MEASUREMENT AND EVALUATION OF BLASTING GROUND VIBRATIONS AND AIRBLASTS AT THE LIMESTONE QUARRIES OF ASSIUT CEMENT COMPANY (CEMEX)

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This research has been carried out in the limestone quarries of Assiut Cement Company (CEMEX). Ground vibrations and airblast overpressure induced by bench blasting in the quarries of the company have been measured and evaluated to find out the site-specific attenuation and to assess the risk of structural damage. Statistical treatment has been applied to the measured data. From the regression analysis of the individual peak particle velocity components (longitudinal, transverse, and vertical) and vector sum, attenuation relationships have been established. These relations can be used in predicting the peak particle velocity as well as to calculate the maximum allowable charge per delay. Also, the measured frequencies are analyzed to investigate the damage potential to the company’s structures and buildings close to the production faces.

**KEYWORDS:** Bench blasting, ground vibrations, airblast, damage criteria.

GROUND VIBRATIONS DAMAGE CRITERIA

Ground vibrations and air overpressures are an integral part of the process of rock blasting and consequently they are unavoidable. The ground vibration or seismic energy is usually described as a time-varying displacement, velocity, or acceleration of a particle in the ground. Ground vibrations and air overpressures traveling through the ground and atmosphere may damage adjacent structures when they reach a certain magnitude. Researchers around the world are still working hard to provide damage criteria and continue to improve it to increase its reliability. 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 [1-14].

**Limiting Peak Particle Velocity**

By the late fifties, it was generally agreed that the particle velocity of ground motion near the structure was the best damage criterion. It has been widely accepted that, if the peak particle velocity (PPV) is less than 2 in/sec (50 mm/sec), the
probability of damage to residential structures would be low. Higher PPV would increase the probability of damage. This damage criterion was assumed independent of the frequency in the range from 1 to 500 cps and independent of the component of the PPV if it was longitudinal, transverse, or vertical. Some researchers allowed higher PPV of 2.8 in/sec. This criterion needs continuous monitoring with seismographs capable of measuring PPV. Despite that some organizations adopting the criterion of maximum particle velocity lowered its level from 2 in/sec to as low as 0.23 in/sec, this was not enough to stop public complaints and court cases [1-7]. The criterion has been ruled inadequate because the frequency content of the waveform and type of structure were not specified [7].

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 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. If the charge length to the diameter ratio is less than 6 or the distance from the shot is so far that the charge can be point source (or spherical), the scaled distance takes the form \( d/W^{1/3} \) [5-7].

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). The minimum \( d/W^{1/2} \) was recommended to be 20 for safe blasting on sites where no instrument readings were made. On the other hand, \( d/W^{1/2} \) was recommended to be 50 for sites that were actually instrumented and if peak particle velocities of less than 2 in/sec were obtained. However, this criterion alone was inefficient because it did not take into account the predominant frequency of the blast wave [2].

Blast Damage Criterion of Variable Particle Velocity versus Frequency

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. 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 \(^{1/2} \). An alternative recommended blasting level set of smooth criteria (known as z-curve) was recommended by the USBM. They have more severe measuring requirements, involving displacement and velocity as well as frequency [4,6,7]. 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 [10].

In 1983, the United States Office of Surface Mining (OSM) published its final regulations to offer more flexibility in meeting performance standards and to prevent
property damage. The operator has been given the choice of employing any one of three methods suggested to satisfy the OSM regulations. These methods are limiting particle velocity criterion, Scaled distance equation criterion, and Blast level chart criterion (z-curve). The OSM criteria resemble that of RI 8507 but with fewer restrictions [4,7,15,16].

Now, the industry standards require that the allowable PPV should be measured along with its frequency. Different countries have different tolerances. For example, Table 1 presents the French standards (damage criteria) using peak particle velocity and frequency for different types of structures [12,13].

Table 1. French Standards for peak particle velocity [13].

