Assessment and Mitigation of Blast Induced Vibration and Overbreak in Kol Dam Hydroelectric Power Project, India – A Case Study

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ABSTRACT

Pre-splitting is the commonly used controlled blasting technique for perimeter control in mining and construction industry. Overbreak and damage to the final slope of excavation adversely affect safety as well as economics of the project. 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, enhanced carrying capacity of rock, 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 case study of Kol dam hydroelectric power project (KHEPP). This 800 MW project is under construction on river Satluj in Himalaya, India. The excavation in the project consists of preparation of seven benches having slope of 1:4 starting from elevation level (EL) 715.0 m to EL 618.0 m in the approach channel area, each bench having height 15 m and berm width of 5 m.

Three sets of joints in the two dominant rock types of approach channel area namely pink limestone and yellowish dolomite, posed geological challenges for the safe excavation. Spacing of the these parallel joints ranges from 0.30 m to 2m. The rock is intensely folded in some parts and shear zones are also present in this area. The joint set in limestone and dolomite made whole rock formation in a block size ranging from as small as 0.5 m^2 to as large as 5.0 m^2. The block formation was prone to overbreak leading to unstable slope.

Apart from the geological challenges, the domestic houses close to excavation area are 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. The blast design gave good result with minimum overbreak and vibration less than 10 mm/s. The technique helped in preparation of the stable slope in the benches as per the required profile and also prevented damages to the domestic structures. This paper gives details of site specific technical challenges and details of the blast design, details of an in-house arrangement for maintaining drilling accuracy and the techniques evolved for preventing structural damages induced by blast vibrations.

Keywords: Controlled blasting technique; Pre-splitting; Ground vibration; Half cast factor.

1. INTRODUCTION

Due to rapid growth of the country and sudden spurt in industrial requirement, Government of India has planned number of infrastructural projects specially to meet energy deficit of the country. The large numbers of hydroelectric projects are under construction stage all across the country.

Kol dam hydroelectric power project (KHEPP) with an installed capacity of 800MW (4 x 200 MW) is situated at kyan village of Bilaspur district (Himachal Pradesh) in Northern India. It is about 25 km from district headquarter on river Satluj, 4 km upstream of Dehar power plant. Construction of this project is undertaken by the National Thermal Power Corporation (NTPC) Ltd. It envisages utilization 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 200 MW 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. 1. Total quantity of excavation in approach channel area is approximately 8.2 million m^3. Excavation in this area consists of construction of seven benches having slope of 1:4, height 15 m and berm width of 5 m.

