Chapter 3

THE GUIDED APPROACH

In the field of rock blasting, extensive fundamental research has been conducted during the last two decades. The researchers attempt to represent the reality of the blasting process by theory, models, laboratory tests and experiments. In practice, conventional design methods based on engineering judgment and experience are still extensively used to deal with the full scale reality. Most results of fundamental research are still far away from applying to practice. This implies that there exists a gap between theory and practice. Hence efforts are made in this study to bridge the gap by giving more attention to the practical aspects of rock blasting and by integrating the theory and practice to arrive at an optimum blast design.

A blast may not produce the desired results either due to use of an unsuitable explosive or due to an improper blast geometry and initiation sequence. In the event of failure of a blast, quite often the rock is blamed as it does not respond, some times the explosive is also blamed. However, most of the times the blast fails due to an improper blast design and implementation. A good blast design must ensure that: a) the potential explosive energy is adequate, b) the potential energy is actually released, and c) the released energy is used to fragment and displace the rock mass.

In order to provide a procedural guidance for blast design, a new approach, called the guided approach is proposed for those who are involved in planning, design and execution of blasts at surface mines for optimal fragmentation and reduced environmental effects. The guided approach is a balanced approach in which all the factors which interact and even those which cannot be quantified are taken into account. Fig 3.1 illustrates the key steps and components of the guided approach. The blast designer is guided by a sequence of events and steps in the blast design process. The guided approach consists of all relevant elements that include objectives, study of the existing practice, site characterisations, selection of explosives, environmental considerations, determination of blast design parameters, initial design, field trials, assessment of blast performance and optimisation. Of these, selection of explosives, environmental considerations and calculation of design parameters are voluminous and hence are discussed in separate chapters.

In developing this approach, the design principles for rock engineering (Bieniawski, 1992) such as state-of-the-art, minimum uncertainty, optimisation, and simplicity have also been taken into consideration.
Fig 3.1 Key steps of the guided approach to blast design at surface mines.
Step 1: Objectives

Among the fundamental elements of the guided approach is the establishment of objectives. Generally, for a blast design, the main objective is optimal fragmentation but ground vibration and flyrock control may be more critical at some mines. It is necessary to draw up a list of objectives which must be achieved by the blasting operation. Some objectives may have high priorities over others due to site-specific conditions. The guided approach helps not only to achieve a particular objective but also a combination of objectives.

Step 2: Study of the existing blasting practice

Although the existing practice is commonly reviewed by a blast designer, none of the existing approaches recognizes this as one of the important steps in the blast design process. A critical review of the existing blasting practice helps in identifying the shortcomings and in exploring the possibility of improving the blast results by introducing new techniques or new products. It also helps in establishing a baseline for comparison of results and benefits accrued by the modified design. The objectives may be redefined or priorities may be decided after studying the existing practice.

In order to study the existing practice, it is suggested to collect blast records from the mine and to enter the data into the computer in a spreadsheet or database file so that desired information can be retrieved and analyzed. In case, previous blast records are not available or if it is felt that they are not reliable, a few blasts with the existing practice can be studied. The average values of design parameters and the range within which they have been varied for various rock types in the mine are to be established.

Step 3: Site characterisation

Detailed site investigation is essential to characterise a site. The site characterisation provides input for determination of blast design parameters, forms the basis for charging the blastholes and also enables to estimate the cost of excavation for a given mine. It gives an idea whether it would be difficult or easy to achieve the desired degree of fragmentation with good control over environmental hazards.

The guided approach incorporates the most important, simple and readily available site characteristics that have relevance to rock blasting. They are used for estimating various blast design parameters and selection of explosives as described below.
1) Rock type

Rocks are classified into igneous (granite, gabbro, diorite, basalt, andesite), sedimentary (sandstone, coal, limestone) and metamorphic (marble, gneiss, schist). The rocks at a mine can be divided into different geological domains. Updated geological plans and sections prepared by the mine can provide this information. The site geology provides valuable information as the geotechnical properties are closely linked with the origin and formation of rock. Fresh (unweathered) igneous and metamorphic rocks are usually difficult to blast. Rocks can be further classified as waste or ore, coal or overburden.

2) Compressive strength

Compressive strength is the ultimate compressive stresses that the rock can withstand before failure. Based on the compressive strength, the rocks are rated as hard, medium hard or soft (Table 3.1). Since compressive strength and Point Load Index are correlated, the compressive strength can also be estimated from the Point Load Index as (Goodman, 1989):

\[
\sigma_c = 24 I \tag{3.1}
\]

where

- \( \sigma_c \) = compressive strength (kg/cm²).
- \( I \) = Point Load Index

Table 3.1 Rock categorisation based on compressive strength

<table>
<thead>
<tr>
<th>Compressive strength (MPa)</th>
<th>Rock rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 70</td>
<td>Hard</td>
</tr>
<tr>
<td>30-70</td>
<td>Medium hard</td>
</tr>
<tr>
<td>&lt;30</td>
<td>Soft</td>
</tr>
</tbody>
</table>

Though tensile strength is also important, it is related to the compressive strength. The dynamic strength values of rock are not considered in this study because they are difficult to determine on routine basis.

