Controlled blasting in proximity to urban residential structures

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***Abstract*—This paper deals with the excavation of 19500 m2 area in granitic hard rock to a depth of 10 m by controlled blasting to accommodate foundation for 75 m tall, 16 floor commercial building in the city of Bengaluru, India. The major task was to excavate granitic hard rock close to constructed residential structures (10 m) and under construction (60 m). To start with, trail blasts were carried out at a distance of 50 m from the existing residential structures. In order to restrict the maximum charge per delay and the air overpressure from trunk lines, blasts were initiated with shock tubes. In the blasting zone, excavation was carried out in five different locations at varying distances from the structures. Controlled blasting in urban areas does not end with controlling the flyrock, vibrations or air overpressure levels within the permissible limits, but the most contributing factor happens to be the human perception. The human response with regard to vibrations and the structural response too was studied. Blast designs were altered site specifically and in addition to that continuous monitoring of ground vibration was under taken to ascertain that the intensities were within the limits. Sufficient number of rubber blasting mats of 1.1t each were used for muffling the blasting area and the flyrock was restricted within 10 m from the blasting area. It was observed that the rubber mats were not only effective in controlling the flyrock but they have reduced the air overpressure levels too considerably. In total around 80000 m3 of hard rock was successfully excavated without any grievances as the vibrations were limited to below the perception level of the residents rather than the transmissible level of the structures from the neighbours/residents.**

Keywords—Controlled blasting; blast vibration; structure response.

I. INTRODUCTION

Large infrastructure projects like multi-storeyed buildings, underground metros, under passing's, over bridges etc. are currently being planned and executed worldwide, many in highly populated areas. Expansion is leading to land crunch in cities and is necessitating construction of high rise buildings to create residential structures, office spaces, parking lots etc and below ground to facilitate transport, storage, etc. To build these infrastructure, large quantity of earth work has to be carried out which engages different activities and machineries. Excavation of soil is done by means of hydraulic excavators and hard rock by mechanical means or by drilling and blasting. Any excavation in urban area needs special measures due to existence of buildings and other civil structures nearby. Inadequate project assumptions, lack of funds, incorrect priorities, ignorant project engineers or misjudgments of project operations can lead to structural damages, increased costs and unexpected delays. Unfortunately, knowledge of how to perform a proper risk analysis is often missing.

Hard rock excavation by drilling and blasting generates noise and vibrations which can affect nearby residents and industrial activities in the vicinity. Lacking understanding of risks associated with blasting projects may lead to over-conservative design assumptions, resulting in unnecessary costs. Alternatively, underestimating vibration risks can result in unexpected damages to buildings, complaints from the public and unforeseen costs and delays. By applying a planned risk management concept, the cost-effectiveness, can be enhanced without generating uncontrollable risks. Proper management of risks associated with blasting projects requires fundamental understanding of vibration propagation in soil and rock and their interaction with structures. Rapid technical advances in rock excavation by blasting have taken place. Relatively inexpensive, vibration monitoring and data acquisition systems are available today, which provide valuable information about wave propagation in the ground and dynamic interaction of structures and foundations.

Bengaluru is one of the fastest developing cities in the world. At one of the business districts of Bengaluru city, Bagmane Estates Pvt. Ltd., are constructing Bagmane Constellation Business Park. In this project it was proposed to construct ten commercial complex towers each consisting of 13 to 16 floors. Two towers are already under use. In view of expansion, the management planned to construct two towards adjacent to the existing towers which are about 60m apart and residential layout is located at around 10 m from the planned excavation boundary. The strata in the proposed construction area of 19500m2 needed to be excavated to a depth of 10 m from the existing surface level.

The authors were involved in designing of controlled blasting operations for excavating hard rock in proximity to urban structures and establishments. Controlled blasting in urban areas does not end with controlling the ground vibrations or air overpressure levels within the permissible limits, but the most contributing factor happens to be addressing the human perception. Our broad challenge was to control blasting effects through regulation, project design, specifications, and on-site execution and field oversight. Blasting was designed in such a way that the vibration levels at these structures falls within the safe limit of vibration levels and acceptable to human perception.

To start with as blasting was carried out at a farthest point of 50m from the critical structures, during this operation there were no major concerns and difficulties. As the blasting operations progressed towards the structures specific concerns with regard to air overpressure, vibration, flyrock and human sensitivity arose which were addressed such that there were no damages nor claims. This paper discusses in detail the risks involved and controlled blasting approach adopted for the successful excavation of hard rock in proximity to populated residential and commercial establishments.

