Experimental Techniques To Reduce Blast Vibration Level, Tourah, Cairo, Egypt.

M. Khaled [1], K. Abdel Rahman [2] and A. Abo Makarem [1]

[1] ASEC Company for Mining "ASCOM" - Cairo, Egypt.
[2] National Research Inst. of Astronomy & Geophysics - Cairo, Egypt.

Abstract

There are four large limestone quarries, located nearby Cairo metropolitan. Drilling and blasting operations are used to extract limestone for the cement industries. In these quarries, the blast vibration should be kept below a certain limit. One of these quarries is Tourah Portland Cement Company (TPCC) limestone quarry which, lies near important and historical large caves, within Tourah Mountain. Therefore, control of blast vibration level becomes very critical.

A series of multi-holes blasts have been performed to answer several questions about the optimum scaled distance that can be used safely to avoid caves damage, what constitutes true timing and initiation system?, and their relation to the blast vibration level?.

Four Tri-axial geophones located in a linear array, over a distance of 1.0 km (0.621 miles) from the quarry faces, they have synchronized by means of a GPS timing reference. The data retrieved from the geophones and subjected to different steps of processing and analysis.

The field tests showed that there was a significant difference in the blast vibration level between top and bottom initiation systems, containing the same explosive charge per delay intervals. In the upper bench, the results showed that the blast optimization of vibration level requires small delay intervals at distance more than 800.0 m (875 yards), between shot point and caves.

This study helped TPCC limestone quarry to remain operating since the government permitted the continuation of blasting operations. In addition, the advantages of using Nonel system in comparison with VA electrical detonators, could lead to convince the government to raise the permitted explosive charge per day.

Introduction

The detonation of an explosive charge in the blast hole gives rise to a strong initial shock wave, which then decays, into stress waves in the surrounding rock. The initial shock wave pressure exceeds the strength of the rock, and a very complicated shear stress pattern occurs, which ultimately leads to crushing of the rock around the blast hole. As the wave moves radially out from the blast hole, the amplitude (pressure) decreases and the wave becomes a purely elastic compressive and shear wave (P & S waves respectively). Additional wave, (Rayleigh wave) is formed as a result of the interaction of the P-wave with the free surface.

It has been estimated that, the shear stress in the surrounding rock increases as the square root of the explosive charge and decreases linearly with increasing distance from the charge [Persson et. al, 1994].

From the above, the problem of ground vibration is alarming when blasting operations are going on near a historical site, like Tourah caves. TPCC limestone quarry, belonging to Tourah Portland Cement Company, Cairo, Egypt, is located nearby the caves of Tourah Mountain, which were used during the ancient Egyptian period.

The local authorities arranged many restrictions for the blasting operations around Tourah caves in order to protect it from blasting vibrations. One of these restrictions is lowering the maximum explosives charge to 3 ton (6613.86 pound) per blast and the maximum permitted particle peak velocity (PPV) is 5.0 mm/second (0.196 inches/second). Otherwise, the blasting operations are liable to be stopped completely.

Therefore, the effect of using certain appropriate initiation system and delay interval is of great importance to avoid potential damage of Tourah caves, through decreasing the blasting vibrations level.

Location and site geology

The limestone quarry of TPCC is opened at the south west foot slopes of Tourah Mountain, which forms the eastern high escarpments overlooking the Nile River, and situated 23 km (14.3 miles) south of Cairo, on Maadi - Helwan road Fig. (1). Geologically, this area belongs to Mokattam Formation (Middle Eocene).

The quarry deposit is mainly composed of thick bedded limestone, mostly earthy white to faint yellow in the upper 60.0 m (196.8 feet) turning to grayish yellow and grey downwards. In the upper 60.0 m (196.8 feet) two segments of 4.0 m (13.1 feet) each, are composed of nodular limestone. The hardness of the limestone deposit is considerably varying from moderately hard to very hard. Fissures are more frequent near the top and less frequent downwards. Most of these fissures are filled with iron oxides and siliceous sediments. The noticeable structures in the area are a group of step faults running east-west, and perpendicular to the investigated site.

