also scatters the peak vibrations [9]. Monitoring of large number of blasts in many areas in the United States for recording PPV and combining the data has led to the establishment of safe scaled distances for field use (Bollinger, 1971). However, this criterion alone was inefficient because it did not take into account the predominant frequency of the blast wave [4,9].

Blast Damage Criterion of Variable Particle Velocity versus Frequency [6,8,9]

Despite that some organizations adopting the criterion of maximum particle velocity lowered its level from 2 in/sec to as low as 0.23 inlsec, this was not enough to stop public complaints and court cases. The criterion has been ruled inadequate because the frequency content of the waveform and type of structure were not specified .In the seventies, a comprehensive study of ground vibration produced by blasting on tens of homes and hundreds of production blasts to reanalyze the blast damage criterion has been carried out. The United States Bureau of Mines (USBM) in RI 8507, concluded that particle velocity is still the best single ground vibration descriptor. For frequencies above 40 Hz, a safe particle velocity maximum of 2 in/sec is recommended for all homes. The chance of damage from a blast generating PPV below 0.5 in/sec is small (5% for the worst cases). For those who want to be relieved from the responsibility of instrumentation of all shots, they could design for a conservative square root scaled distance of 70 $ft/lb^{1/2}$. The typical vibration levels at this scaled distance would be 0.08 - 0.15 in/sec. An alternative recommended blasting level set of smooth criteria recommended by the USBM is shown in Fig. 1. They have more severe measuring requirements, involving displacement and velocity as well as frequency. The levels of PPV at various frequencies given in RI 8507 are supported by the researches carried out after its publication. It has been concluded that these criteria preclude blast damage [19].

OSM's Federal Regulations:

In 1983, the United States Office of Surface Mining (OSM) published its final regulations concerning the control of ground vibrations and air blast. The OSM regulations were designed to offer more flexibility in meeting performance standards and to prevent property damage. The operator has the choice of employing any one of the following three methods to satisfy the OSM regulations.

Method 1- Limiting particle velocity criterion: requires that each blast be monitored by a seismograph capable of monitoring peak particle velocity. Provided that the maximum particle velocity stays below the levels specified in Table 1.

Method 2- Scaled distance equation criterion: requires the operator to design shots in accordance with Table 1, which specifies a scaled distance (SD) design factor for use at various distances between a dwelling and a blast site.

Table 1. Maximum permitted particle velocities (method 1) and scaled distance factors permitted at various distances from blast (method 2).

Distance from blast site (ft)	*Method 1* Maximum allowed peak particle velocity (in/sec)	*Method 2* Scaled distance (SD) factor to be used without seismic monitoring
0 to 300	1.25	50
301 to 5000	1.00	55
5,001 and beyond	0.75	65

Method 3- Blast level chart criterion: This method allows an operator to use particle velocity limits that vamy with frequency as illustrated in Fig. 1. This method requires frequency analysis of the blast-generated ground vibration wave as well as particle velocity measurements for each blast .This method may represent the best means of evaluating potential damage to residential structures as well as human annoyance from blasting.

Any seismic recordings for any component of the particle velocity at a particular predominant frequency that fall below any part of the solid line graph are considered safe. Any values that fall above any part of the solid line graph will increase the likelihood of residential damage and human annoyance.

Table 2 presents the German and French standards (damage criteria) using peak particle velocity and frequency for different types of structures.

It has been reported that there are several causes for structural cracking other than blasting vibrations such as bad designs, thermal stresses, sttlement, moisture conditions, swelling, wind, traffic, etc. Good public relations program to explain the phenomena can help decreasing the number of complaints [4-9, 18].

AIR BLAST

Air blast another undesirable output from blating. Air blast damage and annoyance are directly related to factors such as blast design, weather, terrain conditions, and human response. The disturbance of air blast is propagated via a compression wave that travels through the atmosphere similar to a P-wave travelling through the earth. Under certain weather conditions and poor blast designs, 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. These are measured and reported as an" over pressure ', i.e. air pressure over and above atmospheric pressure. Over pressure is usually expressed in pounds per square inch (psi) or in decibels (dB). Decibels are an exponential expression for sound intensity that approximates the response of the human ear [4,6,8,9]. The relationship between psi and dB is given by:

$$dB = 20 \log (P/P_0) \qquad (3)$$

and

$$psi = 2.9 \times 10^{-9} \times \text{anti log} (dB/20) \qquad (4)$$

Where:

dB = over pressure in dB,
log = common logarithm,

anti log = $10^{[x]}$
P = over pressure in psi,
P_0 = reference pressure =2.9×10^{-9} psi.

Fig. 2 illustrates over pressure equivalence for both types of units as well as effect of over pressure level on human annoyance and structural damage .There are four main types of air blast over pressure defined as:

1. Rock pressure pulses; the first pressure pulse to arrive at a recording station. It is generated by the vertical Components of the ground motion.
2. Air pressure pulses; produced from direct rock displacement at the face or mounding at the blast hole collar.
3. Gas release pulses; gas escaping from the detonating explosive through rock fractures.
4. Stemming release pulses; gas escaping from the blown-out stemming.

Atmospheric coditions such as temperature inversions (increase of temperature with altitude) and surface winds can affect air blast considerably. If these conditions exist, they can increase the peak over pressure by a factor of 5-10. Hence, it is important to avoid blasting under these conditions. Although it is possible that high air blast over pressure could cause structural damage, those produced by routine blasting operations under normal atmospheric conditions are not likely to do so.

