Technical Note on The Prediction and Control of Flyrock During Rock Blasting

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ABSTRACT

Flyrock is one of the major undesirable effects of blasting during construction, because it is the main cause of fatal accidents and serious injuries. This Technical Note presents a brief review on various causes of excessive flyrock, methods to predict the maximum distance of flyrock and the measures to be adopted for its effective control at a blasting site.

Key words : Flyrock, Blasting pattern, Accurate drilling, Burden, Stemming, Powder factor, Delay period

1. INTRODUCTION

Flyrock is one of the most hazardous unwanted effects of rock blasting used in quarrying, mining and construction activities In contrast to the other unwanted effects like ground vibration and airblast, which generally cause structural damage and annoyance to people living very close to the blasting site, the flyrock may be responsible for damage to property as well as fatal accidents and serious injuries at very long distances from the blasting site. More than 50% of the 103 accidents from different mining sites in United Kingdom during 1980-85 are reported to be due to flyrock up to distances ranging from 350 to 900 m (Bhandari, 1997). The authors have witnessed property damage up to 300 m at several construction sites. It is, therefore, imperative to have a reliable prediction of the maximum distance of flyrock and use suitable means and measures to control it within the safe and secured distance around a blasting site.

Excessive flyrock may occur if a significant part of the explosive energy intended to be used for breaking and displacing the rock mass in a controlled manner, is used to

throw the rock fragments violently. Blast design errors like improper burden, use of shallow holes, faulty drilling, inappropriate delay period, wrong sequence of firing and unfavourable geological set up (e.g., presence of open joints, mudseams, voids and cavities, etc.) are the principal cause of flyrock (Fletcher and D'Andrea, 1986; Schneider, 1996, 1997). Though, it is a difficult task to estimate the exact distance of flyrock from a blasting site, several studies (Lundborg et al., 1975; Roth, 1979; Gupta et al., 1988) have proposed empirical relations between the maximum distance of flyrock and the various blast design parameters like diameter of blast hole, powder factor and stemming to burden ratios. However, the results of these studies differ so widely that it becomes difficult to rely upon a particular relationship. The paper reviews several such relations for prediction of maximum flyrock distance and provides the general guidelines to take suitable decisions for a particular application.

The control of flyrock within secured distance around the blasting site can largely be established by proper selection of various blast design parameters. Selection of proper burden plays the most crucial role, as blasts with very small or very large burden may be associated with excessive flyrock. The powder factor is another important parameter, which influences the generation of flyrock. The precision in drilling is very important in controlling the flyrock, because even small errors in drilling may result in substantial increase in the powder factor, which may aggravate the flyrock problem. The secondary blasting used to break the large size boulders produce dangerous flyrock, eventhough the charges used are small. Improper delay timing, scatter in delay period and faulty initiation pattern are also the major cause of flyrock. The flyrock can be controlled effectively by selecting the various parameters described above in an appropriate way. In addition, examining the bench face, laying out blast hole pattern, accurate drilling, dewatering of holes before loading, stemming weak beds and voids and avoiding secondary blasting, are useful to minimise the flyrock effects. If the secured area is too small, suitable muffling arrangements may also be needed.

2. ESTIMATION OF MAXIMUM FLYROCK DISTANCE

To estimate the maximum distance of flyrock from a site of blasting, several investigators (e.g.; Lundborg et al., 1975; Roth, 1979; Gupta et al., 1988; etc.) have proposed empirical correlations in terms of various blast design parameters like diameter of blasthole, powder factor and stemming to burden ratios. Some of the widely used relations are described as below:

Lundborg et al. (1975) developed the co-relation to estimate the maximum distance, L_{max}, of flyrock from the blasthole diameter, D, as

$$L_{max} = 30.745D^{0.66} \tag{1}$$

Here L_{max} is in meters and D is in millimeters (mm). In construction blasting, blasthole diameters commonly used are 32, 76 and 102 mm, which will approximately

result in maximum flyrock distances of about 300, 535 and 650 m, respectively (Eq. 1).

