Facing the Drilling and Blasting Difficulties at Helwan Quarry, Egypt.

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ABSTRACT

Helwan limestone quarry is located at a distance of 35 km (21.7 miles) to the south of Cairo downtown. Drilling and blasting operations are used to extract the limestone for the Helwan Cement Company (HCC). In 1980's a new urban community was constructed adjacent to the quarry. This situation led to shifting of the old quarry 5.0 km (3.1 miles) to its current location, to avoid causing blasting problems to the new community. Unfortunately, the new quarry is opened in a highly faulted area, with weak zones of brittle materials. The drilling and blasting crew is facing many difficulties due to the geological complexity along these zones. Moreover, the extension of this community towards the new quarry makes the control of ground vibrations is very important.

The above mentioned conditions drive us to apply a series of systematic procedures, to ensure consistent drilling efficiency. These procedures consist of assessment of the optimum type of drilling machine, assurance of drilling parameters by measuring both effective burden along the quarry face, and blast-hole deviation. Sometimes, casing of blast-holes is necessary to be applied. Furthermore, both of ground vibrations (PPV), and velocity of detonation (VOD) were recorded, and most of blasts were thoroughly filmed, using a high speed digital video camera, to audit the applied procedures.

The results of this study were used to minimize the drilling difficulties within the faulted areas, improve the safety level of blasting works, and optimize the blasting results through all subsequent quarry operations. Then an adopted technique has been recommended for the future drilling and blasting activities at HCC quarry.

INTRODUCTION

Helwan Cement Company (HCC) is one of the oldest cement factories in Egypt; where its old limestone quarry first started operation in 1929. Over the years the limestone extraction has been developed from manual operation to the drilling and blasting, in order to meet the increasing demand for the limestone. HCC became one of the largest cement factories, and the quantity of limestone required to feed the plant is now more than 5.5 million tons per year.

During the last two decades a new urban community (15th of May City) was constructed adjacent to the old quarry of HCC, Figure (1) and the availability of suitable limestone to feed the plant became a problem for the following reasons:

- The ring road of the new city is running close to the face of the old quarry.
- The lack of safe possible extension of the old quarry in any other direction that would not impact on the new city.

In consequences, the Ministry of housing imposed HCC to investigate other limestone deposit, and open a new quarry, to avoid causing problems to the new community. The geological investigations located an area situated at about 5.0 km (3.1 miles) to north-east of the old quarry. This study is carried out by Asec Company for Mining "ASCOM" at HCC limestone quarry, with the specific purpose of developing an optimum technique to over come the drilling and blasting difficulties, whilst taking into consideration the presence of the new city and thus ensuring its safety.

Fig. (1) Location of HCC new quarry and 15th of May City.

SITE GEOLOGY

The limestone in HCC quarry is thickly bedded, faint yellow, fossiliferous, moderately hard, and exhibiting 3 - 4 of thin hard dolomitic bands. The quarry is situated in an area of relatively low relief land. The western and southern limits of the quarry are bounded by two main valleys joined together at the southwest corner.

Fault systems: The abrupt changes in the elevations of the dolomitic beds along the quarry faces are attributed to the existence of faults that are associated with vertical displacements. Most of these faults could not be detected on the surface because of the limited vertical displacement, and the presence of an almost continuous cover of overburden materials. A few faults are visible on the surface as edges of scarps, and whilst others seem to be associated with lines of weakness that were easily eroded to form steep side valleys. Most of the faults form two sets whose members are more or less parallel, and these sets intersect together and making an angle about 60 degrees with each other.

Fig. (2) Faulted face of Helwan limestone quarry.

Throw of the faults: The fault throw is the amount of relative displacement of the blocks on both sides of a fault plane. Some faults have one displacement component where the two blocks move vertically or horizontally relative to each other as in the normal, reverse and strike-slip faults. These faults have had minor effects on drilling and blasting works.

Other faults of interest are those accompanied with both vertical and horizontal displacement components, which is called diagonal (oblique)-slip fault. This inference is based on the fact that some of the faults exposed in the quarry faces have crushed zones around their planes, which are considered to be far wider than that which could be produced only by the limited vertical displacements. It is thought that combined horizontal and vertical movements would be more likely to produce such phenomenon.