II. Geology of Excavation Area

The strata in the construction area is to be excavated to a depth of 10 m in an area of 19500 m2 (length: 150 m and width: 130 m) from the existing surface level. The soil strata varied varying from 1 to 10 m thick. The soil was removed by shovel and the hard rock was exposed. The rock surface was undulating throughout the excavation area (Fig. 1). The rock in the excavation area was peninsular gneiss with the compressive strength varying from 150 to 200 Mpa and the grain size is course in nature. This rock consisted of dark biotite gneiss of granitic to granodiorite composition containing streaks of biotite. Remnants of older rocks was seen in the form of enclaves (black patches). Weathered rock of about 1 m thick was observed throughout the excavation area. Vertical joints with a spacing of about 2 to 5 m and bedding planes were also observed in the hard rock strata.

Fig. 1. Excavation area close to residential structures

III. Rock Excavation by Blasting

The rock to be excavated was huge (80000 m3) and the granitic rock mass was not amenable for breakage with heavy rock breakers and drilling and blasting method was only method of excavation. Though drilling and blasting is perhaps one of the fastest and economical means of rock excavation, it have some adverse impacts like ground vibration, flyrock and air overpressure. Properly designed and executed blasts could mitigate the adverse impacts to desirable extent but the ill effects due to malfunction of the initiation systems and explosives are beyond the control of the designer and the executioner. Control of flyrock, ground vibrations and air overpressure under these circumstances becomes extremely difficult, expensive and time consuming. Controlled blasting method was adopted to excavate the rock to create a vertical wall needed to construct retaining wall close to the structure.

Before starting the actual blast close to the structure, trail blasts were carried at a distance of 50 m from the structures to know the attenuation characterises of the excavation area.The blasting area was cleaned for soil and loose stone pieces prior to marking to minimise the risk of flyrock and to minimise the effect of dust which is one of the environmental concern in urban area. The marked locations were drilled by jackhammer drilled holes of 32 mm. Accuracy with respect to holes position, verticality, spacing, burden, depth, number of holes was maintained. Plastic plugs were used to avoid choking of drilled holes from water, mud, drill cuttings etc. After completion of drilling, all the holes were checked up with respect to design. Required explosives were transported to the blasting site. No simultaneous drilling and charging was carried out at any instant. Priming of explosive was done at site and the holes were charged as per the approved design (Table 1). The blasts were initiated with shock tube initiation systems comprising of down-the-hole delay (DTH) of 200 ms in combination with surface trunk line delays (TLD) of 17 ms, 25 ms and 42 ms. Soft, wet clay sticks were used as stemming material.

TABLE I. BLAST DESIGN PARAMETERS FOR REGULAR BENCH BLASTING

Parameters	Specification (Jack hammer)
Hole diameter, mm	32 to 38
Burden, m	0.8
Spacing, m	0.8
Hole depth, m	1.5
Number of rows	<3
Number of holes in a row	<10
Total number of holes	<30 (all vertical)
Charge diameter	25 mm
Charge length	200 mm
Charge weight	125 g / cartridge
Charge per hole, kg	0.125 - 0.5
Charge length, m	0.8
Stemming length, m	0.5-1
Stemming material	Wet clay sticks
Total charge	Varying
MCD*, kg	0.125 - 0.5
Initiation system	Shock tube initiation system
Muffling material	Link mesh of 1"x1" of 10 SWG on the blast area and plus 3 m on all the sides, sand bags and above that blasting mats (1.5mx2.7m, 1.1MT) of sufficient numbers, thickness, size and strength to cover the blast completely plus 3 m on all the sides (placed skin to skin for tyres and with an overlap of 0.5 m in case of rubber mats)

MCD*: Maximum charge per delay

Control of flyrock distance can be done through proper blast design, delay sequencing and its implementation under strict supervision in the field by competent authority. However, in case of controlling flyrock within short distances, additional measures to physically arrest flyrock by muffling/covering the blasting area by heavy rubber mats/wire rope mats with other covering materials have led in minimizing the flyrock distance within 20 m [1] To avoid the flyrock, muffling sequence followed was placing sand bags in such a way that the sand bag covered the hole mouth and the trunk line delay detonator (to avoid air overpressure), followed by an over lapping layer of standard wire gauge 14 link mesh (SWG 14, opening size of 35 mm x 35 mm), over which sufficient number of over lapping rubber blasting mats of minimum specified size (1.5 m x 2.7 m, 1100 kg weight per mat) was placed as per the design. A barricade of sound observing sheets of 10 m high was also erected in the entire excavation area. The sequence of controlled blasting operation close to the structure is shown in fig. 2. Sometimes in certain situations blasting may not be possible due to vibration norms and flyrock constraint and alternate means of excavation needs to be adopted.

