Shock Tube Initiation System for Improving Pull in Tunnels

A. K. Mishra*
P .Balamadeswaran*
V. Bhusan**
&
R. N. Gupta**

**Department of Mining Engineering*
Indian School of Mines, Dhanbad-826 004, INDIA
Tel: +91-0326-2210024,Fax: +91-0326-2206396
E-mail: akmishra@perl.ism.ac.in

***Indian Explosives Limited, Kolkata-700 020, INDIA*
E-mail: vishwa_bhusan@ici.com

****National Institute of Rock Mechanics*
Kolar Gold Field, Karnataka, INDIA
Tel: +91-0815-375000, Fax: +91-815-375002
E-mail: nirm@sancharnet.in

ABSTRACT

Today's changing business environment not only calls for stringent safety norms but also a clean environment. In the case of blasting operation, the explosives are not effective unless there is a compatible initiation system. Years of innovation have brought out a number of revolutionary new products like non-electric blast initiation systems to match the performance desired in initiating the explosives. Consequently, in the area of construction jobs such as tunnelling, where blasting plays a vital role, the use of modern initiation techniques like non-electric initiation systems is inevitable. Considering the valuable role played by the non-electric initiation systems in blasting operations, the authors have discussed the benefits obtained with the usage of shock tube initiation system in tunnel blasting.

Keywords: Shock tube, tunnel blasting, blast design, blast pattern, pull, and tunnelling.

1. INTRODUCTION

The tunnelling operation in any hard rock formations can be executed by adopting conventional drilling and blasting methods in spite of the fact that there will be a very rigid ground vibration limits. The geological features and geotechnical characteristics

of the rock formation and the economic factors may threaten the use of modern excavating machineries on the face. Here, the blasting engineer plays an important role while designing each and every blast, as he has to keep the maximum permissible limits of ground vibration in his mind. This complex situation necessitates the introduction of advanced blasting techniques for higher productivity with less damage to the surrounding rocks and also to restrict the ground vibrations within the permissible limits. Since the introduction of emulsion explosives over two decades ago, there have been no radically new commercial explosives but innovations are being introduced in the other blasting areas such as handling and use of explosives, blast design techniques, initiation systems and monitoring systems. This paper discusses the use of shock tube technology in tunnel blasting for improving the productivity in terms of higher pull with less damage to the surrounding environment.

2. TUNNELLING INDUSTRY – A REVIEW

Tunnel excavation, or drifting as it is called in mining engineering, is an important operation both in construction engineering and in underground mining (Persson et al., 1994). The growth of population concentration in urban areas brings with it an increasing need for underground tunnels, for public transport, for water and sewage systems, and for electrical and telecommunication cableways. Apart form the above, the creation of sub-surface space use for storage, cold chambers, vehicular tunnels for traffic, sub-surface parking spaces, underground shelters for military purposes, underground construction works in hilly areas for hydro-electric power projects such as caverns, open-stocks, power houses etc, are some known examples of underground construction. Hence, the planning and excavation of tunnels plays a significant role in the total economy of an excavation project.

3. BLASTING PRACTICES IN TUNNELLING – CURRENT SCENARIO

In surface blasting process, the blasting engineer normally has the options of atleast two free faces – one in front and one on the top surface. But, in tunnelling, there is only one free face, which is the tunnel face itself. The advance of the face is parallel to tunnel face, in which the holes are drilled at right angles to the face so that the face itself cannot be used as a free face for breakage. Hence, the creation of free face is an important operation in the tunnel blasting and it is generated by a cut that will open a cavity into which the production holes in the round can break.

