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Case Study on Impact of Blasting in Surrounding Area of Mines

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ABSTRACT : Blasting operations cause several adverse environmental effects and may result in safety problems. This study evaluates the impacts resulting from blasting operation on nearby buildings and structures as it generates ground vibration, air blast, and fly rocks. In this paper, first blasting operation and its possible environmental effects are defined. Then the methods of blast-vibration prediction and commonly accepted criteria to prevent damage were introduced. With the development of new explosives systems and initiation devices, blast design and execution techniques, the blasting process has now become more efficient and safer than before. Prediction tools can be used before carrying out blasts to control environmental impacts and follow safety norms.

KEYWORDS: Blasting, Vibrations, Environmental Impacts, Safety, Prediction Tools

I. INTRODUCTION

Explosives are vital and indispensable to the mining of every mineral. More than 75% of the explosives production is consumed in mining operations alone across the globe. In India, the mining sector accounts for 80% of the demand for explosives. The annual Indian Consumption of explosives is around 6, 00,000 tones. Despite the large quantity of explosives used, serious incidents involving the legal use of explosive materials are rare. Unfortunately, when incidents involving explosives arise, they are well publicized, whereas the great majority of blasting projects—even the most challenging ones—quietly occur without incident or public recognition. Many projects have been halted or delayed by community groups concerned about the potential damage or environmental impacts of blasting. Experienced blasting professionals know that blasting-- even under the most challenging conditions--can be carried out without incident if proper blasting controls are applied. The regulatory authorities thrusting on safe blasting conditions at mining sites are focusing on development of innovative blasting technologies that are safer and eco-friendly. Technology advancement is aimed at reducing mineral loss, greater control over rock fragmentation size and broken rock bulk density and larger shot sizes without vibration impacts. This paper defines the blasting industry's challenges, explains types of blasting impacts, presents a technology for managing blasting risk, and gives details of software which can be used for controlling various impacts of blasting.

II. THE CHALLENGE

For engineers, blasters and project supervisors, managing risks associated with blasting is becoming an ever increasing challenge as many mines are located close to populated areas. Not only is the work closer to people, structures and utilities, but environmental concerns about blasting effects on animals are also increasing. Without proper planning and controls, blasting is costly and increases social and environmental issues. Regardless of the scale of blasting work, when engineers or planners underestimate the importance of preparing adequate blasting controls and public relations programs, the consequences can be severe. Uninformed citizen groups can stop or delay work by applying a wide array of political and legal actions. Anti-blasting groups have exercised their rights by stopping or delaying work in the following ways:

- Appeals to Government Agencies or Officials
- Endangered Species Act
- Declaring Neighborhoods as Historical Districts
- Legal Injunctions
- Forcing Environmental Impact Studies
- Delaying Project Approvals via Actions at Public Hearings
- On-Site Protests

In the light of public and media scrutiny of blasting operations, a great disservice to our industry occurs when we collectively fail to avoid preventable incidents. Blasting incidents are often caused by complacency and/or ignorance by workers, engineers and inspectors. Problems occur when engineers develop poor specifications, workers have inadequate experience, and inspectors are untrained. We have the tools, skills, and the knowledge and experience to avoid these types of incidents. How often have we assured that blasting could be done safely—because we lacked complete control over all the critical aspects of the work?

Our broad challenge as an industry is to understand how to control blasting through regulation, blast design, and on-site execution and field oversight. Despite the risk, blasting has been and can be performed safely and with economic benefits.

III. POTENTIAL BLASTING IMPACTS

Before blasting begins in new areas, it is important to define how the blasting might impact neighbors, 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. For instance, a downtown building implosion project will have very different risks from a proposed mining project in a national forest. Blasting programs in urban areas must control flyrock, vibration and air overpressure, whereas, the project in the national forest will likely have strict environmental controls on water quality and animal impacts. For example, work might be suspended during time periods when birds are nesting. Due to the growing involvement of governmental agencies in the permitting process for new projects, especially large ones, potential environmental impacts are usually identified beforehand and mitigation measures are explained in environmental impact studies. The risks associated with blasting are wide ranging and some are quite unique. The following table, although not complete, can be used as a general aid for identifying and developing measures to manage blasting risks.

