EFFECTIVENESS AND SAFETY OF OPEN PIT HAUL ROADS, OPERATORS PERFORMANCE, HAUL ROAD DESIGN AND TOLERABLE METHODS

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Abstract—Blasting involves the breaking of rocks using explosive that rapidly change due to chemical reaction forming huge volumes of gases with high pressure and temperature causing kinetic energy. The blasting process is primarily a rock– explosive interaction that entails application of pressure generated by detonation of explosives, on rock mass, over a few milliseconds. This rock– explosive interaction results in rock breakage and heaving of the broken rock mass (muck). In comparison to the mechanical methods that rely predominantly on the compressive breakage, blasting exploits the tensile strength of the rock mass. This is probably the reason that blasting is still the most prevalent and economical method for rock breakage. Blasting, in general, results in ‘desired’ and ‘undesired’ outcomes that may be ‘regular’ or ‘random’ in nature. Any mismatch between the energy available and the work done will increase the adverse or undesired blast results like excessive throw and fly rock. Fly rock and excessive throw occur due to deviations in blast design execution, use of excessive explosive energy than the required levels to fragment and throw the rock mass, and/or presence of rock mass features, not accounted for during blasting.

Key words: Drilling, Blasting, Fragmentation, Explosives, Fly rocks, Rifling, Catering, Injuries, Mucking.

1. INTRODUCTION

Blasting involves the breaking of rocks using the chemical energy in the explosive. The blasting process is primarily a rock explosive interaction that entails application of pressure generated by detonation of explosives, on rock mass, over a few milliseconds. This rock explosive interaction results in rock breakage and heaving of the broken rock mass and muck. In comparison to the mechanical methods that rely predominantly on the compressive breakage, blasting exploits the tensile strength of the rock mass. This is probably the reason that blasting is still the most prevalent and economical method for rock breakage used in both Mining and Construction industries. Blasting, in general, results in ‘desired’ and ‘undesired’ outcomes that may be ‘regular’ or ‘random’ in nature as shown in table1.1.1. These also form the objectives of the mine mill fragmentation system MMFS. Any mismatch between the energy available and the work to be done will increase the adverse or undesired blast results like excessive throw and fly rock. Fly rock and excessive throw of muck or heavy sand particles occur due to deviations in blast design execution, use of excessive explosive energy than the required levels to fragment and throw the rock mass, and/or presence of rock mass features, not accounted for during blasting. The said rock mass and blast design anomalies favour the hallow out of high-pressure gases emanating from the blast holes in the direction of the...
weakest zone and result in fragments travelling unwanted distances than desired. Such fragments are called ‘fly rock’. These Fly Rock can be as deadly as a bullet or a missile in term of destruction and devastation.

Fly rock is one of the crucial issues in bench blasting, as it is not only a safety concern but also affects the productivity. Percentage of accidents occurring due to fly rock Table1.1.2, justifies its importance irrespective of the fact that the problem is seldom reported.

For instance, Mishra, (2013) reported 17.35% in total accident due to explosive in both coal and non-coal mines of deep hole blasting. Adhikari (1999) reports that 20% of accidents that were related to fly rock occurred in mines in India, Mishra, (2003) reports more than 40% of fatal and 20% of serious accidents resulting from blasting occur due to fly rock in mines in India. It can be noted that almost 70% of all injuries is directly contributing to the fly rock and lack of blast area security. So the prediction of fly rock and its control is still elusive.

Fly rock, arising from open-pit blasting, still eludes rock excavation engineers, despite a reasonable understanding of throw. Fly rock distance predictions have witnessed a refocus in the past few years due to want of probable solution. Such attempts also have raised certain pertinent questions that need to be answered in order to develop a proper understanding of the fly rock phenomenon, which is expected to facilitate a better investigation regime for forthcoming R&D efforts on its prediction.