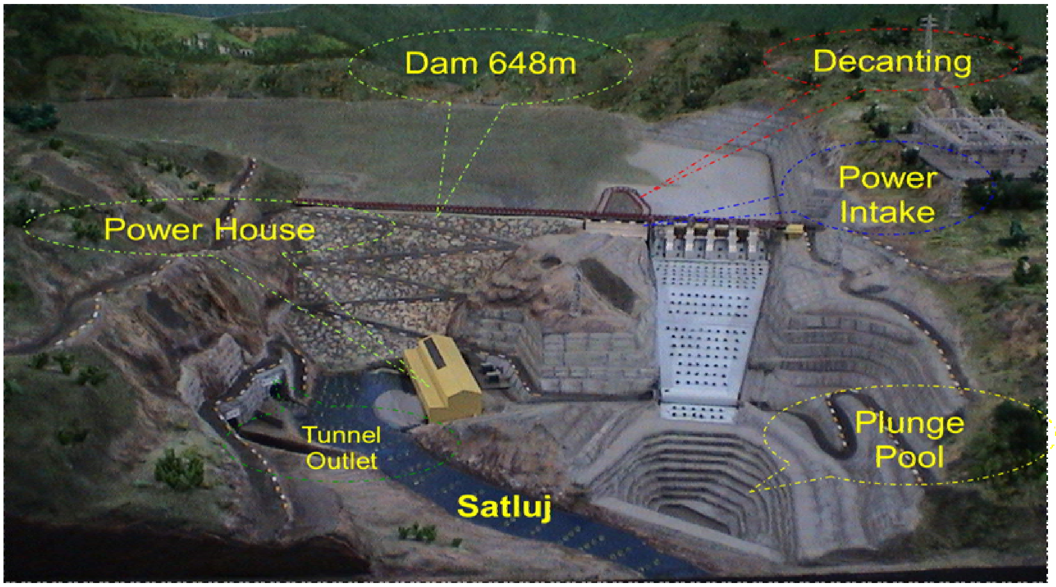

Fig. 1: A model picture of Kol dam hydroelectric power project in India

Pre-splitting is the commonly used controlled blasting technique for perimeter control in mining and construction industry (Worsey, 1987). Overbreak and damage to the final slope of excavation adversely affect safety as well as economics of the project. 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, enhanced carrying capacity, higher structural stability and stable final pit walls or slope at the designed angle thus improving overall safety of wall / slope. Pre-split blasting technique is used in Kol dam site for construction of seven benches in the approach channel area.

2. 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 0.30 m to 2.0 m. 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 5m. The joints are filled with clay material. 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 m^2 to as large as 5.0 m^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. 2. Figure 2 reveals intense shearing, folding fractures in the rock formation in approach channel area.

3. BLASTING IN APPROACH CHANNEL AREA

Apart from the geological challenges of block formation in pink limestone and dolomite rock, a bigger challenge was prevention of damages to the domestic houses and surrounding rock mass from blast induced ground vibration and achieving drilling accuracy in a bench of 15 m height which will lead to stable slope.

The key to structural safety of the rock mass is pre-splitting controlled blasting technique. It is decided that all the benches has to be pre-split prior to any production blast. The technique will help in two ways; 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. The parameters of the pre-splitting blast design are summarized in Table 1.

Fig. 2: Photograph showing joint and folding in the limestone of approach channel area

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

Explosive cartridge details	25 mm x 200 mm x 125 gm, 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)		

The blast design parameters are worked out initially using relations as suggested by Bhandari, (1997), Calder, (1977) and Workman and Calder (1991). The parameters were further refined by taking trial blasts to suit site specific conditions of Kol dam site. The spacing of the holes wer reduced to prevent problem of the boulder dislodgement after production blast due to less joint spacing. After trial blast with different spacing and hole diameter it was found that 64 mm hole diameter with 600 mm spacing gave optimized result with half cast factor (HCF) above 90% and the cost is also cheaper with 64 mm hole diameter compared to 76 mm hole diameter. Holes were charged with continuous and decoupled small charge of 25 mm diameter. A comparison of unit cost for pre-splitting with 76 mm and 64 mm holes is given in Table 2. It is revealed in Table

2 that the unit cost of 76 mm hole diameter is 14.92 % more than the 64 mm holes diameter. Hence it was decided to use 64 mm holes for all the presplit blast.

Table 2: Cost comparison between 76 mm (3 inch) and 64 mm (2.52 inch) hole diameter for pre-splitting

Diameter of hole (mm)	Spacing (mm)	No. of holes	Length of pre-split line	Cost /hole (₹)	Total cost (₹)	% of Total cost (₹)	Excess %
76	700	6	4.2	185.14	1122.84	42.52	14.92%
64	600	7	4.2	216.65	1516.69	55.46	

1USD = 54 ₹ (Indian Rupee)

3.1 Improving Drilling Accuracy

Drilling accuracy is important in any blasting operation and more in pre-split blasting techniques as it directly affects the final slope of the wall. In Kol dam site, benches are 15 m height and the hole depth is 16 m with 1.0 m 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. 3 is fabricated at site. This is an in-house arrangement with available resources at site. Three parts of 15 mm steel rod commonly available in construction site is taken and fabricated as shown in Fig. 3. 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 arrangement made at site for improving drilling accuracy is shown in Fig. 3.

As shown above in Fig. 3, 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 holes drilled with this arrangement improved drilling accuracy which can be verfird by the half barrell marks of the pre-split holes as shown in Fig. 4.

3.2 Charging of Pre-Split Holes

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 was used in presplit blasts. A detonating cord with 10gm/m PETN is taken for passage of the detonation along the entire column of explosive. The spacing between two successive cartridges is kept 800 mm. M/s Orica India make Powergel 801 with 25 mm diameter cartridges having 125 gm (0.275 lb) weight and 200 mm in length is used. A detonating cord measuring 17 m (55.77 ft) is taken and the cartridges are fixed to the detonating cord at 800 mm (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 2.0 kg of explosives and 17 m 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 1 m 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.