TABLE 1: SOCIAL AND ENVIRONMENTAL IMPACT OF BLASTING

CONCERN	PRIMARY IMPACTS	CONTROLS
IMPACTS OF VIBRATION		
Startled or scared people	Complaints	Inform neighbors before each blast. Carry out blasting at fixed time. Take appropriate safety measures.
Damage to buildings	Damage claims, work delays or suspension	Pre-qualification requirements, blasting controls, blast plan submittals and reviews, careful inspection of work, public education, effects monitoring and pre-blast condition surveys.
Damage to rock slopes and final excavation walls	Rock falls, remedial slope repairs and work disruption	Evaluate in situ condition of slopes and install additional support is needed. Develop blasting controls and carefully monitor the work.
Damage to buried pipes and utilities	Unrealistic restrictions on blasting or total ban on blasting	Pre-qualification requirements, blasting controls, blast plan submittals and reviews, careful inspection of work, effects monitoring and blasting effects evaluation study by expert.
Damaged water wells or aquifers	Blasting prohibition or project delays	Blasting controls, pre-blast and/or post-blast inspections, effects monitoring and blasting effects evaluation study by expert.
Ground Vibration effects on historical buildings	Damage to historical monuments	In areas where caves are present, great care must be taken to avoid damage, as they may be SSSIs , of tourist interest.
ENVIRONMENTAL IMPACTS		
Impacts on Animals	Disapproved EIS, blasting prohibition or project delays	Blasting controls, pre-blast and/or post-blast inspections, and blasting impacts and mitigation study by expert
Fines	Both environmental issue and an economical loss for the producers.	Blasting operations should regularly conduct Process Optimization Audits to ensure that they produce the lowest achievable proportion of fines.
Noise (Airblast)	Increase of ambient noise levels with the potential of disturbance to local communities.	Measure airblast noise and design blasts and appropriate stemming to control airblast noise

Agriculture	Reduction of agricultural land Soil pollution Air pollution	
Water pollution	These impacts may reduce yield of crops in the area.	
	Leaching of chemicals in blast holes Strict control measures to prevent air	
IMPACTS ON SAFETY		
Fly rock	Damage and Injury, damage to plant and buildings	Pre-qualification requirements, blasting controls (blast mats—burden requirements—stemming requirements), blast plan submittals and reviews, and careful inspection of work.
IMPACTS ON HEALTH		
Fumes and gases	Harmful oxides (NO ₂) may be released as fumes. The fumes dissipate readily, but if there is a temperature inversion and little wind, then they can linger. Breathing contaminated air after a blast may kill a miner in a few minutes.	While using ANFO appropriate prill and the right amount of diesel is used ensuring that it is thoroughly mixed. Incomplete detonation of the explosive or incorrect mixing of the ANFO presence of excess Water may be used.
Dust	Dust released is a health concern for on-site personnel and surrounding communities.	Watering of the blast area following the charging of blast holes with explosives. Delaying blasting under unfavorable wind and atmospheric Conditions. Use appropriate blast design and explosives.
OTHER IMPACTS		
Work or business disruption	Financial damage claims and/or organized opposition	Public education, blasting controls, monitoring and schedule blasting during non-working
Contractual Claims and Legal Actions	Financial damages	<i>Owners and Engineers:</i> Have appropriate experts review contract documents and Specifications. Prepare pre-qualification requirements that ensure contractor and personnel are capable of performing the work, and carefully carry out pre-blast survey of buildings. <i>Contractors:</i> Carefully evaluate all available pre-bid documents-including all geotechnical information, attend pre-construction meetings, document all blast related information including video, Photographs and vibration records.

IV. ENVIRONMENTAL HAZARDS

Increasing numbers of mining operations are coming under pressure to monitor and reduce blasting related safety and environmental hazards. Ground vibrations, air over-pressure, fly-rock, dust, blasting fumes in some cases leaching of chemicals in the blast holes and polluting ground water are some of the undesired events associated with blasting which collectively affect the surrounding environment adversely.