**Table 1.1.1 Blast outcome, nature and objectives**

<table>
<thead>
<tr>
<th>Blast result</th>
<th>Name</th>
<th>Comments</th>
<th>MBF’s objective(s)</th>
<th>Other comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fragmentation</td>
<td>Regular</td>
<td>Desired</td>
<td>Optimizer</td>
<td></td>
</tr>
<tr>
<td>Thrust (force)</td>
<td>Regular</td>
<td>Desired</td>
<td>Optimizer</td>
<td></td>
</tr>
<tr>
<td>Ground vibration</td>
<td>Regular</td>
<td>Undecided</td>
<td>Minimize</td>
<td></td>
</tr>
<tr>
<td>Air overpressure and noise</td>
<td>Regular</td>
<td>Undecided</td>
<td>Minimize</td>
<td></td>
</tr>
<tr>
<td>Toxic gases and fumes</td>
<td>Regular</td>
<td>Undecided</td>
<td>Minimize</td>
<td></td>
</tr>
<tr>
<td>Flyrock and excessive throw</td>
<td>Random</td>
<td>Undecided</td>
<td>Minimize</td>
<td></td>
</tr>
<tr>
<td>Blast hole</td>
<td>Random</td>
<td>Undecided</td>
<td>Minimize</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1.1.2 Accident statistics of reported fly rock by different authors**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Period</th>
<th>Blasting injuries</th>
<th>Percentage of blast inj injuries in blasting related accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mishra and Modi</td>
<td>1996-2011</td>
<td>30</td>
<td>24.00</td>
</tr>
<tr>
<td>Verbov (9)</td>
<td>2010-2011</td>
<td>18</td>
<td>18.00</td>
</tr>
<tr>
<td>Bagheri et al.</td>
<td>1984-1989</td>
<td>311</td>
<td>46.57</td>
</tr>
<tr>
<td>Loffl`</td>
<td>1978-1988</td>
<td>412</td>
<td>62.20</td>
</tr>
<tr>
<td>Karmegam and Rahariens`</td>
<td>1978-2001</td>
<td>195</td>
<td>37.00</td>
</tr>
<tr>
<td>Adhikari`</td>
<td>-</td>
<td>-</td>
<td>20.00</td>
</tr>
</tbody>
</table>

2. **PROBLEM IDENTIFICATION**

The contribution of fly rock and blast area security to the overall blasting scene. Out of 1,112 blasting injuries (surface and underground combined), fly rock and blast area security accounted for 281 injuries (25.3%). However, fly rock and blast area security issues represent 68.2% of all surface blasting injuries during the 1978-1998 time period. From table 3, it is apparent that the contribution of fly rock and blast area security ranged from 58.7% to 77.4% of all surface blasting injuries. Again, the data accentuates the need for continued research in these areas.

3. **MECHANISMS OF FLY-ROCK**

**Rifling**

This event occurs when stemming material is insufficient. Blast gases can stream up the blast hole along the path of least resistance resulting in stemming ejection and sometimes ejection of the collar rock as harmful fly rock (Fig. 1). The stemming column should contain individual rocks that are of disproportionate size to the blast-hole diameter, these can become lethal projectiles. This
mechanism of fly rock manifestation is closely related to the stemming release pulse for air blast.

![Fly Rock Due to Cratering](image1)

**Cratering**

The stemming region of a blast pattern usually contains a weakened layer due to previous blasting from the bench above. In this region, blast gases easily jet into the air and propagate cracks. The venting gases through this region produce cratering and fly rock events. This is particularly significant if insufficient stemming is used. Similar effects can result if short inter-row delays are applied. These gases will produce excessive air blast and fly rock (Fig 1.1). Cratering effect is also happened if blasting rows are incorrectly initiated (initiating back rows earlier than front rows).

![Face Bursting](image2)

**Face bursting**

This phenomenon occurs when explosive charges are in adjacent of the major geological structures or zones of weakness (Fig 1.2). The high-pressure gases of the explosives jet along the weakness zones (paths of low resistance) and generate noise, air blast, and fly rock.

**FLY-ROCK AND BLAST DANGER ZONE**

Assuming that the fly rock distance is predicted with reasonable accuracy, the objectives of the prediction mechanism do not end, since the regulatory authorities will be interested in the risk involved and back calculations of the range of a fly rock to define the blast danger Zone (BDZ).

Before elucidating BDZ, it is important to define the objects of concern. There are several subjects which come into picture with respect to fly rock in and around the mines. These subjects are designated as ‘objects of concern’ (OC).