The rock in a tunnel round is more effectively confined than in any other rock blast operations. The amount of confinement of rock is usually depends upon the physical characteristics of the rock and the size of the tunnel. Hence, the tunnels of small diameter consume the large amount of explosives than the larger diameter tunnels (Johansen and Mathiesen, 2000). In the tunnel blasting, the amount and type of explosives used depends upon the following factors:

- Rock Characteristics
- The cross section / size of tunnel
- Depth of the borehole drilled

- Diameter of the borehole drilled
- Type of cut used

To achieve satisfactory blasting results an opening or the cut must be initially established into which the surrounding rock could be blasted. The selection of cut is decided by the following parameters:

- Rock conditions
- The cross sectional area of the tunnel
- The width of the tunnel
- Type of available drilling equipment
- Amount of advance required

Basically, the cuts can be classified into the following groups:

1. V cuts: Wedge cuts and fan cuts
2. Parallel cuts: Large diameter parallel cuts and burn cuts

Here, the Parallel cut, of having large diameter, is commonly used in the tunnel blasting operations. Since this type of cut is independent of the cross sectional area of the tunnel and tunnel width, it can be applicable over the entire cross section of the tunnel and for various borehole diameters. The parallel cut consists of one or more large diameter unloaded boreholes. All holes are drilled at a right angle to the face and parallel to the tunnel direction. The breakage is against the opening or void formed by these unloaded holes of diameter 76-150 mm. This opening is gradually opened up by successive detonation of the adjacent loaded holes and the crushed rock is thrown out of the cut.

In parallel cut, the cartridge explosives of a composition, which gives high amount of gas energy with low gas temperature, are used to prevent sintering and reduce the blow-out. During the charging of blast holes, the production holes are loaded with high energy explosives at the bottom of the holes and the weaker explosives in the rest of the hole. The lifter holes, which are basically located in the floor level, usually charged with high-density explosives to produce a muck pile, which is easy to handle. The contour holes are normally charged with the aim of minimising the unwanted fracturing of the rock in the periphery. As the nitro glycerine based explosives, which had proved to be the most suitable explosives in tunnel blasting, are currently non-existing in the Indian market due to safety hazards associated with them, slurry and emulsion explosives to a large extent have replaced it. Further, it must be borne in the mind that the explosives chosen for tunnel blasting should have good post blast fume characteristics to minimize the concentration of toxic fumes after detonation, from the point of view of safety and productivity.

As far as the initiation system is concerned, the electric delay detonators are used in the initiation pattern in such a way that the opening produced by the previous hole can be utilised by the following holes in sequence. The delay interval in the cut must be sufficient for the rock to be blown out of the hole before the next hole is fired. Hence, the cut is fired using millisecond caps. Often, it has been found that drill hole deviation causes problem in case of closely spaced cut holes in a parallel cut used for

deeper rounds. This can be solved by introducing "long delay caps having more than 100 ms delays" for firing of the cut holes in place of "millisecond caps".

Parallel cuts normally give better breakage and fragmentation of the rock with less thrown-out and spreading as compared with other cuts. This result in reduction of the loading time and makes it more convenient to scale the roof, walls and face of loose rock from a position on top of the pile (Johansen and Mathiesen, 2000).

4. SHOCK TUBE TECHNOLOGY IN TUNNEL BLASTING

4.1 Shock Tube Initiation System – Background

Shock tube initiation system was introduced to the mining, quarrying and construction industries in the early 1970s, as a new safer method of initiating explosives and has been growing steadily in popularity ever since. Many excavation industries are now-a-days using shock tube initiation over conventional initiating system. This product basically consists of a plastic tube with an outer diameter of 3 mm and 1.5 mm inner diameter, the inside walls of which are coated with a fine layer of explosive dust, which is typically a mixture of HMX with a small added percentage of flake aluminium (Bhushan and Srihari, 1995). The quantity of explosive is about 15-20 mg/m inside the tube. A shock tube comprises a length of shock tube, which is sealed at one end, and has a delay detonator crimped to the other end. When the sealed end of the tube is fired with a detonator or detonating cord, a mild detonation wave travels through the tube. It is a sort of dust explosion travelling at about 2200 m/s inside the tube. The shock wave is weak that it does not damage the tube (Mishra et al, 1999). When the shock wave reaches the other end, it initiates the detonator, which in turn sets off the explosives primed with it.

