ASSESSMENT OF CONTROLLED BLASTING TECHNOLOGY EMPLOYED AT ADDIS ABABA RIVERSIDE GREEN PROJECT - FRIENDSHIP SQUARE

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ABSTRACT

This research paper presents an overall assessment of the planning and execution of controlled blasting operations that took place as part of the Addis Ababa Riverside Green Development Project. The objective of the paper is to highlight the process of a successfully completed one-of-a-kind operation in Ethiopia. The application of liquid CO2 fracturing blasting technology in the prevention and control of rock burst in the project shows that CO2 fracturing blasting reduces the stress concentration of rock burst system and transfers energy to the deeper part, and there is no open fire in blasting. It is a new, safe, and efficient technology to prevent rock burst, which can be applied widely. Overall, the results of the assessment show that the controlled blasting operation is executed in an efficient manner. It has been discovered that there were only minimal to negligible vibrations recorded on the day of the blasting. Photo analysis techniques also reveal that the rock fragmentation output is of acceptable quality. There was no interference with other operations, gave reproducible results, and minimized entry into sensitive locations. Productivity performance assessment also indicate that 200,000 m3 of hard rock material has been excavated and hauled away in just 21 days which can be labeled as a very efficient performance.

Key words: controlled blasting, pre-splitting method, continuum rock masses, performance assessment

1. INTRODUCTION

The Addis Ababa Riverside Green Development Project integrates landscape, architecture, municipal administration, roads, water conservancy and gardens. The project is located in the "heart" of Addis Ababa City surrounded by landmark buildings such as Prime Minister's Office, Presidential Office, Parliament Building, Sheraton Hotel, etc. Due to the sensitive construction location of the project, environmental problems such as construction dust, noise pollution, impact on traffic and disturbance to residents should not occur.

The rock excavation of the project was about 200,000 m^3, which was the key process of the project. As the project was adjacent to many important institutions, in the middle of densely populated area with intense traffic, conventional blasting operations could not be carried out. Therefore, the project has adopted special static blasting to ensure the blasting safety and construction safety and solve the neck sticking process.

Rock splitting operations still rely heavily on drilling and blasting. The drawback of the drill and blast method is that, if not done carefully, it can occasionally cause uncontrollable cracks as well as micro cracks in both the block and the leftover rock. The propagation of such effects might induce undesirable outputs such as uncontrolled deformation, unfavorable site amplification of seismic events, over excavation, unfavorable sound and vibration, etc. To this end, controlled blasting techniques are employed in the world to circumvent these problems and control the output. Such was the case for the project in question. This research generally aimed to assess and characterize the controlled blasting operations that took place as part of the Addis Ababa Riverside Green Development Project.

Blasting operation in sensitive areas requires special attention to their effects on the surrounding environment. A sudden change in the geometry of the rock mass along with blast induced ground vibration may lead to slope stability problems. Fly rock and throw of blasted materials downwards the valley sides may endanger nearby habitants. Air blast (noise) and ground vibration generated from blasting operation could scare inhabitants of the area causing trauma and unwanted turmoil. All these problems can be tackled amicably, if the blast design is made meticulously, explosive is chosen properly, and safety-concerns are dealt with proper care and guidance of experts working either at the same mine or from outside agency. This paper presents a case study of a controlled blasting operation that was successfully carried out, which potentially makes it the first well-documented case in Ethiopia.

The basic steps in blast engineering are design, implement and observe the outcome of a blast (Fig. 1). The primary goals of rock blasting are to shatter the strata in order to achieve the desired yield with minimal adverse effects. Though side effects such as ground vibrations, noise, and fly rock cannot be fully avoided, they can be reduced by employing appropriate explosives, initiating devices, and blast design in certain geo-mining settings. Higher intensity of unwanted results indicates improper utilization of explosive energy in the fragmenting process, as the total amount of energy released by unit quantity of explosive is constant[1].