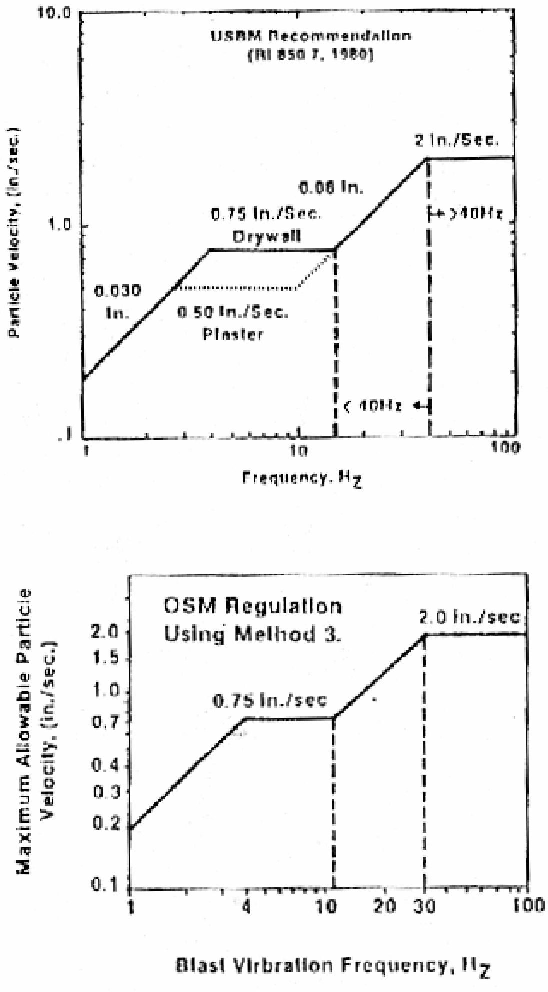

Fig. 1 : Recommended safe levels for blasting vibrations by USBM and OSM.

Table 2. German and French Standards[20].

German Standards			
Structure Type	PPV, mm/sec		
	< 10 Hz	10 – 50Hz	50 – 100 Hz
Commercial	20	20 – 40	40 –50
Residential	5	5 – 15	15 – 20
Sensitive	3	3 – 8	8 – 10
French Standards			
Structure Type	PPV, mm/sec		
	4 - 8 Hz	8 – 30 Hz	30 – 100 Hz
Resistant	8	12	15
Sensitive	6	9	12
Very Sensitive	4	6	9

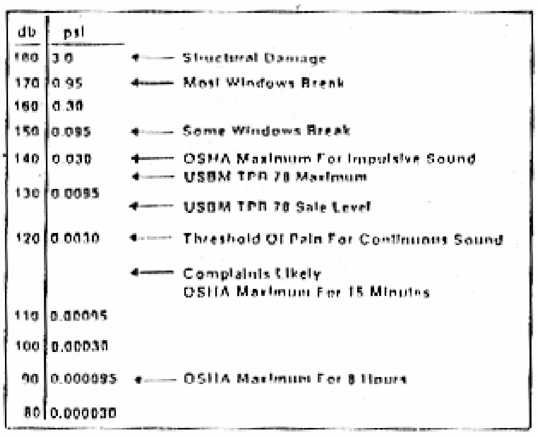

Fig. 2 : Overpressure unit conversion (dB and psi) and effects on human annoyance and structural damage.

Damage Criteria for Air Blast [6,9]

1. Use the maximum air blast over pressure levels as outlined by USBM RI 8485: This set of criteria is based on a minimal probability of the most superficial type of damage in residential-type structures. Any one of the sets will represent safe maximum air blast levels although the best is recommended to be the 133 dB @ 2.0 Hz high pass system. These recommendation levels should provide 95-99 % non-damage probability and 95-90 % annoyance acceptability.
2. In absence of monitoring, a cube-root scaled distance of 250 ft/lb$^{1/3}$ should be maintained for quarries and mines (USBM RI 8485).
3. Where methods 1 and 2 are too restrictive, monitoring of the blast site is recommended to determine safe blasting levels.

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INSTRUMENTS AND FiELD EXPERIMENTAL PROCEDURE

The instruments used include one SSU-2000 DK seismograph system, 10 SSU micro-seismographs, 2 data transfer cases, 1 micro-interrogator, and 2 manual buttons. The SSU-2000 DK seismograph is a complete independent unit. It includes a geophone for recording ground vibration components; a microphone for recording air blast over pressure, a 3-1/2 inch disk drive; a key board to input instructions and parameters, and a printer for printing wave forms and infonnation summary about the blasting event. The 2000 DK unit can store the recorded data of the blast on the disk for later use and/or print the complete wave forms onto paper accompanied by a summary for half wave frequency and peak values of the components of the ground motion as well as air blast levels. On the other hand, the micro-seismographs need to be synchronized and programmed by the SSU-2000 DK unit. Communication between the micro-seismographs and the SSU-2000 DK unit can be carrout through the data transfer cases. The micro-interrogator is also used to communicate with the micro-seismograph to obtain summary of the data recorder on it while it is installed in place of recording. The manual button is used to switch micro-seismographs on and off to control the beginning and ending of the recording time to save their memory for recording useful blast data. To use the seismograph, it is installed in the ground oriented toward the blast and its surface is kept as level as possible. Good coupling seismograph and the ground is very important [22,23]. 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.