<table>
<thead>
<tr>
<th>Structure Type</th>
<th>Peak Particle Velocity, mm/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 - 8 Hz</td>
</tr>
<tr>
<td>Resistant</td>
<td>8</td>
</tr>
<tr>
<td>Sensitive</td>
<td>6</td>
</tr>
<tr>
<td>Very Sensitive</td>
<td>4</td>
</tr>
</tbody>
</table>

**AIR BLAST**

Airblast vibrations are generated by the blast and propagated outward through the air under the influence of the existing topographic and atmospheric conditions. Four mechanisms are usually responsible for the generation of air blast vibrations: the venting of gases to the atmosphere from blown-out unconfined explosive charges, release of gases to the atmosphere from exposed detonating fuse (initiation system), ground motions resulting from the blast, and the movement of rock at the bench face. Audible air blast is called noise while air blasts at frequencies below 20 Hz and inaudible to the human ear are called concussions. This is measured and reported as an “overpressure” it means air pressure over and above atmospheric pressure. The noise can either be continuous (lasts more than 1 second) or be of impulsive nature such as a shock from explosions. Overpressure is usually expressed in pounds per square inch (psi), Pascal (Pa), or in decibels (dB) [6,7,14].

The pressure developed by noise and shock waves is the primary cause of window rattling. Nicolls et al, through the Bureau of Mines conducted extensive research in blasting and concluded that overpressure less than 0.75 psi would not result in any window damage and overpressure of 1.5 psi or more would definitely produce window damage. Maximum value recommended by Nitro Consult and generally accepted for sound pressure is equal to or less than 142 dB (250 pa). On the other hand, the USBM RI 8485 recommended that less than 133 dB over pressure level (at 2 Hz high-pass system) should provide 95-99 % non-damage probability and 90-95 % annoyance acceptability [2,6,7].

Assiut Cement Company (ACC) plant and quarries are located about 15 km north west of Assiut city. The company has begun production in October 1985. Now, the company is one of the largest cement producers in Egypt. It produces about 3.3 million ton per year. The limestone quarries lie west of the cement plant. Figure 1 shows a contour map of the company’s quarries [17].
Fig. 1: Contour map of the limestone quarries of Assiut Cement Company.
AIM OF THE RESEARCH

When ground vibrations and airblast over pressure levels are high, they can cause human annoyance and even cause damage to nearby structures. The objective of the present study is the measurement and evaluation of the ground vibration and airblast levels under the current blasting practices at the limestone quarries of Assiut Cement Company. The records and measurements are investigated and analyzed to find out if the current bench blast design complies with the safe regulated levels or it does not. Published damage criteria will be used for such judgment. This objective is 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 are recorded and maximum overpressures are measured as well. These measurements are carried out for different explosive charge weights at various distances. Buildings and constructions close the quarry, are given the first priority in the quantity of measurements.

INSTRUMENTS AND FIELD EXPERIMENTAL PROCEDURE

The instruments used include one SSU-2000 DK seismograph system, 10 SSU micro-seismographs, two data transfer cases, and two manual buttons. The SSU-2000 DK seismograph is a complete independent unit. 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 carried out through the data transfer cases. 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 [18,19].

The procedure of using the seismographs include the following steps[15,16]:
1. The seismograph is installed in the ground oriented toward the blast and its surface is kept as level as possible.
2. The horizontal distance between each seismograph location and the blast has been measured using a total station.
3. The seismographs are switched on about 30 minutes before the blast is fired, and the seismographs are switched off, uninstalled, cleaned, and carried out to the office about 30 minutes after the blast firing.
4. Micro-seismographs are placed into their data transfer cases in a predetermined order and their data is down loaded to the SSU 2000 DK unit. Full waveforms and summary of the recorded data are printed out and saved to the disk.