3) Density

Density is the mass per unit volume. Low density rocks are deformed and broken easily, whereas dense rocks are difficult to blast. The density of rock controls fragmentation as well.
as throw of the blasted material. Density (or specific gravity) of rock has been used for blast
design (Konya and Walter, 1990, Berta, 1990).

4) Penetration rate of drilling

Penetration rate varies with the variations in the strength of the strata and reflects the
relative ease with which the rock is fragmented during blasting. Continuous record of the
penetration rate against hole depth provides a basis for distribution of explosive charges in
sedimentary formations. In igneous rocks too, rocks can be locally categorised based on the
penetration rates into different units, for which separate blast design parameters can be
specified. Penetration rate can be either recorded manually or using automatic drill monitoring
systems (Hendricks et al, 1990; Baldwin and Vynne, 1995). Penetration rate and other drilling
parameters have been used in blasting (Leighton et al, 1982; Jimeno and Hevia, 1987).

5) Block size

Block size in a rock mass can be estimated by $J_v$ (Palmstrom, 1985) or by $\text{RQD}/J_n$ (Barton
et al, 1974) where

$$J_v = \sum \frac{1}{S_i} \quad (3.2)$$

$J_v$ = number of joints per unit volume of rock mass

$S_i$ = joint spacing for different sets ($i = 1, 2, 3...$)

RQD = Rock Quality Designation (Deere, 1968)

$J_n$ = number of joint sets

$\text{RQD}/J_n$ has been incorporated in an equation for prediction of fragmentation by Kou and
Rustan (1993). RQD can vary from 10 to 100 and $J_n$ from 0.5 to 20. It means $\text{RQD}/J_n$ can
vary from 0.5 to 200. Such a large range is not suitable for inputs in blast design.

It is proposed to use $J_v$ as it takes into account all the joints in three-dimensions. The
block size is categorised into three groups as large ($J_v < 3$), medium ($J_v = 3-10$), and small ($J_v
> 10$). If joint spacings are not known, it can be calculated from RQD as (Palmstrom, 1985)

$$J_v = 33 - \frac{\text{RQD}}{3.3} \quad (3.3)$$

Information about RQD, the number of joint sets and their spacing may be available at the
mine. Otherwise, joint mapping for this purpose is essential.
6) Blasthole logging

Geological section of blastholes or blasthole logging is required if the strata consist of interbands of soft and hard rock. It is to be noted whether a clear parting or bedding plane exists at the grade level. Geological features like cavities, open joints and clay seams provide a line of least resistance to the explosion gases and affect not only fragmentation but also create environmental hazards. The cavities may get filled with explosives during charging and may result in higher concentration of charges causing flyrock and air overpressure. The presence of the geological features renders a site unfavourable and special care is required during design and implementation of the blast.

7) Hydrogeology

The presence or absence of water in blastholes is important. Ground water table from field observations or piezometer readings should be collected.

In summary, the various site characteristics and their relevance to blast designs are given in Table 3.2.

Table 3.2 Relevance of site characteristics to blast design

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Site characteristics</th>
<th>Relevance to blast design</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rock type</td>
<td>Classification into different rock units, powder factor</td>
</tr>
<tr>
<td>2</td>
<td>Compressive strength</td>
<td>Burden, stemming, selection of explosives.</td>
</tr>
<tr>
<td>3</td>
<td>Density</td>
<td>Powder factor, for matching rock and explosive properties</td>
</tr>
<tr>
<td>4</td>
<td>Penetration rate of drilling</td>
<td>Relative hardness of the rocks</td>
</tr>
<tr>
<td>5</td>
<td>Block size</td>
<td>Selection of hole diameter, burden, spacing, stemming, powder factor, matching rock and explosive properties</td>
</tr>
<tr>
<td>6</td>
<td>Blasthole logging</td>
<td>Charging pattern of blastholes, control of flyrock, air overpressure</td>
</tr>
<tr>
<td>7</td>
<td>Hydrogeology</td>
<td>Type of explosive, hole depth, decking, stemming material</td>
</tr>
</tbody>
</table>
Step 4: Selection of explosives and initiation system

Selection of suitable explosives is an important component of the guided approach. Various types of explosives are manufactured in India and the choice is available among NG-based explosives, slurries, emulsions, ANFO and HANFO. The choice is also available between cartridge and bulk loading systems. In Indian mines, too much importance is given to the cost of explosives alone, which is against the basic definition of optimum blasting. A methodology is suggested for selection of explosive considering the volume of rock excavation, the presence or absence of water in the blastholes, the rock mass properties, the performance evaluation of explosives for a given condition and the unit cost of production. The details are presented in Chapter 4.