Moreover, some faults show a decrease in the amount of the down-throw in a given direction, and beyond a point at which the displacement become nil, the direction of the down-throw becomes reversed, i.e. the fault is a pivotal fault. Both oblique-slip and pivotal faults create major difficulties for both drilling and blasting activities at HCC quarry (ASEC, 1991).

QUARRY OPERATIONS

The HCC quarry is located at the south east foot slopes of Helwan Mountain. The quarry forms a more or less rectangular shape. It's composed of one single bench, of 60 m (65.6 yards) height.

The drilling work is accomplished by three drilling rigs (Atlas Copco - rock 606), and one rig (Sandvik -Titon 500). The blasted limestone is loaded by 6 loaders (966 CAT), and is hauled by 22 on-road tipper trucks, each of 20 tons. There are three hydraulic hammers and two bulldozers for the secondary breakage and earth moving works. The crushing system is situated at 6.0 km from the quarry faces, and consists of two hammer crushers with nominal capacity about 750 tons/hour, and other two jaw crushers followed by hammer crushers, as a second stage with 250 tons/hour. Limestone is then transported by belt-conveyer (with actual capacity of 1200 ton/hour) to the plant located 8 km from the crushers.

QUARRY PROBLEMS

The principle difficulties that the HCC quarry crew is facing in attempting to drill and blast the rock in a safe and cost efficient way, as follows:

- The quarry is unique in that, it is operating in a highly faulted area. This requires the penetration rate of the drilling rigs to be low. This is necessary to ensure very careful pull down and low rotation speed in order to maintain borehole wall integrity. On many occasions the drill plugged in the hole when intersecting fault zone of brittle materials, this resulted in approximately 19% of the blast holes requiring being re-drilled. Moreover, this equated to 351 wasted hours down time per year by the drilling rigs.

- The charging operation of explosives was also very difficult; since the faulted holes require that more care is taken when charging them. In many cases the previous blast has resulted in back-breakages of the remaining wall or sliding of the adjacent blocks, and toe problems. This resulted in on occasions of significant quantities of blasting agent (ANFO) leaking from the blast holes and fills the surrounding pockets of the fault zone, and then being initiated during the main blast. In other blast holes, which are not confined enough, the explosive energy easily vents out through the opened fissures and bedding planes, which causes bad fragmentation result, and non-stable remaining wall.

- Today, the city of 15th of May is experiencing an extraordinary growth of population, and the nearest buildings of the city are now located at 600 m (656 yards) from the new quarry. The owners of these buildings express their concern that blast vibration may crack the foundations. Some of the previous blasts produced high PPV values, upsetting the inhabitants of the city; this has resulted in the regulatory authorities restricting the blasting activities to only one day per week instead of 4-5 days per week. This in turn has resulted in more than 20 tons (4409.5 pounds) of explosives being fired in one day, which then creates more problems in designing the initiation patterns for the blasts.

APPLIED TECHNICAL APPROACHES

Evaluation of the previous studies

The applied technical approach at HCC quarry was produced as a result of a series of trials that began by the evaluation and validation of both the structural geological map and the seismic refraction study of the area, in order to detect the location, direction and elevation of each fault, as follows:

- The structural geological map: This was obtained through correlating the different beds penetrated by the core-holes (ASEC 1991). From Figure (3) it is evident that the present quarry face is located between several faults; most of them are parallel to the main face while, few are perpendicular to it.

- The seismic refraction study: Later on the compressional wave velocities were measured along the quarry faces (ASCOM 2000). The obtained profiles indicated four stratigraphic boundaries, with gradual increase in velocities from 1900 – 2600 m/sec (2077 – 2843 yards/sec) with depth. The four boundaries are separated by thin hard bands that have a very high compressional velocity ranges from 3000 - 3500 m/sec (3280 – 3827 yards/sec), as in Figure (4). The seismic profiles were a valuable tool in the determination of faults elevation to be considered during charging operation of explosives in each blast-hole.