Shock tube initiation system can be used to replace several products currently used to initiate blasts – detonating cord, electric detonators and capped fuse. The advantages of the system are:

- Safety
- Simple and reliable
- Low explosives content
- Point initiation
- Non-destructive in nature hence no explosive desensitisation
- Reduced noise and fly rock
- Infinite delay combinations
- Prevents deflagration

4.2 Shock Tube Initiation System in Tunnel Blasting

In the tunnel blasting operations, the choice of the initiation system plays a critical role in the development of tunnel. Since the blast result is a direct function of the timing accuracy of the initiation system, it is important that the intervals used should be sufficiently long enough for the broken rock to be heaved away from the face before the next holes are detonated. Soft rock formations require longer delay time

between intervals than harder rock, which is more easily blasted. In such circumstances, it would be suitable to have long delay detonators in the blasting operations for obtaining efficient blast performance. Hence, the blasting engineer can choose non-electric system of initiation such as shock tube initiation system to achieve the desired results in terms of required pull and better fragmentation. This system can also control the over break which in turn will provide a smooth profile and reduced cost of support.

As the shock tube initiation system provides a true point initiation, the conventional drilling pattern or cut can be redesigned in order to utilise the system effectively. Hence, the blasting engineer can increase the existing spacing and burden of the drill holes to the minimum of 1m x 1m and can conduct the blasting operations using shock tube initiation system. If there is any hope of increasing the spacing and burden further, then it can be done subsequently till the satisfied results are consistently obtained from the blasts conducted using shock tube initiation system. While carrying out the blasts with the expanded pattern, the explosive charge per hole has to be improved as the depth of the hole is increased, in addition to the significant reduction in number of holes. Further, increased charge length may result in lessening the large stemming length as it was in case of the conventional pattern using the electrical initiation system. This causes better utilisation of explosive energy. While increasing the hole depth, we must ensure that the collapsing of drill holes should not take place otherwise there is a chance that full length of drilled hole might not be available for charging.

Thus, switching over to shock tube initiation system will not only offer an improvement in the blast results in terms of higher pull but will also cause remarkable reduction in the number of holes required to be drilled. Hence adopting shock tube initiation system will result in less drilling cost besides considerable saving in the drilling and charging cost.

4.3.1 Suggestions while using shock tube initiation system in tunnels

While using the shock tube initiation system in tunnel blasting, the following practices should be followed to ensure the smooth blasting with an improvement in the blasting efficiency:

- The drill holes should be drilled as per the markings given for the specific type of cut.
- The drilled holes should be cleared ahead of charging to examine the condition of the hole and to ensure its required depth.
- The primer cartridge should be always pushed to the back of the hole with out tampering.
- The loading pole can be used to ensure the proper charging of explosives and also to measure the depth of hole.
- During the charging, the shock tube should be stretched tight to avoid damage from the loading pole.

- It is always better to involve the experienced and statutorily responsible persons while using the shock tube initiation system during the blasting.
- The training programmes should be conducted periodically for the blasting crew, on the blasting practices involving the shock tube initiation system.