Fig. 2. Sequence of controlled blasting

IV. Ground Vibration and Air Overpressure Monitoring

When an explosive charge is detonated inside a blasthole it is instantly converted into hot gases and the expanding gases exert intense pressure on the blasthole walls. A high intensity shock wave travels through the rock mass which attenuates sharply with distance. As seismic waves travel through the rock mass, they generate particle motions which are termed as ground vibrations. The velocity of oscillation of rock particles is called “particle velocity” and its maximum value is called “peak particle velocity (PPV)”. It is measured in millimetres per second (mm/s). Damage caused by ground vibration is dependent on peak particle velocity and the frequency (Hz) of the ground motion. Apart from ground vibration, blasting is accompanied by a loud noise called air blast or air overpressure. Air overpressure, or air blast, is the term used to describe the pressure waves in the air exerted from an explosion [2][3](Dowding, 1996,. Siskind, et. al., 1980). Air overpressure, however, is not simply the sound that is heard, it is an atmospheric pressure wave consisting of high frequency sound that is audible (20 to 20,000 Hz) by human beings and low frequency sound or concussion that is sub-audible (<20 Hz) and cannot be heard by human beings.

To know the attenuation characterises of excavation area, six calibrated seismographs were used for monitoring ground vibration and air overpressure (Minimate Plus from Instantel, Canada). These instruments are microprocessor-based portable units and each unit consists of a standard external transducer for monitoring ground vibration and a mike for measuring air overpressure. Radial distances between the blast location and the monitoring stations were measured using binocular type laser based instrument for short distance and for long distance Global Positioning System was used. The trigger level set for ground vibration was 0.51 mm/s and for air overpressure it was 121 dB.

The selected monitoring stations (Fig. 3) for ground vibration and air overpressure were prepared for mounting of transducers as per the suggested guidelines of International Society for Explosives Engineers (ISSE). In order to ensure good coupling of the geophone, the selected locations were cleaned, a pit of 30 cm x 30 cm x 30 cm was dug and the geophone was placed, levelled and buried intact. In case the monitoring location comprised of mass concrete, compacted bitumen road, rock surface the geophone was coupled using plaster of paris (POP). The mike was installed on the stand supplied along with the seismograph. In order to derive the site specific predictor equation for blast vibrations it is essential to monitor blast vibrations at different distances from the blasting rounds. This means, sometimes measurements are made not at the critical structure but at a closer distance from the blasting round. Hence the monitored levels could be higher than the permissible level but the recordings are not at the structure and hence not a concern.

In some cases the monitoring stations were 8 to 10 m before the structures. The events recorded are stored in the instrument. The event analysis and documentation was done with the help of Analysis Software supplied along with these units. The record provides complete documentation of the events, full wave form and frequency spectrum.

Many factors influence the intensity of ground vibration, air overpressure and fly rock and the most contributing parameters are maximum charge per delay and the distance between the blast to the monitoring location (Table 2). For all practical purpose, in most cases, restricting the maximum charge per delay seems to be the solution for controlling vibrations and air overpressure. In most cases, the reduced maximum charge per delay leads to reduction in the hole diameter, reduction in the bench height or dividing the charge per hole into different decks. The monitored ground vibration levels varied from 0.54 to 40 mm/s, while the maximum charge per delay varied from 0.125 to 1.5 kg. The monitored distance varied from 10 to 50 m while the scaled distance varied from 12 to 152.