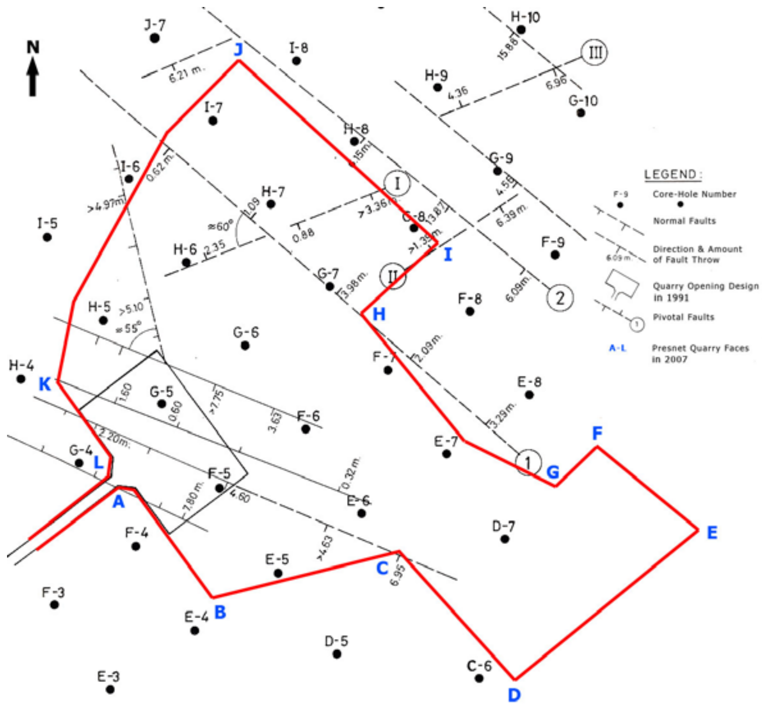

Fig. (3) Structural geological map and HCC quarry faces.

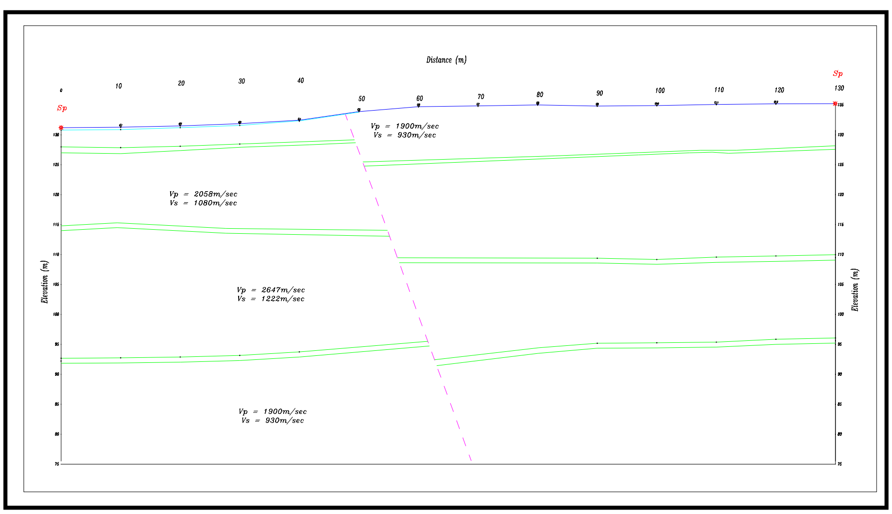

Fig. (4) Seismic refraction profiles of Helwan limestone quarry.

Controlled drilling

As it is not possible to control what can not be measured; measuring the position, depth, and deviation as well as the effective burden in front of each blast-hole is the basis of effective control. Initially, the position and depth of blast-holes were determined by using the total station (Lica-TC1103). Because these traditional instruments can not offer any information about the blast-face (burden) regarding the position of blast-hole path, recently the authors have introduced the MDL's Laser-Ace Burden finder instrument Figure (5), with scanning capability that allows us to shoot several points along the blast-face, and display the actual face profile. All measured data gathered from the proposed quarry face to be blasted are used to design the required blast-holes, according to burden thicknesses and rock volume in front of it, as in Figure (6).

Fig (5) Burden Finder instrument.