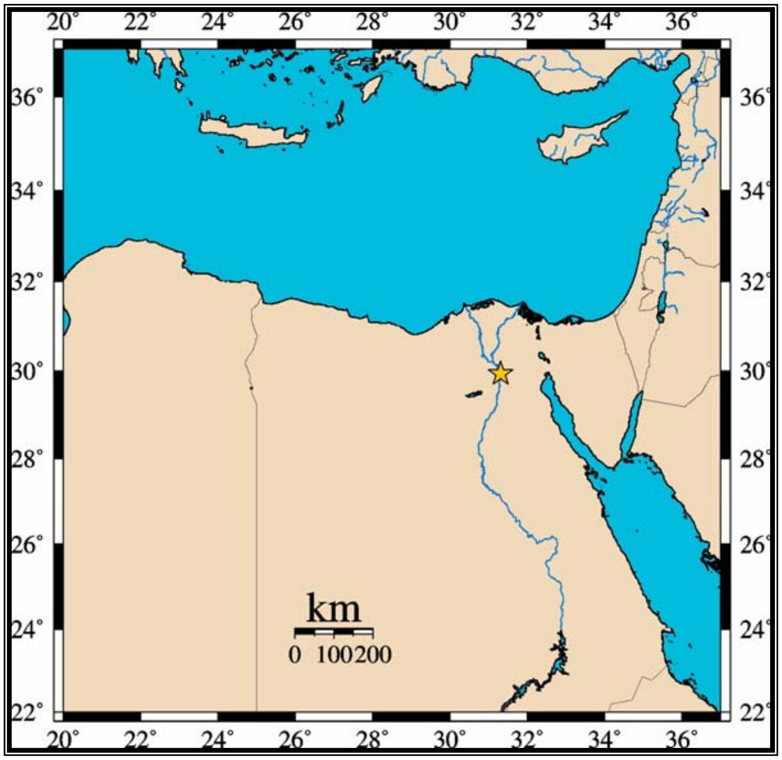

Fig. (1) Location map for Tourah area.

Quarry operation

The TPCC limestone quarry faces form a more or less semi-circular shape, with a circumference of 2.8 km (1.74 miles). The quarry is composed of 2 benches, the upper bench varying in thickness, depending on surface topography with average 35.0 m (114.8 feet). The height of the lower bench attains approximately 55.0 m (180.4 feet).

The limestone is excavated by drilling and blasting. The material blasted from the upper bench is pushed by bulldozers from bench down to the quarry floor, and all loading and hauling operations are performed at the quarry floor. In order to keep the upper bench suitable as a drilling and blasting bench, its width is constantly kept narrow, and ranging between 5.0 to 10.0 m (16.4 to 32.8 feet).

Blast Monitoring

Series of blasts were monitored with four digital strong motion instruments (REF TEK-130 SMA), deployed in a linear array at distances of 530, 680, 810 and 910.0 m (580, 743, 885 and 995 yards) from the shot point. The number of blast holes in each blast was 5 holes and 7 holes in the lower and upper bench respectively, in order to keep the total explosive charge per blast not more than 3 ton (6613.86 pounds).

A three similar deck charges were applied in the blast hole of the lower bench with 55.0 m (180.4 feet), while only two deck charges in the upper bench with 35.0 m (114.8 feet) height. In each deck a 20 kg (44.1 pounds) of gelatin dynamite (prime ring), and 180 kg (396.8 pounds) ANFO (blasting agent), were initiated in each delay intervals, by VA electrical detonators. All blasts are similar to great extent in the burden, spacing and hole diameter were 6.0 m (19.7 feet), 8.0 m (26.2 feet) and 165.0 mm (6.5 inches) respectively.

The initiation system and delay intervals may play a significant role in the resultant peak particle velocity (PPV), so it is decided to study the effect of changing the initiation system in both lower and upper benches.

Effect of initiation system.