5. FEATURES OF SHOCK TUBE INITIATION SYSTEM IN TUNNEL BLASTING

5.1 Benefits of the System

- This system offers more safety while usage, as the non-electric is immune to static electricity, stray currents and induced currents.
- This has got better control over initiation times to improve fragmentation, which results in higher pull.
- The improved fragmentation and optimum profile results in reduced down costs like mucking, hauling, support requirement, etc.
- The use of shock tube system has considerably reduced the number of holes with a considerable increase in the depth of the hole.
- The accurate delay timings with the shock tube initiation system giving a very wide range of delay sequences, can easily replace electrical initiation system in tunnel blasting and the blasts are better with an increased pull because of availability of an extended range of accurate delays.
- An increased pull results in an increased rate of advance and reduced drilling and blasting cost.
- It also reduces the vibration levels, air blast and fly rock produced in blasts.
- Since it has got the advantage of point initiation, the priming can be done near the collar or bottom or middle of the blast hole.
- As the connection with non-electrics and hook-up is easy and there is no requirement to test the circuit for electrical continuity, the hook-up is fast and it saves considerable time in the total cycle of operation.
- Reduced cost due to savings in hook-up time and enhanced safety make the system an ideal choice for the tunnelling operations.
- Under the collapsing/squeezing ground conditions usually occurs in tunnel projects, the holes are normally inserted with drill rods until the charging is completed to save the drill hole, which is a hazardous operation with electric detonator but while with shock tube, it can be safely practised.

5.2 Limitations of the System

- It is costlier than the other conventional systems.
- It requires proper supervision during the usage in the field.
- The handling of misfire involving the shock tube initiation system is comparatively difficult to handle.

6. CASE STUDY

6.1 Project-Introduction

Tala hydro-electric project is located in the country of Bhutan where a lot of tunnelling activities are being undertaken. M/s. HCC, Mumbai, has executed a part of tunnelling construction, in two packages, namely, C1 and C4 packages, which they have got the contract. C1 package has got the toughest stretches in the beginning of Head Race Tunnel (HRT), which is 6 km long with 73.5 meters dam adit. HRT is horse-shoe shaped with face area of 48.5 meters^2, i.e. approximately 6m wide at the floor and 7.4 m high. The rock is basically a quartz biotite gneiss formation containing quartz augens. Since the drill holes are collapsing prematurely due to the prevailing unfavourable geological conditions, the study was conducted with a view to establish a parallel cut pattern for the above Head Race Tunnel with ensuring a consistent pull of 3 meters and above.

6.2 Existing Blasting Practice

The blasting was practiced with a wedge cut pattern in combination with electric delays, in tunnel. The number of holes drilled for the blast varied from 100 to 110, with explosive consumption of around 250 kg, which resulted in average pull of 2.2 m to 2.5 m. The emulsion explosives of 32 mm diameter have been used with a charge factor of 2.0 to 2.3, in 45 mm diameter drill holes. The results obtained from the blasts show that poor pull was attained from the use of wedge cut, ineffective blasting caused by poor coupling due to charging of 45 mm diameter drill holes with 32 mm diameter explosives and more importantly, the unsafe blasting practice exists with the conventional electric detonators.

During the charging, it has been found that the collapsing of drill holes under the present geological conditions is a regular phenomenon. It requires the holes to be re-drilled or flushed with drill rod, which causes difficulties to the crew as the face has been already charged with electrical detonators. The choice of initiating system plays a critical role in the progress of the tunnel. The total consequence of correct and optimum drilling and charging depends on the proper choice of initiating system, which, should be very safe and effective. The blast result is the direct function of the timing accuracy of the initiating system.

Considering the advantages offered by shock tube initiation system, the management decided to make use of the shock tube initiation systems in the place of electrical detonators, with changes in the blast design in view of safety and tunnel.

6.3 Blast with Shock Tube Initiation System

The management of the project carried out a total of 19 blasts in two phases, with changing pattern from wedge cut to parallel cut using 40 mm diameter explosives and long period delay detonators. Initially 7 blasts have been carried out with number of holes varying from 100 to 110, consuming the explosives of around 250 – 280 kg.

The blasts gave mixed results with some of the blasts giving good pull while others requiring reblasting of a number of holes. The blast details are summarised in Table 1. The main problem identified with the pattern was that number of holes had been more resulting in less explosive being charged per hole. Consequently stemming in hole became larger compared to burden and hence explosive energy was not effective in breaking the rocks. Based on the experience of the above blasts, a total of 12 blasts were carried out with the modified pattern in which the number of holes have been reduced by increasing spacing and burden to 1m x 1m. The results are summarised in Table 2.