4.1 GROUND AND AIR VIBRATIONS

During blasting some of the energy released by explosives cannot be utilised in breaking rock and creates vibration in the surrounding rock and air. Although damage or the fear of damage is the major concern for neighbors of surface blasting operations the reality is that vibration levels at adjacent residential properties rarely if ever even approach the levels necessary for even the most cosmetic of plaster cracking. Air vibration (airblast overpressure) from blasting varies with geological conditions, the charge mass, blasting specifications, confinement of the charge, distance from the blast, topographic shielding, direction relative to the free face and meteorological conditions at the time of the blast.

The perception of blast vibration is further complicated by the presence of ground vibration and air vibration, which separate with distance because of the different propagation velocities. Both air and ground vibration are commonly perceived by secondary noise, such as rattling of dishes, windows or sliding doors, and without monitoring it may not be possible to recognize whether air or ground vibration is responsible.

Ground vibration is perceptible at between 0.2 mm/s and 0.5 mm/s depending on the activities of the receiver at the time, whether indoors or outside, and the frequency and duration of the vibration. Some people do become concerned when ground vibration exceeds 3-5 mm/s.

4.2 HEALTH IMPACT

Blasting operations can generate large quantities of dust. This dust when released in an uncontrolled manner, can cause widespread nuisance and potential health concerns for on-site personnel and surrounding communities. Though the blasting dust plume is raised for few minutes but most of the dust settles in and around mining area and some of it is dispersed before settling down. Depending on meteorological conditions the dust dispersal can travel to substantial distances endangering health of communities. The impacts of blasting operations on the air quality depend on the nature and concentrations of the emissions, meteorological conditions and the nature of the receptors humans, flora, fauna or materials.

Generation of fines and dust is influenced by several blasting and rock parameters (Kumar and Bhandari, 2001, 2002). However, production of fines and dust need to be reduced and controlled for better environmental conditions (Hagan, 1979). Dust generation and dispersion from blasting operations depends on factors such as meteorology, bench height, blast design information, and rock. (Bhandari et al, 2004). Concern is expressed about nitrogen-oxide (NO_x) releases from blast sites and their potential health impacts on workers, as well as their aesthetic and environmental impacts on nearby communities.

However, blasting dust is produced as a concentrated 'cloud' that is highly visible and potentially may affect near neighbors downwind of the blast. The blasting of near-surface weathered materials that contains a high proportion of fines often creates large dust emissions.

V. SAFETY

Explosives handling and blasting operations are high consequence risk activities. There are many safety hazards associated with use of explosive, transport and storage. Statistical review of accidents as per DGMS shows that

during following types of accidents taken place within the specified danger zone of blasting (Ranganatheshwar and Prasad, 2014).

- Due to improper shelter about 69% of fatal accidents caused in coal mines and 47 % in non coal mines. This factor contributed 90% in opencast mines only and 56 % in underground districts of coal mines.
- About 12.5% of total accidents due to explosive handling are because of misfires.
- └ In spite of several stipulated precautions to handle blasting in thunder stormy situation about 6 % of fatal accidents caused due to the lightening.
- Improper storage site of explosives and detonators cause about 6 % of accidents in opencast non-coal mines.
- Blasting and supervision by unqualified persons lead to about 20% of accidents as small mine owners seem reluctant to appoint a qualified blaster, mine manager.

One of the safety hazards during blasting is flyrock. Flyrock occurs where energy is vented into atmosphere and propels rocks. This can happen where burden and stemming is too small or holes are initiated out of sequence, due to drilling inaccuracy, due to overcharging, due to geological conditions such as cavities and mud seams, or due to sympathetic detonation. Flyrock can still be generated even in the best-designed blast. Damage due to flyrock from blasting is one of the main causes of strained relations between mining operation and neighbors. Flyrock occurs where energy is vented into atmosphere and propels rocks. This can happen where burden and stemming is too small or holes are initiated out of sequence, due to drilling inaccuracy, due to overcharging, due to geological conditions such as cavities and mud seams, or due to sympathetic detonation. Flyrock can still be generated even in the best-designed blast. Flyrock distances can range from zero for a well controlled mine blast to nearly 1.5 km for a poorly confined large, hard rock mine blast and many fatalities have occurred. In a circular, The Director General of Mines Safety India in 1982 had recommended that personnel be removed up to 500 m, though previous limit was 300m only. Thus, where large diameter blasting is carried in hard rock mining, extra precautions are required to control the flyrock damages in the surroundings.