For bench blasting, Jimeno et al. (1995) established the dependence of the maximum throw of flyrock on the powder factor as shown in Fig. 1. From this figure it is seen that the use of a powder factor of 0.2 kg/m^3 may eliminate the flyrock problem, but blasts with such low powder factor are commonly associated with poor fragmentation and excessive ground vibration. A powder factor of 0.5 kg/m^3 would result in a maximum flyrock distance of around 1.53 times the blasthole diameter. For blasthole of diameters 32, 76 and 102 mm and a powder factor of 0.5 kg/m^3, the maximum flyrock distances would approximately be 50, 115 and 155 m, respectively. These are much smaller than the corresponding distances estimated from Eq. 1, where flyrock are produced due to the crater effect.

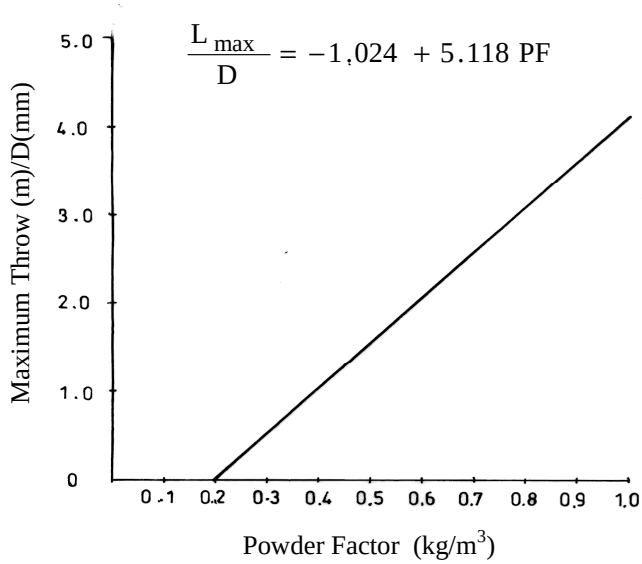

Fig. 1 – The maximum throw of flyrock of powder factor (modified after Jimeno et al., 1995)

The American model is based on the studies carried out by Roth (1979) in granite and limestone type of rock formations. Roth has provided a nomogram for ANFO as explosive material as shown in Fig. 2. From knowledge of the maximum burden and the blasthole diameter, the maximum flyrock distance could be estimated readily from this nomogram. For example, for 114 mm diameter and 3 m burden, expected flyrock distance from blasts carried out in granite is only 40 m. If water gel is used as explosive material, the flyrock distance obtained from the nomogram of Fig. 2 is to be increased by 50 %.

Gupta et al. (1988) have studied the dependence of L_{max} and the ratio between stemming (T) and burden (B) at four limestone mines and proposed the following empirical relationship:

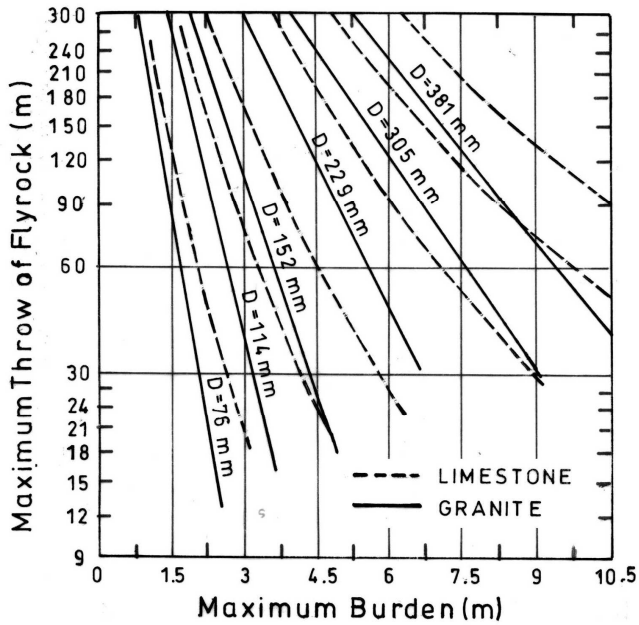

Fig. 2 – The nomogram for estimating the maximum throw of flyrock from a knowledge of blasthole diameter and maximum burden (modified after Roth, 1979)

$$\frac{T}{B} = 155.2 L_{max}^{-1.37} \tag{2}$$

The maximum flyrock distance is found to vary between 52 m and 40 m for stemming to burden ratio varying between 0.7 and 1, which is the commonly used range of T/B ratio.