Object of concern assume importance since the consequences of fly rock entail similar cost of damages irrespective of structures, persons, livestock and equipment belonging and not belonging to the owner of a mine. The definition of OC thus lays foundation for definition of a BDZ.

\[
\text{Risk} = \text{Probability of an event } p(E) \times \text{consequence of an event } C(E)
\]

Probability of a fly rock range exceeding the permissible limit, at a particular mine, can be worked out from monitored data of a mine and its probability density function that generally assumes a Weibull distribution. However, the consequence (cost and/or penalties) of the fly rock event is not known or is difficult to estimate (since it involves fatalities also), a threat ratio \((T_r)\) representing \(C(E)\) as shown in eq. (1.1),
was defined by Raina (2004) to represent the consequence.

\[
C(E) = T_r = \frac{R_{perm}}{R_{obj}}
\]  

(1.1)

Where \( R_{perm} \) is the permissible or acceptable range of fly rock, \( R_{obj} \) the distance of OC from the blast site and \( T_r \) threat ratio.

\( C(E) \) is a measure that can provide a method to define BDZ in a dynamic manner while evaluating the risk due to fly rock.

\[\text{Fig 1.4 Number of fatal and serious accidents due to blasting in Indian mines}\]

**Fly-rock And Blast Area Security – Mining**

The contribution of fly rock and blast area security to the overall blasting scene. Out of 1,112 blasting injuries (surface and underground combined), fly rock and blast area security accounted for 281 injuries (25.3%). However, fly rock and blast area security issues represent 68.2% of all surface blasting injuries during the 1978-1998 time period. From table 3, it is apparent that the contribution of fly rock and blast area security ranged from 58.7% to 77.4% of all surface blasting injuries. Again, the data accentuates the need for continued research in these areas.

**Blasting Injuries – Construction**

A review of the Occupational Safety and Health Administration (OSHA) data was conducted as a means for determining the extent of fly rock accidents, injuries, and fatalities in non-mining blasting operations. The Code of Federal Regulations, OSHA citation history, and the OSHA Technical Manual on blasting or the use of explosives were examined. In reviewing the Code of Federal Regulations, which is a codification of the general and permanent rules published in the Federal Register by the Executive departments and agencies of the Federal government, it was determined that the fly rock concerns would best be identified under OSHA Code of Federal Regulations Title 29, part 1926: Safety and Health Regulations for Construction, subpart U: Blasting and the Use of Explosives, sections 1926.900 - 1926.914. However, in overview, the only standards which applies to either fly rock or blast area security are: 29CFR1926.909; 29CFR1910.109 (e)(1)(iii) and (iv); and 29CFR1910.109 (e)(5). A thorough investigation was conducted of OSHA’s data base on issued citations and inspection reports for the time period of October 1997 through 1998. It was determined that fly rock is classified under North American Industry Classification System (NAICS) 1629, Division C: Construction, Major Group 16: Heavy Construction, Not Elsewhere Classified, Blasting except building demolition-contractors. In overview of the citations issued, there are four (4) citations standards that are related to blasting or use of explosives. During this period there were nine (9) citations issued with penalties totaling $4525.00. This dollar amount is relatively low and therefore, the authors assume that the citations were not issued for injuries or fatalities. OSHA’s Technical Manual provides technical information and guidance on occupational safety and health topics. However, there are no specific topics here which address the prevention of fly rock injuries or blast area limits. The sections that may address fly rock issues are generalized but do not specifically deal with fly rock.

A survey of the literature also points to a departure in identified causative variables and those used for prediction (Table 2.1). One of the important
observations from Table 2.1 is that despite the fact that improper burden, geology and associated anomalies are identified as major causes of fly-rock, these do not find place in predictive models as parameters. Table2.1 gives an idea about the fact that the geology and many other variables do not find place in the prediction of fly-rock distance despite the fact that stemming and specific charge assume importance in predictions. Based on the above comparison (Table2.1), the following conclusions can be drawn and major factors and research gaps in fly-rock prediction identified:

1. Rock mass properties are mentioned as a cause but find little place in predictive models.

2. Specific charge $q$, a ratio of explosive quantity in a blast hole to the product of blast geometry, viz. burden $B$, spacing $S$ and bench height $H_b$, i.e. $(B \times S \times H_b)$. Some models still use $q$ and $B, S, H_b$ in a single equation despite the fact that these are in-built in the specific charge. The conditions in which blast geometry was varied keeping specific charge constant are not mentioned in the derivation of such models. Under such circumstances the repetition of influencing factors in the fly-rock predictive models is obvious.