ANALYSIS AND DISCUSSION OF RESULTS

ACC 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 of rocks along the path of the waves induced by the blasts. In Figure 1, the locations of the current working faces are at the north west of the map. The small back areas with circles on top are the nearest buildings and structures to the working faces. The height of the lower face ranges from 47 to 59.5 m, while the height of the upper face varies from 25 to 42 m. Blast hole diameter in the
lower bench is 113 mm (4.5 inch). Other parameters of the lower bench blast include: burden = 4.5 m, spacing = 6.5 m, stemming length = 3 m, subdrilling = 2 m., single row and angle of inclination, $\alpha = 7.5^\circ$. On the upper bench, the blasthole diameter is 150 mm(6 inches). Other parameters of the upper bench blast include: burden = 6 m, spacing = 8.5 m, stemming length = 3 m, subdrilling = 2 m., single row and angle of inclination, $\alpha = 10^\circ$. Main explosive charge 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 9 –13.5% with an average of 10%. The specific charge ranges from 0.28 to 0.29 Kg/ m$^3$. Usually the initiation is carried out by connecting the down hole detonating cords to a trunkline detonating cord for each group of holes to be detonated per delay. Then each group is connected to an electric blasting cap and connected to the other caps in a series electric-blasting circuit. The applied delay time is 25 msec.

Twenty one full scale production blasts have been carried out with number of blastholes per blast ranging from 11 to 31. Weight of charge per delay ranged from 240 to 1550 Kg and total charge weight per blast ranged from 4810 to 12380 Kg. The distance between the seismographs locations to the center of the blast ranged from 46 to 1226 m. Seismographs have been used to record the ground vibrations and air blast during each blast. Distance from each seismograph location to the center of the blast or center of the largest weight per delay 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 some blasts. The records have been investigated for time of blast, shape of waveform, and calibration chart of seismographs 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 (SD2) and cube root (SD3) scaled distances have been calculated for each blast and seismograph site.

Twenty one tables have been made summarizing the data for each blast including geophone number (G#), SD2, SD3, peak particle velocity (PPV) for longitudinal (L), transverse (T), and vertical (V) components of ground motion along with their frequencies (f), and their vector sum resultant (R); air blast (sound) over pressure in Decibels. On the top of each table, the date, time, and bench blast parameters are also provided. Table 2 is an example for such tables. It is for blast # 14 (9) fired on the 19th of November 2005. The number before brackets is the sequence of the blast in the study while the number between brackets is the sequence of the blast in the quarry. In the tables, the geophones number 4653, 4655, 4656, 4657, and 4660 are close to the nearest structures, Administration building, German Crusher, Russian Crusher, Explosive Magazine 1, Romanian Crusher, and entry of the quarry respectively. These locations are shown on the top of the table. The five geophones in the bottom of the table are much closer to the quarry faces to provide more reliable and useful statistical analysis. Figure 2 is an example of the multiple reports of the full waveforms of the obtained records.
Table 2: Summary of the data for blast # 14(9), carried out on the 19th of November 2005.

Date : 19/11/2005  Time : 16:23
Max. Charge Weight (w)/delay = 1130 kg , \( w^{1/2} = 33.62 \text{ kg}^{1/2} \), \( w^{1/3} = 10.42 \text{ kg}^{1/3} \)
Blast Location: Upper bench.
Firing Method: Electric caps + Detonating cord down lines.
Total charge (W) = 900 (G) + 8600 (ANFO) = 9500 kg.
Avg. % G/ANFO+G = \( (900 / 9500) \times 100 = 9.5 \% \).
Depth of b. h. = 25.5 – 39 m, # of b. h. = 20.
B = 6 m, S = 8.5 m, T = 3 m, J = 2m, Dia. = 6 in, \( \alpha = 10^\circ \).

