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Reducing environmental hazards of blasting using electronic detonators in a large opencast coal project - a case study

The core objectives of Indian Ministry of Coal in its vision statement is securing the availability of coal to meet the demand of different sector of economy in an eco-friendly and sustainable manner. Coal India produced 567.37 million tonnes of raw coal in 2017-18 out of which contribution from opencast mines was 536.82 million tonnes (i.e. 95%). Deep hole blasting for high capacity excavators like draglines, 20 cum shovels becomes imperative for achieving high production targets. Thus, environmental hazards associated with deep hole blasting is also bound to happen. One of the serious problems faced by deep hole blasting is that of ground vibrations. In Khadia opencast coal project the power plants, Rihand dam is in vicinity and local population in and around mines, controlling ground vibration was of paramount importance for the project. Hence, it became a challenge for reduction of environmental hazards involving deep hole blast for dragline; shovels using electronic detonators, for providing precision delay and maximizing the vibration of explosive energy. The blast design parameters using electronic detonator for various blasts of dragline benches were tried to know the resultant profile of ground vibrations near human settlement of Khadia project. This has also resulted in improvement of powder factor (volume of rock fragmentation per kg of explosive used).

This paper deals with, as to how the environmental impacts due to ground vibrations of rock blasting, are reduced resulting in no complaints for dwellers and any authorities in and around Khadia project.

1.0 Introduction

Blasting is the principal method of rock breakage in mining throughout the world. This may be probably due to distinct advantages like economy, efficiency, convenience and ability to break the hardest rock (Singh, Roy and Sinha, 2008). However, only a portion of the total energy of the explosive is consumed in breaking rocks while the rest is dissipated. With increasing mining activities in areas close to human settlements, ground vibrations has become a critical environmental and social impacts as it can cause human annoyance and structure damage (Agrawal and Mishra, 2019; Siskind et al., 1981; Mishra, Nigam and Singh, 2017). The mining and explosives industries rapidly embracing new technology in order to improve overall performance, efficiency, cost effectiveness in various types of blasting also to mitigate its adverse effect (Mishra, Agrawal and Raut, 2019; Agrawal and Arvind Kumar Mishra, 2018). Most recently technology that is developed to improve techno-economics, reduction of adverse effects in usage of explosives and blasting is precise, accurate delay timing using electronic detonators system. Flexible timing allows blasters to make small hole to hole and row to row changes to account for drilling in accuracies (Agrawal and A K Mishra, 2018b). The mining method at optimum is multi-seam mining, using dragline in successive parallel strips 70 m meters wide and up to 1500m long. This method involves removing the top soil to a depth of approximately 190 meters, drilling and blasting the overlaying waste material and the removal of this overlaying burden by draglines. The timing/delay element of blasting of blasthole firing is enabled through a delay element in the detonator. In the pyrotechnic detonator this relates to burning through some material before the fuse head is reached. The delay element length would determine the delay period (Garai et al., 2018; Yang and Lownds, 2011). The long awaited arrival of high accuracy electronic detonator provides new opportunities to the explosive end user (Mishra, 2013; Agrawal and A K Mishra, 2018a). The blasting community can become better equipped and able to improve upon the current approaches and methodologies used in blast design. The last few years have seen dramatic progress in blasting technologies, the quality and performance of products (Singh et al., 2016). The high accuracy detonator brought with it new meaning to one of the fundamental aspects of blast design: accurate controlled sequence of blasthole detonation is one of the most critical parameters that has a direct impact on overall blast performance in many ways (Silva, Jenks and Sharon, 2016; Agrawal and Mishra, 2017).

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2.0 Location and geology

Khadia project is located in Singrauli area of Northern Coalfields Limited between latitude 24 deg 7' 26" and amp; 24 deg 8'47" and between longitude 82 deg 41'40" and amp; 82 deg 44'47" has been named after Khadia village located in the south of the block. The area is covered under the topo sheet No.63 L/12 and amp; special sheet No.9 and amp; 11 of Survey of India. It is connected by metalled road to NCL HQ, Singrauli and to Shaktinagar-Varanasi Highway as well as to Rewa Highway. Nearest railway station being Shaktinagar, Eastern Railway. It is bordered in northern side by MP Forest Land, in south side by Shaktinagar super thermal power station of NTPC, Shaktinagar, in the western side by Dudhichua project and in the eastern side by Krishnashila project (Fig.1). The strike is NW-SE in the west which swing to ENE-WSW in the eastern part of the area. The strike is E-W in the central part of the area. The dip varies from 1 in 20 to 1 in 25. The mining strategy is partially outsourced using PC-dumper combination of OB removal, partial OB is removed using dragline and shovel. The coal is extracted using shovel-dumper combination (Figs.2 and 3). The mining strategy and section of mines is shown in Fig.2. The overview of the Khadia Project is presented Fig.3.