Regarding to the limestone in the upper bench, is anisotropic and fissured. So, the loss of seismic energy due to absorption is very high. Moreover, the geometrical spearing minimizes the seismic energy density as the distance increased from the shotpint. Figure (2) shows, the values of PPV which are greater in the top than the bottom initiation systems, till about 800.0 m (875 yards) distance from the shotpoint, after which the values were reversed.

It is noticed that, in case of top initiation the decrease of seismic energy through the above mentioned factors is very small, because of the short propagation path. In consequence, we expect higher PPV values at short distances, which are gradually decreased with distances, due to the increasing effects of the geometric spreading and absorption. While, in case of bottom initiation, the propagation distance of the wave permits a large loss of energy due to the same causes, and smaller PPV values are obtained.

The above described phenomenon is reversed in the lower bench as show in Figure (3). This can be interpreted by the higher velocity of the compacted limestone than those of the explosive materials. The upward propagating seismic waves, from bottom initiation, will accumulate compressional stresses at the surface more than those produced from top initiation, and the PPV values of the bottom initiation will be larger. The decrease of energy due to geometrical spreading and absorption produce an intersection point between the PPV – monitor distance relations for top and bottom initiation, i.e. the two values are equal at a distance of 800.0 m (875 yards) approximately from the blast hole.

The intersection point of PPV – monitor distance relations from top and bottom initiations depends on:

- The distance between the top and bottom explosive charge, and the monitor location X^1 and X^2 respectively.
- The velocity of seismic (P-wave) through the rock.
- The length of the explosive charge in the blast hole.
- The detonations of the explosive materials used.

The above mentioned factors have the following consequence: In each case, the intersection point exists only, where the total detonation time (Δt) of the explosive equals the difference in propagation time through the rock, i.e. Δt rock = (X^2-X^1) / V_p rock, where V_p is the compressional wave velocity.

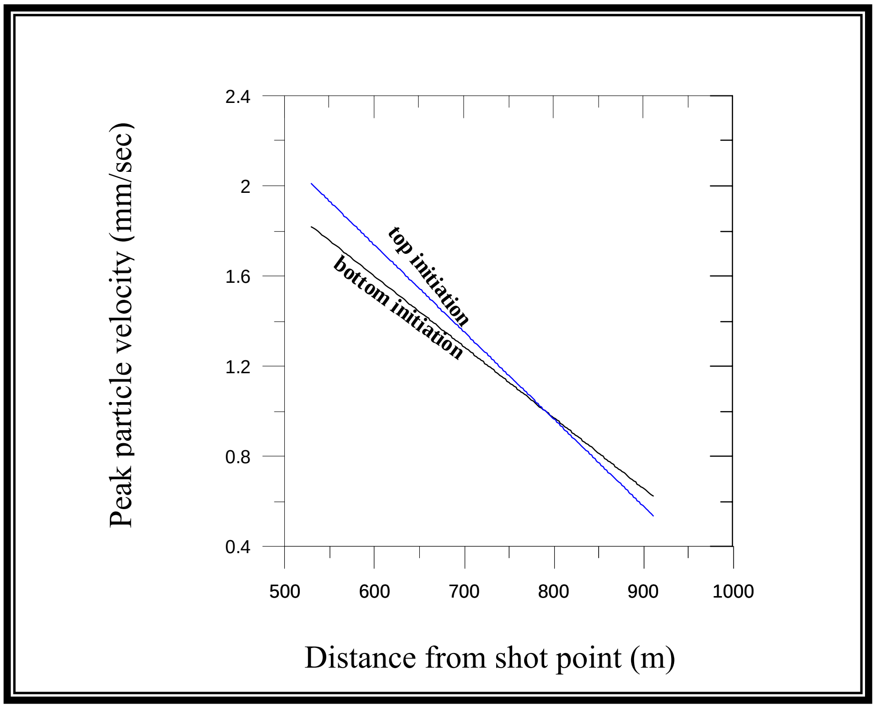

Fig.(2) Effect of the initiation system, in the upper bench.

