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Application of Controlled Blasting Techniques for Development of Stable Slope-A Case Study

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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, overbreak 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 $0.5m^2$ to as large as $5.0m^2$. 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.

Keywords: Controlled blasting techniques; Pre-splitting; Rock mass damage; Half cast factor

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 (Lyall, 1993; Workman et al., 1991; Singh et al., 2009). 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 (Worsey, 1987; Gustafsson, 1973).

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 (Bhandari, 1997; Fourney, 1978). 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 (Chiappetta, 2001; Singh et al., 2009).

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 (John, 1998).

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.

CSIR-Central Institute of Mining and Fuel Research, Dhanbad through its 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 has been adopted for developing benches in the desired profile in this project site. A brief review of various wall control blasting techniques and experience in designing and implementation of pre-split control blasting techniques in the Kol dam project site is discussed in this paper.

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 (Holmberg and Hustrulid, 1981; Olofsson, 1998). 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 subgrade 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.

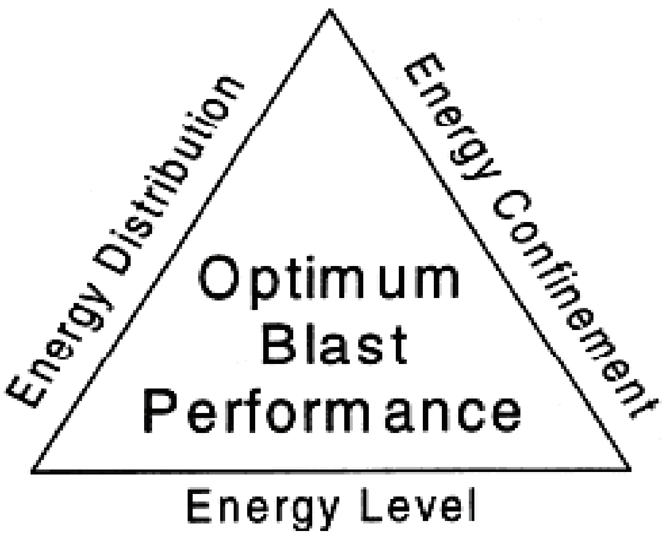

Figure 1 - Three key parameters for optimum blast performance

The parameter 'energy level' means selection of suitable explosive strength, which is indicated by velocity of detonation of the explosive. A good competent rockmass requires explosives with higher VOD and vice-versa. Commercially available explosives are marked with their strength rating so explosive selection is madeaccording 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 (Fourney, 1993; Dey, 2004).

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.

Following are four techniques used for wall control blasting

i. Buffer blasting
ii. Trim (Cushion) blasting
iii. Line drilling
iv. Pre-splitting

2.1 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 (Holmberg & Hustrulid, 1981).

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 overbreak. 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. Buffer blasting may not be recommended for incompetent rock mass as it is fired with production holes and there is passage of blast induced ground vibration to remaining rock mass, which may further cause damage to the remaining rock mass.

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. Following are the guidelines for designing buffer blast:

i. Locate the modified production row 1m out from toe of the slope
ii. Reduce production charge weight by 50% in the last row
iii. Use air decks and minimize the stemming length in the last row
iv. Minimize subgrade drill when drilling adjacent to the next catch bench
v. Reduce the burden and spacing of the last row by 25%
vi. Increase the delay timing between the last two rows of holes