ECC quarries have two faces. The blasts in the present study have been planned to cover all the working faces on the upper and lower benches. That is to have a good average of the response to rocks along the path of this investigation as well as the locations of seismographs are plotted on the map. Gamma Matrix building (G.M.) is also shown on the lower right side of the map. Fig. 4 shows a plan of the Gamma Matrix building drawn to a bigger scale to show the locations of the seismograms around the building. The height of the lower face ranges from 22 to 28 m, while the height of the upper face varies from 3,5 up to 16 m. Blast hole diameter is 100 mm (4 inch). Other parameters of the bench blast include: burden = 4 m., spacing = 4 – 5.5 m., stemming length = 3 m., subdrilling = 1.5 m., number of rows = 1-4. Main explosive charges is ANFO while Ammonia Gelatin Dynamite has been used as priming, bottom, and boosting charges. The percentage of Ammonia Gelatin Dynamite to the total charge weight ranges from 8 – 13.5% with an average of 10%. The specific charge ranges from 0.3 to 0.32 Kg/m^3. Usually the initiation is carried out by connecting the down hole detonating cords to a trunkline detonating cords for each group of holes to be detonated ber delay. Then each group is connected to an electric blasting cap and connected to the other caps in a series electric-blasting circuit. Some of the blasts in this investigation have been initiated completely electrically without using any stonating cord. The applied delay time is 25 msec.

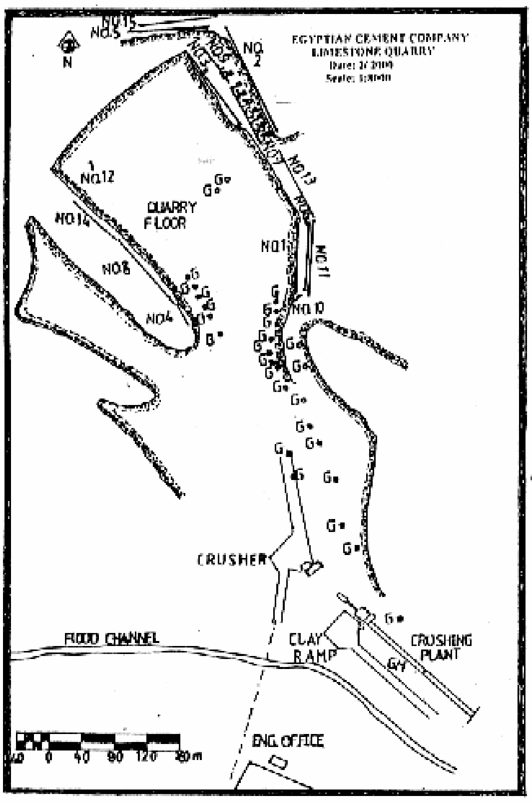

Fig. 3 : Map of the limestone quarry of the ECC. No. # is number of blast, G- location of a seismograph.

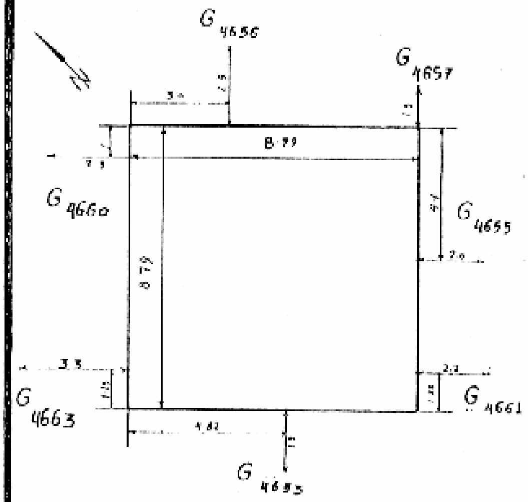

Fig. 4 : A plan of the Gamma Matrix building. Dimensions are in meters and G# represents the seismograph number.

RESULTS AND DISCUSSION

Fifteen blasts have been carried out with number ofblastholes per blast ranging from 4 to 56. Weight of charge per delay ranged from 140 to 975 Kg and total charge weight per blast ranged from 140 to 4900 Kg. The distance between the seismograph location to the center of the blast ranged from 84 to 824 m. Nine seismographs has been used to record the ground vibrations and air blast during each blast. Distance from each seismograph location to the center of the blast has been measured. The records of the seismographs have been printed including full waveforms, summary of peak values of ground motion as well as air blast over pressure. In addition, the combined chart of the USBM and OSM safety criteria has been printed for each particle velocity component for each blast and recording site. The records have been investigated for time of blast, shape of waveform, and calibration chart of seismographs. That is to make sure that the data is for real blast and exclude the accidental non-blast records triggered due to any other source (movement of personnel or truck; secondary blasting, or firing of warning charge). Square root (SD) and cube root (SD1) scaled distances have been calculated for eacli blast and seismograph site. Fifteen tables have been made summarizing the data for each blast including geophone #(G#), SD, SD1, PPV for longitudinal (L), transverse (T), and vertical (V) components of ground motion along with their frequencies (f), and their vector sum resultant (PPVR); air blast (sound) over pressure in Decibels and Pascal. On the top of each table, the date, time, and bench blast parameters are also provided. Table 3 is an example for such tables. It is for blast *#2* fired on 26 February 2000. Fig. 5 is provided here as an example of the printout of the SSU 2000 DK seismograph obtained for each blast. This printout is for seismograph No. 2547 at a distance of 280 m from blast # 8. This blast has been detonated on the 24th. of March, 2000 with maximum charge of 378 kg per delay.