Based on the observations from 47 experimental blasts conducted in six limestone quarries, Adhikari (1999) has indicated that maximum range of flyrock is around 300 m. However, except some stray incidents, the flyrock distances are predominantly scattered between 25 m and 150 m, which is quite compatible with the range of values expected from the nomogram of Fig. 2. The Director General of Mines Safety, Dhanabad has recommended the danger zone of flyrock to be about 500 m radius around the surface mining site (DGMS, 1982). However, adoption of 500 m as the danger zone/ secured area for construction blasts may not always be possible, as the construction blasting is often carried out in urban environment near thickly populated areas.

From the foregoing description it is seen that the maximum flyrock distance depends mainly on the blasthole diameter, burden, stemming column length and the powder factor. All these parameters used for construction blasts are quite different from that for the mining blasts. The range of parameters often used in construction blasting and

the expected range of flyrock distances computed from various relations discussed above are presented in Table 1.

Table 1- Comparison of expected maximum flyrock distances from various relations in vogue

Parameter	Range of Values	Distance (m)	Basis
Diameter of holes (mm)	32 to 102	300 to 650	Eq. 1
Burden (m)	1.5 to 3.0	12 to 120 for 76 mm dia. of hole	Fig. 2
Stemming to burden ratio	0.7 to 1.0	40 to 52	Eq. 2
Powder factor (kg/m^3)	0.3 to 0.7	52 to 260 for 102 mm dia. hole	Fig. 1

From several test and production blasts conducted in widely varying geological conditions, it has been observed by the authors that the maximum flyrock distances range from 250 to 300 m for blasts with wagon drill (76 and 102 mm) holes and 50 to 100 m for blasts with jack hammer (32 mm) holes. These observations are comparable with the range of values obtained from Fig.1. The danger zone/secured area for construction blasting may be decided by using a safety factor of 2 to 3 with the values based on Fig. 1.

3. FACTORS INFLUENCING THE FLYROCK

Improper 'burden' may be one of the most significant causes of excessive flyrock. A small burden may not be able to contain the explosive energy and result in excessive flyrock, whereas an excessively large burden may give rise to cratering or blowouts. Thus, selection of burden is crucial in controlling the flyrock. The following relationship proposed by Sarma (1986) finds wide applications to obtain an appropriate value of the burden,

$$B = 37.8 \left(\rho_e / \rho_r \right)^{0.33} D \qquad (3)$$

In this expression, B is the burden in meter, D is the blasthole diameter in meter, and ρ_e and ρ_r are the density of explosive and rock, respectively. The variation of ratio of burden to blasthole diameter with density of rock for some commonly used explosives is shown in Fig. 3.

The 'powder factor' is another important parameter which influences the characteristics of the flyrock generated during construction blasting. Use of excessive powder factor (using more quantity of explosive charge than required) results in

generation of violent flyrock. The rock type and the fragmentation requirement often govern the choice of powder factor. Langefors and Kihlstorm (1978) have recommended a powder factor of 0.4 kg/m^3 for blasting with burdens between 1 and 10 m. From econimical point of view, Gustafsson (1973) has suggested a powder factor of 0.5 kg/m^3 for quarry blasting. Based on observations from limestone quarries, Adhikari (1999) has used 0.45 kg/m^3 as the optimum powder factor and concluded that flyrock distance would be less than 60 m when ratio between the powder factor and optimum powder factor is less than or equal to 1.15. Based on observations from several case studies of construction blasting, Tripathy et al. (1999) have concluded that use of powder factor of 0.5 kg/m^3 gives minimum ground vibration. It may be noted here that faulty drilling of blastholes could increase the powder factor in a blast and hence the flyrock. As an example, a drilling error of 10^0 from vertical for a blasthole of 6 m depth and 3 m burden at the top may result in a decrease of about 1.05 m in the burden at the bottom. This will increase the powder factor by about 22 % as illustrated in Fig. 4. The energy from this extra powder factor is exhibited in the form of excessive flyrock. The effect is more prominent in deeper blastholes.