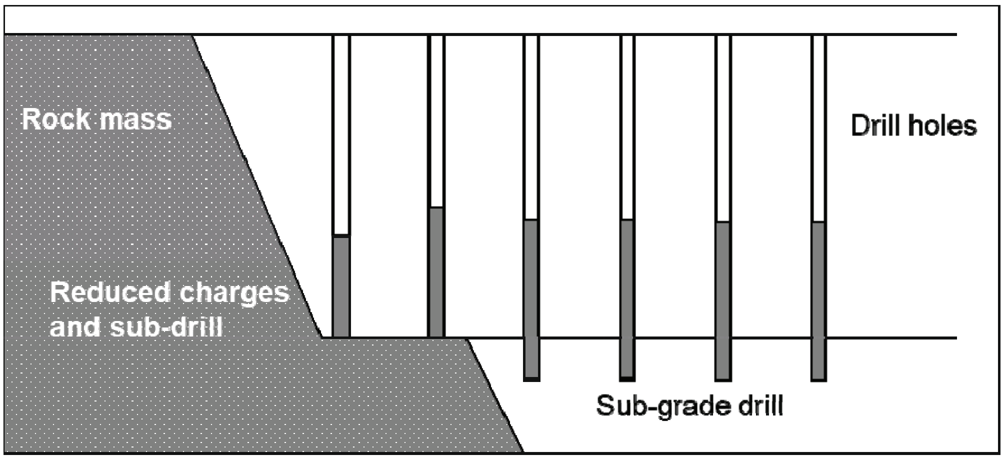

Figure 2 - Buffer blasting in competent rock

2.2 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 such as week rock mass condition and steeper slopes. The geological structures at the site to control the blast design parameters such as borehole burden, spacing, stemming length, powder factor. Geological set-up such as dominant, persistent structures works as back-break planes. The degree of heterogeneity within the rock mass is also important when developing a blast design. Discontinuities (joints, bedding, foliation, or faults, for example) can allow the explosive's energy to be wastefully dissipated along the weakness plane (Wylie and Mah, 2004). Optimum fragmentation is usually obtained when the face is parallel to a major discontinuity set. For better performance of trim blasting, a free face must be established to fragment and displace the rock horizontally away from the wall (Holmberg and Persson, 1980; Holmberg, 1993). 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 Fig. 3. 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. Fig. 4 illustrates trim blasts in unfavorable geological conditions.

The critical design elements for trim blasting are:

i. Standoff of trim row from toe of slope (determined by rock strength)
ii. Catch bench width (for buffer row locations)

iii. Sub-grade drill depth (particularly important adjacent to the bench crest)
iv. Trim row spacing is typically less than the burden dimension
v. Face burden (horizontal relief)
vi. Bench width to height ratio (should be less than 2)
vii. Timing configuration
viii. Overall energy level (depends on rock strength)
ix. Energy distribution (trim row may require air-deck)