VI. ADVANCED TOOLS AND TECHNIQUES

With the development of new explosives systems and initiation devices, blast design and execution software tools, the blasting process has now become more efficient and safer. Blasting operations are utilizing technology systems that underpin rock blasting in open pit and underground mine operations, such as predictive modeling, blast design, radio-controlled detonation, real-time monitoring of drilling, charging and post-blast data analysis. Information Technology (IT) systems are being used to record, manage and analyse data being generated. Developments in information technology have gone through leaps and bounds, which have led to ripple effects in raising the standards of technology in drilling and blasting. Several tools can be used in assessing blast face conditions, assist in designing blast, executing blasts, during and after blast monitoring, recording all results and analyzing records. Information must be collected during drilling about the rock strata so that loading pattern of blast holes can be decided. Many tools and techniques have taken the guesswork out of explosives loading and blasting operations (Rodgers, 1999). Some of them are:

Face profiler systems using laser technology profiles the rock face by pointing profiler to the floor, toe and crest – then take accurate measurements and calculates bench heights, minimum and optimum burdens, computes drill hole angles and offsets, and hole depths. Drills may have a tendency to follow the faults, weakness planes, weak rock, cavity or similar other geological weakness creating borehole deviation.

Hole Deviation measurement tools, operators discover light burden areas and are able to thwart safety issues. The cable deviation measurement tools uses sensors that measure borehole deviation at fixed intervals from the collar position and transmit the findings instantly to a field computer.

Another tool is the **3-D laser profiling system**, which includes equipment and software that allows the user to make precise burden measurements without venturing near the crest of the bench. This system, too, transmits its findings instantly to a field computer. From these field computers, the data from both

tools are merged in blast design software to adjust the blasting plan by compensating for any initial "guesstimation" of the burden and for drilling inaccuracy.

Another technology that has great importance for drilling accuracy, and the integration of drilling and blasting operations is **Global Positioning System (GPS)** as applied to drill positioning on individual blast holes. New GPS-enabled applications help drill and blast engineers develop more appropriate and more suitable blast designs. Engineers can create designs in the office and upload them to the drill rigs by remote means; drillers can see the patterns from their drill rigs as sent by drill and blast engineers from the offices. Engineers can monitor and follow up drilling progress in real-time from the offices, from any location, depending on how they are connected.

The most significant changes in blast technology have taken place in **explosive-delivery systems**. One factor is the continuing trend away from the use of cartridge products in favor of bulk products for both surface and underground operations: new surface and underground delivery-vehicle technologies that boost blast accuracy and safety: high-precision pumps and blending and measurement devices, robotic arms that place the product in the hole, and remote controls. When considering blasting technologies, operating companies tend to be highly cost conscious, which mitigates opportunities to develop value-added or innovative products.

Electronic detonators are now commercially available. Advantages include more- precise delay timing (resulting in increased blast efficiency and control) and greater compatibility with remote-controlled loading of explosives and wireless detonation. However, these initiating systems have higher costs and trials have given some issues of some manufacturers in watery holes and in underground operations.

6.1 BLAST DESIGN SOFTWARE

Optimum blasting just does not happen. It requires suitable planning, good blast design, accurate drilling, the correct choice of explosives and initiation system and methods, adequate supervision and considerable attention to detail. The rock type and structure; size, length and inclination of blast holes, drilling pattern and accuracy, type, quantity and distribution of explosives; charging and initiating techniques all play a significant role in the overall efficiency of a mining operation. During the design stage environmental constraints such as vibration limits or flyrock restriction with respect to any structure can be prescribed. Blast design software can be used which considers all the above aspects (Figure1). A mine can be set up in one of two ways; either the plant is set up to accept whatever fragmentation the blasting group produces, or the plant dictates to the mining teams the fragmentation distribution they desire.