This makes the models statistically redundant. There are possibilities to combine different variables of rock mass and blast design in a better manner to reduce the number of variables in a fly-rock distance prediction model.

3. Density of the explosive has been used in a few models only, but the actual borehole pressure has not been modeled and estimated for prediction of fly-rock distance.


5. Stemming is used a major factor in prediction of fly rock distance. The nature of stemming which is different from the rock being blasted is altogether ignored.

Table 2.1. Comparison of causative factors and their use in fly rock distance prediction

<table>
<thead>
<tr>
<th>Causative parameter</th>
<th>Prediction parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Citations</td>
</tr>
<tr>
<td>Burden</td>
<td>13</td>
</tr>
<tr>
<td>Geology</td>
<td>13</td>
</tr>
<tr>
<td>Stemming</td>
<td>10</td>
</tr>
<tr>
<td>Excessive explosive</td>
<td>6</td>
</tr>
<tr>
<td>Inadequate delay</td>
<td>6</td>
</tr>
<tr>
<td>Improper blast layout</td>
<td>5</td>
</tr>
<tr>
<td>Poor confinement</td>
<td>4</td>
</tr>
</tbody>
</table>

This brings us to the question about our understanding of the fly rock problem. In this context, it is important to remember that fly rock distance prediction involves two scientific domains, viz. (a) the impetus imparted by the Explosive pressures to the fragment under the influence of confinement, and (b) the trajectory physics of uneven shapes travelling in air and their rebound from the landing surface.

These two domains are detailed further.

(A) Impetus in terms of the initial velocity of fly rock is dependent on: (i) Blast geometry and its departure from the design; (ii) Rock type; (iii) Rock mass and its anomalies.

(B) Post-release trajectory physics defined by: (i) Launch angle of the fly rock; (ii) Shape of the fly rock;

(iii) Size and weight of the fly rock; (iv) Magnus effect;
(v) Rebound from the surface of landing.

Thus, it is imperative to lay down the basis for fly rock distance prediction and in support of which McKenzie mentions ‘A reliable fly rock model must be able to provide reasonably accurate estimations of both projection Velocity and projection distance, ideally as a function of the fragment size and blast design’. It is assumed that rock mass conditions are included in the blast design for fly rock distance predictions.

4. CONCLUSION

The damages and injuries that are cause by the fly-rock and their effect are devastating especially when there are softer and loosely packed earth strata. Therefore, it is important to identify those engineering design parameters and control measure that could be used for controlling fly-rocks no matter how loosely packed or soft/hard rock we are dealing and this could be achieved only by using systematic engineering control measures and the best part is there are only two activities and procedure that need studious calculation and effort namely

1. Drilling Pattern and Diameter of the drill hole and
2. Blasting pattern and the type of explosives and delay techniques used.

The parameter that we would be working on in Phase II in order to come to a common platform on best methods that could be adopted to avoid fly-rocks are starting with the Empirical Equations that Supports Blast Designs which could be used by engineering’s to reduce fly-rocks followed by the best suitable surface blast design that could be adopted which will optimise only the fly-rock fragmentation and the most suitable drilling parameters that would enable optimum use of explosive for a good throw in the bench having heavy or medium fragmentation of the rocks. The secondary factors are underlying the most suitable burden and spacing for minimum drilling with maximum area covered and this is directly proportional to the correct and best materials used for stemming with the quantity of material used in relation to the depth of the hole, the type of explosive used in relation to the velocity of detonation and the type of delay. Electric or non-electric detonators that are going to be used. The other factor is the direction of the drilling hole to make sure proper toe is obtained while good fragmentation is obtained. It is very important that our hypothesis results could be predict which will be possible by establishing a derivation method where fly-rock could be predicted and appropriate safety actions could be taken and this could be validated by conducting and recording the field investigation and check if the designed parameters are optimum followed by Fly-rock analysis and chart out an observation based on pre-blast and post blast observation and this will help in prediction of the fly-rock distance so that adequate safety methods and avoidance procedure could be adopted.

3. REFERENCE

4. ISEE, Blaster’s Hand Book (1998)
5. Modified Mining Plan & Progressive Mine Closure Plan of Parthipura Limestone Mine (Lease: M/s Mahi Cement), Table No34,
PP 55.