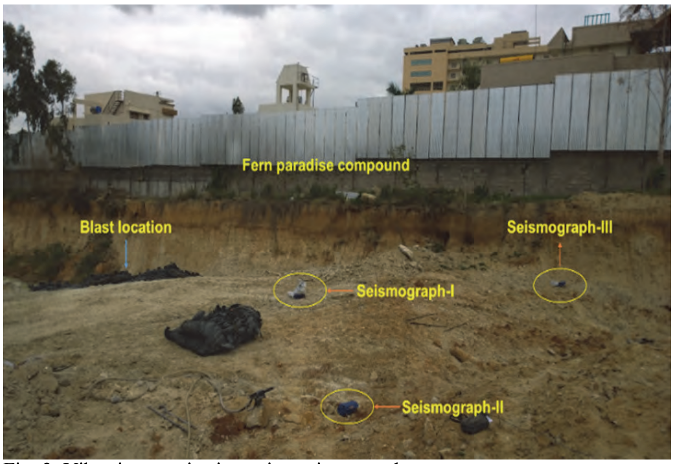

Fig. 3. Vibration monitoring using seismograph

TABLE II. REMEDIAL MEASURES TO AVOID BLASTING ASSOCIATED PROBLEMS

Causes	How to control?
Damage due to ground vibration	Proper blast design, sufficient burden, distance between the blast location and structure, maximum charge per delay
Damage due to air overpressure	Proper blast design, sufficient burden, distance between the blast location and structure, maximum charge per delay, blasting mats
Damage due to flyrock	Proper blast design, sufficient burden, stemming, Muffling using sand bags, link mesh, blasting mats
Damage to buildings	Pre investigation, Proper blast design, distance between the blast location and structure
Scared people	Informing neighbours before each blast.
Work or business disturbance	Public education, blasting controls, monitoring and schedule blasting during non-working hours.

A. *Estimation of blast induced vibrations*

A mathematical model developed by US Bureau of Mines, which relates peak particle velocity, charge weight and distance was used.

$$V= K (D/\sqrt{Q})^b \qquad (1)$$

Where V = peak particle velocity (mm/s)
$(D/\sqrt{Q})$ = scaled distance
D = radial distance from blast to monitoring station (m)
Q = maximum charge per delay (kg)
K and b are site constants

For a new area in which the seismic transmission characteristics are unknown, site constants are determined by monitoring the ground vibration at different distances for known drilling and blasting parameters.

B. *Estimation of Peak Particle Velocity*

For deriving the site specific predictor equation for excavation area thirty six blasts were monitored. In total, 137 data sets recorded were used for regression analysis. Fig. 4, shows a plot of peak particle velocity (vector sum) against square-root scaled distance on a log-log graph.

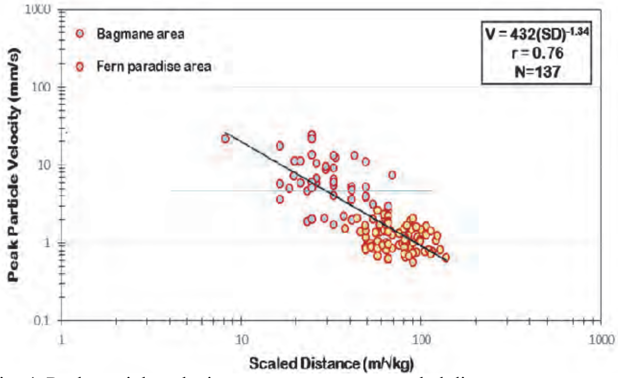

Fig. 4. Peak particle velocity versus square root scaled distance

The derived predictor equation is:

$$V = 432 (D/\sqrt{Q})^{-1.34} \qquad (2)$$

Where, V = peak particle velocity, (mm/s) D = distance from blast to monitoring station (m) and Q = maximum charge per delay (kg). The frequency of the ground vibration was determined by analysing the records of the blasts using the software provided with the instrument. From Fast Fourier Transform (FFT) the frequency of ground vibration monitored was found to be greater than 10 Hz. For the reco rded frequency range (>10 Hz), the permissible particle velocity for the brick/stone and cement structures around the blasting areas as per the DGMS circular happens to be 10 mm/s (Table 3). Considering higher factor of safety, a peak particle velocity of 5 mm/s was recommended safe for the structures located near the blasting site. In order to ensure the vibration levels to be within the suggested levels the maximum charge per delay was computed for a vibration level of 5 mm/s. This took care of the scatter and still ensured the vibrations were well within 10 mm/s at the specified locations. Though many precautions were taken, blasting being in the heart of a residential area and commercial establishments any aberration from the accepted limit could lead to legal complications and undue delays to project.

Further keeping this in mind for regression analysis the peak vector sum was considered instead of one of the peak components which leads to conservative estimate of the permissible maximum charge per delay. With the accurate site specific measurement the attenuation model led to estimation of safe maximum charge per delay for use in blast design thereby minimising the complaints. In total about 80000 m3 of hard rock was safely and successfully excavated to the required depth without any litigations. Fig. 5 shows the photograph of preconstruction site and post construction activities under progress in the excavated site.