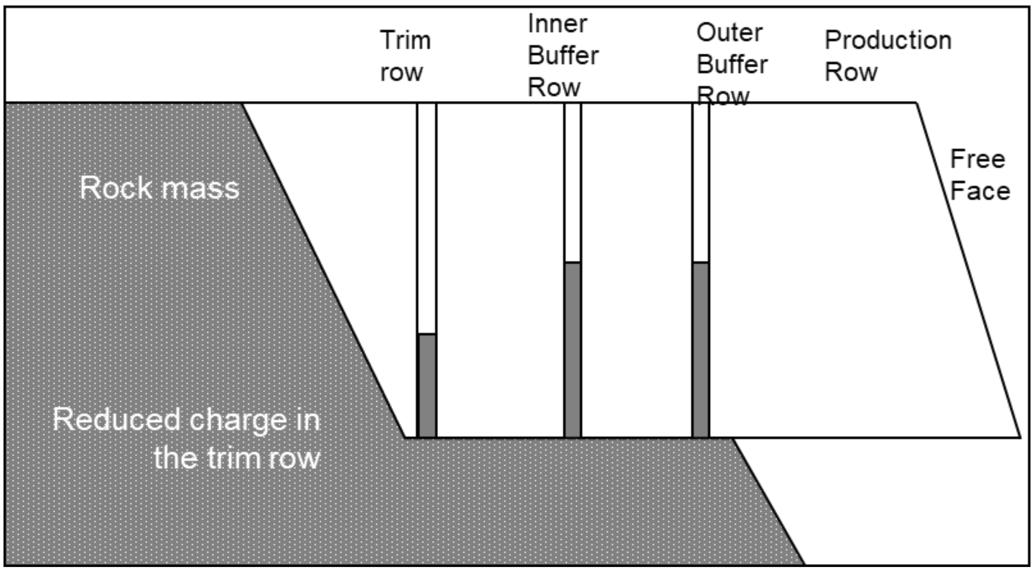

Figure 3 - Trim blast design for favorable rock mass conditions

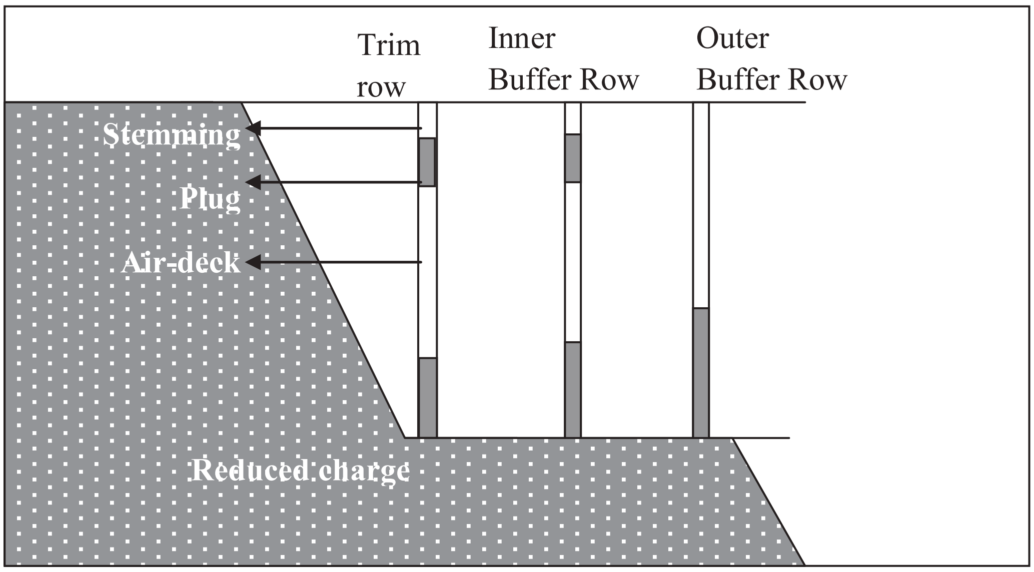

Figure 4 - Trim blast design for unfavorable rock mass conditions

2.3 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 provide a plane of weakness to which final row of blastholes can break. The stress waves of the blast create a plane of breakage between the holes (Olofsson, 1998).

The hole diameter for line drilling is usually 50-70mm. 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.

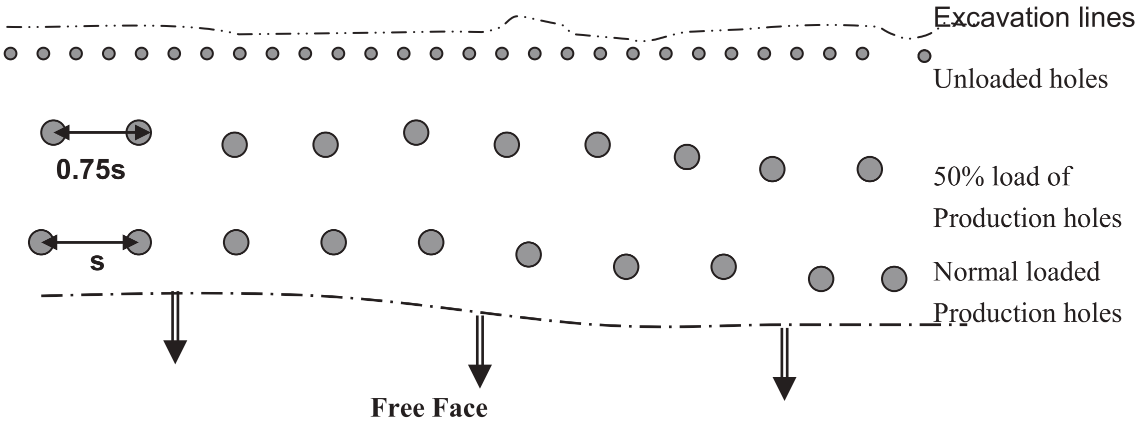

Figure 5 - Line drilling along the final excavation

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. Fig. 5 illustrates the line drilling technique of wall controlled blasting.

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 (ISEE, 2011).

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 (Konya & Walter, 1990).

2.4 Pre-split Blasting Technique

Rock mass with joints between holes and intersecting the face at less than 150^o constitute an unfavorable geological condition for pre-split technique (Wylie and Mah, 2004). Lesser angle causes fractures to intersect the jointing planes having large pieces of material falling out from the face during the excavation process. In a weak material, the skill of the excavator operator is extremely critical. Some machines can exert considerable thrust, whereby they can dig into an unblasted wall severely damaging the final contour. Other geologic factors, which affect the outcome of control blasting techniques are soft seams or mud seams. If the bench is intersected by numerous mud seams, it is difficult to produce good results.

In pre-split technique holes spacing and charge concentration is an extremely important factor. In most rock types the pre-split blasthole 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 (Singh et al., 2009). 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, and overall energy level (Homberg, 1993).

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. 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.

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 blasthole 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 (John, 1998). Unless airblast is a concern, the pre-split holes should be left open to reduce borehole pressures and protect the crest region of the hole. Pre-splitting can be the most expensive and labor intensive of all the wall control methods. However, the long-term benefits can outweigh the costs if a maximum slope angle is required (Calder, 1977).