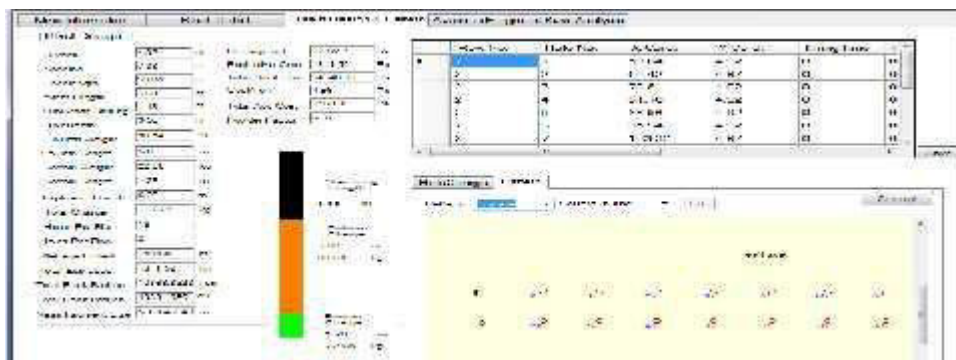


Figure1 Blast Design Software (BLADES)

BIMS is software which helps to store, access and manage the information needed to take critical decisions for their mine/quarry operations. The system stores blast details, blast parameters, blast pattern, face profile, explosive consumption, charging details, costs, weather information, pre-blast survey, post-blast evaluation data, fragmentation information, photograph(s), videos, accidents, misfires, vibration record and information for vibration analysis (Figure 2). The stored blast information data can be retrieved quickly for analysis.

The system generates reports for individually identified blast, monthly explosive consumption report, cost report, vibration monitoring report, and monthly blast performance report. The storage of this information in database format allows querying to retrieve scenarios, which meet certain criteria, and to use this information to further optimize the outcome from a blast. Use of software provides the mine manager's to take quick decision based on accurate and reliable information.



Figure 2: Blast Information Management System (BIMS) provides storage of photographs, videos and performance of blast

Routine mine blast operations experience must be gathered and stored in a systematic way so that it can guide present and future design changes. Blasting information management software and measurement techniques can be used to monitor, access and analyze the blasting performance so that appropriate modifications can be made to design the optimum blast (Bhandari 2011).

Regular feedback is required to ensure that the blasting objectives are routinely achieved, and if not, to determine what aspect of the process requires attention. Apart from special investigative blast monitoring, routine blast audits are necessary to check implementation of blast designs on the field. Blasting audit should be carried out to monitor blast execution and performance and then quantify blast results. Photographs and Video analysis in slow motion helps in analyzing blasts.

VII. PREDICTION AND CONTROL OF HAZARDS

Objective of Controlling Adverse Impact needs management and mitigation measures that ensure that blasting activities:

- do not result in air blast overpressure and ground vibration that exceeds permitted guidelines;
- do not damage property, infrastructure or historical heritage sites; and
- do not cause injury or death to person(s).

Much work has been carried out on the environmental aspects such as ground vibration and airblast control (Richards and Moore, 1995). Operators are now aware about the steps which need to be taken. Norms and standards regarding ground vibration and air blast as specified by regulating agencies must

be complied with. It is therefore, vital for the industry to do all that it can to reduce the vibration levels experienced at these adjacent properties without imperiling the financial viability of the enterprise. In one case a review of seismograph readings showed that vibration levels at neighbors were low up to 2mm per second, as expected, but air blast levels exceeded significantly and appeared to be the source of complaints.

The control of vibration and air overpressure centers on the quantity of explosives fired on any single delay, usually known as the maximum instantaneous charge weight. The ground vibration level (commonly measured as peak particle velocity in mm/s) is related to charge mass and distance. Ground vibration levels from blasting increase with increased charge mass, and decrease as the distance from the blast site increases. Splitting the explosive charge mass into discrete charges fired on separate delays will reduce the maximum charge per delay. Site parameters are determined for each location. However, it must be remembered that site parameters may vary substantially with different geological and weathering conditions within different parts of the mine. Commonly determined maximum charge need to be detonated within selected time period. A time period of 8 ms has been widely used, but this can result in substantial error on occasions. Wave front Reinforcement can be avoided or reduced by changing the blast pattern design by Pattern Analysis to check for the effect of blasthole positions and delay timing. The combined effects of blasthole spacing, burden, and sequential initiation timing also need to be considered. Ground and airblast vibrations can be altered by change of delay timing and sequence.

