

CONTROLLED BLASTING TECHNIQUES FOR DEVELOPMENT OF ROAD INFRASTRUCTURES IN HILLY TERRAIN

H. K. Verma

CSIR-Central Institute of Mining & Fuel Research Regional Centre, CBRI Campus, Roorkee drharsh77@gmail.com

ABSTRACT

Blasting is a process of breaking the rock mass to excavate the ore and materials. Many open blasting operations are faced with the apparently conflicting requirements of providing large quantities of fragmented rock and of minimizing the amount of damage inflicted upon the surrounding slopes. A slope in strong hard rock is not necessarily stable, nor is a slope in weathered weak rock necessarily unstable. In some cases the reverse is true, depending on the geometry of joints and weak planes. Many slope failures in hard rock occur with no or very little warning. Detection and monitoring may not be feasible, or require sophisticated instruments and procedures that are not practical at some locations. An important element in avoiding catastrophes is to study the site geology for dangerous conditions, implement the types of blasting procedures that minimize failures, and evaluate the potential use of reinforcement or other mechanical stabilizing procedures.

Apart from undesired profile of excavation, the conventional blasting damages the surrounding rock mass and structures like buildings, etc. These damages can be minimized by use of controlled blasting technique. The controlled blasting technique (CBT) is used to produce the desired stability of pit walls/slope. The CBT used for slopes is specifically termed as wall controlled blasting technique (WCBT). WCBT includes buffer blasting, trim blasting, line blasting and pre-splitting. Among these, the pre-splitting is the most commonly used technique. This technique has several advantages such as minimum damage from back-break, enhanced carrying capacity, higher structural stability and stable final pit walls or slope at the designed angle thus improving overall safety of wall/slope.

Key words: Wall control blasting technique, Rock mass damage, Construction blasting vibration, Pre-splitting

INTRODUCTION

Blasting is a process of breaking the rock mass to excavate the ore and materials. Many open blasting operations are faced with the apparently conflicting requirements of providing large quantities of fragmented rock and of minimizing the amount of damage inflicted upon the surrounding slopes.

Conventional blasting cause cracks and fractures in the rock which has been fragmented and also in the remaining rock, whereas the rocks mass itself is very often part of structures which must have certain strength. Lack of attention to blasting adjacent to final wall slope can lead to slopes that are psychologically uncomfortable and even dangerous to work beneath. There are evidences to suggest that a substantial number of slope failures have been aggravated or even precipitated by poor blasting practice. Damages to the final wall slopes can be minimized by use of controlled blasting technique.

All the controlled blasting techniques (CBT) are based on common objective of uniform distribution of explosive energy along the hole column so as to reduce the crushing, fracturing and over break of the remaining rock and least disturbance to the strength of the intact rock mass (Devine, 1966). The CBT used for slopes is specifically termed as wall controlled blasting technique (WCBT). The goal of WCBT is to make the transition from a well fragmented rock mass to an undamaged slope in shortest possible distance. These techniques are used to obtain a pit wall, free of back break and loose rock that will stand safely at the required wall angle for extended periods of time. Usually the method is employed for preparing the final pit wall and slope construction work for producing a high quality wall at the cut limit.

WCBT includes buffer blasting, line drilling, trim blasting and pre-splitting. Among these, the pre-splitting is the most commonly used technique. This technique has several advantages such as minimum damage from back break, enhanced carrying capacity, higher structural stability and stable final pit walls or slope at the designed angle thus improving overall safety of wall/slope. Several blast design factors influence the stability of the wall such as

horizontal relief away from the wall, energy concentration adjacent to the wall, blast size and duration of the blast (Bhandari, 1997). The horizontal relief available away from the face is important as it provides excess explosive energy to be utilized in throwing the fragmented rock mass which would have otherwise caused back breakage.