Block production and block splitting still rely heavily on drilling and blasting. The drawback of the drill and blast method is that, if not done carefully, it can occasionally cause uncontrollable cracks as well as micro cracks in both the block and the leftover rock. When compared to other procedures, recovery by this method is poor. In order to achieve the desired results, efforts have been made to establish controlled crack growth. There is a great deal of interest in preventing fractures in undamaged brittle materials for a variety of practical uses, such as controlling over break and fragmenting rocks [3]. Generating stress concentrations along those favored paths is one technique to achieve controlled fracture propagation along certain directions while preventing growth along other ones.

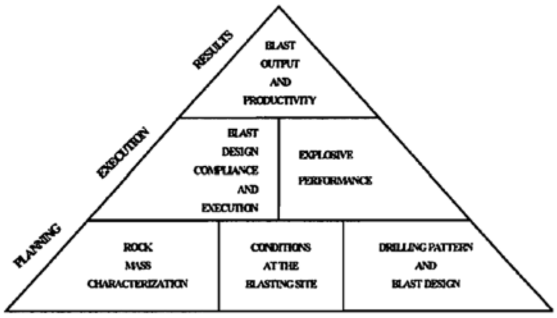

Figure1 Blast optimization pyramid [2]

Controlled blasting has two senses of meaning and applications. In one sense, controlled blasting means controlling of ground vibration, fly rock and air overpressure (noise) within safe limit. On the other hand, controlled blasting means minimization of over-break and under-break beyond the boundary of the excavation area. The first one is generally applied when blasting operation is to be conducted near residential structures/buildings or another sensitive environment. The latter is applied both in surface as well as underground to obtain smooth and stable final excavation wall. Proper selection of blast design parameters and systematic blasting operation is crucial for controlled blasting operations. Blasting operation in ecologically fragile hilly areas requires special attention to their effects on the surrounding environment. A sudden change in the geometry of the rock mass along with blast induced ground vibration may lead to slope stability problems. Fly rock and throw of blasted materials downwards the valley sides may endanger nearby habitant located at the foothill and close by areas. Excessive propelling of fragmented rock caused by the explosive energy is called fly rock. Inadequate burden, improper stemming, deviation in drilling, excessive powder factor, unfavorable geological conditions (e.g., open joints, weak seams, cavities, etc.), too much delay timing, and back break are considered the main causes of the fly rock [4, 5]. Air blast (noise) and ground vibration generated from blasting operation could scare the fauna of the area causing birds and wildlife to migrate to other areas. All these problems can be tackled amicably, if the blast design is made meticulously, explosive is chosen properly, and safety-concerns are dealt with proper care and guidance of experts working either at the same mine or from outside agency [6].

Controlled blasting techniques produce the macro crack in a desired direction and eliminate micro crack in the remaining rock. Macro crack development in desired direction is required for extraction of dimensional stone and at the same time, there is need to reduce micro crack development in the block and remaining rock. Blasting techniques have been developed to control over-break at excavation limits. Some techniques are used to produce cosmetically appealing final walls with little or no concern for stability within the rock mass. Other techniques are used to provide stability by forming a fracture plane before conducting any production blasting. On permanent slopes for many civil projects, even small slope failures are not acceptable, and the use of controlled blasting to limit damage to the final wall is often required. The principle behind these methods is that closely spaced parallel holes drilled on the final face are loaded with a light explosive charge that has a diameter smaller than that of the hole [7].

There are four methods of controlled blasting, and the one selected depends on the rock characteristic and the feasibility under the existing conditions. The four methods are line drilling, cushion blasting, smooth-wall blasting, and pre splitting (also pre-shear) [8].