Fig. 5. Photographs showing pre excavation and construction activity after excavation

TABLE III DGMS PRESCRIBED PERMISSIBLE LIMIT OF GROUND VIBRATION (INDIA).

Type of structure	Dominant excitation frequency, Hz		
	<8 Hz	25 Hz	> 25 Hz
A) Buildings/ structures not belonging to the owner			
Domestic houses/ structures (Kuchha, brick and cement)	5	10	15
Industrial Buildings (RCC and framed structures)	10	20	25
Objects of historical importance and sensitive structures	2	5	10
B) Buildings belonging to owner with limited span of life			
Domestic houses/ structures (Kuchha brick and cement)	10	15	25
Industrial buildings (RCC & framed structures)	15	25	50

C. *Estimation of air overpressure*

The measured 137 sets of air overpressure levels were plotted against cube root scaled distance. The cube root scaled distance is the distance divided by the cube root of the maximum charge per delay. The air overpressure is influenced by a number of factors like weather condition, topography of the area, direction of the wind, wind velocity, location of the blast with reference to sensor location etc. Unlike ground vibrations, predictions of air overpressure do not follow a definite trend and it is common to have large scatter in the data sets. In general the measured air overpressure levels were well within the suggested limit of 133 dB. It is recognised that noise level of 133 dB and below will likely not cause structural damage but they will generate numerous complaints from affected parties.

V. GROUND VIBRATION LIMITS FOR URBAN BLASTING

Mining by blasting is largely regulated, whereas the blasting for construction is limitedly regulated. Normally the excavation for construction occurs in more populated areas than mining areas but the regulations for construction is not stringent. [4]Jeff and Dwayne (2014) observed that while analysing blasting related complaints in the Canadian municipalities, regulations typically do not prescribe the need for notification of planned blasts, pre-blast surveys and blast monitoring.

A structure readily catches the blast induced ground vibration when the frequency of ground vibration falls close to the natural frequency of the structure [5] [3] (Dowding, 1985; Siskind et al, 1980). At resonant frequency, the structure absorbs most of the energy of ground vibration and oscillates with a larger amplitude for a longer period. Because of this amplification, structural damage may occur even at a relatively low peak particle velocity. Amplification factor is defined as the ratio of structural vibration to that of the ground vibration. It has been found to vary between 3.2 and 5.2 [3] (Siskind et al, 1980), and between 1.00 and 2.82 [6] (Adhikari et al, 1989). [7] Athanasopoulos and Pelekis (2000) report that with regard to high rise structures (up to 22 floors) the blast vibrations decreased in the upper floors. Similar studies conducted by [10] Athanasopoulos and Pelekis (2000) for pile driving revealed that ground level motion was amplified in the upper levels (up to 7th floor) beyond which the rate of amplification ratio decreased with the floor levels. Similarly, Cathy et al, (2014) have found that the tall structures develop lower strains when compared to midrise buildings for the same ground displacements.

When blast-induced residential structure wall strains were correlated with horizontal ground displacements and velocities corresponding to displacements, the lowest safe horizontal ground vibrations to protect materials with failure strains of 200 and 300 μ-strains (plaster and dry wall) were 12.7 and 20.3 mm/s (frequency range 10 to 20 Hz). The study also suggested that 102 mm/s horizontal ground velocity may be reasonable to protect historic and landmark structures comprising four or more floors when peak frequencies are above 160 Hz for a frequency above 40 Hz the limit could be 51 mm/s.

Probability studies made by [10] revealed that no cosmetic or threshold cracking takes place below a particle velocity of 12 mm/s. Residential structures typically resonate at frequencies in the range of 3 Hz to 8 Hz indicating a problem. However, the above study indicated no danger even upto 12 mm/s with such low frequencies. [8conducted studies on correlation of vibration level to blasting damage to surface structures. Pre- and post-blast observations were made for any noticeable change in the existing cracks or for the formation of new ones. At site one, no new damage or extension of existing cracks were observed in any of the structures at PPV exceeding just above 20 mm/s at frequencies varying by and large between 5 and 27 Hz. Even at site two, peak particle velocity in excess of 20 mm/s was too low to cause any damage to these structures over a frequency range of 4 to 40 Hz. Adrian et al, (2002) from their studies with regard to structural response of brick veneer houses to blast vibration observed from their experiments in Australia that environmental strains and rainfall contribute to the extension of existing cracks in a structure [9]. No observable damage occurred until the ground vibration levels (PPV) exceeded 70 mm/s while the damage at vibration levels of 70 - 220 mm/s was confined to the lengthening of existing cracks and the formation of new cracks in plasterboard.