Table 1 – Details of blast carried out with initial pattern (ICI, 1999)

Blast No.	No. of Holes	Hole Depth	Explosives Used (kg)			Pull Obtained (m)	Powder Factor (kg/m^3)	Remarks
			40 mm	32 mm	Total			
1.	113	3.5	235.5	50	285.5	3.5	1.68	Switching over from Wedge cut to Parallel cut
2.	103	3.5	246	25	271	2.0	2.79	2 holes choked in cut
3.	102	3.5	242	25	267	2.0	2.75	Face uneven
4.	117	3.5	185	43	228	3.0	1.57	Overhang and side tightness removal (50 kg of explosives used)
5.	125	3.5	281	0	281	3.0	-	75 holes re-blasted using 150 kg of explosives
6.	104	3.5	240	42	282	3.0	1.94	Bottom and side tightness removal
7.	104	4.0	185	100	285	1.5	-	80 holes re-blasted using 150 kg of explosives

From the table, it is evident that all the blasts gave superior result with good pull being obtained in all blasts. Initial 8 blasts were carried out with a drill depth of 3.5 m and pull obtained varied from 3.0 m to 3.5 m giving a charge factor of 1.80 to 2.00 kg/Cu.m. Initially, 40 mm diameter cartridges were used in periphery holes also but later on periphery holes were charged with 32 mm diameter cartridges (primer of 40 mm diameter cartridge and column of 32 mm diameter cartridges) so as to ensure the less disturbance to the surrounding rock. The blasting pattern for Head Race Tunnel is shown in Figure.1. Encouraged from the results, the drill depth was increased to 3.7 m for the last 4 blasts, which resulted in obtaining the pull of 3.5 m from the first three blasts and 3.7 m from the fourth blast. As the collapsing of holes is a regular feature in the face, the extra length of hole drilled will go waste. Moreover it was observed

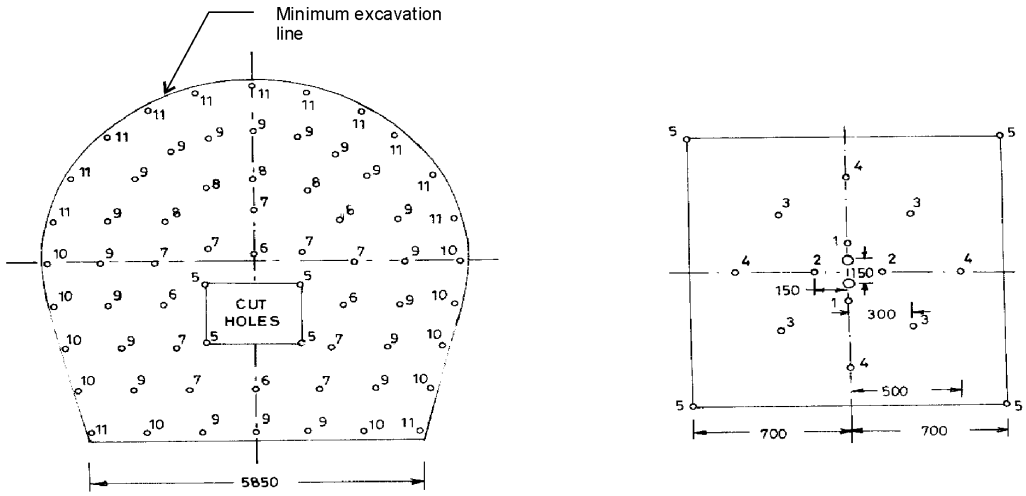
that charging some holes to 3.5 m and some to 4.0 m would result in an uneven face for the next blast. The cost analysis has been presented in Table 3 for both the designs.