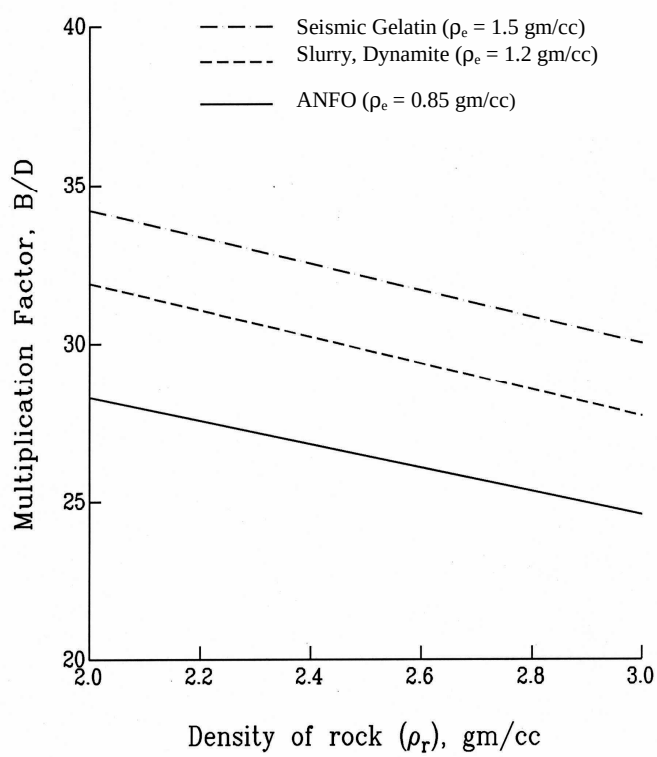

Fig. 3 – Variation of burden with rock and explosive properties (modified after Sarma, 1986)

Scatter in delay period, improper delay timing and faulty initiation pattern are also the cause of excessive flyrock. In general, the delay period has a maximum scatter time of ± 10 % of the rated delay period. Because of this scattering in delay period, some holes may fire well in advance than it is desired. Such holes are fired with highly

confined conditions and give rise to excessive flyrock. The delay timings between the rows of holes need to be so arranged that it must allow enough time for the fragmented rock to move so that the muck does not pile up in front and prevent the horizontal movement of the fragmented materials produced from detonation of subsequent charges. Too fast a timing between rows of hole will increase the flyrock problem. When row-to-row timing is too fast, the previous row has not had a chance to move, there is added resistance on the second row and the holes experience a much larger burden. Hence, they can not relieve laterally and tend to blow out vertically causing flyrock problem. The effect of inadequate delays between rows to aggravate the flyrock problem is illustrated schematically in Fig. 5 (Dick et al., 1983). Further, error in initiation sequence such that a back row fires before detonation of front row may result in excessive flyrock.

