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Coalbed Methane Recovery and Commercial Utilisation

BACKGROUND OF THE PROJECT

Global warming is the greatest challenge being faced by the world today. This has resulted due to rapid industrialization and greater use of energy resource in the post- industrial era. This concern is shared by all countries developed and developing and India is a forerunner in this international endeavour.

To achieve the envisaged growth rate of 8-10% in India, requirement of commercial energy will increase manifold. Going by the present trend and the perceived trend for the coming years, coal will remain the most important source of energy supply in the country. Several studies carried out by national/international agencies including Integrated Energy Policy of India confirm the dependence on coal in energy supply scenario.

The usage of coal for generation of energy, however, is not very environment friendly and going by the international concern and also by the policy of Govt. of India to follow low carbon path, adoption of clean coal technology is a priority area for Indian coal industry. The coal industry is gearing up for this and thrust is being given on implementation of clean coal technology, which includes pre-combustion beneficiation, advancement in combustion processes and development of coal based energy resource like CBM/CMM, VAM etc.

India is bestowed with huge resource of coal, some of which are of high rank and gassy. These coal seams are invariably associated with methane, which is a powerful greenhouse gas, having 25 times global warming potential than carbon dioxide. Such coals are mostly available in the Damodar Valley Coalfields. The indicative characteristics of these coals for CBM development are shown in Table -1.

PROJECT JUSTIFICATION

Under R&D efforts, a demonstration project on "Coalbed Methane Recovery & Commercial Utilization" has been successfully implemented at Moonidih coal mine of BCCL in Jharia Coalfield. This demonstration project is a path finder for coal mine methane development in Indian mining scenario as methane gas embedded in coal seams have been successfully recovered through vertical wells on surface and the recovered gas is being used as fuel in gas-based generators for electricity generation for domestic use in Moonidih project colony.

This research project was undertaken by Central Mine Planning & Design Institute Ltd., (CMPDI) in association with Bharat Coking Coal Limited, (BCCL).

PROJECT GOALS

- To harness methane to minimize safety risk in mines, to utilize potential energy source and to mitigate damage to atmosphere;
- To bring to the country state-of-art methodology for resource assessment and recovery techniques of CBM with due regard to Indian conditions and
- To demonstrate utilization of the exploited methane, a very clean fuel.

METHODOLOGY

The project concept was to effectively capture methane in working coal mines. UNDP experts had identified mines in Jharia coalfield for the project on the basis of potentiality and available information. Maturation of coal in this area has resulted in widespread occurrence of coalbed methane resources. For developing the coalbed methane resource, following methods were envisaged:

- to drill ahead of mining to pre-drain the gas in coal seams from surface by vertical drilling for which mining is planned,
- to recover the gas in-seam by long hole horizontal underground drilling.
- to recover the gas from surface by vertical drilling in the gob areas.

USAGE

Methane gas recovered through above methods was envisaged to be brought to the surface and is to be used as:

Multi funded (MOC, UNDP, S&T, and ONGC) Project executed by CMPDI in association with BCCL

Fig 1: Gas based generators generating electricity at Moonidih

- Fuel for electricity generation by gas based generators and
- Fuel for gas based engine vehicle where recovered gas will be compressed.

WORK DONE UNDER THE PROJECT

The project has acquired suitable infrastructure like heavy duty high-tech drilling rig unit and other equipment required for taking up CBM related large diameter deep drilling. The associated personnel were trained, experienced and geared-up to take up CBM well completion job in suitable areas.

Three vertical CBM wells were drilled and recovery of gas from three wells has been established.

Details of coal seams encountered and targeted for CBM production in the three vertical wells are shown in Table - 2.

The permeability of coal core samples measured in laboratory varies from 0.28-1.04 mD and 1.16-1.32 mD. The samples used for the permeability measurement may not be representing the entire section of the coal seam as the permeability determined is on small core samples (6-8” length).

Capacity of the subsidiaries of Coal India Limited (CIL), namely CMPDI and BCCL, has been strengthened including their capability of recovery of CBM/CMM through vertical wells from surface. For this purpose equipment for drilling of vertical wells has been installed. After drilling of well and geophysical logging of uncased wells, cementation of the wells are done in two stages. Specialized geophysical logging followed by perforation (hired services) and hydro-fracturing were done in all the production wells drilled to full depth.