The various types of initiation systems available presently in India are 1) detonating cord downlines in blastholes initiated by millisecond electric delay detonators, 2) detonating cord downlines initiated by surface trunklines which are delayed using cord relays, 3) shock tube initiation system in combination with detonating cord and detonating relays, and 4) total shock tube system. Although the shock tube system is internationally popular, the detonating cord continues to be the common initiation system in Indian surface mines. The disadvantages of the detonating cord as a downline system are 1) desensitisation of explosives column, 2) stemming ejection, 3) top initiation of blastholes, 4) excessive noise, and 5) cutoffs.

Keeping the state-of-the-art principle in view, it is recommended to use the latest initiation system for better accuracy, reliability, and safety. However, availability and economic criteria may limit the use of certain explosives and accessories.

Step 5: Environmental considerations

Ground vibration, air overpressure, and flyrock are the unwanted side effects of a blast. Improper blasting causes economic and operational difficulties and create serious safety and environmental problems, particularly when blasting near inhabited areas. It is important, therefore, that all blasts be carefully designed in such a way that they are compatible with mining conditions and surroundings. Norms and standards, regarding ground vibration and air overpressure (Siskind et al., 1980a, Siskind et al., 1980b, Anderson, 1993), specified by regulating agencies should be complied with. However, compliance with the regulations does not guarantee that there would be no complaints. There were serious complaints about the blasts at a number of mines where the recorded values were within permissible limits. All cracks in the structures in the surrounding areas were attributed to blasting operations. The controversies exist because the human response to ground vibration and air overpressure is
much lower than the permissible limits. During vibration studies at several mines in India, the reaction of people of the neighbouring villages to vibration was negligible when peak particle velocity (PPV) was within 5 mm/s, moderate up to 10 mm/s and severe conflicts and controversies at PPV above 10 mm/s. Complaints about the noise start from 120 dB. Therefore, the mines can keep their neighbours happy by controlling PPV within 5 mm/s and air overpressure within 120 dB. Flyrock should be restricted within the one-half distance between the blast and the nearby dwellings.

The registered complaints may be about the ground vibration but the real problem may be due to excessive noise produced from secondary blasting. The blasting engineer has to find out the root cause of the problem before attempting to solve it.

It is imperative to utilise the blast energy in breaking rock by controlling the dissipation of energy in unwanted forms. In conforming with the law of energy conservation, energy used in one cause cannot be available for other purpose. Methods to assess and control environmental effects due to blasting are discussed in detail in Chapter 5.

**Step 6: Determination of blast design parameters**

For given mine parameters like bench height, the blast designer has to determine blasthole diameter, burden, spacing, subgrade drilling, hole depth, stemming, powder factor, initiation sequence and delay timing. These parameters affect the energy transfer from explosive to rock mass and the utilisation of an explosive energy for the same rock with the same explosive. An appreciable knowledge of the effect of all these parameters is essential for safe, economic and efficient blasting.

While evolving methods for the calculation of design parameters, the influences of design parameters on blast results are initially examined and the most significant parameters are identified. The calculation procedure is driven by the questions that the procedure is supposed to calculate rather than the details of all the factors that influence the parameter. The most important parameters that influence blasts are the blast geometry and initiation sequence. These parameters are discussed in Chapter 6. The essence of blast design is to distribute explosive energy appropriately throughout the blast volume by detonating it in the right sequence and at the right time. The distribution of explosive energy is obtained through hole diameter, hole depth, burden and spacing. By changing the geometry and initiation timing, the degree of fragmentation can be altered in any type of rock. Utmost importance is given to simplify the calculation procedure using readily available input data keeping the "simplicity
principle in mind. Parameters that are not included in the calculation of initial design are taken into account at the evaluation stage.

In keeping with the trend of blasting, the blast designer should plan for large blasts, depending on the production target, bench height, capacity of drilling machines and environmental constraints. Small and frequent blasts in a mine interrupt the production and should be avoided. Moreover, boulders usually come from the first row of holes and decrease in multirow blasts. It is therefore recommended to drill a minimum of 3 to 5 rows of holes.