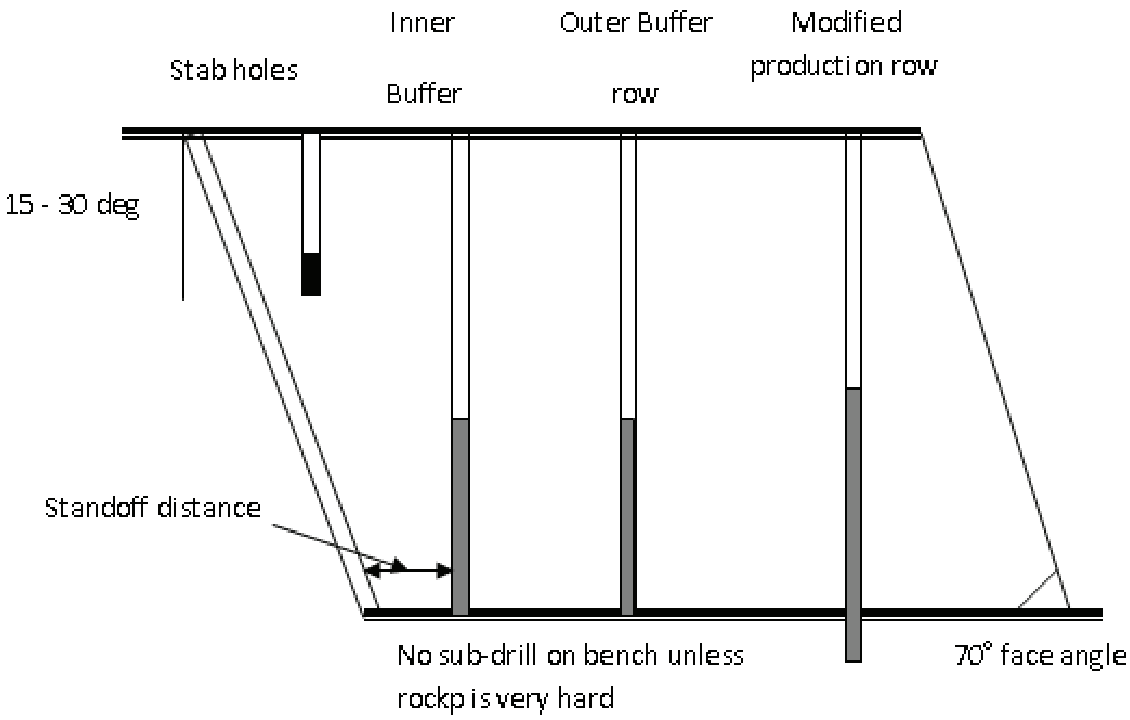

Figure 7 - A typical pre-split blast design in unfavorable rock mass conditions

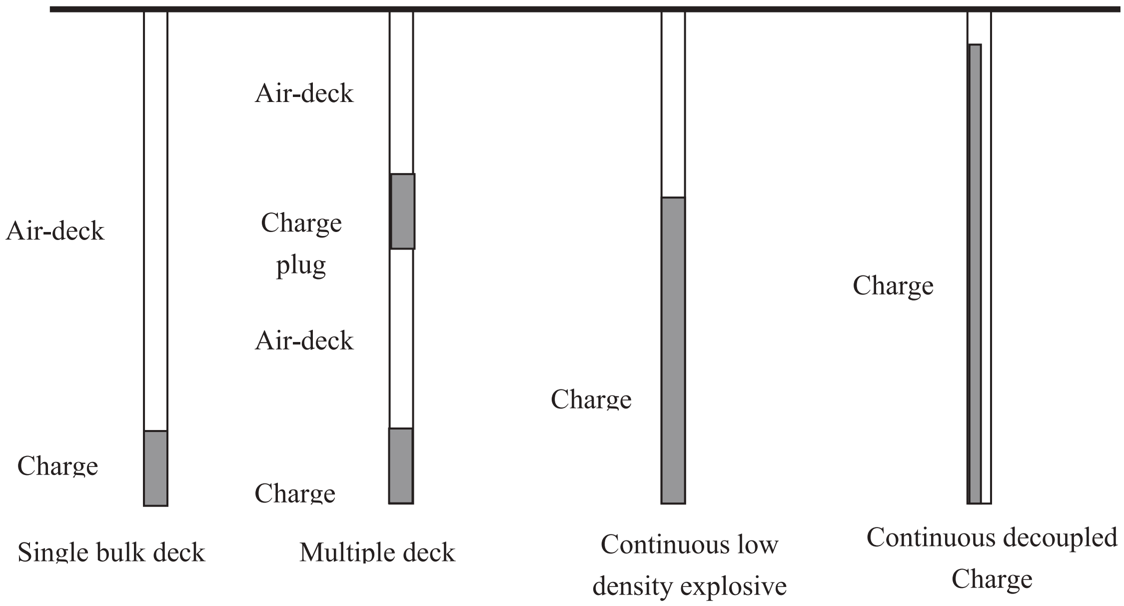

Figure 8 - Pre-split loading options

3. PRE-SPLITTING IN KOL DAM HYDROELECTRIC POWER PROJECT

Kol dam hydroelectric power project (KHEPP) with an installed capacity of 800MW (4 x 200MW) is situated at Kyan village of Bilaspur district (Himachal Pradesh) in Northern India. It is about 25km from district headquarter on river Satluj, 4km upstream of Dehar power plant. Construction of this project is undertaken by the National Thermal Power Corporation (NTPC) Ltd. It envisages utilisation of power potential of the Sutlej river for electricity generation. The project involves construction of a 164m high rock & gravel fill dam across the river Sutlej and installation of four units of Francis turbine 200MW each.In order to ensure proper flow conditions of flood water to the spillway weir and in particular, to allow the stream flow lines to be correctly orientated, major earthworks is to be carried out upstream of the spillway to create approach channel. The geometry of this approach channel is shown in Fig. 9. Total quantity of excavation in approach channel area is approximately 8.2Mm^3. Excavation in this area consists of construction of seven benches having slope of 1 : 4, height 15m and berm width of 5m. CSIR-Central Institute of Mining and Fuel Research Dhanbad and its regional research Centre at Roorkee carried out comprehensive investigations and optimized the pre-splitting blasting technique for construction of seven benches in the approach channel area.

3.1 Geology of Approach Channel Area

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 0.30m to 2.0m. The spacing of the joint increases towards the middle (i.e. in between 0 Reducing Distance (RD) to contact) and the spacing decreases as we go away from the centre. The oblique joint is present at interval of 5.0m. The joints are filled with clay material. The joint orientation was favorable for slope excavation.