Hydro-fracturing is a process developed by the oil industry for increasing productivity of a reservoir. Three potential coal seams in three wells were hydro-fractured and stimulation data are shown in Table-3.

GAS INITIAL IN PLACE (GIIP)

In-situ gas content, proximate and high pressure adsorption isotherm of coal core samples collected from CBM wells indicated good potentiality of gas in Moonidih block. In-situ gas content is compared with adsorption capacity of coal core samples revealed moderate saturation of coal seams. Through demonstration project several other very important inputs have been generated which will be helpful for assessment of the commercial viability of an identified area.

Coalbed methane reserve estimates calculated through different methods viz. Mavor, et al., (1996), Generalized and Gas Research Institute (GRI) methods for Moonidih block. The CBM-CMM reserve estimate through Generalized, Gas Research Institute (GRI) and Mavor, et al., 1996 methods comes to 11.09, 12.23 and 8.52 BCM respectively. Recovery of gas through vertical wells has been an attractive proposition in CBM recovery. However, predicting the performance of CBM wells for gas recovery in the long run is nevertheless a challenging task.

CBM Resource in the Moonidih Block

Generalized method	GRI	Mavor et al.,1996
11.09 BCM	12.23 BCM	8.52 BCM

Generalized method:

$$Gi = A \text{ x } h \text{ x } l_c \text{ x } TG$$

Where, *Gi* - gas in place (total reserve), *A* - drainage area, *h* - coal thickness l_c - coal density, *TG* - total gas content

Gas Research Institute (GRI) method

$$G = 1359.7 \times A \times h \times \ell c \times Gct$$

Where,

G - gas in place (total reserve), A – gas drainage area, h – lignite/coal seam thickness, lc - coal density, Gct - gas content.

Fig 2: CBM Rig Unit deployed at Moonidih

Table- 1: Indicative characteristics of coals for CBM development

Coalfield	Area (Sq Km)	No. of coals seams		Cumulative coal thickness(m)	V Ro%	ASTM Rank	Gas content (m^3/t)
Raniganj	1550	Raniganj Formation	10	30 - 40	0.5 - 0.85	High volatile bituminous A-C	5 - 7
		Barakar Formation	7	30 - 120	0.93 - 1.39	High volatile bituminous A to medium volatile bituminous	0.5 - 10 (erratic due to large scale pyrolitization)
Jharia	450	Raniganj Formation	24	8 - 35	0.86 - 0.9	High volatile bituminous A	Not available
		Barakar Formation	18	Up to more than 100	0.9 - 1.3	Medium to low volatile bituminous	7 - 26
East Bokaro	237	Barakar Formation	22	Up to more than 100	0.8 - 1.69	High volatile bituminous A to low volatile bituminous	3 - 22
West Bokaro	207	Barakar Formation	13	More than 40m	0.8 - 1.25	High volatile bituminous A to medium volatile bituminous	6 - 10
South Karanpura	194	Barakar Formation	42	Up to more than 100	0.51 - 0.91	High volatile bituminous A-B	5 - 10

Geological Parameters of project site

Geological Parameters	Moonidih
Area (Sq.Km)	14.25
Number of coal seams	Over 30
Coal seams worked/being worked	Seam-XVIII to XV mined to varied extent by Longwall method
Geological reserves	1000 Mt (for Seam-I to XVIII in ascending order)
Geological structure	Complex
Dip of coal seams	Moderate (5-10^0)
Pyrolitisation in coal seams	Most of the seams are pyrolitised to varied extent.
Seams considered for CBM extraction	Seam-XVIII-XI
Gassiness of coal seams	5 to more than $10m^3/t$
Permeability of coal seams	< 1mD