When the rock is reasonably competent, smooth-wall blasting techniques can be used to take advantages in underground applications. Horizontal holes are charged with small-diameter, low-density decoupled cartridges strung together and by providing good stemming at the collar of the hole. Charges are fired simultaneously after the lifters. If the rock is incompetent, smooth-wall blasting may not be satisfactory [9]. Cushion and pre splitting blasting are the most commonly used methods, with the main difference between the two beings that in cushion blasting, the final row holes are detonated last in the sequence, while in pre-shearing, the final line holes are detonated first in the sequence. Cushion blasting method is a control technique which is used to cleanly shear a final wall after production blasting has taken place. In cushion blasting method, the cushion holes are loaded with light, well-distributed charges. The sole purpose of a cushion blast is to create a smooth, stable perimeter. It offers no protection to the wall from the production blast [7]. Pre splitting consists of creating a plane of shear in solid rock on the desired line of break. It is somewhat similar to other methods of obtaining a smoothly finished excavation, but the chief point of difference is that pre splitting is carried out before any production blasting and even in some cases before production drilling [6]. Pre- splitting utilizes a detonation before the production blast in terms of lightly loaded and closely spaced drill holes. The purpose of pre-splitting is generating a fracture plane across which the radial cracks from the production blast cannot travel. Secondarily, the formed fracture plane may be smooth and allow the use of steeper slopes with less maintenance. Pre-splitting should be thought of as a protective measure to keep the final wall from being damaged by the production blasting [9].

2. MATERIALS & METHODS

The research design adopted for this specific project is qualitative study setting. A desktop study of relevant literature and data were conducted. All relevant literature on controlled blasting and geology of Addis Ababa were assessed.Qualitative methods are especially useful in situations when historical data was not available.

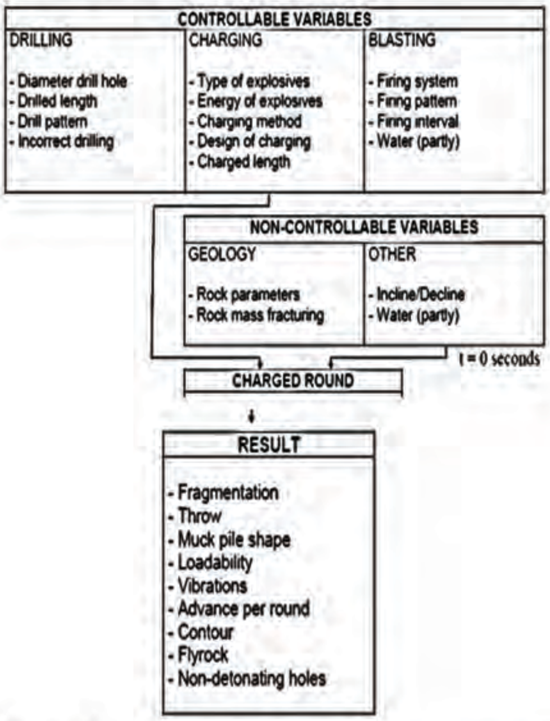

Figure 2 Summary of controlled blasting operation variables

Majorly, secondary data has been utilized in this study. The available geological data has been analyzed using a software called Roc Science to determine the strength of the underlying material. This information was then used to check whether the planning and execution of the blasting operation was up to the required quality. The performance of the controlled blasting operation has been reported in terms of ground vibrations, rock fragmentation and assessment of productivity. Seismograph readings were consulted to check the level of vibration induced because of the blasting operations while photo analyses technique were adopted to qualitatively assess the productivity.

For the assessment of controlled blasting operations, the controllable variables, non-controllable variables and expected outcomes used for objective assessment are highlighted in Figure2.

3. RESULTS AND DISCUSSION

3.1 Pre-Blasting and Blast Initiation

3.1.1 Rock Mass Characterization

Rock samples were collected during several site visits. The sample that is less fractured is used to uni-axial compression test. The rocks that are very fractured and could not be used to perform the conventional compression test were used in the point load test whose outputs are summarized in Table1.

Table1 Rock mass characterization

Parameter	**Value**
Rock mass type	Basalt
Intact rock material constant, mi	17±4
Modulus of Elasticity of the intact rock, Ei	50GPa
Uniaxial compressive strength of the intact rock, UCS	80MPa
Poisson's ratio, ν	0.2

The Generalized Hoek-Brown (H-B) criterion better simulates the rock mass situation in this project. From Roc Data analysis the reduced value for intact rock constant mb and the Hoek-Brown criteria constants s and a have been imported into the Rock Soil model to complete the material property of the rock mass [10].