Another important factor influencing the controlled blast design is energy concentration in the penultimate and last row of the blast. It is advisable to work out the energy concentration by undertaking trial blast in the less sensitive area. Controlled blast consisting of more than two rows prohibits horizontal relief to the broken rock. Therefore, the blast size and duration of the blast rounds will also affect directly the performance of the controlled blasting techniques. The last major factor that controls wall stability is the field implementation of the excavation plan. Even well conceived damage control programs will not perform properly if there is no commitment to quality. Quality, in this case, refers to proper face clean-up, accurate drilling and precise charging of the blastholes.

CSIR-Central Institute of Mining and Fuel Research (Erstwhile, CMRI), Regional Centre, Roorkee has carried out controlled blasting for the development of benches and monitoring of the blast induced vibration at Kol Dam Hydroelectric Power Project, Himachal Pradesh. Pre-split blasting technique is adopted for developing benches in the desired profile in this project site. Experience in designing and implementation of pre-split control blasting techniques in the Kol dam project site is discussed in this paper.

WALL CONTROL BLAST TECHNIQUES

There are three key parameters for achieving efficient wall control blast performance. In sensitive zones, each of these key parameters must be in balance with the others to efficiently protect the wall. These three key parameters are illustrated in Figure 1. The distribution of the explosive energy will be based on the charge diameter and blasthole pattern used. Excessive charge diameters can increase slope damage due to uneven energy distribution. In many cases, it is necessary to air-deck such holes to improve the distribution of energy and reduce damages.

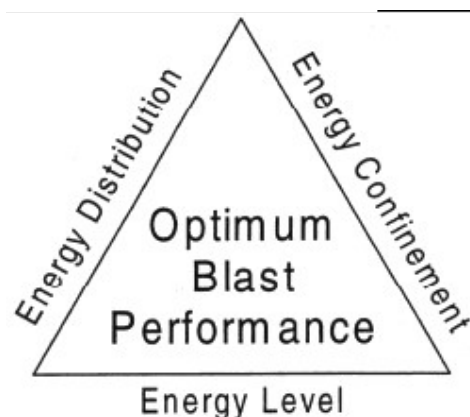


Fig. 1: Three key parameters for optimum blast performance (Blair, 1987)

In wall control blasting the degree of confinement of the explosive energy adjacent to the slope will play a major role in the amount of damage produced. The blast designer should always provide the explosive energy with a path of least resistance away from the wall. The goal of wall control blasting is to make the transition from a well fragmented rock mass to an undamaged slope in shortest possible distance (Holmberg, et al., 1987). In such situations, blast designer try to limit the blast damage by reducing the explosive energy. This in turn can adversely affect productivity of excavator. In reality, the designer should develop blast design that direct the explosive energy away from the wall while providing satisfactory fragmentation.

Following are four techniques used for wall control blasting

1. Buffer blasting
2. Trim blasting
3. Line drilling
4. Pre-splitting

Buffer Blasting

Buffer blasting is most successful when the rock is quite competent or on slopes designed with a higher factor of safety. However, the buffer row, which involves modifying the loading and pattern for the last row of the final production blast, is essential to good pre-split blast results.

The primary disadvantage of buffer blasting is that the wall is not protected from crack dilation, gas penetration and block heaving. In buffer blasting, the energy level is decreased adjacent to the wall to reduce over break. This is often achieved by simply reducing the charge weight (30 to 60%) in the row nearest. However, most rock types require additional design modifications to minimize damage.

These modifications can include air decking, reducing the burden and spacing dimensions (by 25%), minimizing sub drill and increasing the delay interval between the last two rows of blastholes. These potential design changes are shown below in Figure 2.

One of the key elements in the success of buffer blasting is standoff of the last row of holes. The blast hole standoff is the distance from the last row of holes to the final slope. This offset controls both the wall stability and ease of excavation of the toe. The optimum standoff distance will depend on the strength and structure of the rock mass and should be determined by carefully analyzing blast performance (John 1998).