Table- 2: Details of Coal Seams encountered and targetted for CBM production

Seam	1st Well		2nd Well		3rd Well	
	Roof Depth (m)	Thickness (m)	Roof Depth (m)	Thickness (m)	Roof Depth (m)	Thickness (m)
XVIII	538.90	4.6 (J+MP)	532.80	3.5 (J+MP+C+J)	468.41	3.52 (J+MP)
XVII Top	**594.40**	***1.80 (C)***	**588.30**	***2.10 (C+J+M+C)***	523.23	1.84 (C)
XVII Bot	632.65	1.10(SC)	612.05	1.55	552.57	1.34
XVI Top	**733.77**	***5.12 (C+J)***	725.50	6.1(J)	666.37	6.14(J+MP)
XVI Bot	747.10	0.90	740.20	1.40	681.49	0.98 (L5)
XV Top	**879.70**	***4.0 (C)***	**867.70**	***4.2 (C)***	**802.69**	***3.88 (C)***
XV Bot	**884.70**	***5.45 (C)***	**872.60**	***5.05 (C)***	**807.71**	***4.87 (C)***
XIV	951.40	10.45 (J+MP)	951.00	8.10 (J)	878.69	14.46 (J+MP)
XIII	965.85	12.80 (J+MP)	963.35	13.55 (J+MP)	897.73	8.48 (J+MP)
XII			**1016.25**	***5.75 (C)***	**940.21**	***5.50 (C)***
XI			1036.15	9.80 (J+MP)	957.01	9.32 (J+MP)
X					**1006.03**	***7.62 (C)***
Closing Depth		1059.30		1071.30m		1108.40m

Note: Seams indicated with bold letters and italics have been subjected to hydro-fracturing

Mavor et al., 1996 method

$$Gi = Ah\left[\frac{\phi f(1 - Swfi)}{Bgi} + Cgi\ell c(1 - fa - fm)\right]$$

Where, Gi - gas in place (total reserve), A - gas drainage area, h - coal thickness,
f – cleat/fracture effective porosity, Swfi - cleat/fracture water saturation,
Bgi - formation volume factor of gas at initial reservoir pressure,
Cgi - initial sorbed gas concentration (gas content), lc- pure coal density,
fa - ash content by weight, fm - moisture content by weight.

CHALLENGES FACED BY THE PROJECT

The demonstration project had to face several technological and logistical challenges during its implementation, which include the following:

Jharia coalfield in general and Moonidih area in particular, has a complex geological structure on account of pyrolitization (burning of coal seams), poor permeability of coal seams (generally <1 mD). Permeability is an important parameter for production of methane gas from any target area.

The equipment and other tools were not indigenously available for this type of coal mine methane project, in coal mining areas, as it was implemented for the first time in the Indian coal mining history.

The import of equipment was time consuming and also consumables and spares were not indigenously available.

There was a general lack in expertise in the specified areas, particularly in reservoir modeling, hydro-fracturing and de-watering technologies, which are so very essential for extraction of methane from coal seams.

Underground drilling was attempted twice at Sudamdih in association with International experts, but in-seam drilling technology and gas recovery could not be established due to unsuccessful commissioning of the steering tool.

EVALUATION OF THE PROJECT BY UNDP EXPERTS

On successful implementation of the project, it was evaluated by independent experts appointed by UNDP. Their key observations are as under:

- The initiative taken by the GoI in collaboration with GEF/UNDP for taking up this project

Table-3: Stimulation data of hydrofractured coal seams in three wells

Seam	Depth Interval (m)	Thickness (m)	Perforation Interval (m)	Maximum Pressure (psi)	Proppant Pumped (tonne)	Fluid Pumped (BBL)
1st CBM Well						
XVIIT	594.40-596.20	1.80	595.10-596.10	2383	40	1145
XVIT	733.77-738.90	5.12 C+J+C+J	734.50-736.50	1540	40	847
XVT & XVB	879.70-883.70 884.70-890.15	4.00 5.45	881.50-883.50 886.60-889.00	3855	52	1000
2nd CBM Well						
XVIIT	588.30-590.40	2.10 C+J+C+MP	588.40-589.50& 589.90-590.40	2763	40	979
XVT & XVB	867.70-871.90 872.60-877.65	4.20 5.05	874.40-877.40	4858	47	950
XII	1016.25-1022.00	5.75	1020.0-1022.0	2253	45	1050
3rd CBM Well						
XVT & XVB	802.69-806.57 807.71-812.57	3.88 4.87	805.50-806.50 810.50-812.50	4300	35	1325
XII	940.21-945.71	5.50	943.60-945.60	4300	46	1200
X	1006.03-1013.65	7.62	1010.50-1013.50	1200	58	1330

Fig 3: Dewatering and recovery of gas in CBM well by SRP pump at Moonidih

CBM gas being flared at Moonidih

of Coalbed Methane (CBM) recovery and commercial utilization appear to be an outstanding thing to happen in Global efforts to mitigate the GHG and resultant environmental degradation.