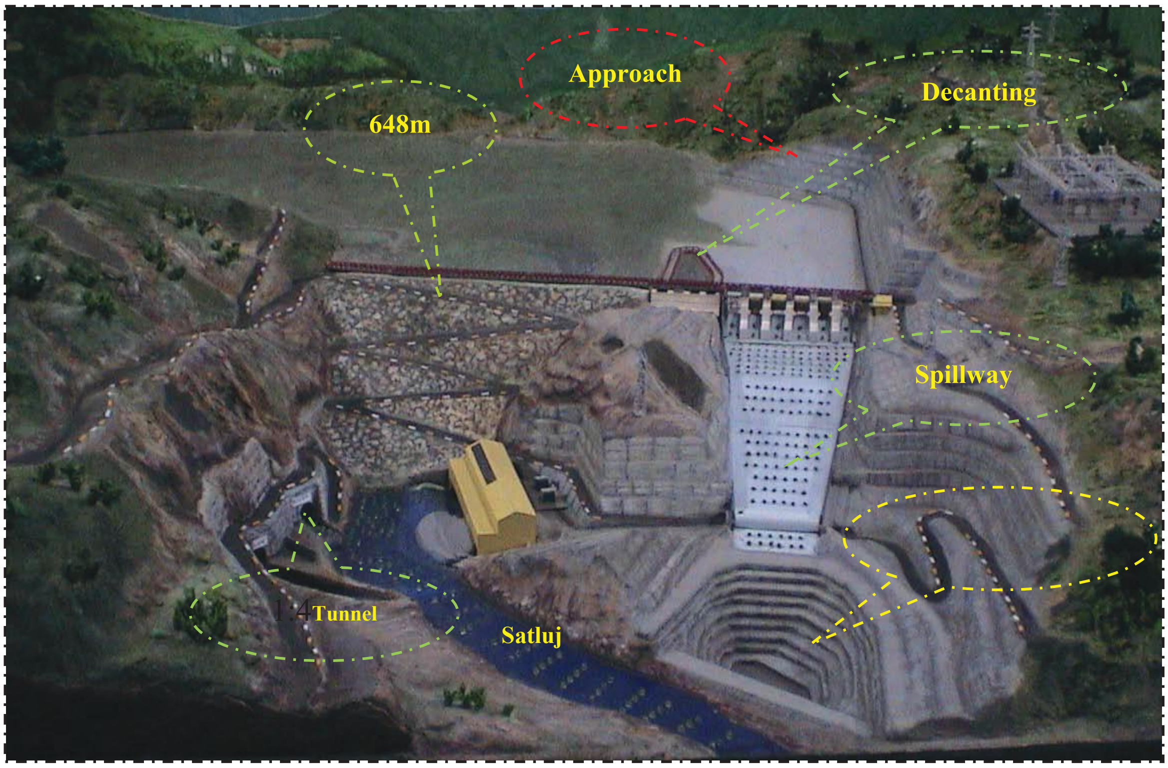

Figure 9 - A model picture of Kol dam hydroelectric power project in India

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 0.5m^2 to as large as 5.0m^2. The block formation was prone to overbreak leading to unstable slope. The structural features of the rock mass in approach channel area are shown in Fig. 10. Figure 2 reveals intense shearing, folding fractures in the rock formation in approach channel area.

3.2 Pre-splitting in Approach Channel Area

Pre-splitting controlled blasting technique was used for construction of seven benches in approach channel area with two objectives, firstly, a breakage line along the final line of excavation achieved by pre-splitting will help in minimizing the intensity of the blast vibration in the structures located across the final line of excavation. Secondly, back-breakage is minimized as the extension of the cracks induced by the production blast will be terminated at the pre-split line. It is decided that all the benches has to be pre-split prior to any production blast.

Figure 10 - Photographs showing joints and folding in the rock mass at Approach Channel Area

Apart from the geological challenges of block, achieving drilling accuracy in a bench of 15m height which will lead to stable slope was also difficult. In Kol dam site, benches are 15m height and the hole depth is 16m with 1.0m sub-grade drilling. For achieving a greater degree of accuracy in drilling in absence of any mechanized drilling arrangement, a set-up as shown in Fig. 11was fabricated at site. This is an in-house arrangement with available resources at site. Three parts of 15mm steel rod commonly available in construction site is taken and fabricated as shown in Fig. 11. These two triangular welded members are held together in such a manner that the two pieces held together will guide the drill rod to achieve the accurate drill angle. The two triangular shape welded section is prepared and the bottom of the rod is pierced to the ground between two points in a pre-split line and member in the triangular section with slope 1:4 is kept facing in the direction of the drilling. Two guiding ropes are also attached between the two welded section along which the drill rod moves. The drilling crew ensures that the drill rod is in touch with the guiding ropes and parallel to the slope member of the triangular steel section when drilling. The arrangemnet has significantly improved drilling accuracy and in success of the pre-splitting blasting technique at Kol dam site.

Small piped charges, as available in many developed countries are not available in India. Therefore, an in-house arrangement at site was done for charging of the holes. Due to unfavorable geological conditions small continuous decoupled charges were used in pre-split blasts. A detonating cord with 10g/m PETN is taken for passage of the detonation along the entire column of explosive. The spacing between two successive cartridges is kept 800mm. M/s Orica India make Powergel 801 with 25mm diameter cartridges having 125g (0.275lb) weight and 200mm in length is used.