3.0 blasting and its impact

Deployment of large draglines and large capacity shovels requires deep hole blasting with high explosive consumption. In such circumstance's reduction of impacts of blasts in the nearby villages and power plants while ensuring the efficiency of mining operation is a challenging task. The main impacts due to blasting are

- Ground vibration
- Noise/air blast over pressure
- Flyrock
- Human response.

Fig.1: Satellite view of Khadia project of Singrauli coalfields, NCL. (Source: Google Earth)

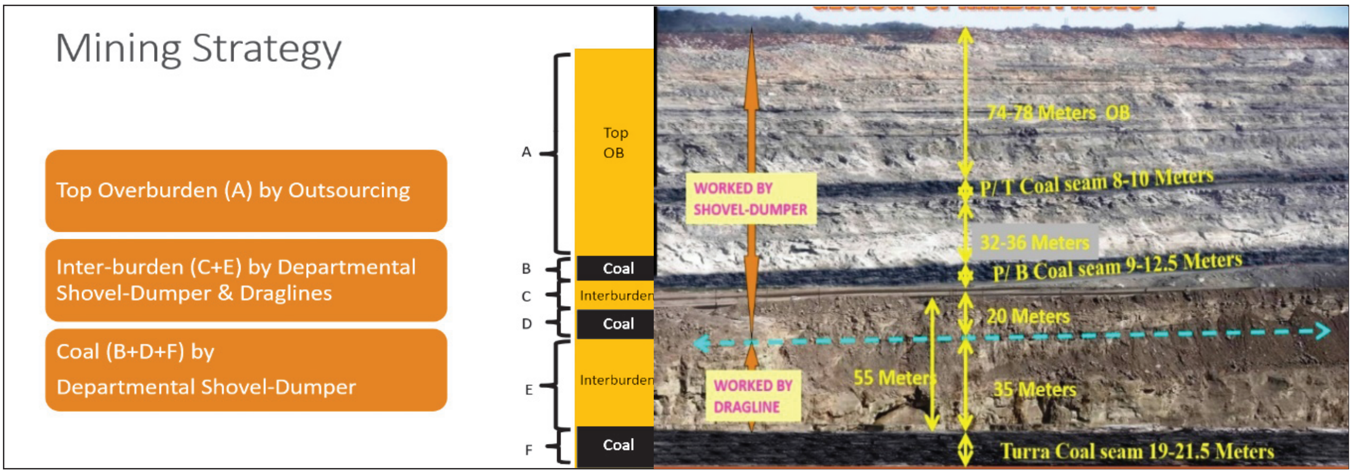

Fig.2: Section of seam and partings in mines with their mining strategy in Khadia mines, NCL

Fig.3: An overview of Khadia mines, NCL

When a certain amount of explosive i.e. site mixed emulsion charge in holes detonates, intense energy is liberated leading to dynamic waves set around the different blastholes. The energy liberated is spread to the rock mass around the blasting patch as strain energy. This energy transmission takes place concentrically in the form of shock waves. The energy carried in the waves crushes the nearby rock into small fragments. The region under strain energy due to waves is known as shock zone. Outside the shock zone, the waves energy gets weakened to some degree and results in the radial cracking of the next rock mass. The gas generated due to detonation of explosive presses these cracks and helps in increasing the gaps and its fragmentation. The phenomenon of crack enhancement takes place in the transition zone. As further weakening of shock waves takes place beyond the transition zone, generation of the gases cracks reduces and also there is no permanent deformation in the surrounding rock mass beyond the transition zone. The further shock waves transform into the blast-induced ground vibrations. The ground vibrations lead to movement of ground particles and measured in three mutually perpendicular direction i.e. vertical, longitudinal and transverse causing structural damage. Although the alterations in the amplitudes, accelerations, frequencies and particle velocities in three orthogonal directions cause the structural damage but the frequency and PPV (peak particle velocity) are the major factors considered for assessing the structural response.