- The project has brought to the country state-of-art technology for planning and execution of such projects in Indian conditions. It is expected that this project will be a fore runner in generating useful data on CBM recovery and utilization besides imparting experience and confidence in Private and Public investors in India to replicate such projects for gassy underground mines and substitution of coal & diesel by utilization of CBM in its place.

ACHIEVEMENT OF THE PROJECT

This unique and high technology demonstration project was successfully implemented at Moonidih with all out effort of the entire team. Being implemented for the first time in the country, the project has created enough awareness in the Indian coal mining industry and the industry is now at a threshold of replicating such projects in other suitable areas. The project will open a new era in harnessing and utilization technique of coal mine methane, which is otherwise a wasted clean energy resource. The other achievements of the project are summarized as under:

- The project was successfully implemented through the in-house efforts of CMPDI & BCCL team,
- Capacity built-up both in terms of equipment and manpower.
- Proving the efficacy of the technology for CMM extraction and its utilization in Indian mining scenario.
- Utilization potential of recovered methane has been established and electricity that is being generated from the harnessed CMM has created enough awareness among the local populace.

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MineTech, Volume 33 No 1, P 9-14 Mar , 2012

Delineation of barrier thickness against waterlogged workings in underground coal mines by Ground Penetrating Radar

Disaster due to inundation is one of the major threats of coal mines. The problem of detecting abandoned mine workings and evaluation of barrier thickness against a water body is a long pending issue of the coal mines of India. A review of previous work on the subject in the geophysical literature, did not offer any effective solution to this problem. Earlier attempts made in India met with only minimal degree of success.

There are many causes for inundation. Among these, unapproachable underground water-logged workings, undelineated aquifers, voids and solution-holes etc. play very important role for such serious disaster. The inundation hazard in a mine may be due to one or more factors such as the mines with low cover having a roof of unconsolidated fractured rocks, breakage of overlying rocks due to pillar extraction, working below river or other water bodies, connection of present working with the old water-logged workings, connection with the unknown aquifers etc. Determining a 'safe' barrier thickness between abandoned waterlogged workings and current workings often met with uncertainties and subsequently impending threat of inundation. These uncertainties may be due to many reasons such as conventional surveying failed to calculate the exact barrier thickness; the mine plans and sections of old workings are not correctly and properly maintained; the geological anomalies present in the barrier are hidden; extent of weakening of barrier strengths is in question, etc. Unknown dimension of barrier pillars and not knowing the precise location of adjacent old workings are the primary stumbling block that adversely affect the production and safety in underground mines. Mine safety and planning need to be sensitised, especially in areas where historical records are incomplete or nonexistent. Determining the thickness of remaining barrier against unapproachable and often water-filled old workings in coal mines is a complex problem and imposes challenge to researchers and mine operators.

There have been several instances of inrush of water due to old galleries getting connected by new development headings, resulting in disasters involving heavy fatalities and loss of machines. This type of disaster has occurred in may coal producing countries and may occur in future until a suitable tool to investigate barriers thickness is in regular use. According to recommendations of DGMS(Tech)(SOMA) Circular No.1 of 2001 of Gaslitand Court of Inquiry, detailed precautionary measures against danger of inundation should be laid down while working beneath or in the vicinity of rivers and major surface water bodies, particularly during the rainy season. Inter-mine barrier is an effective means to prevent transference of danger from one mine to another. In mines where the barrier have become ineffective due to interconnections or otherwise, the same may be restored early, even artificially, by constructing suitable dams, explosion proof stoppings and other methods. From DGMS (Tech) Circular No.5 of 2003 (Recommendations of Bagdigi Court of Inquiry), it has been learnt that connection between adjoining old water logged workings and current workings ultimately takes place due to eating away of the prescribed coal barrier between the two mines. DGMS has stipulated that a safety barrier thickness of not less than 60 m must be maintained between abandoned workings and contemporary mine developments as shown in Figure 1. It has been estimated that a large number of underground coal mines in India are under threat of adjacent unknown waterlogged mines/workings. Therefore, evaluation of barrier thickness up to 60 m is essential to check mine disasters caused by inundations.