3.3 Modified Scheme of Production Blasts

Treatment of the penultimate row of production blasts is very important in all controlled blasting techniques. It was observed in initial production blasts that su-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 damage was more that 0.5 depth. Photograph showing damages in the crest portion of the bench is given Fig. 5

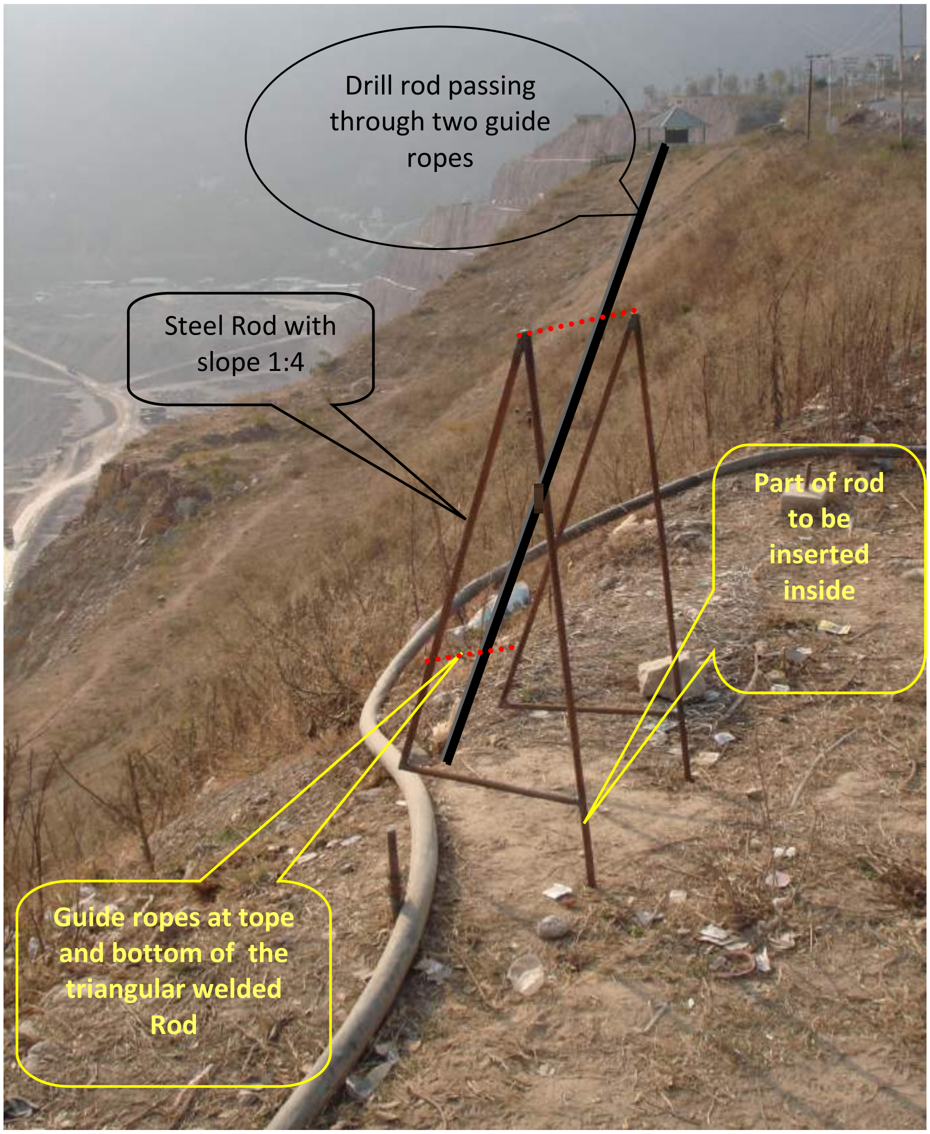

Fig. 3: Photograph showing arrangemnet for improving drilling accuracy at Kol dam site

Fig. 4: Photographs showing drill holes marks after pre-split blast in approach channel area

Fig 5: Photographs showing damage in the crest of the benches due to production blasts

There after a modified pattern for taking production blast is planned as shown in Fig. 6. In both the rock formations dolomite and limestone, stab holes were introduced. Subgrade drill holes in inner and outer buffer rows are discarded. Charge concentration to inner buffer row and outer buffer row are reduced proportionate to the reduced burden. Reduction in the burden and charging was 25% to that of the normal production blasts. The stab holes were essential as the both rock formation were hard and stab holes prevented any undercut in the benches and also ensured proper fragmentation. The scheme of blasting as shown in Fig. 7 gave good result. Damage in the crest portion is eliminated to a large extent. Result of modified production drilling and blasting scheme is shown in Fig. 7. It is clear from the Fig. 7 that damages in the crest part of the benches are reduced to a large extent. This is reflected in the overbreak survey also as it prevented problem of block dislodgement from the damaged crest part of the benches.