These environmental impacts of blasting need to be controlled and limits under the permissible limits set by regulatory bodies such as DGMS for smooth and safe workings without compromising with the productivity. In Khadia mines, a lot of efforts have been made to improve the blast performance where environmental impacts can be reduced and improve fragmentation and productivity. Some of the techniques adopted at mine are:

1. Use of electronic detonators for precise blast timing.
2. Line drilling to control the blast induced ground vibration.
3. Fragmentation monitoring and analysis.
4. Optimization of blast design parameters to achieve the desired blast performance as per each bench formations.
5. Determination of site specific blast-induced ground vibration predictor equations and maximum charge per delay to restrict the vibrations at critical locations.
6. Use of decking in deep hole dragline blasting.
7. Continuous monitoring of blast-induced ground vibrations using seismographs.
8. High speed videography of blasts to analyze the flyrock and measures to restrict the flyrock.
9. Prediction and control of PPV using signature hole analysis technique whenever blasting near sensitive areas.
10. Adopting controlled blasting techniques.

The adoption of electronic detonators as initiation system in Khadia mines has changed the blast performance results drastically. To verify the blast performance improvements achieved, the blasts with electronic detonators and detonating fuse were monitored closely and the results recorded are analyzed.

4.0 Analysis

The use of electronic detonators and control blasting techniques such as line drilling has been practiced in mines and the results of blasts with or without controlled techniques are compared.

4.1 Blasting with Electronic detonators

A total number of 22 different production blasts are conducted at Khadia mines using electronic detonators with optimized blast design parameters. The blast-induced ground vibration in magnitude of PPV are recorded at varied distance using seismographs and fragmentation analysis are performed. The details of blasts conducted is mentioned in Table 1.

Table 1: Details of blast conducted with Electronic detonators in Khadia Mines, NCL.

No Of Holes	Hole Dia (mm)	Average Hole Depth (m)	Spacing (m)	Burden (m)	Q total (kg)	Max Charge Per Delay (kg)	Distance of monitoring	SD (m/kg$^{0.5}$)	PPV (mm/s)	Mean fragment size (m)	Powder factor (m^3/kg)
41	311	42	12	10	121941.5	1803.5	200	4.70	51.07	2.5	1.69
35	311	39.8	12	10	86799.5	1803.5	300	7.06	30.04	2.8	1.93
59	311	33.45	12	10	127975.4	1302.5	100	2.77	115	0.8	1.85
23	311	33.28	12	10	47511.5	1302.5	300	8.31	19.35	0.9	1.93
43	311	32.23	12	10	97236.25	1302.50	300	8.31	27.4	1.3	1.71
44	311	16	9	8	29565.25	721.25	300	11.17	16.26	1.8	1.71
44	311	16	9	8	29565.25	721.25	500	18.61	8.591	2.98	1.71
31	311	40.54	12	10	88576.15	1903.75	300	6.87	32.51	3.7	1.70
32	311	32.75	12	10	82832.1	1302.5	300	8.31	24.5	0.3	1.52
37	311	38.22	12	10	87531.5	1703.25	300	7.26	11.66	0.76	1.94
1	311	33.5	10	12	2275.00	1303.00	150	4.15	55.88	2.3	1.77
43	311	32.23	10	12	97236.25	1302.50	300	8.31	27.4	1.45	1.71
44	311	16	9	8	29565.25	721.25	300	11.17	16.26	3.1	1.71
44	311	16	9	8	29565.25	721.25	400	14.89	8.591	1.34	1.71
2	311	32	12	10	3808.00	1252.75	400	11.30	4.826	1.76	2.02
2	311	32	12	10	3808.00	1252.75	600	16.95	3.066	1.4	2.02
31	311	40.54	12	10	88576.15	1903.75	300	6.87	32.51	0.4	1.70
32	311	32.75	12	10	82832.1	1302.5	300	8.31	24.5	0.78	1.52
1	311	37.5	12	10	2710	1603	300	7.49	29.46	1.09	1.66
1	311	37.5	12	10	2710	1603	500	12.48	6.495	1.24	1.66
1	311	37.5	12	10	2710	1603	400	9.99	17.53	2.67	1.66
1	311	37.5	12	10	2710	1603	600	14.98	3.941	2.45	1.66

4.2 Blasting with Detonating Fuse and Cord relay

A total number of 9 different production blasts are conducted at Khadia mines using detonating fuse and cord-relays with optimized blast design parameters. The blast-induced ground vibration in magnitude of PPV are recorded at varied distance using seismographs and fragmentation analysis are performed. The details of blasts conducted is mentioned in Table 2.