Discussion of Ground Vibration Results:

Fig. 6 presents the statistically obtained propagation law^s using square root scaled distance as well as the measured data points. The components of the peak particle velocity in the longitudinal (radial)) direction (L), in the transverse direction (T), in the vertical direction (V) and the vector sum of the three components (PPVR) have been analyzed separately. These relations have been obtained in the form of Equation (1). The reason for obtaining the propagation law for the individual component is that the damage criteria are applied for the highest vibration level component. Fig. 7 presents the statistically obtained propagation laws using the cube root scaled distance as well as the measured data points. These propagation laws are obtained in the form of Equation (2). Both Fig. .6 and Fig. 7 show the attenuation of the ground vibration level with the increasing scaled distance. Also, the radial and transverse components of peak particle velocities are very close in magnitude and are significantly higher than the vertical component. Scatter in the data points is wide and this typical for ground vibration measurement[6-9]. This scatter is due to many factors such as joints, rock inhomogeneity, and inaccuracy of blast variables (burden, spacing, subdrill, stemming length, delay time, .. .etc.) and variation in the superposition pattern of the different waves.

Table 4 summarizes the values of the constants K, m, and the coefficient of determination (R^2) of the obtained propagation equations of the individual components (L, T, and V) and the vector sum (PPVR). The coefficients of determination show that the obtained relations are statistically in excellent correlation. In addition, the results of statistical correlation for the blasts, which were initiated electrically, and those initiated using detonating cord are provided in the table.

From Table 4, it can be observed that the determination coefficients for cylindrical propagation model (using SD) are lower than for the spherical model (using SD1). This means that using the propagation laws in the form of Equation (2) is more representative and more reliable for predicting PPV. In addition, it is interesting to see that the determination coefficients for the vector sum (PPVR) are higher than those of the components. That is because the vector sum is affected neither by the seismograph orientation wrt each blast hole nor by its leveling accuracy but the components do. That is because of the fact that the orientation of the seismograph is different for each hole. Hence, the magnitude of the components is affected differently but the vector sum is the same. In addition, it can be seen that the determination factors are higher for the electrically initiated blasts than for detonating cord-initiated blasts. This is true for both the cube root and the square root scaled distances. This means that the electric initiation gives more consistent detonations than detonating cord initiation. Fig. 8 and 9 show that the level of ground motion is higher in the case of electric initiation than in the case of detonating cords initiation. On the other hand, the rate of decay is faster for the ground motion in case of electric initiation than in detonating cordinitiation.

Table 3. Summary of the data for blast # 2 carried out on llic 26^{th} of February, 2000. Blast #2:
Date: 2/26/2000, Time: 16:08:47, W = 975 Kg, $W^{\wedge 2}$ == 31.22, $W^{\wedge 3}$ = 9.91
Detonating Cord.
No. Ofblastholes=71
Total charge = 300 (G) +3060 (ANFO) ⁼ 3360 Kg
Total Vol. Of rock == 10584 m^3
Sp. Ch. = 3360/10584 =0.317 Kg/ m^3
Ave. % ofG/ANFO + G == 300/3360 xlOO = 8.9 %
Depth of b. h. = 3.5 - 12m
B =4 m, S == 4.5m, T=3m, J=1.5m, B. H. Dia. =4", a =10°

Two rows

G#	D,m	SD	SD1	S. Level	PPV, mm/sec		
					L	T	V
2547	440	14.09	44.40	122 dB 23.99 Pa	1.5 f31.2 R2.5	2. 7.4	1. 6.3
4664	568	18.19	57.31	133 dB 85.97 Pa	1.5 fl1.1 R2.	2. 22.7	1.5 14.2
4665	700	22.42	70.63	134 dB 91.97 Pa	1. f5.1 R1.5	1.5 8.4	0.5 41.6
4660	770	24.66	77.70	129 dB 55.98 Pa	1 .	1.5 8.4	.7 7.
4656	770	24.66	77.70	134 dB 95.97 Pa	1.2 f6.9 R1.7	1.7 7.9	.7 55.5
4657	770	24.66	77.70	138 dB 161. Pa	1. f9.6 R1.5	1.2 8.7	.7 55.5
4655	770	24.66	77.70	130 dB 61.96 Pa	.7 f6.2 R1.5	1.2 7.6	.7 8.6
4661	770	24.66	77.70	129 dB 51.98 Pa	.7 f6.4 R1.5	1.2 8.	.7 9.6
4653	770	24.66	77.70	125 dB 35.99 Pa	1. f7. R1.5	1.2 7.3	.7 10.4

Table 4. Summary of the constants K, m, and coefficient of determination (R^2) for propagation equations of the different components of PPV and PPVR.

Component	Equation (1), SD			Equation (2), SD1		
	R^2	K	m	R^2	K	m
L	0.757	339.9	1.6257	0.7826	1611.	1.616
T	0.7825	273.4	1.521	0.7852	1026.	1.477
V	0.7452	163.51	1.448	0.7739	662.6	1.442
All PPVR	0.8086	341.0	1.490	0.8303	1376.	1.474
Electric PPVR	0.8757	438.8	1.531	0.8823	2165.	1.573
Det.Cord PPVR	0.5974	74.78	1.067	0.63162	167.8	0.9945

Fig. 10 presents the obtained relations between the frequencies of the longitudinal, transverse, and vertical components of the ground vibrations, and the distance from the center of the blast. The figure shows the general trend of frequency decrease with increasing distance from the blast. The frequencies have wide scatter.