3.1.2 Conditions at the Blasting Site

Drilling of rock was carried out using Jackhammers driven by air compressors for shallow depth rock and intermediate excavations & hydraulic wagon drills for other as required. Rock and intermediate excavation area was determined and approved by the Engineer. The total hard rock excavation is 200,000m^3 out of this 17,000 m^3 is basalt and sound rock, which is very difficult to excavate using jackhammer excavator and control blasting, was applied.

3.1.3 Drilling Pattern and Blast Design

Controlled blasting methods are used to control blast induced effects such as, over-break, fractures within remaining rock walls and ground vibrations etc. In construction industries, blasting is the predominant method for fragmentation of consolidated mineral deposits. Controlled blasting methods are used to control adverse impact such as: - over-break, reduce ground vibration, reduce fractures within remaining rock walls, reduce noise, reduce dilution.

For our purpose among the various techniques of controlled blasting such as line drilling, trim (cushion) blasting, smooth (contour or perimeter) blasting, pre-splitting etc., were considered in selecting and employing various parameters of blast design; using modern technology such as precise timing delays, varied density of explosives product by using bulk explosives; muffle blasting at very critical and congested areas. In the end, pre-splitting techniques was adopted since this method is essential to determine the radii of cracking zones.

As it is possible to determine the radii of cracking zones around the blast hole, we can use this principle to determine the extent of the damaged zone in the rock mass surrounding the excavation. As first, the damaged zone extent depends on the explosive pressure in the contour blast holes. It is well known that contour blast holes are placed closer and charged with less explosive than other blast holes in the blasting pattern. Therefore, if blast holes are charged less, the length of the tension cracks around the excavation decreases and vice versa. The shape of the damaged zone depends on the excavation cross section and its shape is the same as the shape of excavation cross section, but it is offset for the radius of the damaged zone. Depending on how much rock mass is jointed, we can differ two possible situations. The first situation is when primary block size is larger than the maximum length of the blast induced radial cracks in zone r4. In this case, pressure wave that induces radial cracks is not limited by pre-existing joints in rock mass and radial cracks may reach their maximum length. Therefore, for this situation, the extent of the blast damaged zone is equal to the maximum length of the radial cracks in cracking zone r4.

Damaged zone extent and shape of the damaged zone around the excavation depends on the blasting pattern, cross section of the excavation and the structure of rock mass (primary block sizes). One should imagine rock mass as a set of interlocked monolith blocks that are separated by pre-existing rock joints. In this manner rock blocks may be considered to be an elastic part of rock mass and their plasticization is done through the blasting process when blast induced radial cracks are formed. It is well known that discontinuities as joints and fractures in rock mass limit pressure wave propagation and therefore may limit propagation of radial cracks induced by explosive charge. This also means that pre-existing joints and fractures define the extent and shape of the blast damaged zone around the excavation, as explosive charge will break only the rock block in which it is placed. In other words, pre-existing joints define domain for pressure wave propagation.

Numerical investigations, using distinct element modelling, on radial crack and pressure wave propagation in jointed rock mass are presented by Aliabadian and Sharafisafa [11].

It's well known that contour blast holes are placed closer and charged with less explosive than other blast holes in the blasting pattern. Therefore, if blast holes are charged less, the length of the tension cracks around the excavation decreases and vice versa. The shape of the damaged zone depends on the excavation cross section and its shape is the same as the shape of excavation cross section, but it is offset for the radius of the damaged zone. Depending on how much rock mass is jointed we can differ two possible situations. The first situation is when primary block size is larger than the maximum length of the blast induced radial cracks in zone r4. In this case pressure wave that induces radial cracks is not limited by pre-existing joints in rock mass and radial cracks may reach their maximum length. The second situation is when the primary block size is smaller than the maximum length of blast induced radial cracks. In this case, pressure wave propagation is being limited by pre-existing joints in rock mass, and therefore blast-induced radial cracks are limited in their length by pre-existing joints. It is obvious that more jointed rock masses are less subjected to blast induced damage and vice versa. The size of the blast damaged zone, in this case, depends primarily on maximum distance between pre-existing joints in rock mass, or primary block size.