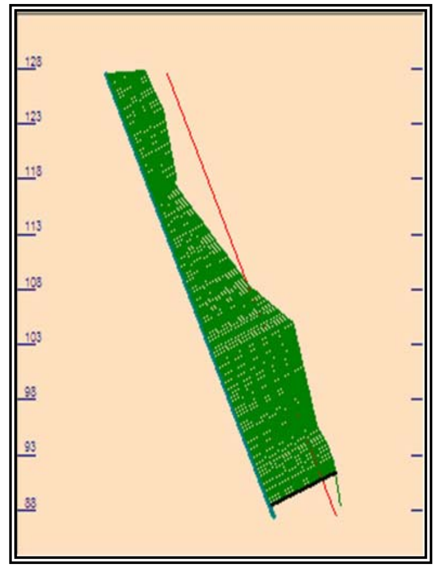

Fig (6) Blast-holes profile.

Once the designed blast-holes are drilled, the second evaluation step is applied by using a Cabled Boretrak instrument, as a mean of checking the drilling performance and measuring both deviation and azimuth degree for each blast-hole, Figure (7). Holes can be displayed individually or in groups to determine holes` spacing. The software then provides a 3D image of the actual drilled holes integrated with the corresponding blast-face profile, which highlights the over burdened or dangerously under burden areas, as in Figure (8).

The authors discovered unexpected high degrees of deviation of the drilling angle, of 3.0 m (9.8 feet) in 60 m (197 feet) on average, which were drilled by the existing pneumatic drilling rigs. This was found to be due to the limited capability of the rigs, which resulted in poor drilling performance and accuracy in these difficult geological conditions when drilling holes of up to 60.0 m (197 feet) depth. To overcome this problem, a program had been started to gradual replace the pneumatic drill rigs by new hydraulic drill rigs. The new hydraulic rig were found to be able to reduce the value of the deviation rate from 0.05 to 0.01 m/m (1.9 – 0.36 ft/ft). For example, Figures (9 & 10) show two blast-holes which were designed to have a drilling angle of 10^o. The drilling angle is found to be 7.6^o when using the old pneumatic rig, compared with 10.2^o in case of using the new hydraulic rig.

Moreover, the new hydraulic rig has the ability to drill blast-holes with high drilling angle (up to 35^o) instead of drilling double or triple holes, with many disadvantages. This solved the problem of inaccessible burden. Also the penetration rate increased from 14.7 to 24.5 m/hour (48.2 – 80.4 feet/hour), and the average down time lost hours due to the dills being stuck decreased from 6.3% to 1.8% of the total drilling time, in comparison with the pneumatic rigs. In turn, all of these procedures improved the yield of rock value from 31 - 39 m^3/m. (334 - 420 ft^3/ft). The worst drilling problem that was faced was the repeated plugging of blast-holes after being drilled that were located in the fault zones. This was overcome by inserting PVC lining tubes, in order to protect the bore-hole walls. In spite of being an expensive and time-consuming process, it was found to be the most cost effective solution. The visible sign of the degree to which drilling control had been improved was that the blast-holes then left a half barrel mark on the remaining wall.

Fig. (7) Cabled Boretrak instrument.

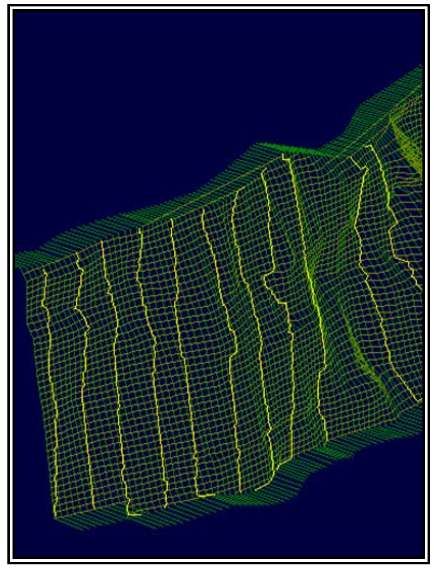

Fig (8) 3D image of the blast face.