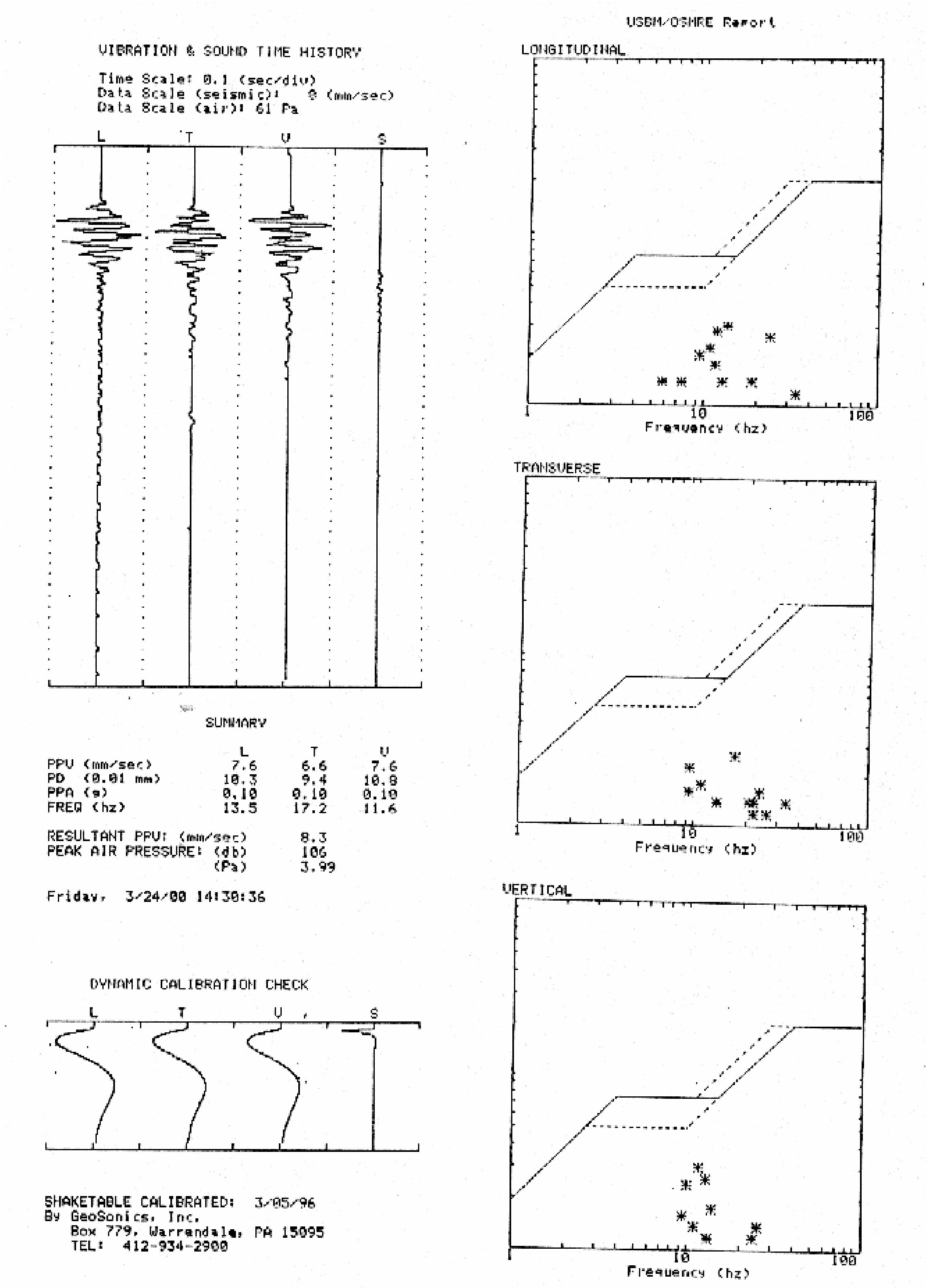

Fig. 5 : Typical printout of the SSU 2000 DK seismograph obtained for each blast.

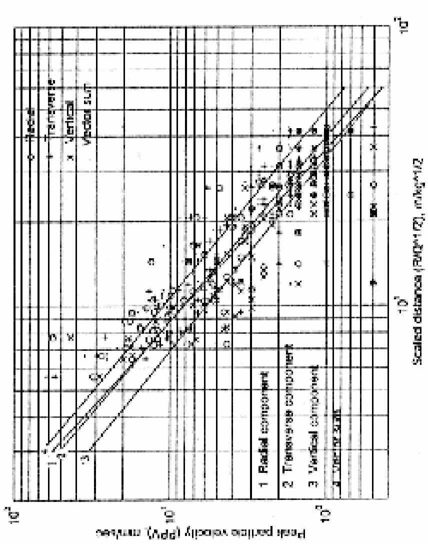

Fig. 6 :Statistically obtained propagation laws using square root scaled distance for the components of the ground motion and their vector sum.

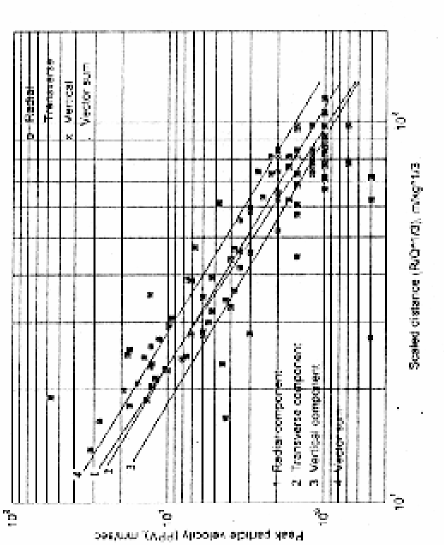

Fig. 7: Statistically obtained propagation laws using cube root scaled distance for the components of the ground motion and their vector sum.