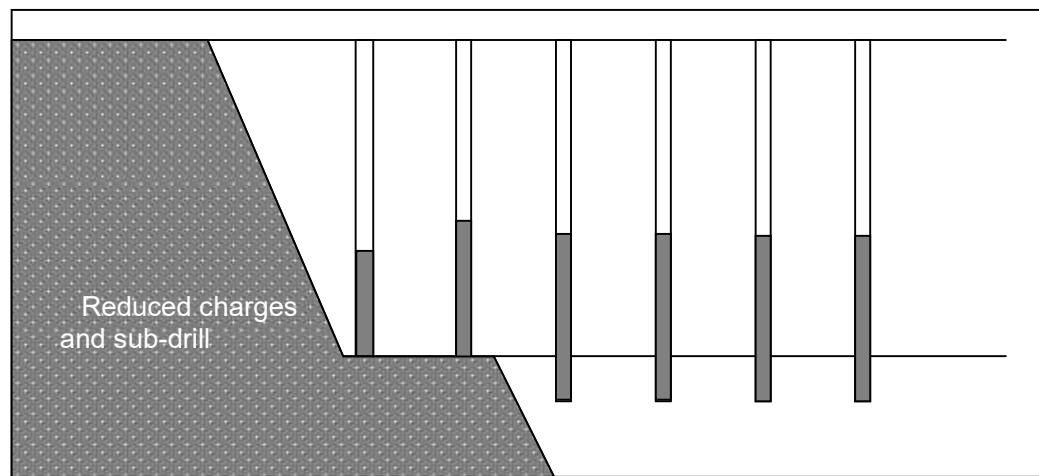


Fig.2: Buffer blasting in competent rock

Following are the guidelines for designing buffer blast:

1. Locate the modified production row 1 m out from toe of the slope
2. Reduce production charge weight by 50% in the last row
3. Use air decks and minimize the stemming length in the last row
4. Minimize sub-drill when drilling adjacent to the next catch bench
5. Reduce the burden and spacing of the last row by 25%
6. Increase the delay timing between the last two rows of holes

Trim Blasting

The second method for wall control is trim blasting. Trim blasts are generally used for rock mass that are too sensitive for modified production blasting. Three types of blast holes are used; trim, buffer and modified production holes. For better performance of trim blasting, a free face must be established to fragment and displace the rock horizontally away from the wall. If the free face does not exist the explosive energy path of least resistance will be uncontrolled and wall damage can be excessive. A typical trim blast for favorable conditions is shown below in Figure 3.

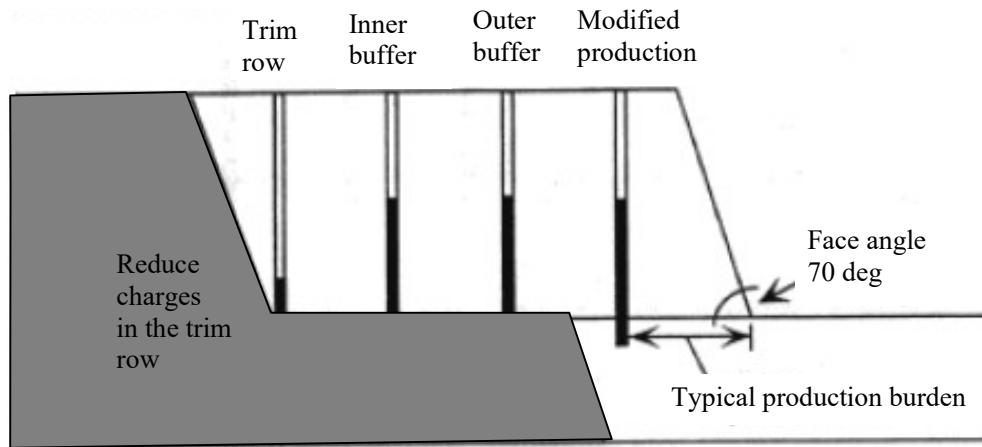


Fig. 3: Trim blast design for favorable conditions

It is advisable to use airdecking in at least in the trim row to improve energy distribution and reduce backbreak. Air-decks may also be required in the other rows to compensate for the reduced burden and spacing dimensions. Figure 4 illustrates trim blasts in unfavorable geological conditions.