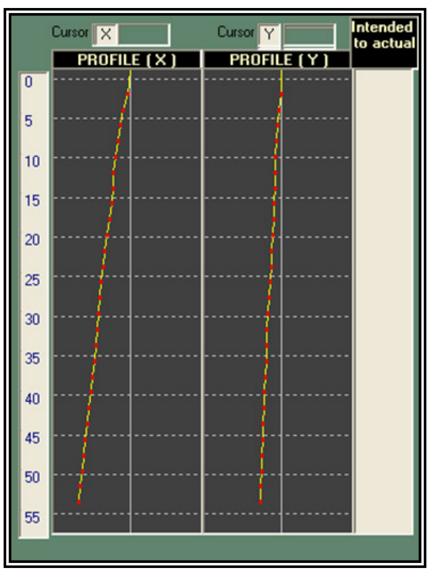

Fig. (9) Deviation of pneumatic rig.

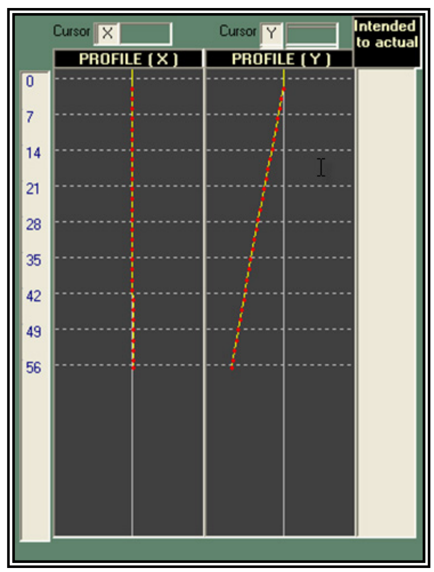

Fig (10) Deviation of hydraulic rig.

Blasting evaluation

With conventional blasting, the explosive charge seldom varies from one hole to another (except in case of a very significant difference in geometry). That said the geometry does vary in most cases, and it is not uncommon to detect a difference in the volume to be blasted between holes within the same shot. Such differences are barely visible to the eye. When roughly the same explosive charge is used for all holes, these variations cause considerable differences in the powder factor. This can result in inconsistent fragmentation and can generate abnormally high vibration levels, (Chavez et al 2007).

This was the case in HCC quarry, where the calculation of specific charge for each hole was impossible. Now the drilling measurements make it possible not only to calculate the quantity of explosives separately for each blast-hole, but also to distribute it along the blast-holes according to the actual rock volume to be blasted. Thus, the charging system was converted from continuous to deck loading system, in all blasts.

A series of blasts was designed and fired to compare the continuous to the deck loading systems. All blasts used the same burden 5.5 m (18 ft), spacing 7.5 m (24.6 ft), hole diameter 165.0 mm (6.5 in), sub-drilling 1.5 m (4.9 ft) and stemming 3.0 m (9.8 ft). All blasts were initiated by electrical detonators, with an inter-hole and inter-deck timing of (25) millisecond. The key variable was the total explosive quantity, which was reduced by about 8.4 % for the blasts in case of deck loading, relative to the continuous loading. Significant improvements were found with the deck loading blasts, in terms of vibration, fragmentation and even muckpile height.

Figure (11) illustrates the deck loading system, which consists of 3 explosive charges separated by 2.0-4.0 m (6.6 - 13.1 ft) decks of crushed stones, and 3.0 m (9.8 ft) of top stemming. The maximum number of holes in each blast was initially 7, arranged in a single row to comply the limited delay intervals of electrical detonators (1-20). In order to increase blast-holes number, it was necessary to convince the Egyptian authorities to permit us to use the non-electrical detonators. Thus, the Nonel system was introduced to HCC quarry, in 2006's for the first time. Since then the unlimited delay interval of non-electrical detonators was applied to increase the total number of blast-holes in any one blast.

Prior to each blast, all the usual drilling measurements are gathered together as well as specific information from the driller relating to whether any faults planes had been intersected. This data was used to support the shot firer to calculate both depth and length of each deck. Those holes that were found to be too deep were backfilled, while short and / or highly deviated holes were re-drilled. The loading procedure adopted was as follows: firstly the Nonel detonator (U 425) was inserted into cartridges of gelatin dynamite 10 kg (22.1 Ib) as a primer, to be lowered to the bottom of the blast-hole. The lower portion of the holes are loaded with ANFO as a blasting agent, for a certain depth and covered by crushed stone for decking. Using the same mentioned procedure, other two Nonel detonators (U450), (U475) are applied for both middle and top portions. Both of burden and spacing were increased by 0.5 m (1.6 ft) as a result of the improvements had been achieved in the blasting design.