New (1990) gives an assessment of the magnitude of vibration which the common types of structures are daily subjected to during normal use [10]. It was seen that common masonry dwellings experience a PPV of 11 to 17 mm/s when doors are slammed several times during a day and still structures do not suffer any damage. During the excavation of the TBM launching shaft for Tan Tah Kee Station, Singapore, rock was encountered at a depth of 13 m below the ground level and another 10 m had to be excavated in order to reach the final depth. The permissible vibration limits followed in case of this Singapore project was 300 mm/s for the Earth Retaining Stabilising Structures (ERSS) and 15 mm/s for residential buildings and buried utilities [11].

Rock excavations for Stockholm City Station, Sweden was carried out under and over T-Centralen, the central underground metro station. The approach tunnels had to cross under existing metro tunnels in an area of high horizontal rock stress with as little as 3 m of rock cover, extremely close to sensitive installations. In order to control vibrations within a permissible limit of 100 mm/s when blasting as close as 10m from an existing heating-supply tunnel electronic initiators had to be used. While blasting close to a multi-modal interchange the vibrations were limited to 50 to 60 mm/s. For the tunnels directly passing under Gustav Vasa Church a permissible limit of 18 mm/s was set with an “alarm” level of 13mm/s. In practice, the PPV values in the service and rescue tunnels were limited to 13 to 17 mm/s [12] (Jonson, 2012). In Brazil the regulations have limited the permissible level to 15 mm/s [13] (Denise, 2005). It can be observed from the above review that the vibration limits for urban structures are lying close to about 15 mm/s though the permissible levels can be much higher.

This suggests lower permissible values probably are governed due to shift in tolerance rather than engineering concerns or because of the researchers throughout the world have experienced difficulty in defining acceptable damage standards. The impediment to a generic standard could be the variability in standardisation of structure and its materials of construction. In general, it can be seen different countries adopt different standards of safe limits of vibration. As there are no defined standards for urban blasting invariably the vibration standards applicable in mines are being practised globally. In India too, the permissible ground vibration limits prescribed for mining blasts by Directorate General of Mines Safety (DGMS), which considers PPV and the frequency of ground vibration for deciding the permissible levels (Table 1) (Anon, 1997) [14] is adopted for urban blasting. Probably this is because the blasting procedure and structures are similar in both cases of blasting (Mining and Civil). However, [15] Gupta et al, (2013) report that the frequencies in the mining blasts are different from that of the construction blasts. They state that though, both the blasts are characterized by same peak particle velocity, a structure with fundamental frequency of about 10 Hz would respond to the mining blasts with relative displacement of about three times that of typical construction blasts as mining blasts, in general produce much higher structural response in the low frequency range (about 4 to 25 Hz) compared to construction blasts. The frequencies due to construction blasts are generally beyond the frequency range of most civil engineering structures which can be gainfully used in defining the safety criteria for construction blasts [15] (Gupta et al, 2013). During the monitoring of ground vibrations at Sir M. Visveswaraiah station (Sir. M. V. station) box area (bottom up method) at BMRCL site [16] Balachander et al, (2011) too observed that the frequency of the vibrations was above 25 Hz and in conformity with the observations of [15] Gupta et al, (2013).

VI. Public Response to Blasting Activity

Crack has been an integral part of any residential or a commercial structure. A building without cracks would be unusual. We can find cracks in the walls and ceilings of structures and nobody cares about them or takes note of their existence. Probably this attitude is because everybody subtly accepts that there could have been certain lapses at their end while constructing. A common man understands that many causes ranging from poor construction to normal environmental stresses have contributed to the development of these cracks. However, when a blasting activity is being carried out at a construction site the people around frequently complain about damage to their structure due to ground vibration. This may be due to the fact that human beings are far more sensitive to ground vibrations and noise than structures. People inside buildings will respond differently than people outside and will respond more adversely inside their own houses than when they are inside other buildings. People tend to complain about ground vibrations even below the accepted damage levels because of many reasons. One of the most important factors is the presence of secondary sounds such as rattling windows and doors. As the threshold of perception for motion (without sound effects) is roughly 0.51 mm/s [17] (Anon, 1998) for most people at typical blasting frequencies, the rattling is attributed to vibration. Information regarding the need for blast and the significance of vibration levels will lead to less complaints from the neighbours. The air overpressure level of 125 dB will produce vibrations in the wall and rattle loose items, and together tend to produce more noise inside a structure than outside. This is in confirmative with Braden and William (2010) [18] that outside of the immediate vicinity of the blast area, window breakage accounts for a significant amount of the risk associated with urban explosions. In this regard psychophysiological perception of the blast is generally more important than the numerical values of the ground vibration and air overpressure.