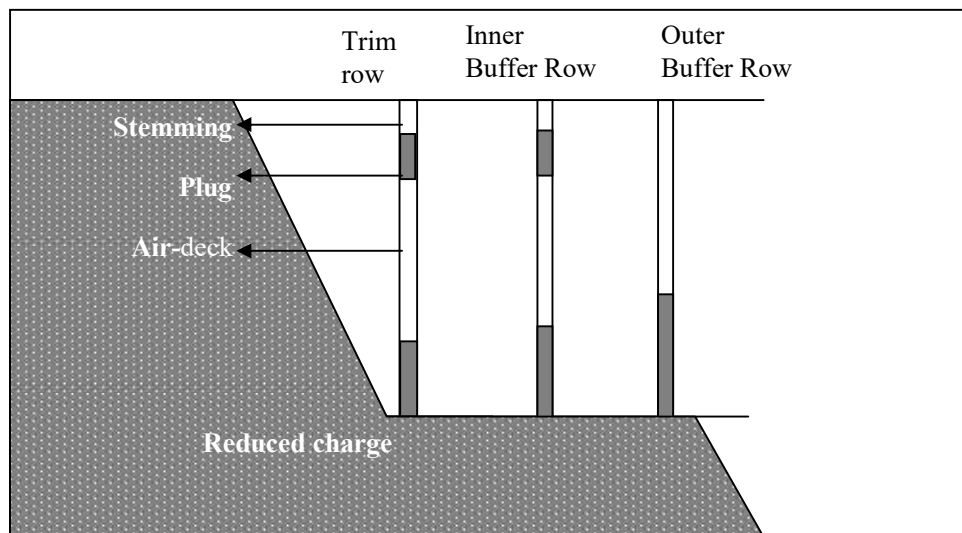


Fig.4: Trim blast design for unfavorable conditions

The critical design elements for trim blasting are:

1. Standoff of trim row from toe of slope (determined by rock strength)
2. Catch bench width (for buffer row locations)
3. Sub-drill depth (particularly important adjacent to the bench crest)
4. Trim row spacing is typically less than the burden dimension
5. Face burden (horizontal relief)
6. Bench width to height ratio (should be less than 2)
7. Timing configuration
8. Overall energy level (depends on rock strength)
9. Energy distribution (trim row may require air-deck)

Line Drilling

Line drilling involves the use of closely spaced, small diameter drill holes along the perimeter of final excavation. Line drilling is really not a blasting technique as these holes are left open and not loaded with explosives but provide a defined line along which the final blast can break. The line drilled holes provides a plane of weakness to which final row of blast holes can break. The stress waves of the blast create a plane of breakage between the holes.

The hole diameter for line drilling is usually 50-70 mm. Holes are spaced two to four times the holes diameter. The maximum practical hole depth for effective line drilling depends upon how accurately the holes can be aligned at depth. Depth of drill holes is seldom more than 10m. As additional preventive measures, the last row of production holes adjacent to line drilling are drilled closely and charged lightly using air decking and detonating cord down the line.

Line drilling is limited to areas where even a light load of explosives in the perimeter holes would cause unacceptable damages. Typically, line drilling is used in very soft material. In hard rock, the hole spacing required is so close that pre-splitting becomes more cost efficient. Line drilling can be used in conjunction with modified production or trim blast designs. The line drilled row is normally placed between 50 and 100% of the normal production burden from the trim or production row.

Line drilling is not often used in mines because the cost is too high. For those construction jobs where back break may be very costly, this procedure can be used. It is sometimes used in mines for critical situations such as preparing a wall for a crusher installation, in this case half-depth holes may be drilled between the normal pre-split holes to insure that the wall breaks cleanly at the crest. Figure 5 illustrates the line drilling technique of wall controlled blasting.