Most of the blasts were recorded by a high speed digital video camera (MREL) Figure (12). The films had shown an efficient stemming retention on most of the deck loading blasts. These films were used to diagnose back-breakage problems of the remaining wall, and sliding phenomenon of blocks adjacent to blast. Through studying these video films, a specific blast design has been developed for different areas of the quarry.

A blast consists of multiple rows (3), instead of one row was tested. The loading system for both front and middle rows are the same as previously mentioned, while the back row has been loaded by a combination of ANFO and dynamite (powder), in order to reduce gas volume. The orientation of the initiation is V shape, for the front and middle rows, while the back row is initiated instantaneously to insure sharp split along the remaining wall. The only disadvantage of this solution is the high conducted vibration level. To avoid this vibration problem, each blast-hole in the back row consisted of 5 instead of 3 decks.

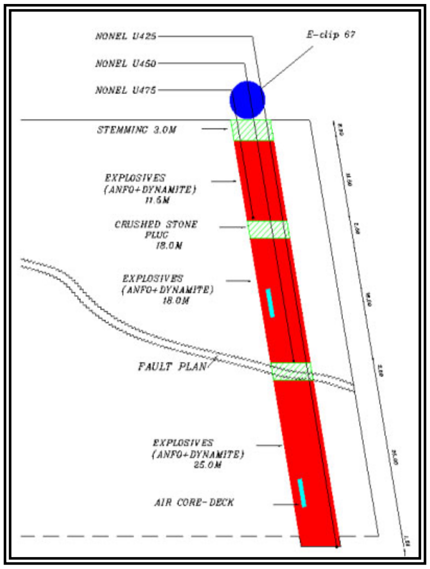

Fig. (11) Cross section of deck loading systems. Fig. (12) High speed digital video camera.

In case of the single row blast, on one occasion, it was found that the resulting quarry face did not respect the alignment of blast-holes. The back break was found to be more than 18.0 m (59.1 ft), and followed the existing fault plane. This left huge blocks in the muck pile that took long time to break. A three rows blast was then designed next to the previous one, and the result was excellent, regarding fragmentation, stability of remaining wall, and even toes movement.

A point of interest is that, the air core-deck system which is very simple, and quick to use was tested. It was dropped in the blast-holes at the time of loading. Air core-deck creates an axial air gap (9 x 120 cm), and does not interrupt the column of ANFO. It is found that the air core-deck is effectively replacing about 8% of the ANFO volume.

Another proposal taken to avoid repeatable stuck problems, occurring at the level of 120 m (a.s.l.) due to intersection of the existing plane of weakness with the blast-holes, the (GH) face, in Figure (3) was divided into two benches. The average thickness of the upper bench is 20 m (65.6 ft), while the remaining thickness of the lower bench is 40 m (131.2 ft). The construction of the new bench was started in 2007, by blasting the upper portion of the existing face (20 m), as shown in Figure (13), and then the blasted limestone is pushed by bulldozers from the created bench down to the quarry floor. The loading and hauling operations are performed at the quarry floor.