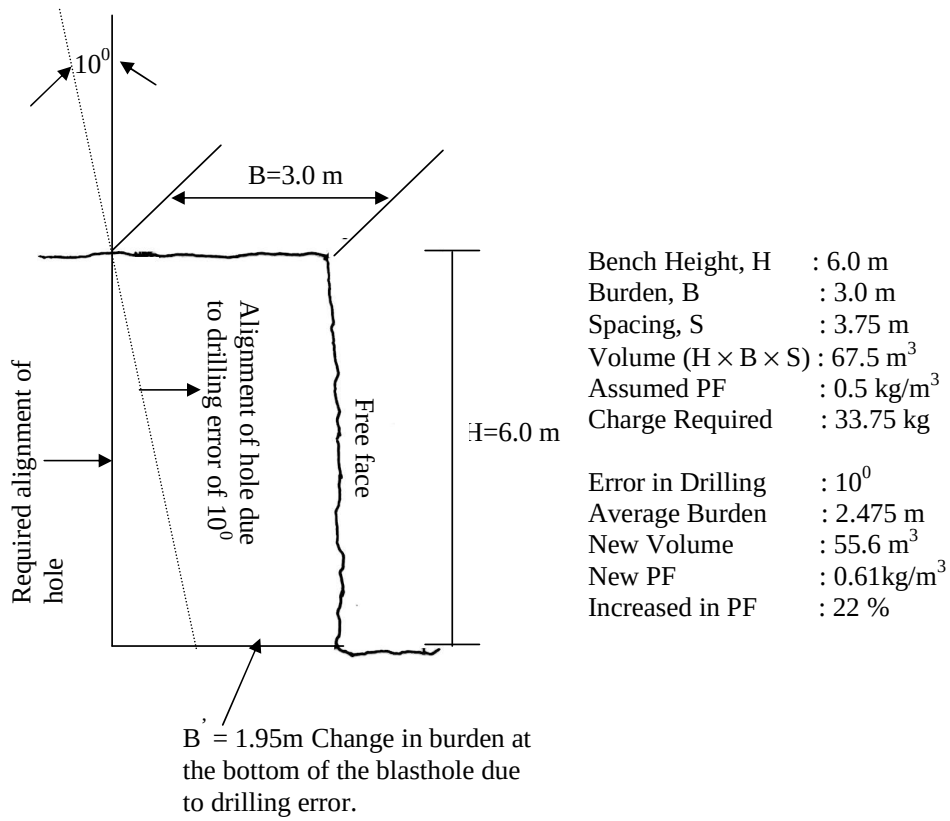

Fig. 4 – A schematic diagram to illustrate effect of drilling error on the powder factor

4. CONTROL OF FLYROCK

The various aspects need to be consider for minimizing the flyrock problem are discussed briefly in the following:

4.1 Blast Design Parameters

The first step to control the flyrock starts with proper selection of the various blast design parameters like depth and diameter of blastholes, burden, spacing, and bench

height, stemming column length, powder factor, delay period and sequence of initiation. The burden distance could be estimated using the results in Fig. 3. The other parameters like spacing, sub-drilling, depth of hole, etc. could be then approximately found by using empirical relationships (Dick et al., 1983) in terms of the burden. The stiffness ratio (the ratio between bench height and burden) may affect the flyrock significantly. Field experience indicates that a stiffness ratio between 2 and 3 is able to control the flyrock distance effectively.

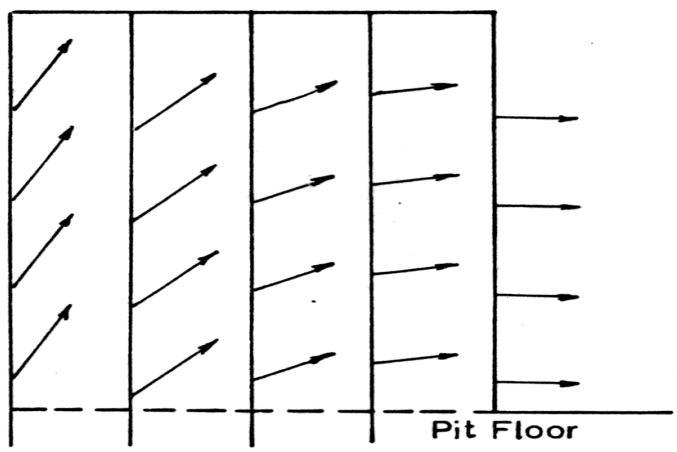

Fig. 5 – Schematic diagram showing the effects of inadequate delays between rows to aggravate the flyrock problem (after Dick et al., 1983)

4.2 Powder Factor

As discussed before, the powder factor is very important to control the flyrock and it is governed by the rock properties and the fragmentation requirement. Based on powder factor data used at different construction projects having rock formations with different seismic wave velocity, Tripathy et al. (1999) have found the following relationship:

$$PF = -0.734 + 0.497V_C - 0.0465V_C^2 \pm 0.0514 \quad (4)$$

Here, PF is the powder factor in kg/m^3 and V_C is the compressional wave velocity in km/s. For initial approximation, a powder factor between 0.4 kg/m^3 and 0.5 kg/m^3 could be used to estimate the requirement of explosives for the blast. This charge is to be distributed in a number of holes and to be fired with suitable delay.