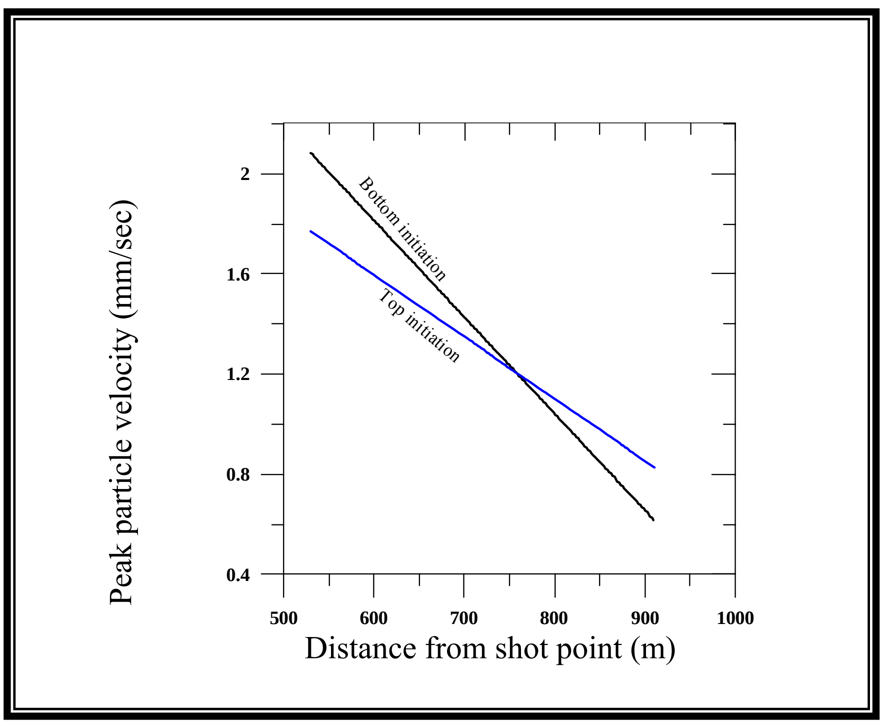

Fig.(3) Effect of the initiation system in the lower bench.

Effect of the delay interval

It is noticed that the values of the PPV in the upper bench are greater in case of using 25 ms. delay interval between each explosive charge, than 50 ms. delay interval, till 800.0 m (875 yards) distance approximately, from shot point. After which the values were reversed, as shown in Fig (4). At this case the initiation with small delay interval (25 ms.) will produce small interval between the up going wave fronts and the accumulation of stresses at the recorder location. In consequence, the increase of the delay causes large time intervals between seismic wave fronts and small PPV values.

While in case of the lower bench, the PPV values were greater with 50 ms than with 25 ms delay intervals. At this stage of the test the authors could not define an interpretation for the manner of the data shown in Figure (5).

Effect of non-electrical detonators

The non-electrical detonators (Nonel) were used in several blasts, and their vibrations were monitored. The analysis of data showed that, in every case, the non-electrical detonation yields significant lower PPV values than the electrical detonation. In addition, one of the advantages of non-electrical system that, gives us a chance to redistribute the hole's explosive charge into five deck charges instead of three in case of electrical system. Moreover the number of holes per blast can be increased, without duplicating the delay intervals.

The above mentioned advantages of non-electrical detonators allow us to negotiate with the local authorities, to increase the maximum permitted explosive charge more than three tons per blast, without increasing the maximum permitted values of PPV.

Concept of the Scaled Distance

Scaled distance is defined as the dimensionless parameter for distance. It is derived as a combination of distance and charge weight influencing the generation of seismic energy. In most cases, the PPV is used to express what vibrations the actual object can withstand without being damaged when blasting is carried out. The investigations show that, a usable empirical relationship between the PPV, weight of explosive charge (W) and the distance (R) [Persson et al., 1994] is:

$$PPV = \frac{K}{\left(\frac{R}{\sqrt{W}}\right)} \alpha \qquad (1)$$

Where, K and α are constants depending upon the rock, explosive and blast-design parameters. K represents the initial energy transferred from the explosive to the surrounding rock, and it is the line intercept of the relation at Scaled Distance = 1 on log-log graph. In addition, the attenuation rate of the PPV due to geometric spreading and influences of rock characteristics are included in the slope factor (α). The term $(R/ W^{0.5})$ is the scaled distance.