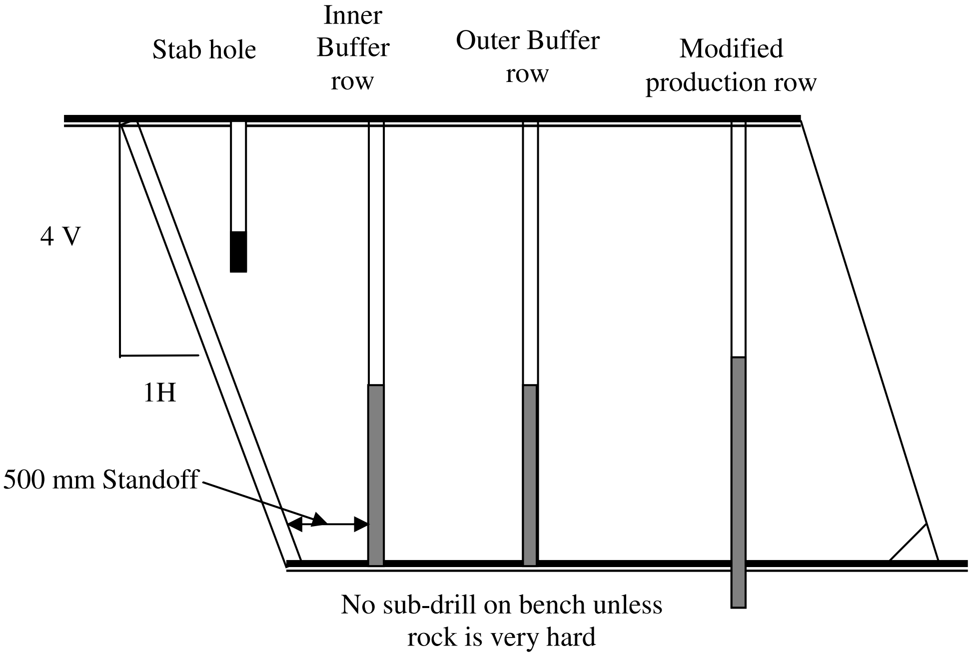

Fig. 6: Scheme of production blasts in the approach channel area of Kol dam project

3.4 Evaluation of Blast Vibration

During trial blasts for optimization of blast design parameters, vibration was measured using three seismographs for all the presplit blast to optimize the maximum charge per delay (MCD). After monitoring large number of blasts vibration, data is analysed to find out safe maximum charge per delay.

It is found that the frequency of the vibration falls between 8-25 Hz. The safe permissible peak particle velocity for structures not belonging to the owner is 10 mm/s as per Indian Standard as specified by Director General of Mines Safety, India (DGMS, 1997) through their circular which consider peak particle velocity (PPV) and the frequency of ground vibration as given in Table 3.

In Kol dam hydro-electric power project site, the nearest structures are at a distance of approximately 100 m. These structures are brick mortar domestic houses. Apart from the domestic houses, various project structures such a four power intake modules are all beyond 100 m distance and all are concrete structures. Therefore, the main concern for vibration is the domestic houses belonging to villagers in the close proximity of approach channel area. As the vibration frequency ranges between 8-15 Hz, the corresponding safe PPV value is 10 mm/s as per DGMS, India criterion (Table 3).