In view of the above facts, CIMFR, Dhanbad has undertaken this research project to provide plausible solution to the long pending safety issue of Indian mining industry from the Coal S&T funding of Ministry of Coal, Government of India. The primary

Research work carried out by CIMFR, Dhanbad in association with M/s International Ground Radar Consulting Inc, Canada.

aim was to develop a Ground Penetrating Radar (GPR) system to delineate the barrier thickness up to 60 m to check inundation hazard in underground coal mines.

Under this programme of study, a new GPR system named "MineVue" is developed having depth of penetration of 60 m in underground coalmines of India. Field experiments were carried out in three mines of Eastern Coalfields Limited and five mines of Bharat Coking Coal Limited. Extensive trials were carried out for the development of new GPR for the penetration of 60 m, the world's first Intrinsically Safe Long Range Ground Penetrating Radar System named as "MineVue".

The extensive data collected helped in designing the GPR for the said purpose. The newly designed survey was carried out on the ground surface at Bhagabandh Colliery to see the applicability of the developed system for detecting tunnels from surface through surface clays, silts and sandstones.

MineVue radar data from the first site, located along 1st X-Cut between 3 & 4 Dip at K. B. Colliery, BCCL clearly shows a dry tunnel at approximately 38 m from the wall, as shown in Figure 4. The mine part-plan shown in Figure 5 agrees with this interpretation.

The Second site was surveyed using MineVue system along 7th Rise of 2nd X-Cut at K. B. Colliery, BCCL. Radar data indicates that water-logged gallery may be there at the distance of 66 m from the coal face (Figure 6), which is also being confirmed by the mine plan shown in Figure 7.

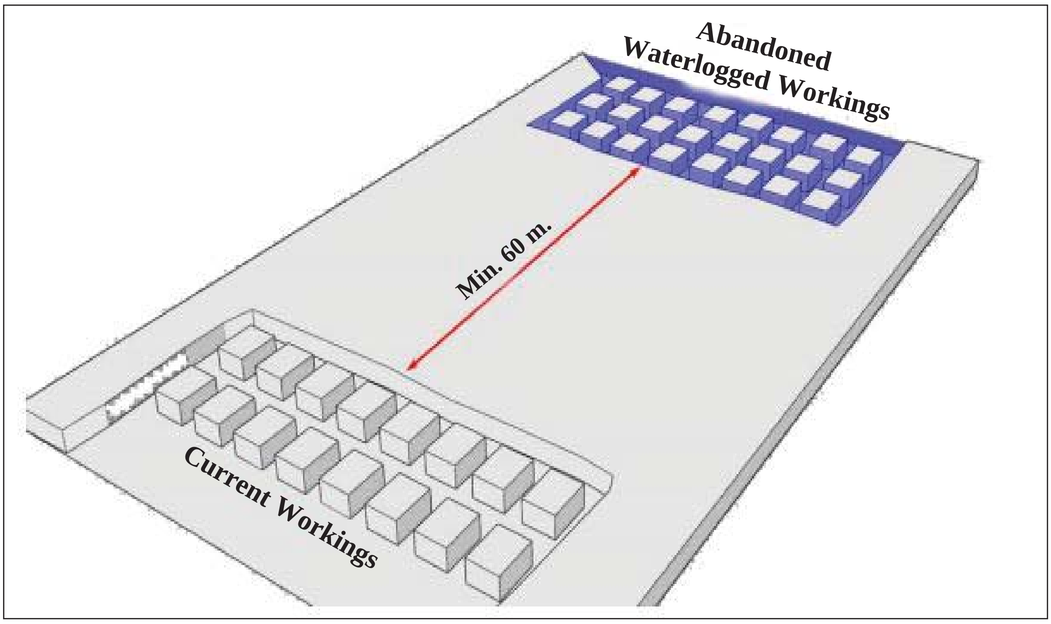


Figure 1: Illustration of current workings approaching abandoned waterlogged workings.