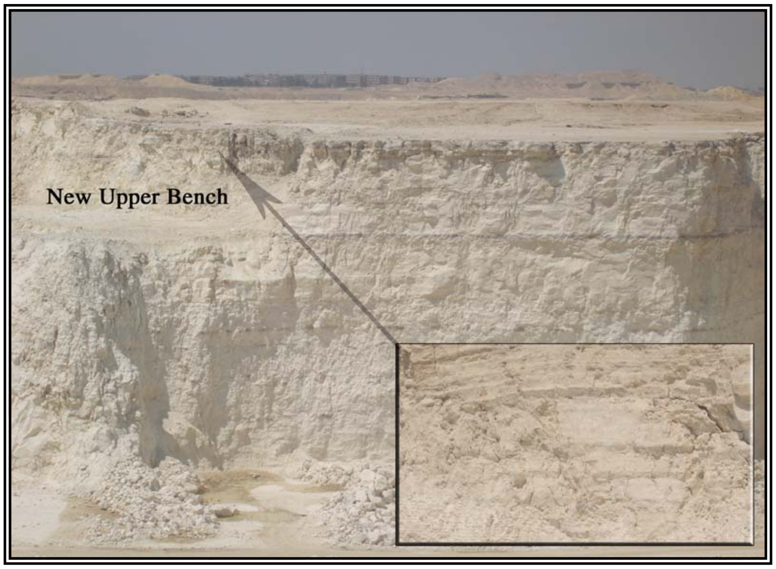

Fig. (13) New upper bench, at (GH) face.

In addition, the velocity of detonation (VOD) was also recorded. The use of deck loading system achieved an improvement in VOD values (6 %) in comparison with the continuous loading. Adding air core-deck to deck loading system did not make any significant difference, this implies that the deck loading system with air core-deck were considerably more efficient than the continuous loading system.

BLAST EFFECTIVENESS

Cost optimization

The authors remain concerned about minimization of blasting cost, to make the procedures developed more applicable. Since the result of blasting affects all subsequent quarry operations, then it's important to determine to what level would the blasting cost be optimized, rather than minimized? To answer this, the cost of each step of adopted technique was optimized towards the goal, with respect to geological conditions and needs of the subsequent quarry operations. The cost optimization was mainly achieved by reducing the powder factor (explosive [in grams] / rock volume [in m^3]) gradually, see Table (1). Cost analysis showed that the reduction of powder factor leads to 8.9 % saving in blasting cost per ton.

Blasting system		Rock volume (m^3)/blast-hole	Explosive (kg) per blast-holes	Powder factor (g/m^3)
Continuous loading, with electrical detonators.		2475	952.0	384.6
Deck loading	Electrical detonators.	2475	872.0	352.3
	Non-electrical detonators.	2880	872.0	302.8
	Non-electrical detonators, with air cord-deck.	2880	748.8	272.5

Table (1) Relationship between blasting system and powder factor.

Vibration results

Both drilling and blasting operations performed at HCC quarry are contracted out to ASCOM while, National Researches Institute of Astronomy and Geophysics (NRIAG), is elected by the local authorities to monitor the conducted vibrations for all blasting operations around Cairo metropolitan.

Vibration data recorded by NRIAG station, which located at 1450 m (0.9 miles) from HCC quarry was analyzed in conjunction with blasting data derived from the quarry. Data from 360 blasts were gathered during the last 2 years, and plotted in Figure (14). In general, a significant reduction in PPV values was noticed with every change in applied procedure during this study. According to the fitting line of the data, it could be concluded that the values of PPV for the blasts performed by the final adopted technique (controlled drilling, deck loading with air core-deck system, and non-electrical detonators) was reduced by 46.50% than that of blasts before this study. This resulted in the development of the final optimum technique which was applied in HCC quarry, in order to achieve the highest compliance safety level for the city of (15th May).

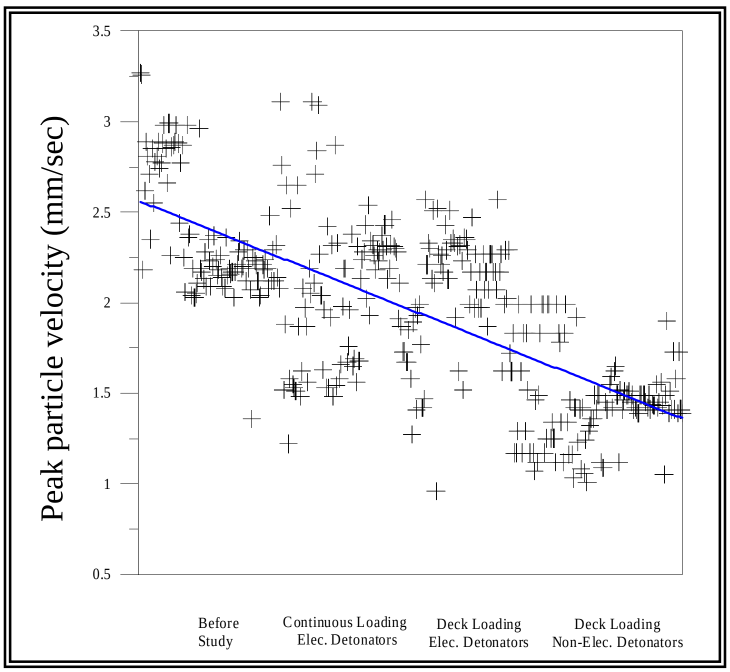

Fig. (14) Relationship between PPV values and applied techniques.