Table 2: Details of blast conducted with detonating fuse and cord relay in Khadia Mines, NCL

No of Holes	Hole Dia (mm)	Average Hole Depth (m)	Spacing (m)	Burden (m)	Q total (kg)	Max Charge Per Delay (kg)	Distance of monitoring (m)	SD (m/kg$^{0.5}$)	PPV (mm/s)	Mean fragment size (m)	Powder Factor (m^3/kg)
37	311	38.22	12	10	99948.50	1703.25	500	12.12	11.66	3.2	1.70
35	311	37.6	12	10	92482.00	1603.25	400	9.99	25.67	2.3	1.71
36	311	37.19	12	10	96242.50	1603.25	700	17.48	10.72	4.1	1.67
36	311	37.19	12	10	96242.50	1603.25	600	14.98	12.34	2.3	1.67
38	311	44.5	12	10	121516.10	2004	300	6.70	45.67	3.44	1.67
43	311	40	12	10	124070.30	1703.25	500	12.12	18.79	1.98	1.66
39	311	41.5	12	10	123560.00	1903.75	700	16.04	8.63	4.1	1.57
43	311	36.78	12	10	111920.75	1603.25	500	12.49	11.34	5.06	1.70
54	311	37.21	12	10	142090.00	1603.25	500	12.49	15.67	1.6	1.70

5.0 Discussion

The trials blasts are conducted using electronic detonators and detonating fuse with cord relay initiation systems. The blasts result i.e. fragmentation and blast-induced ground vibration are monitored and analyzed. The results obtained are compared to analyze the improvement in blast performance.

5.1 FRAGMENTATION

It has been found that the mean fragmentation achieved during blasting with electronic detonators are lesser in comparison with that of blasts conducted using detonating fuse and cord relay initiation systems. The fragmentation analysis are performed using Fragalyst 4.2 software. The fragmentation analysis report of blasts performed for electronic detonators blast and detonating fuse blast is shown in Figs. 4 and 5 respectively. Based on the analysis of blasts fragmentation using Fragalyst 4.2 the mean fragment size of each blast with different initiation system i.e. electronic detonators and detonating fuse is compared and plotted in Fig.6.

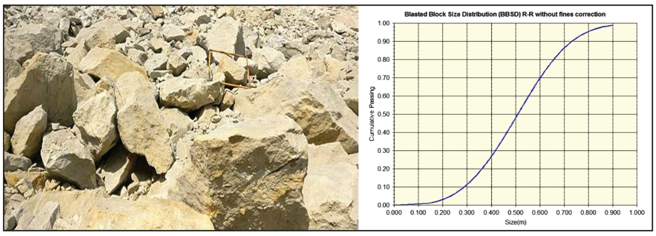

Fig.4: Fragmentation analysis report for electronic detonator blasting at Khadia mine using Fragalyst 4.2

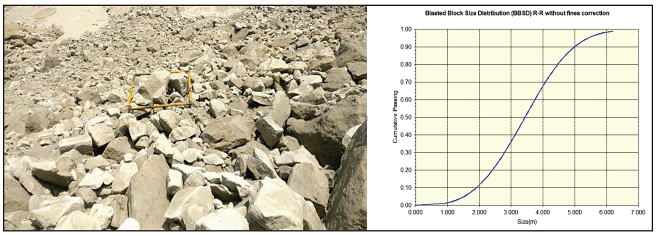

Fig.5: Fragmentation analysis report for detonating fuse with cord relay blasting at Khadia mine using Fragalyst 4.2

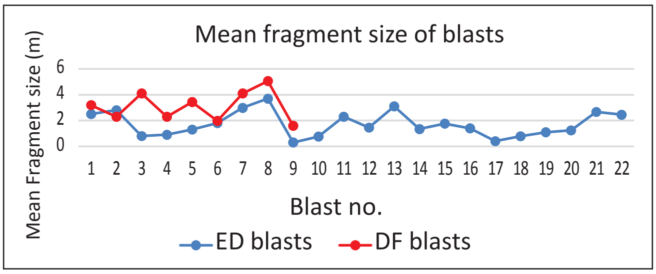

Fig.6: Plot showing mean fragment size of blasts conducted with electronic and detonating fuse at Khadia mines