<table>
<thead>
<tr>
<th>G #</th>
<th>D, m</th>
<th>SD2</th>
<th>SD3</th>
<th>Airblast amplitude</th>
<th>PPV, mm / sec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L</td>
<td>T</td>
</tr>
<tr>
<td>4653</td>
<td>792.9</td>
<td>23.59</td>
<td>76.09</td>
<td>123 dB 27.99 pa</td>
<td>1.2 f 10.2 R 2.0</td>
</tr>
<tr>
<td>4655</td>
<td>771.5</td>
<td>22.95</td>
<td>74.04</td>
<td>132 dB - pa</td>
<td>1.8 f 9.4 R 2.5</td>
</tr>
<tr>
<td>4656</td>
<td>848.0</td>
<td>25.23</td>
<td>81.38</td>
<td>136 dB 123.96 pa</td>
<td>1.2 f 6.8 R 2.0</td>
</tr>
<tr>
<td>4657</td>
<td>636.0</td>
<td>18.92</td>
<td>61.04</td>
<td>137 dB 135.96 pa</td>
<td>1.0 f 5.2 R 2.0</td>
</tr>
<tr>
<td>4660</td>
<td>552.1</td>
<td>16.42</td>
<td>52.98</td>
<td>138 dB 147.96 pa</td>
<td>2.2 f 12.8 R 2.5</td>
</tr>
<tr>
<td>4661</td>
<td>441.8</td>
<td>13.4</td>
<td>42.40</td>
<td>138 dB 157.95 pa</td>
<td>2.2 f 11.6 R 2.5</td>
</tr>
<tr>
<td>4662</td>
<td>395.5</td>
<td>11.77</td>
<td>37.96</td>
<td>138 dB 147.96 pa</td>
<td>2.0 f 9.2 R 4.0</td>
</tr>
<tr>
<td>4663</td>
<td>367.7</td>
<td>10.94</td>
<td>35.29</td>
<td>140 dB 203.94 pa</td>
<td>2.5 f 15.6 R 3.5</td>
</tr>
<tr>
<td>4664</td>
<td>340.2</td>
<td>10.21</td>
<td>32.65</td>
<td>140 dB 203.94 pa</td>
<td>4.3 f 31.2 R 6.3</td>
</tr>
<tr>
<td>4665</td>
<td>307.9</td>
<td>9.16</td>
<td>29.55</td>
<td>140 dB 199.94 pa</td>
<td>2.5 f 9.4 R 4.5</td>
</tr>
</tbody>
</table>

\( L \), \( T \), \( V \) refer to the left, top, and vertical directions, respectively.
Fig. 2: Example of the multiple reports of the full waveforms of the obtained records.

The data have been statistically analyzed for the upper bench and the lower bench. Figures 3, 4, and 5 present the statistically obtained attenuation relations between square root scaled distance (SD2) and the radial ($V_r$), transverse ($V_t$), and vertical ($V_v$) components of the peak particle velocity of the ground vibrations as well as the measured data points. The relations in the figures show the attenuation of the ground vibration level with the increasing scaled distance. The amplitudes of the
ground vibrations from the upper bench are higher than those from the lower bench, especially close to the working faces. The reason is that the explosive charge weights per delay are usually higher at the upper bench (blasthole diameter is 150 mm) than that of the lower bench (blasthole diameter is 113 mm). Figure 6 presents the relation between the vector sum (resultant, \( V_R \)) of the components of the peak particle velocity and the square root scaled distance. The four figures can be used for the prediction of the explosive charge weight per delay that can produce a given ground motion amplitude at a certain distance. Figure 6 is the most conservative because in the method of calculation of the vector sum, the peak amplitudes of the components of ground motion are used.

Scatter in the data points is wide and this is typical for ground vibration measurement. 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. Hence, it is important to consider this scatter when using these propagation relations.

Figure 7 presents the percentage of events occurrences according to the frequencies of the peak amplitude of the components of the ground vibration. The predominant frequencies of the components of the ground vibrations are low and range from 4 to 8 Hertz. According to these frequencies, the safe limit of ground vibration amplitude is taken 8 mm/sec for buildings and crushers, while for the explosive magazines (being more sensitive) the safe limit is taken 6 mm/sec (French standards). The ground vibration records close to these structures have been statistically treated separately. The regression line (50% line) and the envelope line (95% prediction line) that contains the events below it with 95% confidence level have been calculated.

Figure 8 presents the regression lines, the safe limits as well as the data points of the resultant of the ground vibration. From the figure, it can be seen that all the data points fall below the safe limits. The levels of the measured particle velocities are safe and comply with the safety regulations.