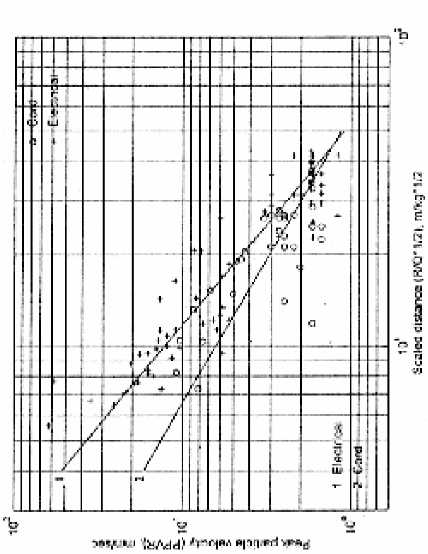

Fig. 8: Effect of initiation method on the ground motion vector sum in case of square root scaled distance. Cord: detonating cord, Electric: electric initiation.

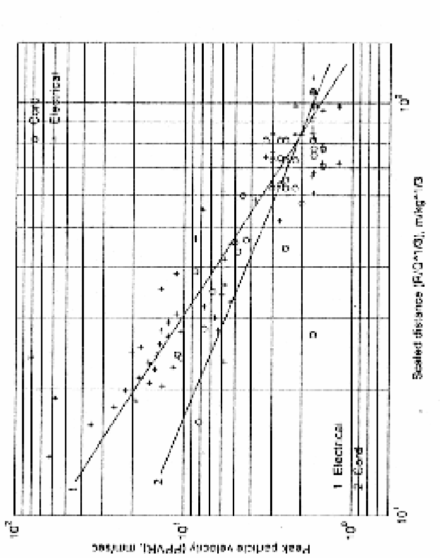

Fig. 9: Effect of initiation method on the ground motion vector sum in case of cube root scaled distance.

The correlation coefficients have been found ranging from 0.32 to 0.54, which show weak correlation between frequency and distance. Nevertheless, useful information can be obtained from the figure. . Tlie majority of the frequencies lie between 5 and 30 Hz. Also there is a noticeable number of < 10 Hz frequencies. These low frequencies are very critical to residential structures because they are in the range of their natural frequencies. This has led us to classify the frequencies in Table 5.

Table 5. Classification of the measured frequencies.

Frequency Range	Frequency Range Percentage		
	All frequencies (303)	Around G. M. (91)	Close to the face (212)
<10Hz	31.7%	71.4%	14.6%
10 - 30 Hz	55.4%	22%	69.8%
30- 100 Hz	12.9%	6.6%	15.6%

From Table 5, it can be seen that the area around the Gamma Matrix building is characterized by very low frequency (71.4% below 10 Hz). This can be attributed to three reasons: the building is the farthest from the face, the overburden (loose sand and gravel) is thicker (up to 3 m), and the area is characterized by backfill soil for recently constructed production lines (lines 1 and 2) and undergoing excavation activities for construction of the new production lines (lines 3 and 4). All these reasons work as filters for high frequencies. Close to the face, many of the seismograph locations were on solid rock. Hence, they show higher frequencies.

Discussion of Air Blast Results

Fig. 12 presents the relations obtained between air blast over pressure and the cube root scaled distance and Fig. 13 presents the relations obtained between air blast over pressure and the distance from the center of the blast. The over pressure decreases with increasing scaled distance. Most measurements at scaled distances greater than 80 m/Kg^{173} fall below 100 Pa (134 dB). This over pressure level is characterized by rattling windows and being heard as banging sound i.e. causing fear and annoyance but not damaging structures.

However, this scaled distance is equivalent to about 800 m absolute distance. Some of the blasts (parts of the working faces) are closer to the Gamma Matrix building than this distance (blasts *if* 1, 2, 3, 4, 6, 7, 8, and 10). This means that some of tlie air blast over pressures would exceed this allowable safety limit (look at the right portion of Fig. 12 and Fig. 13. Also the figures show that the level of air blast over pressure produced by detonating cord initiation is higher than that produced by electric initiation. Not only this but also the rate of decay of the over pressure produced by the detonating cord initiation is much less than that for electric initiation. After a scaled distance of45m7$Kg^{1/3}$ (equivalent to distance of about 350 m), the detonating cord over pressure does not show significant decrease. This means that it will travel significant distances at that high level. In adverse atmospheric conditions such as high-speed winds and/or temperature inversions, the level of airblast over pressure can be increased several times. Hence, the airblast over pressure need to be decreased. This can be achieved by two methods:

1- By switching from detonating cord initiation to electric initiation or NONEL shock tube initiation.

2- By using better stemming material (coarse crushed Stone) instead of the drill cuttings and by increasing the stemming length. However, increasing the stemming length may cause course fragmentation at the collar of the blast holes and compromise has to be made.