Furthermore it is equally important as there is high probability of cracks being produced due to strains in structures induced by environmental or human activity, it is essential to differentiate those damage, which are not due to blasting activity. The most common method is to monitor ground vibration along with damage assessment by visual inspection immediately before and after each blast. [19] Joseph et al, (2001) report that during one of their field studies they released the blast scheduled as public notification but the blast was delayed for approximately a week. However, telephone call was received by the Resident Engineer on the originally scheduled blast day of cracking to the party's house. In contrast improper monitoring of ground vibrations too have led to undue apprehensions with regard to reporting of excessive vibration levels. It further led to an unacceptable statistical scatter of measured data and could not be of any use in blast design to restrict the maximum charge per delay [20] (Cathy et al, 2014). Pal Roy (1994) [21] concluded that often response and complaints are biased either due to service or business interest with the operator or with aim of getting compensation. However, there could be genuine cases where structures are damaged due to improper blasting.

Before blasting begins in new areas, it is wise to define how the blasting might impact neighbours, animals, structures, utilities and the environment in general. Obviously, the degree of risk and impacts will vary depending on the nature of the blasting work. Blasting programs in urban areas must control flyrock, vibration, air overpressure and also public litigations. When the individual feels the vibration is greater than the perception threshold then there is possibility of expression regarding blasting. The expression normally will be related to the vibrations causing damage to the complainant's property. Concern may be expressed that damage has already occurred due to the recent discovery of cracking that may have been present for some time or have been caused by natural processes. More often, however, concerns are based on the fear that damage will be caused at some time in the future as a result of repeated vibration.

In the present case though the vibrations were limited below the permissible limit of 5 mm/s at the structures, the human perceptions were that whenever the vibrations were below 1.5 mm/s there were no complaints from the residents, and when the vibrations were between 1.5 mm/s and 2 mm/s they were uncomfortable and when the vibrations were above 2 mm/s they complained of excessive vibrations (Balachander et al, 2014) [22] (Table 4). The time for blasting was controlled and it was accepted by most residents and it was in line within the normal working hours. No blasting activity was carried out during Sundays and public holidays. In addition blasting was not carried out during school examination times. Specific blasting timing was also consulted with the local hospitals and clinics to ensure that they are informed of the timing and these would not disrupt their operations. By considering the ground vibration and air overpressure as a major ill effect due to blast will reduce the number of unnecessary claims and also increases the faith on blasting as a cost-effective excavation technique while protecting the interests of the public and property owners.

TABLE IV. HUMAN RESPONSE TO GROUND VIBRATION AT THE SITE.

Permitted peak particle velocity (mm/sec)	SD factor (m/√kg)	Human response
1.5	66	No complaints
1.5-2	53	Felt uncomfortable
>2	45	Complaints regarding excessive vibrations

VII. CONCLUSION

With proper planning, design and communication blasting can be carried out in densely constructed areas in any urban environment.The human response with regard to vibrations revealed that whenever the vibrations were below 1.5 mm/s there were no complaints from the residents, and when the vibrations were between 1.5 mm/s and 2 mm/s they were uncomfortable and when the vibrations were above 2 mm/s they complained of excessive vibrations. In total more than 500 blasts were carried out to excavate 80000 m3 of hard rock by increasing the blast size from 45 to 250 m3 per blast. Though the control of flyrock happens to be the most challenging while blasting in proximity to structures, equally of concern are the air overpressure levels. Muffling in urban environment should address two aspects namely control of flyrock and air overpressure. This paper demonstrates the importance of compliance of vibration levels based on site specific human response requirements rather than to standards for successful completion of the project. Controlled blasting with design changes from the site specific vibration monitoring inputs ensure blasting activities without any legal hassles and delays.

REFERENCES

[1] Venkatesh, H S, Balachander, R, and Gopinath, G, 2013. Approach to urban excavation with special reference to metro rail, journal of visfotak – explosives safety & technology safety, Vol. No. 7, March 2013, PP 35-40

[2] Dowding, c h, 1996. Construction vibrations. Prentice hall, Upper saddle river, NJ.