**Prediction of PPV (R) at 50 % and 95 % levels for blasts:**

The prediction of particle velocity requires that the average and upper bound values be well known. The 50% average line is the line of usual regression of the recorded data. The 95% prediction limit line is a line generated from the standard error and data distribution curve under which lie most of the recorded data with 95% confidence level. Ten explosive charge (per delay)-distance couples have been used to compare the recorded amplitude of the resultant ground vibrations with the predicted amplitudes using both relations (50% and 95% lines). The results of calculations are presented in Table 3. Predicted amplitudes from the 50% line are acceptable whereas the 95% amplitudes are higher as expected. The high amplitudes of the 95% line are safer to use, but they put more restrictions on the bench blast design by decreasing the allowable explosive weight per delay. Table 4 gives summary of the obtained relations of the attenuation equations of the components of the peak ground vibration as well as the equation of propagation of the vector sum of the components for both the upper and lower benches. Also, the attenuation equations of the vector sum of ground vibrations in the neighborhoods of the structures are included in the table.
Fig. 3: The relation between the radial component of the particle velocity and the square root scaled distance.

Fig. 4: The relation between the transverse component of the particle velocity and the square root scaled distance.
Fig. 5: The relation between the vertical component of the particle velocity and the square root scaled distance.

Fig. 6: The relation between the vector sum of the particle velocity and the square root scaled distance.
Fig. 7: The percentage of events occurrences according to the frequencies of the peak amplitude of the components of the ground vibration.
**Table 3**: Sample of recorded and predicted values of peak particle velocity (50% and 95% lines) at constructions locations.

<table>
<thead>
<tr>
<th>No.</th>
<th>Location</th>
<th>Explosives Quantity (kg)</th>
<th>Distance (m)</th>
<th>Recorded PPV (R*) mm/s</th>
<th>Predicted PPV (R*) mm/s (50%)</th>
<th>Predicted PPV (R*) mm/s (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Offices Building</td>
<td>1120</td>
<td>1335.4</td>
<td>2.0</td>
<td>1.67</td>
<td>2.04</td>
</tr>
<tr>
<td>2</td>
<td>Explosive Magazines</td>
<td>890</td>
<td>679.9</td>
<td>1.7</td>
<td>2.66</td>
<td>3.25</td>
</tr>
<tr>
<td>3</td>
<td>Explosive Magazines</td>
<td>800</td>
<td>646.7</td>
<td>2.7</td>
<td>2.65</td>
<td>3.25</td>
</tr>
<tr>
<td>4</td>
<td>Russian Crusher</td>
<td>840</td>
<td>944</td>
<td>1.2</td>
<td>1.98</td>
<td>2.42</td>
</tr>
<tr>
<td>5</td>
<td>Offices Building</td>
<td>930</td>
<td>1110.1</td>
<td>1.0</td>
<td>1.80</td>
<td>2.20</td>
</tr>
<tr>
<td>6</td>
<td>Offices Building</td>
<td>1190</td>
<td>1225.8</td>
<td>3.0</td>
<td>1.84</td>
<td>2.25</td>
</tr>
<tr>
<td>7</td>
<td>Explosive Magazines</td>
<td>1010</td>
<td>769.8</td>
<td>2.2</td>
<td>2.53</td>
<td>3.09</td>
</tr>
<tr>
<td>8</td>
<td>German Crusher</td>
<td>1130</td>
<td>788.5</td>
<td>2.2</td>
<td>2.60</td>
<td>3.18</td>
</tr>
<tr>
<td>9</td>
<td>Romanian Crusher</td>
<td>770</td>
<td>529.8</td>
<td>2.2</td>
<td>3.08</td>
<td>3.77</td>
</tr>
<tr>
<td>10</td>
<td>Russian Crusher</td>
<td>1115</td>
<td>565</td>
<td>3.3</td>
<td>3.41</td>
<td>4.17</td>
</tr>
</tbody>
</table>

**Fig. 8**: The 50% and 95% regression lines and the safe limits of the resultant of the ground vibrations in the neighborhood of structures.
### Table 4: Summary of the attenuation equations of the peak ground vibration.