Fig. 7: Photograph showing improvement in pre-split blast results at crest portion of bench

Table 3: DGMS (India) standard for safe permissible level of vibration

Type of Structures	Dominant Excitation Frequency, Hz		
	< 8 Hz	8 - 25 Hz	> 25 Hz
(A) Buildings/structures not belong to the owner			
i) Domestic houses /structures (Kuchha brick and cement)	5	10	15
ii) Industrial buildings (RCC and framed structures)	10	20	25
iii) Objects of historical importance and sensitive structures	2	5	10
(B) Building belonging to owner with limited span of life			
i) Domestic houses /structures (Kuchha brick and cement)	10	15	25
ii) Industrial buildings (RCC and framed structures)	15	25	50

As shown in Fig. 8, a plot between peak particle velocity (PPV) and square root scaled distance (SD) for the monitored distance with different MCD and SD is made to find out attenuation characteristics equation in three different confidence envelop at 50%, 85% and 95%. The equations are given below

$$V = 978\,(SD)^{-1.91} \quad \text{at 50 \% confidence} \tag{1}$$

$$V = 1134\,(SD)^{-1.91} \quad \text{at 85 \% confidence} \tag{2}$$

$$V = 1197\,(SD)^{-1.91} \quad \text{at 95 \% confidence} \tag{3}$$

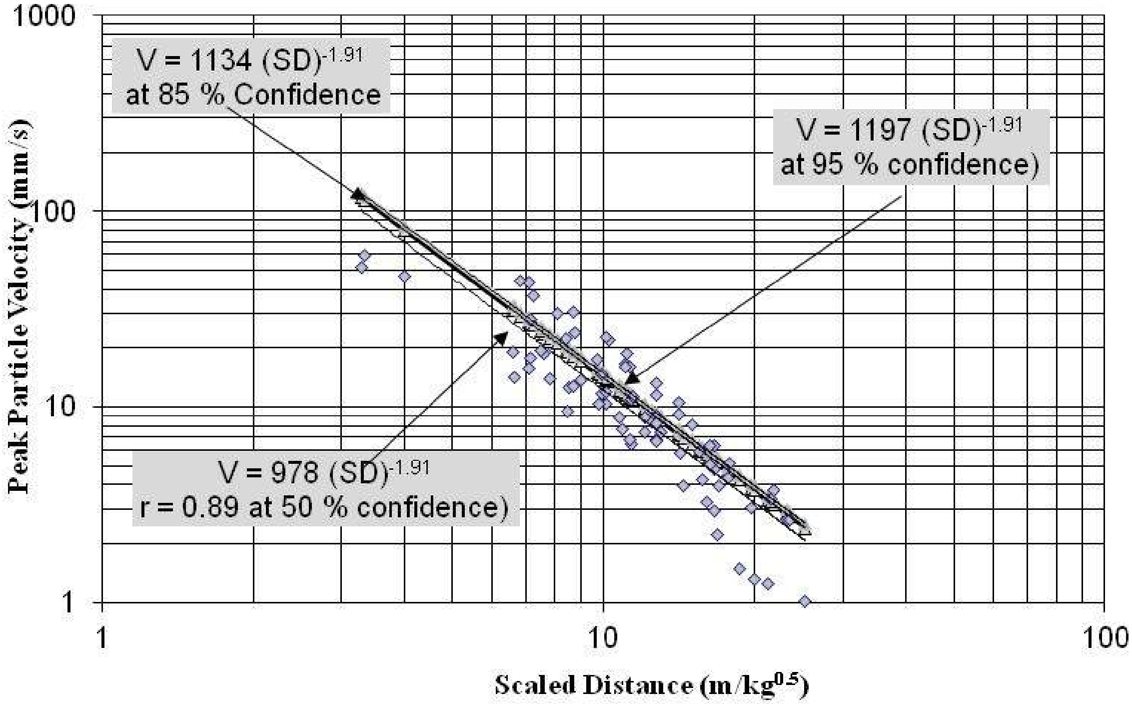

Fig. 8: Plot showing attenuation characterstics of blast vibration in different confidence intervals

Three attenuation equation (Eqs. 1, 2 and 3) are obtained by plotting PPV vs scaled distance (SD) (Fig. 8). These equations are used to calculate safe MCD taking 10 mm/s as safe PPV as per DGMS criterion. The safe MCD using 95% confidence equation is used for the design of the blast to be on safe side. Table 4 gives details of safe MCD in different confidence intervals taking 10 mm/s as safe permissible level. For pre-split blast as well as production blasts in approach channel area 65 kg is found to be safe MCD for structures at a distance of 100m using 95% confidence equation. In this approach channel area of Kol dam project site, more than 10 agencies were doing excavation works simultaneously. As all the agencies were taking blast in the same blasting time interval possibilities of constructive interference giving rise to higher amplitude and velocity could not be avoided. Therefore to minimize possibilities of higher PPV due such interference phenomenon, it was decided to further reduce MCD to 50 kg. Therefore, all the blast used MCD below 50 kg.