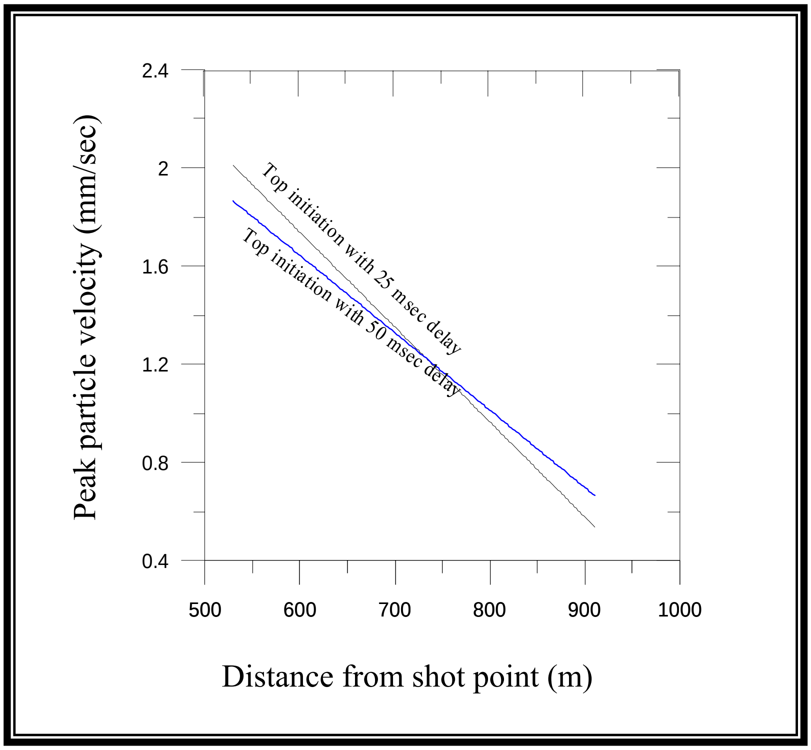

Fig. (4) Relationship between PPV and delay intervals, in the upper bench.

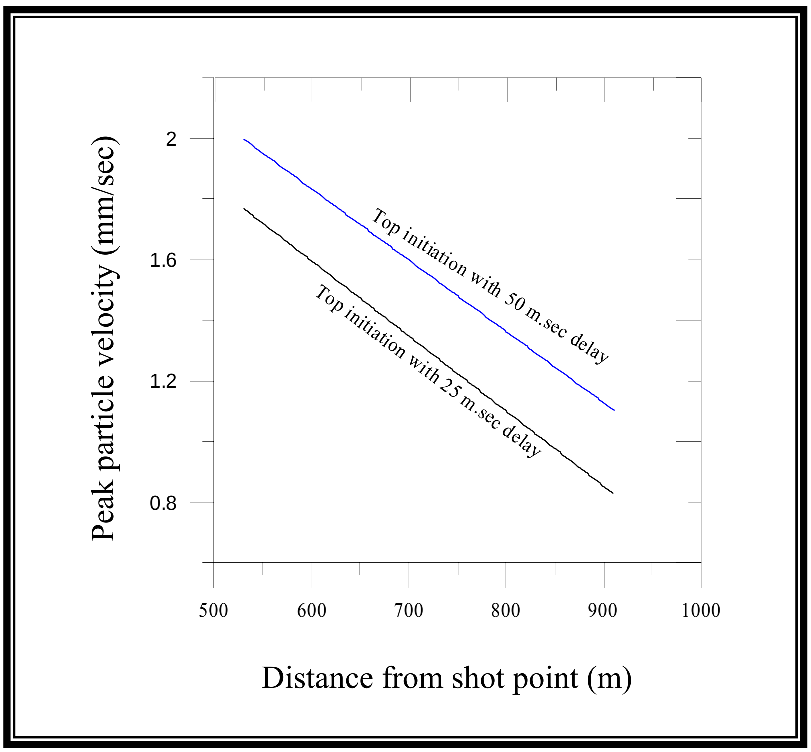

Fig. (5) Relationship between PPV and delay intervals, in the lower bench.