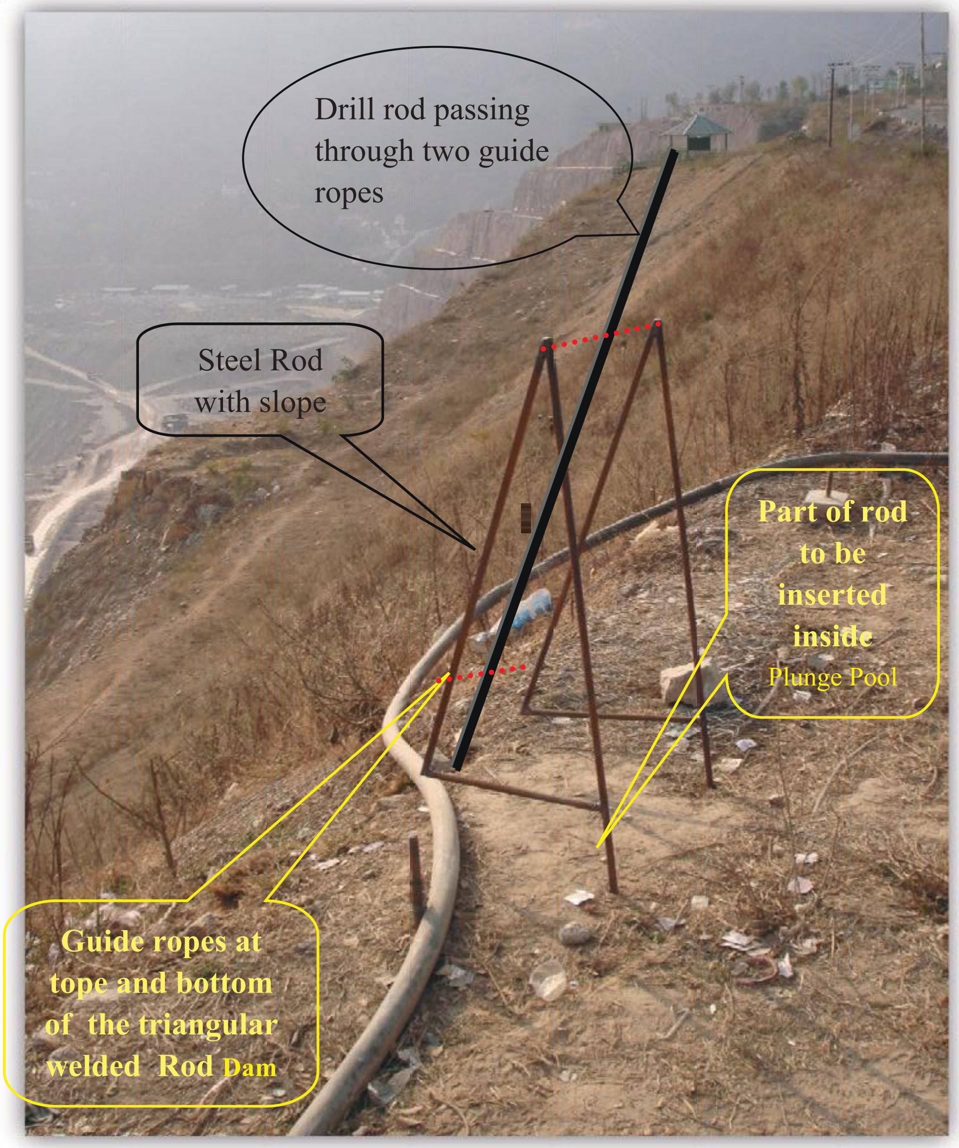

Figure 11 - Photograph showing drilling arrangements to achieved slope angle at Kol dam site

A detonating cord measuring 17m (55.77 ft) is taken and the cartridges are fixed to the detonating cord at 800mm (31.50 inch) interval using a tape. The two cartridges are placed continuously neck to neck at bottom for priming so that the shock from donor cartridges is strong and also to achieve stable detonation to avoid any misfires in receptor cartridges. Total 2.0kg of explosives and 17m of detonating cord are used in each hole. After preparing such charge in the surface the whole explosive and detonating cord is carefully lowered in the 16m deep holes leaving 1m of detonating cord in the surface as a trunk line. The initiation is done using millisecond electric delay detonator which in turn is detonated using an exploder.

Treatment of the penultimate row of production blasts is very important in all controlled blasting techniques. It was observed in initial production blasts that sub-grade drill is inflicting damages in the crest portion of the benches. Damaged crest of the benches were giving rise to problem of overbreak and block formation. The observed damage even upto 0.5m depth in few locations. Photograph showing damages in the crest portion of the bench is given Fig. 12.

Figure 12 - Damage in the crest portion of the rock mass due to sub-grade drilling

The problem of crest damage was tackled using introduction of stab holes before the pre-split holes and reducing the sub-grade in production holes. The optimised charging scheme of the pre-split blast design are presented in Table 1. The drilling pattern is shown in Fig. 13. The charging pattern was used in both dolomite and limistone rock formation with minor changes in the stand-off distance for the stab holes. The problem of crest damage could be solved using above modifications in the initial blasting rounds. Figure 14 shows a successful implementation of pre-split blasting technique with no crest damage.

Table 1 - Blast design parameters for pre-splitting in Kol dam hydroelectric project

Explosive cartridge details	25 mm x 200 mm x 125 g, Emulsion explosive, 80% strength				
Bench slope	1:4 (Horizontal: Vertical)			Bench height (m)	15.0
Sub grade (m)	1.0	Hole depth (m)	16.0	Hole diameter (mm)	64
No. of holes	80	Spacing (m)	0.60	Length of pre-split line (m)	48
Charge/hole (kg)	2.00	MCD (kg)	50.0	Total charge (kg)	180
Specific charge (kg/m^2)	0.23	Cartridge spacing (m)	0.80	Stemming (m)	1.6
Pre-splitting area (m^2)	768	Initiation system	Electric delay detonator (millisecond delay)		