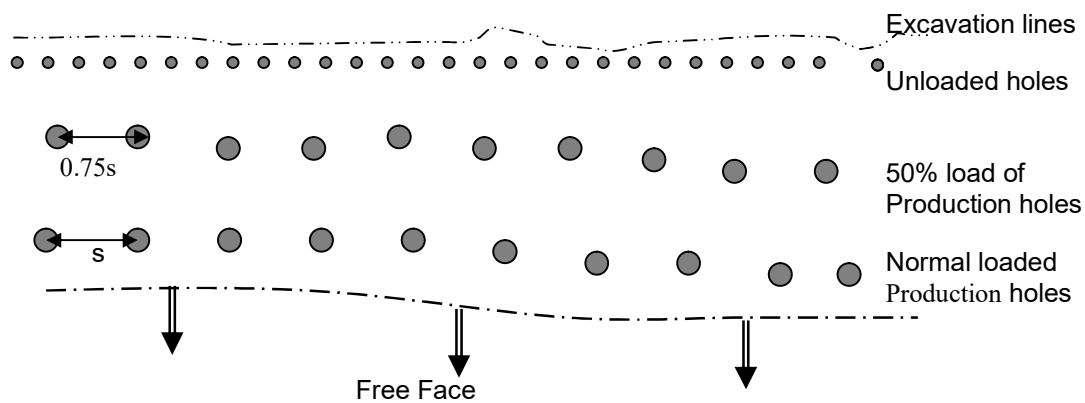


Fig.5: Line drilling along the final excavation

Pre-split Blasting Technique

Pre-splitting blasting consists of a row of lightly charged, closely spaced holes adjacent to the final slope that is fired prior to the detonation of the other holes. This creates a breakage plane to vent explosive gases and reduce crack propagation.

A pre-split blasting is best carried out when the burden is composed of homogeneous consolidated rock. In a badly fractured rock unloaded guide holes may be drilled between the loaded holes. The light explosives charges can be obtained using specially designed pipe cartridges, part or whole cartridge taped to detonating cord down line. A typical pre-split blast for favorable rock condition is shown in Figure 6.

In pre-split technique holes spacing and charge concentration is an extremely important factor. In most rock types the pre-split blast hole should be angled to achieve a more stable wall. The angle selected should be based on the slope design, rock structure, drill type and charging requirements of the blast holes. The key factors that control the success of pre-splitting are drill accuracy, geological structure, hardness, pre-split spacing, pre-split charging, standoff distance of inner buffer row, face burden (horizontal relief), bench width to height ratio (should be less than 2), timing configuration, overall energy level (Lyall, 1993).

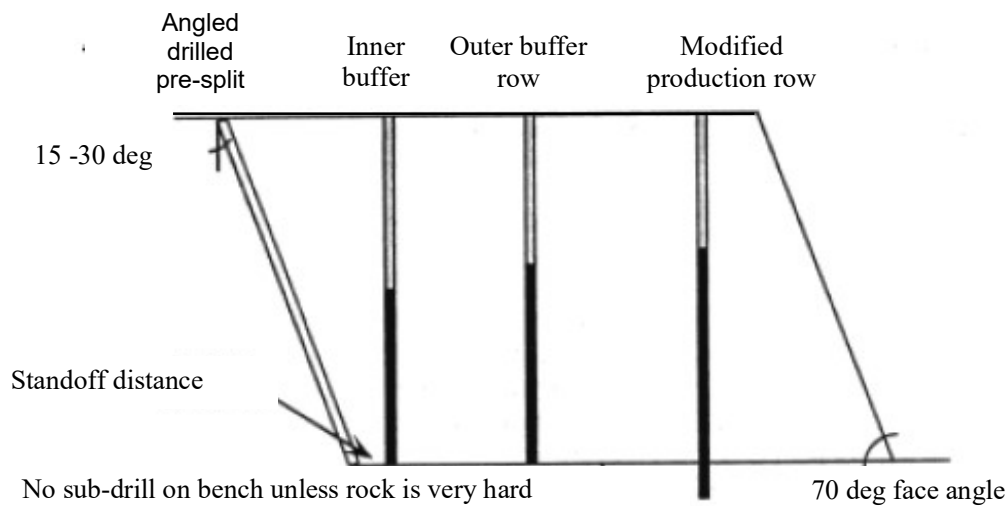


Fig.6: Typical pre-split design

As conditions become more challenging the pre-split design will have to be modified to produce satisfactory results. In hard rock masses a short "stab" hole is often required between the inner buffer and the pre-split to achieve adequate fragmentation as shown in Figure 7. Sub-drilling may be required to establish the proper bench grade when the rock is hard. If the rock mass is highly structured and relatively weak, air decks may need to be used in the buffer rows. The following illustration outlines some of the modifications required for pre-split blast design in unfavorable conditions.