Table 6 summarizes the constants of the relations obtained for air blast over pressure vs. cube root scaled distance from the center of the blast as well as their determination coefficients. The statistical correlation is not strong between air blast over pressure and SD1 as shown in the table. The obtained relations are found to be in the form:

P==A+B*ln (SD1) (5)

Where:
P= over pressure, dB
SD1= cube root scaled distance, m/Kg[173] A **and** B = constants representing site factors.

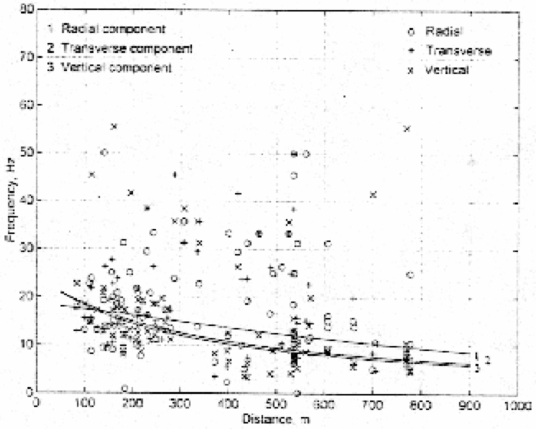

Fig. 10: Relations of the frequency of the components of ground motion versus distance from the center of the blast.

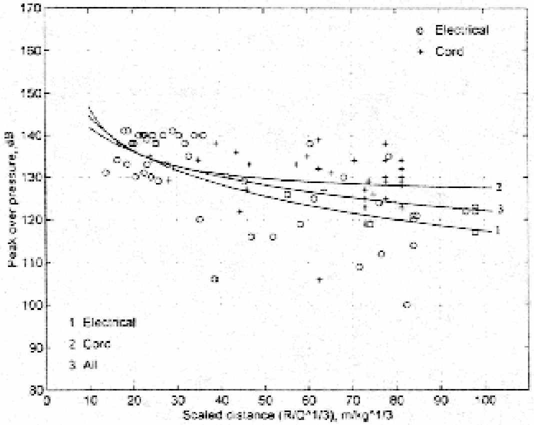

Fig. 11: Relations of the airblast over pressure versus the cube root scaled distance.

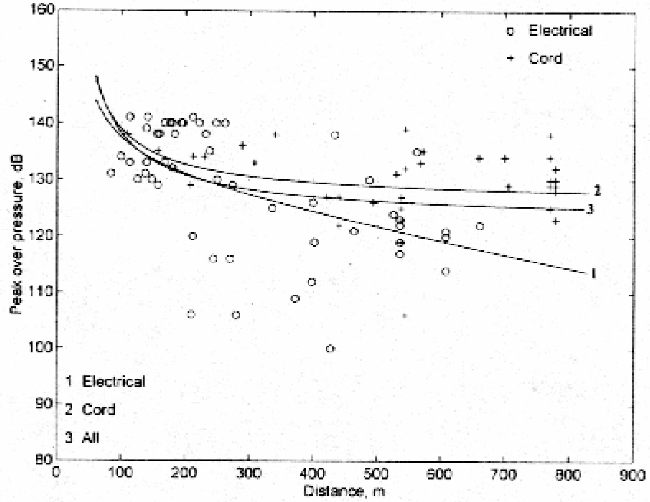

Fig. 12: Relations of the airblast over pressure versus the distance from the center of the blast.

Table 7. Summary of the results of ground vibrations and airblast over pressure (O. P.) around Gamma Matrix building.

Date	Blast #	D, m	W/Delay , Kg	SD1	# of records	Ave. O. P., dB	Ave. PPV, mm/sec. L	T	V
2/26/2000	1	544	661.5	62.46	3	125.7	1.4	2.23	0.9
2/26/2000	2	770	975.	77.7	6	130.8	0.93	1.33	0.7
2/27/2000	3	778	874.	81.38	7	128.7	1.73	2.29	1.5
2/28/2000	4	538	400.	73.0	7	123.3	1.51	1.71	1.44
2/28/2000	5	864	535.	106.5	7*	——	1.	1.	1.
3/23/2000	6	536	164.	41.84	5	121.	1.18	1.22	1.12
3/23/2000	7	732	330.	106.1	5*	——	1.	1.	1.
3/24/2000	8	608	378.	84.09	5	119	1.34	1.98	1.5
3/25/2000	9	824	367.	115.1	1*	-------	1.	1.	1.
3/25/2000	10	494	228.	74.85	1	126.	1.2	1.5	1.

* Seismographs have not been triggered because the vibration level was less than 1.2 mm/sec. An arbitrary value of 1. mm/sec has been assigned for PPV.

Table 6. Constants A, B and determination coefficients of Equation (5) for electric and detonating cord initiation.

Initiation Method	A	B	R^2
Electric	171.8	-11.8	0.4365
Detonating cord	151.2	-5.348	0.1127
All	161.8	-8.59	0.2753

The data shows wide scatter due to many variables related to the blast parameters in addition to atmospheric parameters such as temperature, pressure, and wind speed. The following unit conversions are provided to be handy for comparison of data of different sources: 1 psi = 0.068 atm = 6.895 kPa.

The phenomenon of the decrease of the airblast over pressure and increase of the level of ground vibration in case of electrically initiated blasts compared to those initiated using detonating cord may be explained. In case of electric initiation, there may be one or two points of initiation along the blast hole depending on the number of caps used. This will provide longer time for confinement. On the other hand, detonating cord initiation may be as if it is top and multipoint initiation. The reason is presence of boosting charges through the blast hole: as the detonation wave moves from top through the detonating cord, it may detonate each boosting charge in its way downward. This may cause faster stemming release and longer time for airblast to be supplied with more over pressure.