<table>
<thead>
<tr>
<th>Component of the PPV, mm/sec</th>
<th>Upper bench</th>
<th>Lower bench</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equation</td>
<td>R</td>
</tr>
<tr>
<td>Radial</td>
<td>$V_r = 220.15 \text{ (SD2)}^{-1.55}$</td>
<td>-0.92</td>
</tr>
<tr>
<td>Transverse</td>
<td>$V_t = 195.23 \text{ (SD2)}^{-1.55}$</td>
<td>-0.91</td>
</tr>
<tr>
<td>Vertical</td>
<td>$V_v = 187.95 \text{ (SD2)}^{-1.55}$</td>
<td>-0.90</td>
</tr>
<tr>
<td>Vector sum</td>
<td>$V_R = 206.86 \text{ (SD2)}^{-1.425}$</td>
<td>R = -0.91</td>
</tr>
<tr>
<td>$V_R$, Close to structures</td>
<td>$V_R 50% = 206.86 \text{ (SD2)}^{1.42}$</td>
<td>R = -0.91</td>
</tr>
</tbody>
</table>

**Figure 9** presents the attenuation relation obtained between air blast over pressure and the cube root scaled distance. The relation has a good correlation factor, $R = -0.60$ and has the following form.

$$DB = 218.422 \text{ (SD3)}^{-0.118}$$

The over pressure decreases with increasing scaled distance. Most measurements close to the buildings fall below 133 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, a significant number of the...
airblast over pressures have been found to exceed this allowable safety limit. In addition, the rate of decay of air blast is low. Look at the small slope of Figure 9. This means that it will travel significant distances at that high level. Hence, the airblast over pressure need to be decreased. This can be achieved by switching from detonating cord initiation to complete electric initiation or NONEL shock tube initiation or by using better stemming material (coarse crushed Stone) instead of the drill cuttings and by increasing the stemming length. This will provide additional security against unpredictable atmospheric adverse conditions. However, increasing the stemming length may cause course fragmentation at the collar of the blast holes and compromise has to be made.

In adverse atmospheric conditions such as high-speed winds and/or temperature inversions, the level of airblast over pressure can be increased several times. This increases the risk of damage. 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.

**CONCLUSIONS AND RECOMMENDATIONS**

1- The attenuation relations has been determined for the vector sum as well as for longitudinal, transverse, and vertical components of the ground vibrations.

2- Frequency of the different ground vibration components has been analyzed. The majority of the frequencies lie between 2 and 38 Hz. Predominant frequencies range from 4 to 8 Hertz.

3- Magnitudes of the measured components of ground vibration show that the buildings are safe under the current blasting practice.

4- Airblast over pressures have been determined. It has been found that a noticeable number of over pressure magnitudes are close to and greater than 133 dB (the safe limit of air blast level) around the buildings. Hence, the airblast over pressure levels are marginally safe for the buildings but exceeds the allowable annoyance level.

5- It is recommended to use electric initiation or NONEL shock-tube system to keep airblast over pressure below the safe limits. In addition, increasing stemming length may alleviate the problem.

6- It is recommended to measure the wind speed and direction before blasting to avoid blasting if the wind direction is towards the plant and administration buildings.

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قياس وتقييم الاهتزازات الأرضية والتضاغطات الهوائية الناتجة عن التفجير في مخاجر الحجر الجيري لشركة أسمنت أسيوط (سيمكس)

هذا البحث تم إجراؤه في مخاجر شركة أسمنت أسيوط (سيمكس). الاهتزازات الأرضية والتضاغطات الهوائية الزائدة الناتجة عن التفجير في مخاجر الشركة تم قياسها وتقييمها لإيجاد الاضحاال النوعي للموقع وتحديد مخاطر الضرر بالمنشآت. كما تم تطبيق التحليل الإحصائي للبيانات المقاسة. ومن نتائج التحليل الإحصائي لمركبات السرعة الجزيئية القصوى (طولية وعرضية ورأسية) والمجموع الاتجاهي، تم إيجاد علاقات الاضحاال للسعة مع المسافة الموزونة. هذه العلاقات يمكن استخدامها في التنبؤ بالسرعة الجزيئية القصوى وكذلك في حساب مقدار أقصى شحنة مفرقعات يمكن تفجيرها لكل زمن تأخير. أيضا، تم تحليل التردادات المقاسة لبحث احتمالية الأضرار بمنشآت ومباني الشركة القريبة من واجهات الإنتاج.