**Step 7: Initial design, analysis and design alternatives**

By comparing the existing design parameters with the calculated ones, the shortcomings in the existing design can be identified and the blast designer can arrive at an initial design. For a new mine, the study of existing blasting practice is not applicable and the initial design is based only on the calculated design parameters.

If the blast designer has access to computer simulation programs such as SABREX (Kirby et al, 1987) and BLASPA (Favreau, 1980) he can examine and analyse several alternative designs and can select some alternatives. It may be noted that simplified methods of site characterisation are not adequate for computer modelling and simulation. Additional rock and explosive properties depending on the available software are required. SHOTPlan blast design sequence software (Irving et al, 1995) can be used to analyse different options for initiation sequences.

It is not uncommon to see an improper blast geometry in the field. The failure to recognise irregular geometry is bound to contribute to poor blasting performance. The design should not be rigid, it should be flexible. Given proper justifications there should not be reluctance for its change. It is found that field personnel are sometimes reluctant to change the established site practices. They have some feeling that they will be blamed if the blast goes wrong with the new design. This is a negative approach. However, design should not be randomly changed. There should be proper justification for the change based on monitored data, understanding of the influencing parameters and calculation of design parameters.

**Step 8: Field trials**

When the initial design and design alternatives are decided, the next step involves field trials. This is due to the fact that site-specific geological unknowns are encountered during field trials. There are also uncertainties about the explosive properties and firing timings of the
delay initiators. As the trial blasts cannot be dispensed with, it is advised to reduce the number of field trials through a better knowledge of the range and limitations of the key variables involved.

During field trials, blasts should be monitored. Because of the complex nature of blasting process, the blast monitoring has an important role to play in the decision-making. The purpose of the pre-blast monitoring is to control deviation of the design from the actual. All the details like hole positions, hole depths, nature and condition of holes, type and quantity of explosives, initiation system, sequence and delay timings are to be recorded. Information collected during drilling is invaluable for rock characterisation and design of loading pattern of blastholes. If the field control and implementation of the design is poor, even an optimised design will not produce good results. Latest instruments like digital hole depth indicators, laser profilers etc., may be used to survey the blocks.

In-blast monitoring covers the time period from the first initiation impulse until the broken rock has come to rest and the vibration from the event have died away. Its purpose is 1) to check ground vibration, air overpressure and flyrock, and 2) to check the performance of explosives and initiation systems. High-speed photography, videography, discrete or continuous VOD recorders and seismographs can be used to generate the data.

**Step 9: Assessment of the blast performance**

The most important part of the guided approach is the assessment of blast results. It is necessary to assess fragmentation, muck profile, flyrock, ground vibration, air overpressure and the cost. The evaluation of blasting results indicates whether they are satisfactory and helps in correlating the design parameters with the actual results. If the initial design complies with the objectives then it is finalised as an optimum design. If not, problem areas are identified and necessary modifications in the blast design are then made to overcome the problems. This process is repeated with only those parameters that need further modification and then modified designs are tried until it satisfies the design objectives. Thus, the blast design is an iterative process whereby designs are prepared, tested, evaluated and modified, as necessary.

This is the phase for post-blast monitoring. The fragmentation can be evaluated by several methods such as 1) visual analysis, 2) photographic analysis, 3) loading equipment productivity, 4) secondary blasting/boulder count, 5) bridging delays at the crusher, 6) partial or complete screening, and 7) image analysis.
Latest trend in blasting research indicates that the image analysis techniques (Cheimanoff et al., 1993; Kemeny, 1994; Palangio, 1995; Poniewierski et al., 1995) will be the most accepted method for fragmentation analysis. Quantifying the nature of a blast muckpile is not a routine practice in mining. However, the mines assess fragmentation based on teeth life of a bucket and rope life of a shovel in addition to visual and secondary blasting/boulder count. Based on this, feedback can be obtained from the mines about the performance of a blast design. Other methods which have been used by the author are:

- Monitoring of power consumption by a shovel,
- Cycle time of a loading machine, and
- Number of passes to fill the dumper.

Monitoring of blasts and subsequent operations in detail provides enough data to analyse the effect of blasting on costs. This gives the designer an insight into the blast performance and leads towards the optimisation.

**Step 10: Optimisation**

Optimisation, considered the foremost goal of a blast design, is the stage where the concept of optimum blasting must be fulfilled. The blast design is an optimal design which is finalised from the field trials and their evaluation based on optimisation theory, including cost considerations.

In the process of rock excavation if the objective is changed, one has to seek for another optimal solution. The blast design may require gradual change of parameters to consider the changes in geology. If the site geology varies quite frequently then optimisation becomes very challenging. In this case, it is essential to develop capability of the field engineers to modify the blast design according to the changed condition. A short-term appointment of an outside consultant may not solve the problem.