Evaluation of Measurements around Gamma Matrix Building

Table 7 presents summary of the results of ground vibrations and airblast over pressure measurements around Gamma Matrix building. Magnitudes of the measured components of ground motion, show that the Gamma Matrix building and the Gamma Matrix instrumentation are safe under the current blasting practice. However, considering the airblast over pressure levels, the building and the instrumentation are marginally safe. Hence, some changes in the current blasting practice have to be made to make sure that the over pressure is below the safety margin by greater magnitude. This will provide additional security against unpredictable atmospheric adverse conditions. In addition, it is recommended to measure the wind speed and direction before blasting to avoid blasting if the wind direction is towards the plant.

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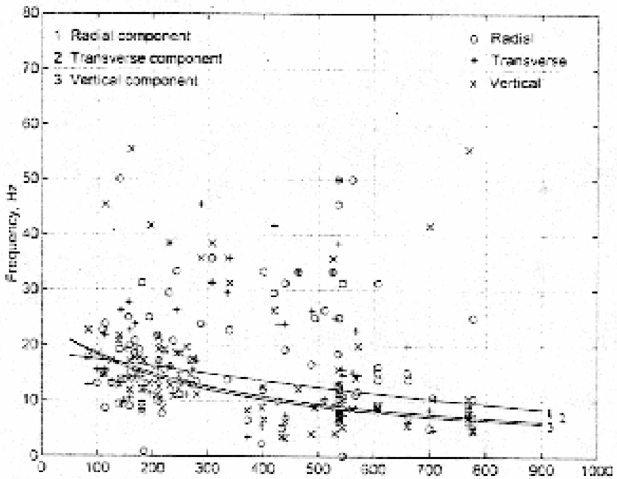

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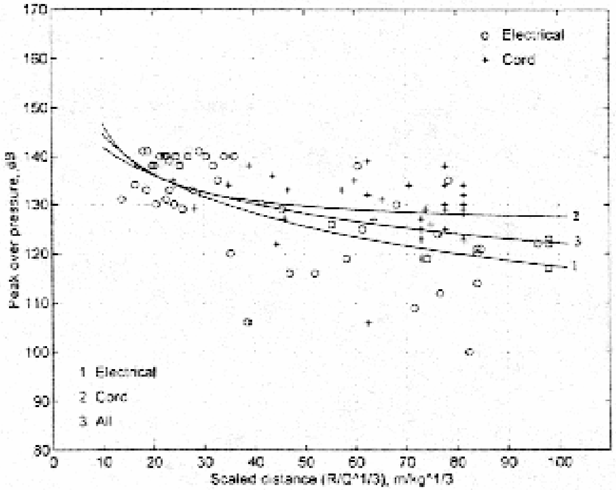

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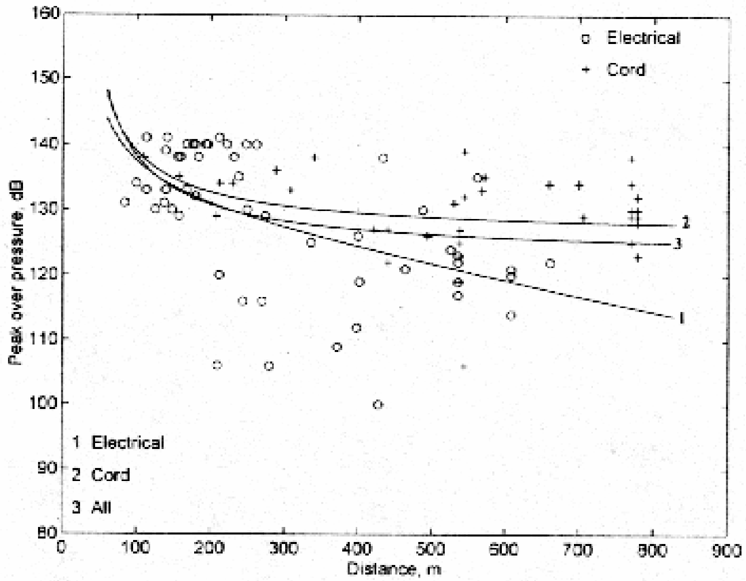

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CONCLUSIONS AND RECOMMENDATIONS

1- The propagation laws have been determined for the longitudinal, transverse, and vertical components of the ground vibrations as well as their vector sum.

2- The propagation laws have been determined using square root and cube root scaled distances. It has been found that cube root scaled distances have stronger statistical correlation with the peak particle velocities than square root scaled distances. Hence, it is more reliable and representative for wave propagation at ECC quarries.

3- Frequency of the different ground vibration components has been determined. The majority of the frequencies lie between 5 and 30 Hz. The area around Gamma Matrix building is characterized by low frequency (71.4% less than 10 Hz). The level of ground vibrations in the current blasting practice is safe for the Gamma Matrix building and instrumentation.

4- Airblast over pressures have been determined. It has been found that a noticeable number of over pressure magnitudes are close to 134 dB around the Gamma Matrix building which is the safe limit of air blast level. Hence, the airblast over pressure levels are marginally safe.

5- Electric initiation produces higher level of ground vibrations and higher decay rate compared with initiation with detonating cord.

6- Electric initiation produces less airblast over pressures than initiation with detonating cord. Hence, it is recommended to use electric initiation or NONEL shock tube system to keep airblast over pressure below the safe limits.

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