Table 2 - Details of blast carried out with modified pattern (ICI, 1999)

Blast No.	No. of Holes	Hole Depth	Explosives Used (kg)			Pull Obtained (m)	Powder Factor (kg/m^3)	Remarks
			40mm	32mm	Total			
1.	86	3.5	308	0	308	3.3	1.92	Pattern re-designed; one oversized boulder
2.	80	3.5	320	0	320	3.2	2.06	2 stripping holes; 5 kg of explosives
3.	87	3.5	313	0	313	3.5	1.84	
4.	80	3.5	282	32	314	3.5	2.23	
5.	88	3.5	300	25	325	3.0	2.23	
6.	84	3.5	253	29	282	3.5	1.66	
7.	85	3.5	277	25	302	3.0	2.08	
8.	85	3.5	266	37	303	3.0	2.08	
9.	78	3.7	264	45	309	3.5	1.82	Hole depth increased
10.	77	3.7	285	44	329	3.5	1.94	
11.	80	3.7	272	45	317	3.5	1.87	
12.	78	3.7	297	27	324	3.7	1.81	

Table 3 – Cost analysis comparison in tunnel blasting (ICI, 1999)

Item	Previous Pattern with Shock Tube Initiation System	Modified Pattern with Shock Tube Initiation System
Face Area (m^2)	48.50	48.50
Drill Depth (m)	3.50	3.50
Average Pull (m)	2.50	3.35
Number of Holes	100	82
Total Explosives (kgs)	250	312
Number of Detonators	100	82
Cost of Drilling @ Rs.50/m	17500.00	14350.00
Cost of Explosives @ Rs. 60/kg	15000.00	18720.00
Cost of Initiation system @ Rs. 70/piece	7000.00	5740.00
Total cost of Drill and Blast (Rs.)	39500.00	38810.00
Volume per Blast (m^3)	121.25	162.50
Cost per m^3 (Rs.)	325.77	238.86



HOLE DEPTH = 3.50 m. EXPECTED PULL = 3.00 m. EMPTY HOLE DIA = 102 m. CHARGED HOLE DIA = 45 mm. No. OF CUT HOLES = 16 + 2 Nos. No. OF STOPING HOLES = 35 Nos. No. OF FLOOR HOLES = 7 Nos. No. OF ROOF + SIDE HOLES = 19 Nos. TOTAL CHARGE = 290 Kg. TOTAL VOLUME = 50 m^2 X 3.00m = 150 m^3 POWDER FACTOR = 1.90 kg / m^3	<u>UNCHARGED LENGTH</u>: CUT & FLOOR HOLES $\leq$ 0.60 m STOPING HOLES $\leq$ 0.90 m ROOF & SIDE HOLES = 1.20 m POWER GEL 801 = 40 mm X 300 mm (400g) CHARGE = 4.0 kg (10 CARTRIDGES) / HOLE CHARGE = 3.60 kg (9 CARTRIDGES) / HOLE CHARGE = 4.0 kg (10 CARTRIDGES) / HOLE CHARGE = 3.20 kg (8 CARTRIDGES) / HOLE TOTAL = 64 + 136.80 + 28.00 + 0.80 = 289.60 kg

Delay No.	Nos. of Holes
1	2
2	2
3	4
4	4
5	4
6	4
7	9
8	5
9	20
10	10
11	13
TOTAL	77 HOLES

Fig. 1 – Blasting pattern with details of charge, etc. for head race tunnel (ICI, 1999)

From the Table 3, it is obvious that one of the major advantages of switching over to the shock tube system of initiation with modified blast pattern is the lowest cost of production, apart from the reliability of initiation and excellent timing accuracy, to realize maximum performance and productivity in the tunnelling operation.

7. CONCLUSION

With consistency of performance and assured more output, non-electric initiating systems are gaining popularity in tunnelling operations and the trend is bound to continue. Although the total explosive consumption increased but the total cost of drilling and blasting reduces significantly with the shock tube initiation system. It can be emphasised that the use of shock tube initiation system helps in getting good pulls besides other advantages such as time saving and safety. Therefore, it is suggested that the careful execution of blast design in the tunnel blasting along with adequate knowledge of modern techniques will be the first step towards providing a cost effective and environmental solution of the usual problems encountered in tunnelling projects.

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