Airblast is responsible for many blast vibration complaints. The significance of airblast from mine blasting is not fully appreciated because its frequencies are substantially inaudible. Airblast is often not measured. The vibration effect of airblast on houses is often confused with that due to ground transmitted vibration.

Wave front reinforcement has been found to cause substantial increases in both air and ground vibrations (Richards and Moore, 1995). Simple alterations to firing pattern can prevent wave front reinforcement. **Pattern Analyser** is a graphical software program for the design which can be used to alter design and initiation pattern to avoid reinforcement and thus lowering the vibration levels. This software can also simulate blast hole detonation sequence. Whereas those experiencing vibration problems they restrict their blasting to charge per hole but may ignore number of holes firing at one time which may increase vibrations. (Figure3)

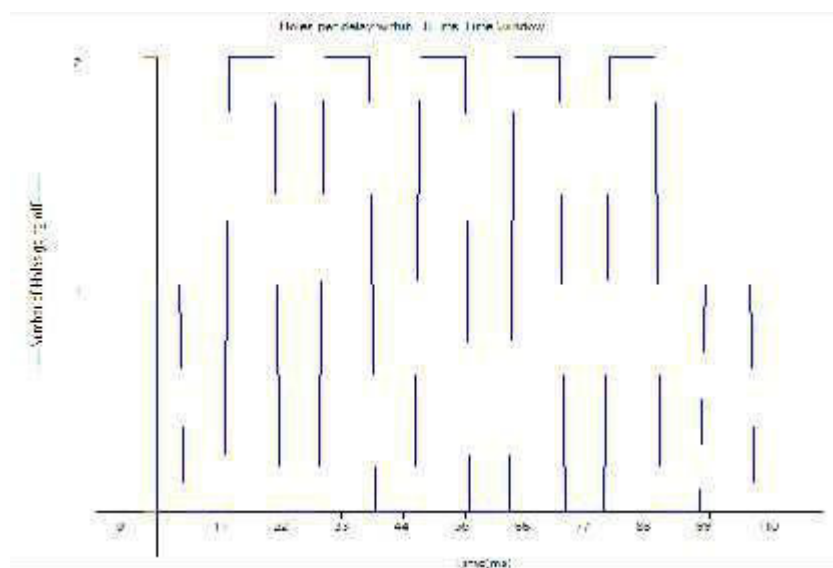


Figure 3: Timing Sequence Window of blasting holes

There is a 'safe' blasting area in blasting is dependent on the knowledge of distance to which flyrock will propel. Software for predicting distance to which a flyrock will travel has been developed (Richards and Moore, 2004). Use blast clearance zone predictor before charging may help in controlling flyrock by altering charging in a hole with reduced burden (Figure 4). Inputs to the software are charge mass, burden or stemming height, and a site constant that lies within a general range that can be tightened by site calibration. The output is the distance that rock will be thrown, and this quantification can be used to establish both safe clearance distances, and the critical range of burdens and stemming heights where the situation changes rapidly from safe to hazardous. Using safety factors danger zones for machinery and persons respectively. If it is not possible remove any structure or person then one can change charging of holes.