3.1.4 Field Monitoring and Control

As it is already known, there are plenty of methods for assessment of blast-damaged zones. Also, there is a lack of precise methods for assessing the extent and quantification of these zones. Many of the existing methods are empirical and highly case dependent, while on the other hand, theoretical methods have limited applicability. An important part of the new rock breakage theory is presented, making it possible to estimate the length and density of the tension (radial) cracks caused by explosive charge initiation.

Specifically, our site is very critical site due to the fact that it is at heart of important historical and high value establishments. The project is located in the "heart" of Addis City surrounded by landmark buildings such as Ethiopian Prime Minister's Office, Presidential Office, Parliament Building, Sheraton Hotel, etc. Due to the sensitive construction location of the project, environmental problems such as construction dust, noise pollution, impact on traffic and disturbance to residents cannot occur.

- East direction →Sheraton =400m far
- East direction → Ethio- telecom tower=168m far
- West direction→Asphalt road =324m
- North direction → Fence of the National palace=108m far
- South direction → Buildings =270m far

Based on the above distances and direction of the locations, we decided the direction of blasting and blasting damaged zone. The direction of the blasting was south west and maximum blasting damaged zone was decided to be less than 108m.

Type of rock from geological classification was basalt rock or very hard rock. From the theoretical calculation based on the type of rock, the excavation/blast-induced damaged zone (EDZ/BDZ) was calculated as follows.

For the distance 2-3 m, D=0.8, r4=2.16m,

GSI bdz=GSIurm-10 where; GSI bdz= value of blasted damaged zone

GSI urm= value of undisturbed rock mass

GSI bdz = GSI urm-10 = 65 – 10 = 55m

3.1.5 Drainage of Large Holes

It has been made sure that the large holes contain no water when the round is blasted. By giving the large holes an eccentricity at the bottrom of the holes equivalent to 3% upward slope, the holes will be self drained. Other cut holes are given the same eccentricity at the bottom of the holes.

3.1.6 Drilling

When designing a drilling, the cut and the contour holes are placed first. Then invert holes and the row nearest the contour are placed. Finally, the easers are placed. Finally, the easers are placed. The easers closest to the cut must allow necessary rock expansion. Hence the maximum burden must not be exceeded. The holes in the rest of the stopping area are then placed from the contour towards the cut. The eccentricity at the bottom of the hole for the different holes must be taken into consideration when deciding burden and spacing. The confinement at the bottom of the holes must be checked.

Placing the cut in the cross section has an influence on the fragmentation, consumption of explosive, the shape on the muck pile and load ability. If the cut is placed high in the cross section, the throw will increase. The fragmentation is better, but the consumption of explosives increases. A low placed cut results in poorer fragmentation and less consumption of explosives. The rock pile is well graded, but can be difficult to load because the rock is packed as most of the holes in the round throw downward. It is common to put the cut symmetrical about the vertical tunnel axis. It is sometimes placed towards one of the walls because some drilling jumbos have blind sectors. Considering rational drilling is very important when the cut is placed and the drilling patter determined. Distributing the drilling between each of the drilling machines is necessary to optimize the total drilling time. Rational charging implies that the cut can be reached from the invert.

3.1.7 Charging

Liquid CO_2 fracturing blasting technology is mainly used in coal mines to increase the permeability of coal seams and gas extraction efficiency. It is rare to apply liquid CO_2 fracturing blasting technology to rock burst prevention and control. Compared with the traditional explosive technology, the liquid CO_2 fracturing technology has no open fire and can be relatively safe in the process of blasting, and the pressure relief effect is remarkable.

The CO_2 cracker is mainly composed of a filling valve, a heating pipe, the main pipe, a sealing gasket, a shearing piece, and an energy release head. The structure and damage range of the CO_2 cracker are presented in Figure 3 and Figure 4, respectively.