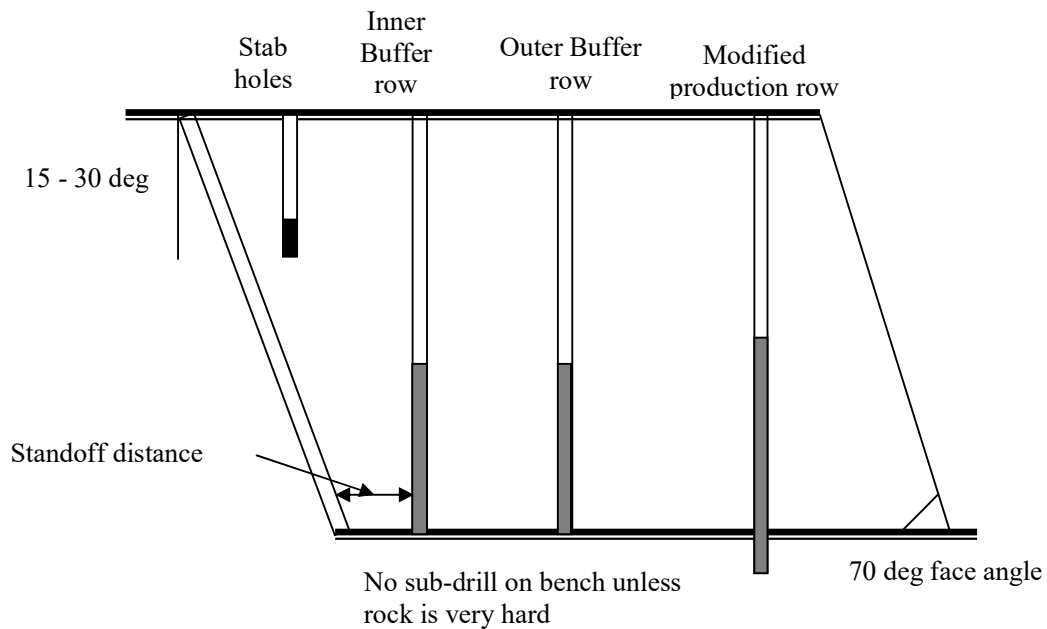


Fig.7: Pre-split design in unfavorable conditions

One of the key elements of pre-split blast design is the charging of the pre-split row. Normally the charge is decoupled to reduce the borehole pressure to well below the compressive strength of the rock. This can be achieved by air-decking or using a charge diameter that is smaller than the blast hole diameter.

Air decking is the least expensive method and is appropriate when the rock mass is relatively massive. It typically consists of placing a small bulk charge in the bottom of the hole and leaving the remaining hole open to achieve decoupling. As the rock becomes more structured better explosive energy distribution is required. To improve the energy distribution multiple small explosive decks, continuous small diameter packaged explosive, or in some cases detonating cord can be used. While continuous explosive is the most expensive option for pre-splitting, it also

provides the best performance in unfavorable conditions. Unless air blast is a concern, the pre-split holes should be left open to reduce borehole pressures and protect the crest region of the hole. Different charging methods using air-deck is illustrated in Figure 8. Pre-splitting can be the most expensive and labor intensive of the wall control methods. However, the long-term benefits can outweigh the costs if a maximum slope angle is required. If the wall is so weak that even well designed pre-split techniques cause damage the next wall control consideration should be line drilling.

