ADVANCED CONTROLLED BLASTING TECHNIQUES FOR ROAD CONSTRUCTION IN MOUNTAINOUS REGIONS

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Abstract *Drill and blast method continue to be the preferred method of rock excavation worldwide. Blasting causes damage to the surrounding rock mass. In surface excavation with desired slopes, over break and damage to the final slope of excavation adversely affect safety as well as economics of the project. Various controlled blasting operations are line drilling, trim blasting, buffer blasting and pre-splitting blasting technique used by practicing engineers to restrict damage to surrounding rock mass along the final wall of excavation and to achieve desired slope. Pre-splitting is the commonly used controlled blasting technique for perimeter control in mining and construction industries. Apart from unsafe slope at the perimeter of rock excavation, pre-split blasting techniques prevents extra cost of rock excavation, backfill material and rock reinforcement. This technique has several advantages such as minimum damage from back-break, higher structural stability and stable final pit walls or slope at the designed angle thus improving overall safety of wall / slope. This paper presents a review of different commonly used controlled blasting techniques highlighting pre-splitting technique through a case study of Kol dam hydroelectric power project (KHEPP). This 800 MW project is constructed on river Satluj in Himalaya, India. The excavation in the project consists of preparation of seven benches having slope of 1:4 in predominantly pink limestone and yellowish dolomite, intensely folded, and posing geological challenges for the safe excavation due to intense folding and parallel joints spacing ranging from 0.30m to 2m. The joint set in limestone and dolomite made whole rock formation in a block size with surface area ranging from as small as 0.5m2 to as large as 5.0m2 . The block formation was prone to over-break leading to unstable slope. An innovative approach has been adopted for improving drilling accuracy and modified pre-splitting controlled blasting techniques at Kol dam hydro power project to achieve stable slopes and minimum rock mass damage. The paper provides insight to presplit controlled blasting techniques and successful implementation.*

1. INTRODUCTION

Drill and blast method (DBM) is commonly used method of rock excavation world-wide due to lower capital requirement, ability to adjust with any shape and size of excavation and flexibility of the DBM system to deal with changing rock mass conditions. Although DBM has witnessed significant technological advancements, it has inherent disadvantage of deteriorating surrounding rock mass due to development of network of fine cracks leading to safety and stability problems. 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. 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 of a substantial number of slope failures that have been aggravated or even precipitated by poor blasting practices.

Damage to the surrounding rock mass can be minimized using various controlled blasting techniques. All the controlled blasting techniques 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 mass and least disturbance to the strength of the intact rock mass. Various controlled blasting techniques are used for construction of slopes is specifically termed as wall controlled blasting technique (ISEE, 2011). The goal of all wall control blasting technique 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, these methods are employed for preparing the final pit wall and slope construction work for producing a high quality wall at the cut limit.

The wall control blasting technique can be grouped under 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, 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. 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 (Jhanwar, 2011). 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 blast holes.

2. WALL CONTROL BLASTING 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 Fig. 1. The three parameters are energy distribution, energy confinement and energy level. The parameter energy confinement represents blast design parameters such as spacing and burden, hole length, and sub grade drilling. Higher spacing, burden and longer hole-length indicated higher degree of energy confinement, which may produce high intensity of ground vibration and leading to back break. Inadequate energy confinement leads to problems such as poor breakage, larger boulders, fly-rock etc. 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. 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.

Three key parameters for optimum blast performance

The parameter 'energy level' means selection of suitable explosive strength, which is indicated by velocity of detonation of the explosive. A good competent rock mass requires explosives with higher VOD and vice-versa. Commercially available explosives are marked with their strength rating so explosive selection is made according to given rock mass condition. Ideally, explosive is selected based on impedance matching. The product of explosive density and VOD shall be proportionate to product of sonic velocity and density of the rock mass and shall form basis for selection of explosives for a given rock mass condition.

The third and important parameter in wall control blasting is energy distribution. It represent distribution of explosives within a hole column. Air decking is one such techniques, which is commonly used for proper distribution of explosive inside a hole by providing aerial spaces, and decoupling. In the present case study, an innovative approach was used to distribute the explosive by tapping the small diameter cartridge explosive to detonating card and then lowering it inside the hole.

Details are discussed in subsequent section while describing the case study in this paper. The results of blasting operation depend on optimizing the above there key parameters as all the parameters are inter related and influence outcome of each other and hence overall blast performance in effective control of the rock mass damage.