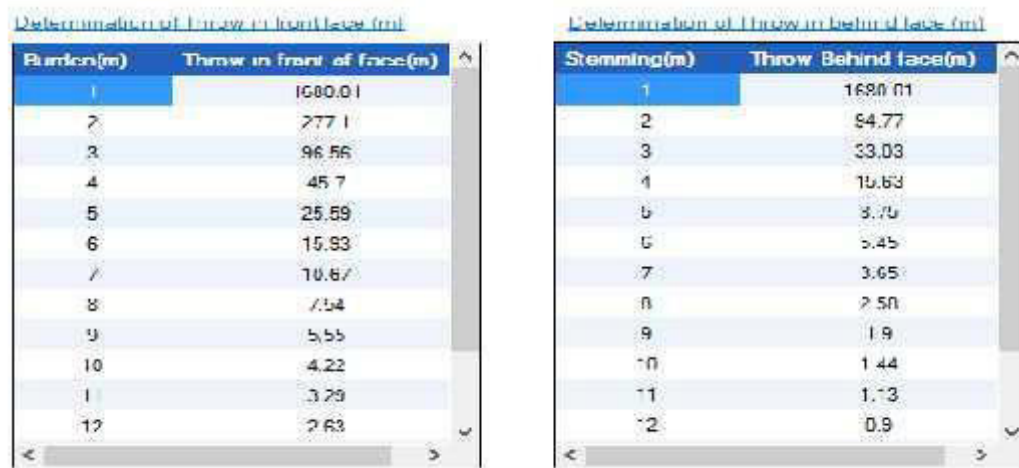


Figure 4 Flyrock Prediction in front and at the back based on blast parameters, explosive distribution and rock

Dust generation and dispersion is controlled by blast design and execution, appropriate stemming material and down the hole initiation. The amount of fines can be reduced by decoupling (by providing an annulus of air between the charge and blast hole wall) because the borehole pressure becomes lower. Decoupling can be achieved either by using cartridge explosives or by placing the bulk explosives in a rigid pipe inserted in the hole.

Another method that can be effective in protecting areas adjacent to the mine from blasting dust involves delaying blasting under unfavorable wind and atmospheric conditions. This requires some flexibility in blasting schedules, but can be highly effective. Planning mining so that adequate buffer stocks of ore are available is required to accommodate delays in blasting. Acknowledge of seasonal and daily wind patterns will give some degree of predictability to the likelihood and frequency of blast postponement. A Case study describes an innovative predictive tool developed that utilizes blast properties and real-time meteorological data to predict the dust impact on residential areas adjacent to the mine. This type of tool has potentially wide application as it could be applied to any dust source, or combination of sources, to predict dust dispersion. By linking the model to 'live' weather station data, the model provides a real-time prediction of dust concentrations.

To some extent this is mitigated by dust retention effects of the pit and the fact that (modern) drilling rigs are fitted with dust collection apparatus. Dust generated from drilling operations appears to be a minor contributor to overall dust emissions in comparison to other sources.



The options for controlling dust from blasting are somewhat limited. Watering of the blast area following the charging of blast holes with explosives may assist. This practice is sometimes utilized to combat dust from certain ore types that have a high content of fine particles.

VIII. BLAST MANAGEMENT PLAN

The purpose of a blast plan is to detail the objectives for the project or task, identify risks, hazards and control, identify site-specific requirements; introduce blasting as part of the overall task, control the blast process from design to, initiation, evaluation and misfire treatment; implement a review process to ensure that the objectives are met; and assure that the safety of the public, site personnel and surrounding properties.

Blast Management plan helps determine how the area can be mined in a cost effective manner, how potential blasting impacts on the nearby community can be minimized. It provides the best possible practices & procedures in a reasonable and practicable manner & an acceptable blasting environment for the nearby community. Blast Clearance Area to be established around each blast to ensure that personnel are not injured by the blasting process, to reasonably prevent machinery and infrastructure from damage. It is possible to blast in very close proximity to established buildings; however, this would require the use of blast mats and extra earth cover over the top of the blast, which will increase the blasting costs substantially.

Studies have shown that initiating a good program of public relations is the most effective way of reducing complaints about blasting. Program content related to blasting activities could include the following: Notification of blasting signals, direct notification, monitoring at nearby properties, education about the blasting process and environmental impact.

IX. CONCLUSIONS

Steps are needed to predict and control ground vibrations, airblast overpressure and flyrock and to reduce generation of fines and dust. Indigenously developed computer aided design and analysis tools, need to be adopted for predicting and mitigating blasting hazards. Use of software tools for blast design, support in execution, blast monitoring and analysis makes it possible that damages and dangers from blasting can be predicted before blasting. These adverse impacts of blasting can be controlled and reduced. Prediction tools can be used before carrying out blasts to control environmental impacts and follow safety norms. The challenge before the mining industry is to make changes in the presently used blasting technology. The developments in the areas of planning and design of blasts, drill monitoring, drill hole deviation, laser profiling systems need to be adopted. The innovative practices in the area of drilling, new bulk loading of explosives & initiation systems, performance measurement and the evaluation of blast outcome and productivity need to be adopted.



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