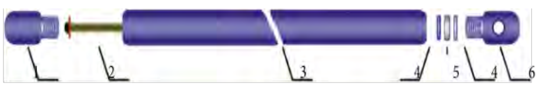

Figure 3 Structure of CO_2 cracker. *Key: 1 - Filling valve; 2 - Heating pipe; 3 - Main pipe; 4 - Sealing gasket; 5 - Shearing piece; 6 - Energy release head.*

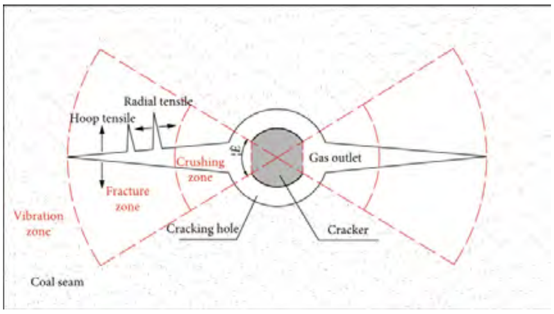

Figure 4 Sketch map of damage range of CO_2 cracker

3.1.8 *Initiation of Blasts*

Time delays have historically been utilized to regulate the orderly flow of material via the free faces, as we have described, or to restrict the amount of explosive that may be discharged at once, which lowers the intensity of ground vibration. With the introduction of electronic initiation, a new era in which we could better utilize physics began. Time delays have historically been offered in 25 ms increments, which is suitable for the purposes for which they have been employed.

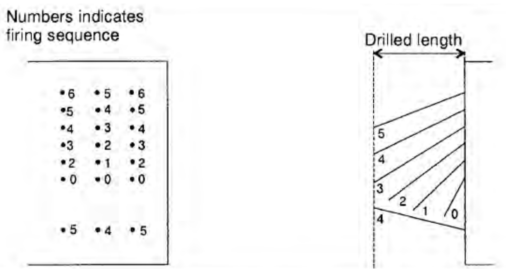

Figure 5 Fan cut, the right-hand section as seen from above

3.1.9 *Explosive Product Performance*

The working principle of liquid CO_2 fracturing blasting is described below. When the temperature of liquid CO_2 is lower than 31°C or the pressure is greater than 7.35 MPa, it usually exists in liquid form. When the temperature of liquid CO_2 is higher than 31°C, it begins to gasify. Taking advantage of the phase transition characteristics of CO_2, liquid CO_2 was filled in the main pipe of the cracker, and the heat pipe was rapidly excited by the detonator. Liquid CO_2 was instantly gasified and expanded to generate high pressure. When the pressure reached the ultimate strength of the constant pressure shearing piece, the shearing piece was broken, and the high-pressure gas was released from the energy release head and then acts on the coal and rock mass, thus realizing the directional fracturing blasting on the coal and rock mass (Figure4). The crushing zone, fracture zone, and vibration zone were formed successively from the center of the explosion position, so as to complete the pressure relief.

3.2 Blast Output and Productivity

3.2.1 *Ground Vibrations*

Most of the explosive energy in a blast is absorbed in the process of breaking the rock. One effect of the remaining energy is to cause air shocks and shock waves in the surrounding rock. This may cause considerable damage if the blast is fired close to vital installations and the round is not carefully designed.

The amount of energy which is transferred through the rock depends on the character of the rock mass and the effect of the blast. On a free surface as in the case of this project, the following types of waves from a blast may easily be recognized.