The above mentioned constants have been determined from Fig. (6) for TPPC limestone quarry, to predict the maximum PPV values. The following predicted equation was derived, with a correlation coefficient of 0.82.

$$PPV = 870\ (R / \sqrt{W})^{-1.68} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

This equation helps in the calculation of PPV values when a suitable instrument is not available in the site, by substituting the value of the maximum explosive charge per delay (W) and the distance (R) from shot point.

Using the equation (2), the maximum permissible explosive charge delay intervals is 1700 kg (3747 pounds), on the present blast holes of TPCC limestone quarry, at distance 910.0 m (995 yards) from Tourah caves. The explosive charge being used presently is 200 kg (440 pounds), much lower than the permissible charge. In addition, considering 5 mm/s (0.196 inch/s) as safe limit of PPV, the safe distance was computed, as follows:

- In case of electrical detonators (200 kg per delay): 305 m (1000 feet)
- In case of non-electrical detonators (120 kg per delay): 235 m (770 feet)

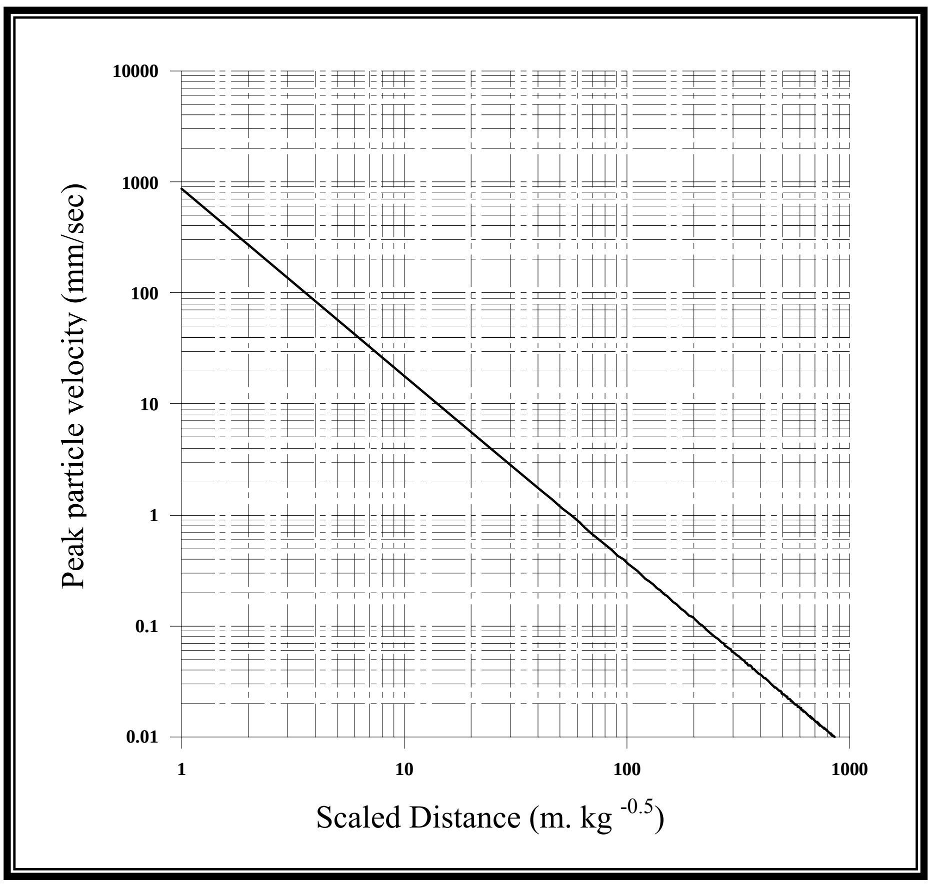

Fig.(6) The general relation between (PPV) values and scaled distance.