3. Different techniques used for wall control blasting

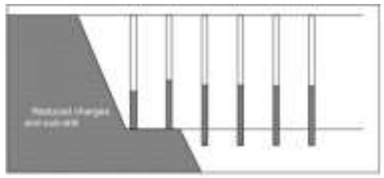
3.1 Buffer Blasting

Buffer blasting is most successful when the rock mass quality is better 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 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. The percentage reduction in charge weight will depend upon the quality of the rock mass and standoff from the final wall. However, most rock types require additional design modifications to minimize damage.

Reduction in charge weight is dependent on the quality of the rock mass and also stand-off distance from the final wall. This measure shall be coupled with other design modification and can be fixed after conducting trial blasts. These modifications can include air decking, reducing the burden and spacing dimensions (by 25%), minimizing sub-grade drill and increasing the delay interval between the last two rows of blast holes.

These potential design changes are shown below in Fig. 2. Reduction in charge, and elimination of the sub-grade drill may be observed in the buffer row in Fig. 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.

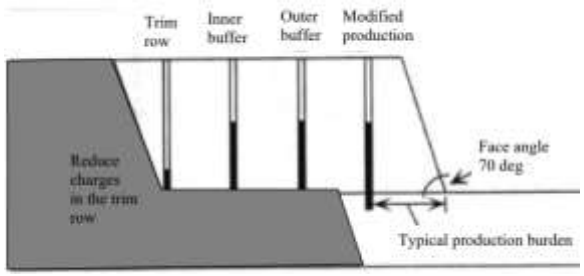
The optimum standoff distance will depend on the strength and structure of the rock mass and should be determined by carefully analyzing blast performance.



Buffer blasting in competent rock

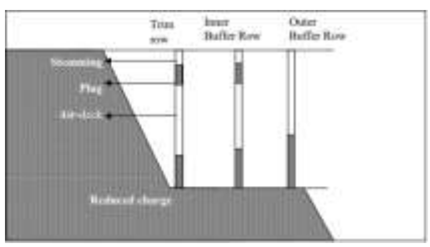
3.2 Trim Blasting

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.



Trim blast design for favorable conditions

It is advisable to use air decking in at least in the trim row to improve energy distribution and reduce back break. Air decks may also be required in the other rows to compensate for the reduced burden and spacing dimensions.

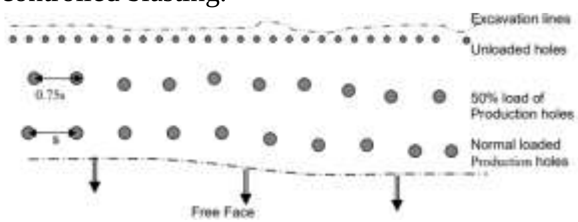


Trim blast design for unfavorable conditions

3.3 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. Figure5 illustrates the line drilling technique of wall controlled blasting.

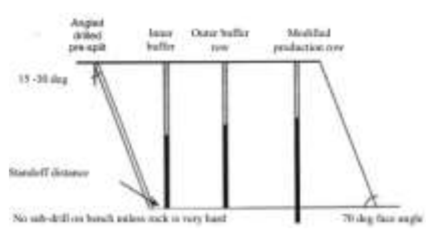


Line drilling along the final excavation

3.4 Pre-split Blasting Technique

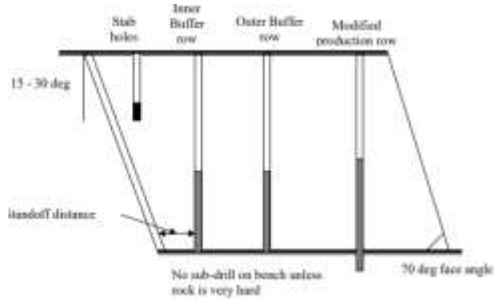
Pre-splitting blasting consists of a row of lightly charged, closely spaced holes adjacent to the final slope that is fired prior to the detonation of the other holes. This creates a breakage plane to vent explosive gases and reduce crack propagation. A pre-split blasting is best carried out when the 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 Figure6. 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.



Typical pre-split design

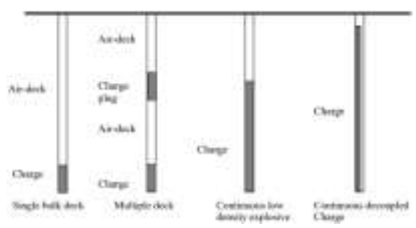
As conditions become more challenging the pre-split design will have to be modified to produce satisfactory results. In hard rock masses a short "stab" hole is often required between the inner buffer and the pre-split to achieve adequate fragmentation as shown in Figure 7. Sub-drilling may be required 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.



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.



Pre-split loading options

4. Conclusions

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 over break 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.

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