Productivity measurements

One of the main objectives of this study is to increase the quarry productivity. It is known that, the production of limestone increases when its fragmentation and way of handling is optimized. Unfortunately, no digital fragmentation analysis system was available during the study, and it was considered inadvisable to depend on manual measurements for the rate of loading and / or hauling on a long term basis. Thus, it was found that the crushes productivity, as recorded on crusher gauges (production in tons / running time in hours), had the best potential to be the most reliable productivity measurement. Figure (15) illustrates the crusher's productivity over the last two years. The average of first year before this study was 1011.2 t/h, while it increases slightly to 1057.8 t/h during the study. In reference to "fitting line", a 3.19% improvement was observed, which was achieved using less explosives than previously used.

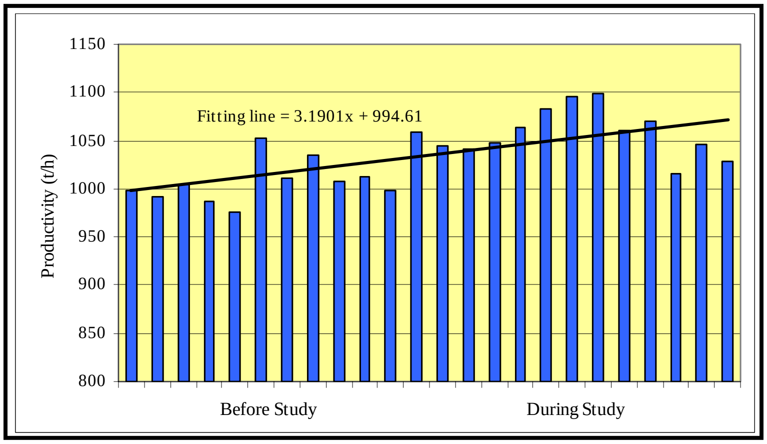

Fig. (15) Limestone crusher productivity (t/h), at HCC quarry.

CONCLUSIONS

The aim of this study is to develop and then adopt techniques that could be applied to drill and blast the complex geological limestone deposit in the HCC quarry, with the least possible effort, expense, and the highest safety level. Two inseparable components formed the basis of this technique; smart measuring tools and proper diagnosis of the obtained data.

Regarding the controlled drilling, the deviation rate was reduced from 0.05 to 0.01 m/m, while both penetration rate of the drilling rigs and yield of rock increased from 14.7 to 24.5 m/h and from 31 to 39 m^3/m respectively. The down time caused by the drill rigs becoming stuck in the blast-holes was decreased from 6.3 to 1.8% of total drilling time. Casing of blast-holes was required on occasion.

Excellent results were achieved (when using the deck loading system, initiated by non-electrical detonators, in conjunction with using air core-deck) both in term of fragmentation and ground vibration level. There was a slight but measurable improvement in crusher's productivity, which could be attributed to the fragmentation improvement. The PPV values were reduced by 46.50%, when compared with the continuous loading initiated by electrical detonators. Moreover, these results were achieved by more than 16% reduction in explosives quantity, and 30.0% increased in powder factor.

Based on the results of this study the following recommendations have been drawn:

1. In certain areas, multiple rather than single row blasting was considerably more efficient in solving the back-breakages problems and overcoming the sliding phenomenon of blocks adjacent to the blast.

2. Division of HCC quarry faces (60.0 m height) into two benches allowed more efficient control of drilling and blasting problems, caused by the geological complexity. In spite of being costly, it was found to be the most efficient solution.

3. As bulk emulsion has better gassing characteristics and less leakage problem than ANFO, then the next logical task will be its introduction into Egypt, for first time.

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