[3] Siskind, D E, Stagg, M S, Kopp, J W, Dowding, C H, 1980. Structure response and damage produced by ground vibration from surface mine blasting. RI 8507, U.S. BUREAU OF MINES,

[4] Jeff L and Dwayne D T, 2014. Urban construction blasting in canada – complaints and associated municipal bylaws, jl of civil engineering and architecture, HTTP://WWW.HRPUB.ORG

[5] Dowding, C H, 1985. Blast vibration monitoring and control, prentice-hall.

[6] Adhikari, G R, Singh, R B, and Gupta, R N, 1989. Structural response to ground vibration from blasting in opencast coal mines, jl. of mines, Metals & Fuels, April, PP 135-138.

[7] Athanasopoulos G A and Pelekis P C, 2000. Ground vibration from sheetpile driving in urban environment: measurements, analysis and effects on buildings and occupants, jl of soil dynamics and earthquake engineering, 19, PP 371-387

[8] Adhikari, G R, Venkatesh, H S, Theresraj, A I, Surendra Roy, Balachander, R, Nitin Kumar Jain, and Gupta, R N, 2005. Role of blast design parameters on ground vibration and correlation of vibration level to blasting damage to surface structures, s&t project: mt/134/02, research funded by min. of coal, govt. of india

[9] Adrian moore, Alan richards, Thomas lewandowski, John wilson, Emad gad, Adrian page, Stephen fityus, and Goran Simundic, 2002.

Structure response to blast vibration, australian coal association research program (acarp) reference no. C9040

[10] New, B M, 1990. Ground vibration caused by construction works, tunneling and underground space technology, vol. 5, no. 3, pp 179-190.

[11] Monalas, F I and Arusu, T, 2012. Blasting works in urban area – a singapore case study, workshop on tunnelling by drilling and blasting hosted by the 10th int. Symp. On fragmentation due to blasting (fragblast 10), New Delhi, India, 24-25 November, PP. 23-30.

[12] Jonson D, 2012. Controlled shock waves and vibrations during large and intensive blasting operations under stockholm city, workshop on tunnelling by drilling and blasting hosted by the 10th int. Symp. On fragmentation due to blasting (fragblast 10), New Delhi, India, 24-25 November, pp. 49-58.

[13] Denise De La Corte Bacci, 2005. Guidelines for mining and quarry blasting for urban areas – brazilian regulation NBR 9653 under current reviewed, proc. of ISEE, vol. 2

[14] Anon, 1997. Damage of structures due to blast induced ground vibrations in the mining areas. Dgms (tech)(s&t) circular no. 7. India.

[15] Gupta, I. D. and Tripathy, G. R., 2013, Comparison of construction and mining blasts with specific reference to structural safety, Indian Mining and Engineering Journal, Vol. 54, No. 4, pp. 13-17.

[16] Balachander, R, Gopinath, G, Theresraj, A I, Vamshidhar, K & Venkatesh, H S, 2011. Report on Technical guidance for rock blasting and monitoring of ground vibration, air overpressure and fly rock during excavation at Underground stations from Chinnaswamy stadium to City railway station, BMRCL site. NIRM Project No. RB 10 06 C. Unpublished. India:

[17] Anon, 1998, ISEE'S Blaster's Hand Book

[18] Braden, T L and William, C W, 2010. VOLUME 2 - Method for developing explosion damage potential contours in urban areas, proceedings of the thirty-sixth annual conference on explosives and blasting technique, ISEE 2010

[19] Joseph egan, Jeff kermode, Martin skyrman and Loren L.turner, 2001. Ground vibration monitoring for construction blasting in urban areas, final report f-00-or-10, state of california department of transportation, unclassified

[20] Cathy, A M, Brent M, James L and Robert B, 2014. Tall structure response to close-in urban blasting in new york city, the jl of explosives engineering, vol. 31, no. 4, july-aug, pp 6-15

[21] Pal Roy, P, 1994. Socio-economic environmental impacts of blasting in sensitive regions and remedial measures, course on mineral extraction tech. for small scale mines, CMRI, India.

Balachander, R, Naveen, G C, Theresraj, A I, Gopinath, G and Venkatesh, H S, 2014. Final report on technical guidance on controlled blasting and monitoring blast vibration at bagmane constellation business park, outer ring road, Bangalore, NIRM report, February.(unpublished)