Conclusions

Reduction of blast vibration level or peak particle velocity PPV has been examined in Tourah Portland Cement Company (TPCC) limestone quarry. Blast experiments have been conducted on the upper and lower benches using top and bottom initiation system. The factors influences blast vibration levels are:

1) Relations between detonation system and rock velocities; where bottom initiation exhibits low PPV values at smaller distances in case of rocks having lower velocities than those of the explosive materials. In practice, the fissured rocks, as those of the upper bench in the study area, represent a typical case for executing bottom initiation of blasts. In the contrary, top initiation is recommended for low blast vibration levels, in lower bench (hard rocks), where rock velocity is greater than the explosive detonation velocity.

2) A unique value of the blast vibration level exists at the critical point of intersection of top and bottom initiation relations. This means that the same PPV value is gained, if one conducts either top or bottom initiations. The distance of this point from the shot point, depends on the length of the explosive charge in the blast hole, and the relation between the total detonation time and the propagation time difference in the rock from explosive to receiver.

3) Delay interval: To gain low level blast vibrations, large delay intervals are applied in the low velocity rocks and vice versa.

4) Non-electrical detonators (Nonel) introduces an excellent way of reducing the blast vibration level; this is apparently because it gives us a chance to redistribute the hole explosive charge into five deck charges instead of three in case of electrical system, and the number of holes per blast can be increased.

The following recommendations have been drawn from this study:

- Considering the safe limit of the peak particle velocity as 5 mm/sec (0.196 inches/sec); the empirical equation for TPCC limestone quarry gives the maximum permissible explosive charge per delay intervals as 1700 kg (3747 pounds) on the present blast holes, at 910.0 m (995 yards) far from Tourah caves, instead of 200 kg (440 pounds) as an explosive charge being used presently, which is much lower than the permissible charge.

- The safe distance was computed, as follows:

In case of electrical detonators, a charge of 200 kg (440 pounds) per delay gives PPV value of 5 mm/sec (0.196 inches/sec) at a distance of 305 m (1000 feet). In comparison, with the non-electrical detonators a charge of 120 kg (264.5 pounds) per delay, will gives 5 mm/sec (0.196 inches/sec) of PPV at a distance of 235 m (770 feet).

Acknowledgments

The authors would express their great thanks to engineer E. El-Bagy and M. Kamal (ASCOM), for their co-operation in performing these investigations. Also, sincerely thanks Prof. Dr. Mahdy Abd El-Rahman, Ain Shams University, Cairo, for his kind support during interpreting the data.

References

- Anderson, D. A., 1993, *"Blast monitoring: regulations, methods, and control techniques. Comprehensive rock Engineering Practice and Projects Excavation, support and Monitoring*", Vol. 4, Pergamon Press Ltd., Headington Hill Hol, Oxford, England, pp. 95 - 134.
- Farag, I.A.M. and Ismail, A. 1959 "Contribution to the Stratigraphy of the Wadi Hof area (northeast of Helwan)". *Bull. Fac. Sci.,* Cairo Univ., 34, pp. 147-168.
- Konya, C. J. and Walter, E. J.,1985 "*Rock blasting*", U.S. Dept. of Transportation, Federal Highway Administration, Virginia, pp.199-257.
- Persson, P.; Holmberg, R. and Lee, J.,1994 "*Rock blasting and Explosives Engineering.* Library of Congress, Cataloging – in- publication data, 551 p.
- Roque, P.; Yang, R.; Katabanis, P. D.; and Bawden, W. F., 1993 "Near field vibration monitoring", *Proc. Of the 9th Annual Symposium on Explosives and Blasting Research,* ISEE, pp.231 - 238.
- Siskind, D. E.; Crum, S. V., Otterness, R. E.; and Kopp, J. W., 1989 "Comparative study of blasting vibrations from Indiana surface coal mines*", BuMines RI 9226, USBM,* P.41.
- Vasudev S. and Prof. Singh, 2006 " Safe blasting near important civil structures: A case study" Vol. 1, Proc. 32th Ann.Conf. Explosives and Blasting Tech; ISEE.