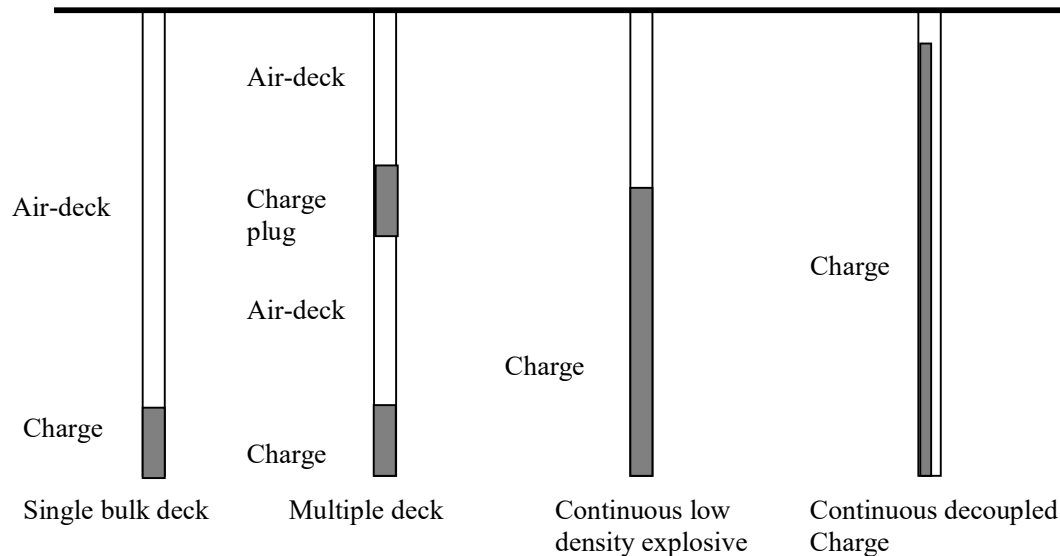


Fig. 8: Pre-split loading options

CASE STUDY: PRE-SPLITTING IN KOL DAM HYDROELECTRIC POWERPROJECT

Blasting in Kol dam hydroelectric power project was carried out under supervision of Central Institute of Mining and Fuel Research (Erstwhile CMRI), Regional Centre, Roorkee since Nov., 2005. CIMFR optimized the blast design for construction package under M/s Italian Thai Development Public Co. Ltd. (ITD-PCL). The blast was optimized for productivity as well as safety point of view. Comprehensive vibration monitoring and analysis was also carried out to conduct blast in a safe manner by limiting the blast induced vibration as well as air overpressure to safe limit.

The excavation in the project consisted of preparation of seven benches having slope of 1:4 starting from EL 715.0 m to 618.0 m. The approx. 100 m of depth was divided in seven benches each of having height approx 15.0 m and berm width of 5.0 m.

Pink limestone and yellowish dolomite are the two dominant rock types found in the approach channel area. Limestone is thinly bedded and dolomite is massive in nature. The contact of these two rocks is visible in this area. There are three sets of joints present in limestone, one parallel to the bedding and two oblique to the bedding. The parallel joint is more common than the oblique joint. Spacing of the parallel joints ranges from 0.30 m to 2.0m. The spacing of the joint increase towards the middle (i.e. in between 0 RD to contact) and the spacing decreases as we go away from the centre. The oblique joint is present at interval of 5m. The joint orientation was favorable for slope excavation. The rock is intensely folded in some part and shear zones are also present in this area. All the above features are found to be absent in dolomite but irregular fractures are present. The joint set in limestone and dolomite made whole rock formation in a block size ranging from as small as 0.5 m² to as large as 5.0 m². The block formation was prone to overbreak leading to unstable slope. Apart from the geological challenges, presences of the domestic structures close to excavation area were also susceptible to damage due to possible high level of blast induced ground vibration.

In all such situations, pre-splitting was carried out in a controlled manner with two basic objectives. First one, to control the overbreak to achieve stable slope and secondly to control vibration for preventing structural damages to the domestic houses. It was found by regression analysis and fast fourier transform (FFT) of the recorded vibration that maximum safe charge allowable for the nearby structures was 62.0 kg, therefore all the blast were curtailed to

maximum charge per delay (MCD) of 50.0 kg to control vibration to less than 10mm/s the safe level of vibration for domestic structures as suggested by DGMS, Dhanbad. It required all blast to be carried out in various parts. Each blast consisted of approx. 80 holes each of 16.0 m depth. The total length of the pre-split line was reduced to approx. 50.0m for a single blast round. Emulsion explosive Power gel 801, manufactured by M/s Orica was used in all the pre-split blasts. The explosive size was 25mm X 200 mm x 0.125 kg. Each hole was charged with 2.50 kg of explosives by providing air decks between successive cartridges. Specific charge was approx. 0.26 kg. The design worked excellently with minimum overbreak and vibration less than 10mm/s. This provided the stable slope in the benches as per the required profile and also prevented damages to the domestic structures. The parameters of pre-split blasting are given in Table 1.