1. Longitudinal waves (Primary or P-Waves) causing oscillation of particles in the direction of wave propagation
2. Transversal waves (Secondary or S-Waves) causing particle oscillation perpendicular to the wave propagation direction.
3. Surface waves, of which Rayleigh waves (R-waves) are the most important. The particles have a retrograde

At the planning stage of the blast the assumption is normally made that the vibrations can be represented by harmonic oscillations. For harmonic oscillations (sinusoidal waves), the following relationship exists between vibration velocity (v), maximum amplitude (A) and frequency (f); and between vibration acceleration (a), maximum amplitude and frequency:

$$v = 2\pi \cdot f \cdot A \qquad (1)$$

$$a = 4\pi^2 \cdot f^2 \cdot A \qquad (2)$$

Vibration velocity, v, is the distance per time unit (i.e. mm/s) which a surface particle has travelled around its point of equilibrium. Vibration velocity, v, is the distance per time unit (i.e. mm/s) which is a surface particle has travelled around its point of equilibrium. This velocity is different from the seismic velocity, which in hard rocks is normally in the order of 4500-6000 m/s for P-waves. The resultant wave has a wide range of different frequencies, depending on ground conditions, distance, detonator characteristics, etc. In most hard rocks the dominant frequencies are in the range of 10-100Hz.

The planning of a blast is in many cases based on empirical equations of the following type:

$$v = k.\frac{Q^{\frac{1}{2}}}{R} \qquad (3)$$

where: v = vibration velocity

k = "k-value"

Q = weight of simultaneously detonating charge

R = distance from detonation

The k-value is not constant, but a parameter dependent on ground conditions and distance from the blast. As a part of general planning procedure, small-scale test detonations are carried out to evaluate the k-value. The next step is then to calculate the maximum permissible charges as a function of distance from the blast using this k-value and the maximum vibration velocity allowed.

Most criteria used for defining "allowable vibrations" are based on critical values of v, a of A. When critical values are defined, it is important to bear in mind that human beings are particularly sensitive to vibrations. For instance, at a frequency of 50 Hz an amplitude of only 2 µm is easily recognized by human beings, while the critical value for building damage is 200 µm or more.

3.2.2 *Assessment of Productivity*

Estimated output for a drilled hole depth 2.6m and 10 holes

Output of 2.6m dilled hole=2.6*.7=1.82m

Therefore; - Area =3*3 = 9m^2

Volume= 1.82*9 = 16.38m^3

Daily output for 100 holes = 819m^3

Total working days = 17000/819 =21days

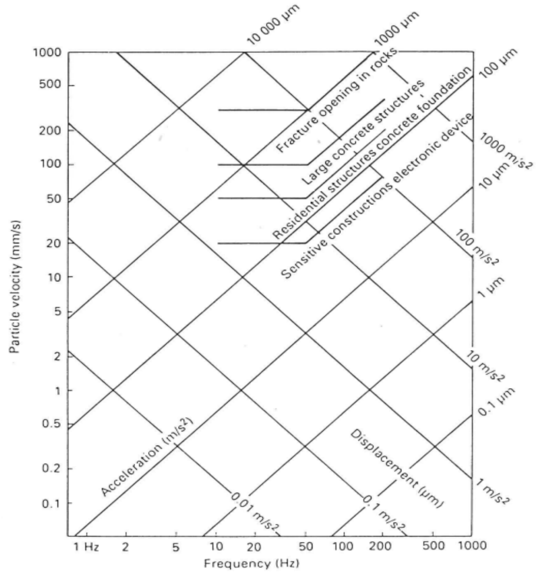

Figure6 General criterion used as first indication of damage risk [12]

4. CONCLUSIONS

Seismograph readings from the site monitoring indicate that there were only minimal to negligible vibrations recorded on the day of the blasting. Photo analysis techniques also revealed that the rock fragmentation output was of acceptable quality. There was no interference with other operations, gave reproducible results, and minimized entry into sensitive locations.

Controlled blasting has been proven to prevent fly rock to occur. The application of liquid CO_2 fracturing blasting technology in the prevention and control of rock burst in the project shows that it reduces the stress concentration of rock burst system and transfers energy to the deeper part, and there was no open fire in blasting process, which has a good pressure relief effect. It can be concluded that the project can be set as a role model for future projects that may involve excavation of hard rock in sensitive locations.

CONFLICT OF INTEREST

Wang Yang andSu Wu are employees of China First Highway Engineering Co. Ltd. Tewodros Gemechu declares no conflict of interest.

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