The fragments analysis is done using Fragalyst 4.2 software and the mean fragment size of different blasts are plotted against the powder factor in Fig.7. It is found that lesser mean fragment size values are obtained with the electronic detonators blasting. The fragmentation analysis reports when compared is found that almost 44% reduction in mean fragment size is achieved using Electronic detonators in comparison with detonating fuse blasts.

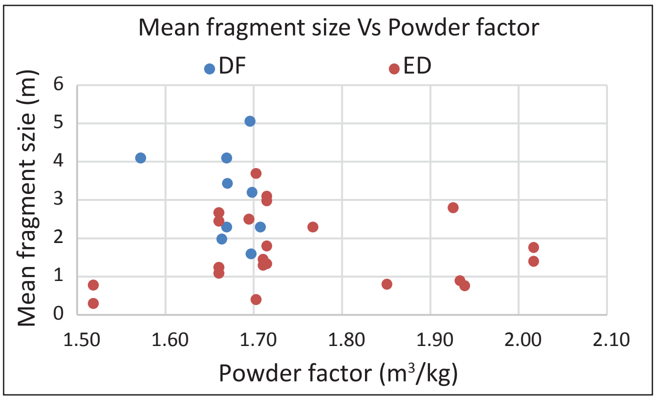

Fig.7: Mean fragment size vs powder factor of blasts conducted with electronic and detonating fuse initiation system at Khadia mines, NCL

5.2 BLAST-INDUCED GROUND VIBRATION

The PPV values for conducted trials blasts using electronic detonators and detonating fuse are plotted against its scaled distance and presented in Fig.8.

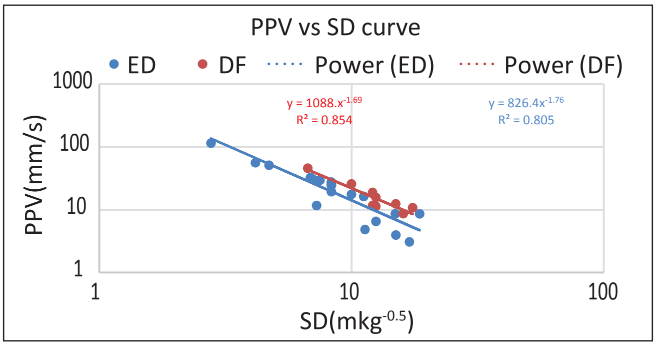

Fig.8: PPV vs SD plot for blasts conducted using electronic detonators and detonating fuse at Khadia mines, NCL

The blast-induced ground vibration predictor scaled distance equation of USBM has been obtained using the regression analysis of practical data collected in mines for electronic detonators and detonating fuse. The site constant values for detonating fuse are found to be different from electronic detonators blasts due to its erroneous detonating timing and inherent cap-scattering. Hence the equation obtained using precise timed electronic blasts is considered to be the most reliable and predictor equation of mine. The predictor equation is:

$$PPV = 826.41 \times SD^{-1.768}$$

$$SD = D/\sqrt{Q}$$

Where,

PPV = Peak particle velocity (mm/s)
SD = Scaled distance ($m/kg^{0.5}$)
D = Distance of vibration monitoring from blast site (m)
Q = Maximum charge per delay (kg)

From Fig.8, it is found that there is significant average reduction of almost 36% in PPV values are achieved using electronic detonators in comparison with detonating fuse.

6.0 Conclusions

Based on the studies conducted at a large opencast coal mine, it may be concluded that a 36% reduction in blast-induced ground vibration can be expected at the scaled distance of 10 m/kg$^{0.5}$ while using electronic detonators in comparision with detonating fuse and cord relay initiating systems. Due to point initiation nature of electronic detonators and flexibility of positioning and sequencing of primer a 44% of reduction in mean fragment size could be achieved at same powder factor. Therefore, mine operators have an option of using digital detonators to reduce the environmental hazards of blasting and enhancing fragmentation which may increase overall productivity of a mine.

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