Table 1: Blast Design Parameters for Pre-splitting in Kol Dam Hydroelectric Power Project

| | | | | | |
|--------------------------------------|--|----------------------|--|------------------------------|------|
| Explosive cartridge details | 25mm x 200 mm x 0.125 kg, Emulsion Explosive, PG-801 of M/s Orica Make | | | | |
| Bench slope | 1:4 (Horizontal: Vertical) | | | Bench Height (m) | 15.0 |
| Sub grade (m) | 1.0 | Hole Depth (m) | 16.0 | Hole Dia (mm) | 64 |
| No. of Holes | 80 | Spacing (m) | 0.60 | Length of Pre-split line (m) | 48 |
| Charge/hole (kg) | 2.50 | MCD (kg) | 50.0 | Total charge (kg) | 200 |
| Specific Charge (kg/m ²) | 0.26 | Cartridge Spacing(m) | 0.80 | Stemming (m) | 1.6 |
| Pre-splitting area (m ²) | 768 | Initiation System | Electric delay detonator (Millisecond Delay) | | |



Fig.9: Benches formed by Pre-split Blasting at Kol Dam Project

CONCLUSION

In India, drilling and blasting is the predominant method of excavation. However, in most of the cases, blasting is resorted in unscientific manner. Conventional blasting cause cracks and fractures in the rock. There are evidences to suggest that a substantial number of slope failures have been aggravated or even precipitated by poor blasting practice.

Damages to the final pit wall and slopes can be minimized by the use of wall controlled blasting technique. The goal of WCBT is to make the transition from a well fragmented rock mass to an undamaged slope in shortest possible distance. This technique helps in reducing the crushing, fracturing and overbreak of the remaining rock and least disturbance to the strength of the intact rock mass.

Pre-split blasting technique has been adopted in Kol dam hydroelectric power project successfully. It has helped in containing blast vibrations within safe limit of 10mm/s by using MCD of 50.0 kg. The excavation of seven benches in 1:4 slope has been completed in scheduled time. The success of the work suggest that excavation of such huge quantity and sensitive nature shall be carried out in scientific manner under supervision of an expert agency to avoid the slope failure which may lead to cost and time overrun.

ACKNOWLEDGEMENT

Authors are thankful to the officials of the NTPC for their support in carrying the study at the Kol dam hydroelectric power project. They also express gratitude to the engineers of ITD-PCL for co-operation during course of the field investigations.

REFERENCES

1. Bhandari, S. (1997). Engineering rock blasting operations, A. A. Balkema, Netherlands.
2. Blair, D.P. (1987). The measurement, modeling and control of ground vibrations due to blasting, Proc., of the Second International Symposium on Rock Fragmentation by Blasting, Keystone, CO, pp 88-101.
3. Devine, J.F.(1966). Effect of charge weight on vibration levels from quarry blasting", U.S.B.M., RI. 6774.
4. Holmberg, R. and Persson, P. (1979). Design of tunnel perimeter blast hole patterns to prevent rock damage, Proceedings, Tunneling '79, London, March 12-16, Ed., Jones, M.J., Institution of Mining and Metallurgy, London, UK.
5. John, L. F. (1998). The development and implementation of efficient wall control blast designs, Proc. Intl. Conf of explosive & blasting techniques, Florida, USA, pp 88 - 92.
6. Lyall, J. (1993). Considerations in pre-split blasting for mines and quarries workman, blasting consultant, Proc. Intl. Conf of explosive & blasting techniques, Florida, USA, pp 357 - 375.