Table 4: Safe maximum charge per delay (MCD) in kg for different distances taking 10 mm/s as safe peak particle velocity (PPV)

Distance	MCD at 50%	MCD at 85%	MCD at 95%
25	5.09	4.36	4.12
50	20.36	17.43	16.48
75	45.81	39.23	37.09
100	81.44	69.74	65.93
125	127.26	108.97	103.02
150	183.26	156.91	148.35
175	249.42	213.57	201.92
200	325.77	278.95	263.73
225	412.31	353.05	333.79
250	509.02	435.86	412.08
275	615.92	527.39	498.62
300	732.99	627.64	593.40

3.5 Evaluation of Pre-Split Blast Results

Overbreak and half cast factor (HCF) are commonly used parameters for evaluation of results of pre-split blast. These parameters are used in the Kol dam also for assessment of the blast results. Result of the presplit blast vis-a-vis overbreak is shown in Fig.9. After eliminating problem of drill hole deviation and treatment of the production holes, overbreak reduced significantly. As shown in Fig. 9, overbreak remained less than 0.1m.

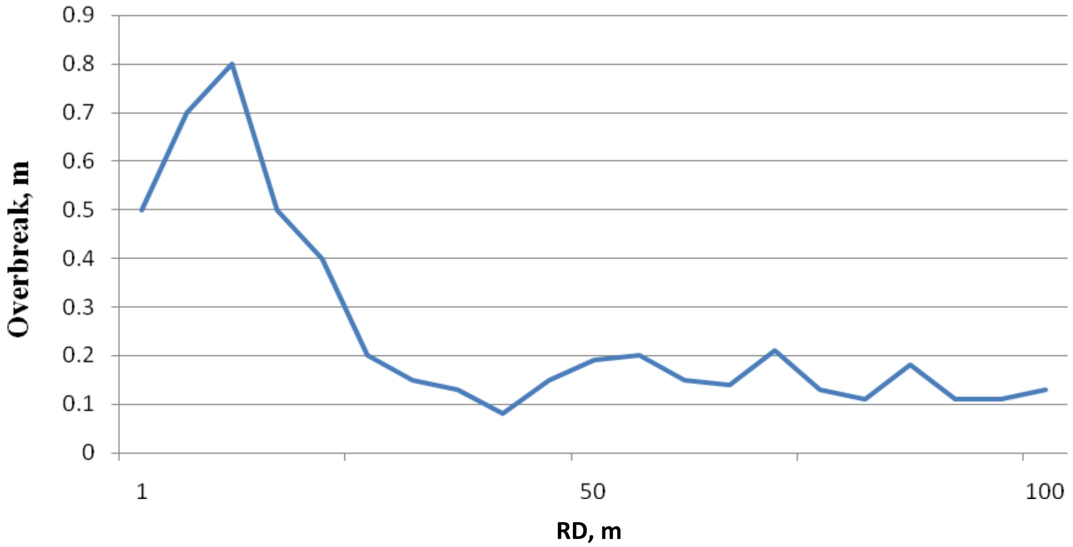

Fig. 9: Plot showing reduced overbreak in approach channel area upto RD 100 m

The half cast factor (HCF) is a measure of the remaining half casts left on the rock walls and back. HCF does not take into account drilling error. Half cast factor is a representative of the back-breakage and more the HCF least will be the damage. HCF in the approach channel area was found to be more that 90%. This is clear from the visible half cast marks of the bore holes in the photographs shown in Figs. 3, 5, 6,and 8. The final shape of the approach channel area with seven benches having slope 1:4 is shown in Fig. 10.

Fig. 10: Photograph showing benches of Kol dam project devloped using pre-split blasts

4. CONCLUDING REMARKS

Pre-splitting controlled blasting technique was used in Kol dam hydroelectric power project in the approach channel area for development of benches with slope1:4 having height 15 m and berm width of 5 m. 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 block dislodgement 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 induced damages. Drill holes were also deviating due to longer hole depth of 16 m.

The pre-split blast was designed with continuous decoupled charge using 25 mm emulsion explosive with 10gm/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 50 kg as per Indian Standard of DGMS. The result obtained by carrying out above exercise gave good result with overbreak less than 0.1 m and half cast factor above 90%.

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