43. Layout of Blastholes and Accurate Drilling

The face encountered at a blasting site is often irregular due to back break and over-breakage produced from the previous blast. Hence, the position of the first row of hole is very important. It is so because, due to unevenness of the face, the burden at some places may be smaller or larger than the actually designed. Blasts with either too small or too large burden are associated with excessive flyrock. In addition to the first

row of holes, due care should also be taken while positioning other blastholes. After layout of blastholes, it is very important to have precise drilling. As discussed in the previous section, even very small errors in drilling may lead to enhancement in the flyrock.

4.4 Careful Loading of Blasthole

Before commencement of loading a hole, it is very much necessary to check that the hole is drilled to the required depth. While loading the hole, it is absolutely necessary to monitor the rise in explosive column. Slower or sudden rise in explosive column may indicate the presence of a void or blockage in the blasthole. Also loading of explosives in mud seams or weak beds should be avoided, because they do not have adequate strength to confine the explosive energy and causes severe flyrock.

If the blastholes are filled with water, they should be dewatered. This is because, stemming materials when mixed with water present in hole results in formation of mud slurry having density greater than that of the explosive. In such case, explosives do not settle at the bottom of the hole resulting in concentration of explosives at the collar of the blasthole causing flyrock to travel a long distance (Gupta et al, 1988).

4.4 Adequate Stemming

The main purpose of stemming is to confine the high pressure gases released from the detonation of explosive. Thus, the stemming should be sufficient to prevent the force of the gases from violently cratering to the surface. Stemming column length should be between 0.7 and 1.0 times the burden. For controlling flyrock within 100 m, the ratio between stemming length and hole diameter should be maintained at 20 or more (Adhikari, 1999). Generally, the drill cuttings are used for stemming, which are not the best suitable materials. Crushed and angular sized materials are more suitable for stemming. The average size of the stemming materials should be approximately 0.05 times the blasthole diameter (FHWA-HI-92-001).

4.5 Delay Timing

The delay timings between rows play very crucial role in controlling the flyrock. While dealing with multiple rows blast, the delay period between two rows should be long enough (at least 2 times than those used between holes in a row) to allow rock from an earlier row to move out so that the next row will have adequate relief. Blasting of misfire holes is associated with dangerous flyrock.

4.6 Muffling Arrangement

In addition to the above precautionary arrangements, it is advisable to use suitable muffling arrangements to cover the blasting site. Covering the blast with wire mesh, iron plates, sand bags etc. helps in mitigating the flyrock problem.

5. CONCLUSIONS

Among the various unwanted effects of blasting, the flyrock is of great concern to the blasting personnels, because it may be critical even at longer distances where ground vibration and airblast are not very significant. Geological faults, excessive powder factor, use of shallow holes and insufficient stemming are the main causes of excessive flyrock. Blasthole filled with water also cause excessive flyrock. The maximum flyrock distance is affected by blasthole diameter, burden, stemming length and powder factor, and could be controlled by adjusting these parameters.

The maximum flyrock distances may initially be estimated by using various empirical relations discussed in this note. However, from several field studies it has been found that the maximum flyrock distance estimated from Fig. 1 by assuming an approximate powder factor between 0.3 and 0.7 kg/m^3 compares well with the observations.

Acknowledgement

The authors are very thankful to Mrs. V.M. Bendre, Director, CWPRS, Pune for providing encouragement during preparation of the paper and according her permission to publish it.

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