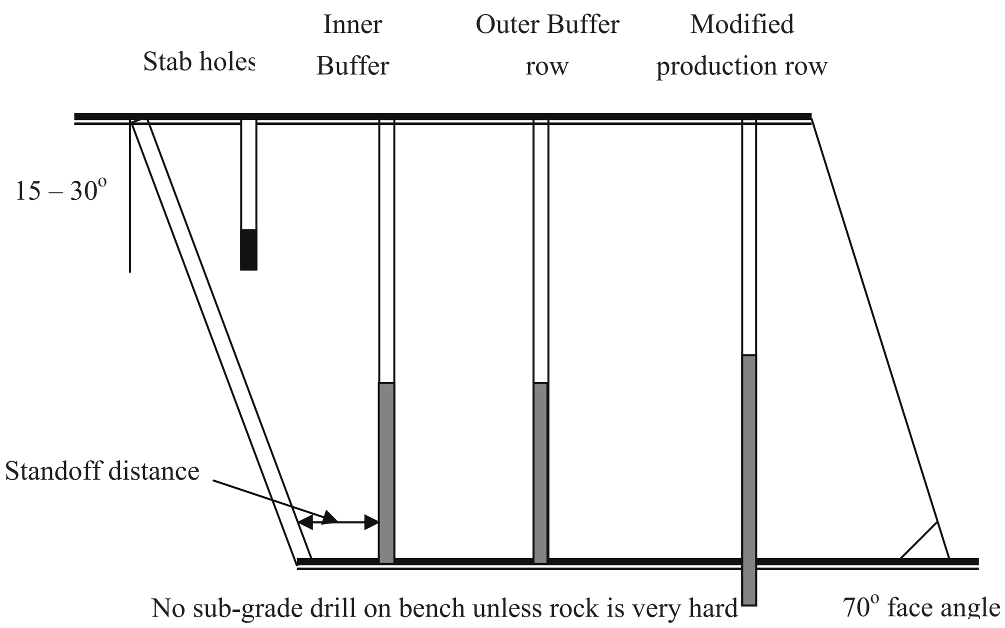

Figure 13 - Opitmised blast design at Kol dam project

Success of the presplitting is evaluated using Half cast factor (HCF). HCF is the percentage of the total half casts which are visible after the rock has been excavated (ISEE, 2011). If only 40% of the drill holes remain visible on the final wall as half casts, then the half cast factor would be 40%. In Kol dam site HCF was found to be more than 95% in most of the benches. This can be seen from the phtographs shown in Figs. 12 and 14.

In addition to presplitting blasting, the production blasts in various benches were optimized by conducting various trial blasts. The complete bench was taken in three slices of 5.0m each. Hole dia used was 105mm. Burden and Spacing in each of the blast round was in the range of 2.0 – 2.5m and 3.0 -3.5m respectively. In all the production blast maximum number of holes were restricted to 50 drilled in not more than four rows.The specific charges used in an optimised blast was 0.50 to $0.65kg/m^{3.}$ In all the production blasts, maximum charge per delay and total charges were restrcited to 50kg and 150kg respectively. Shock tube initiation system was used for initiating and firing sequence.

The optimised blast design together with the prespltng blasting techniques was successfully implemnted for construction of stable benches along the approach channel as shown in Fig. 15.

Figure 14 - Photograph showing improvement in pre-split blast results at crest portion of bench

Figure 15 - Benches formed by Pre-split Blasting at Kol Dam Project

6. CONCLUSIONS

Pre-splitting controlled blasting technique was used in Kol dam hydroelectric power project in the approach channel area for development of benches with slope gradient 1 : 4 having height 15m and berm width of 5m. The rock formation of limestone and dolomite were intensely folded and fractured. The three sets of random joint posed problem of block formation leading to blockdislodgement from the crest of the benches which ultimately resulted in overbreak. Domestic houses in close proximity of the excavation site were susceptible to damages due to blast. Drill holes were also deviating due to larger hole depth of 16 m.

The pre-split blast was designed with continuous decoupled charge using 25mm emulsion explosive with 10g/m detonating cord. An on-site arrangement was made using steel rods which is cheap and easy to fabricate in the site workshop. The arrangement controlled the drill hole deviation. Treatment of the penultimate rows of production blast by reducing burden and charge concentration eliminated damages to the crest of the benches. The safe maximum charge per delay for threshold limit of peak particle velocity of 10 mm/s is found to be 50kg as per Indian Standard of DGMS. The result obtained by carrying out above exercise gave good result with half cast factor above 95%.

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