MineVue radar system was rigorously utilised in collection of data from underground mines and from the surface in coal mining areas as shown in Figures 2 & 3 respectively.

Final trials of the developed MineVue system (ATEX and Non-ATEX versions) was conducted on 29th February, 2012 at the mine sites; Kachi Balihari (K. B.) and Bhagabandh Collieries of P. B. Area, BCCL in the presence of mining officials of BCCL, S&T Division, CMPDI and DGMS, Central Zone. Seven underground panels were selected and surveyed at the K. B. Colliery with MineVue to detect the thickness of the barriers/panels. One MineVue

Figure 2: Mode of surveying in underground coal mines using MineVue radar system

Figure 3: Mode of surveying from the surface using MineVue radar system

The third site was surveyed along 2nd X-Cut between 7th & 8th Dip at K.B. Colliery, BCCL. MineVue radar data indicates that waterlogged gallery/tunnel may be there at a distance of 69 m from the coal face (Figure 8), which is being confirmed by part-plan as shown in Figure 9.

The fourth site was surveyed using MineVue system along 2nd X-Cut between 8th & 9th Dip at K.B. Colliery, BCCL. MineVue data indicates here a waterlogged gallery at the distance of 72 m from the Mine face (Figure 10), which is being confirmed by part-plan shown in Figure 11.

The fifth site was surveyed using MineVue system along 11th Rise of 2nd X-Cut at K.B. Colliery, BCCL. Here, interpreted results indicate that there may be a waterlogged gallery at a distance of 58 m from the Mine face (Figure 12). This is confirmed by part-plan as shown in Figure 13.

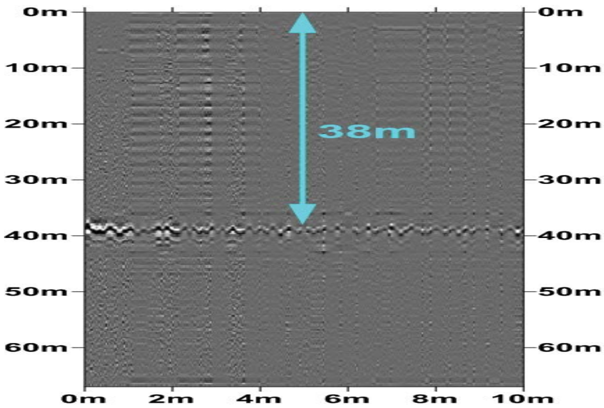


Figure 4 : MineVue data along 1st X-Cut between 3 & 4 Dip at K. B. Colliery, BCCL.

The sixth site was surveyed along 13th Rise of 2nd X-cut at K.B. Colliery, BCCL. The interpreted MineVue data indicates that there may be a waterlogged mine gallery at a distance of 58 m from the Mine face (Figure 14) and is also being confirmed by mine part-plan shown in Figure 15.

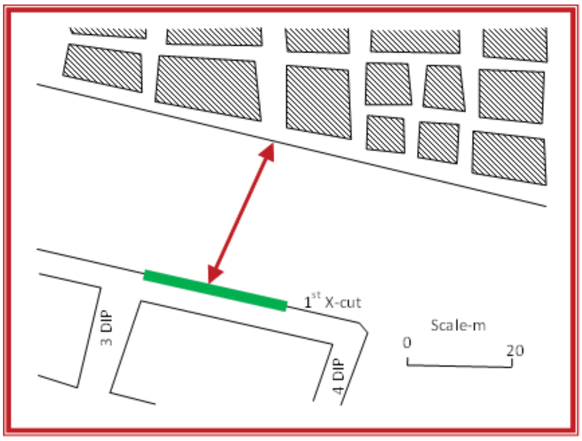


Figure 5: Radar traverse along 1st X-Cut between 3rd & 4th Dip at K.B. Colliery, BCCL.

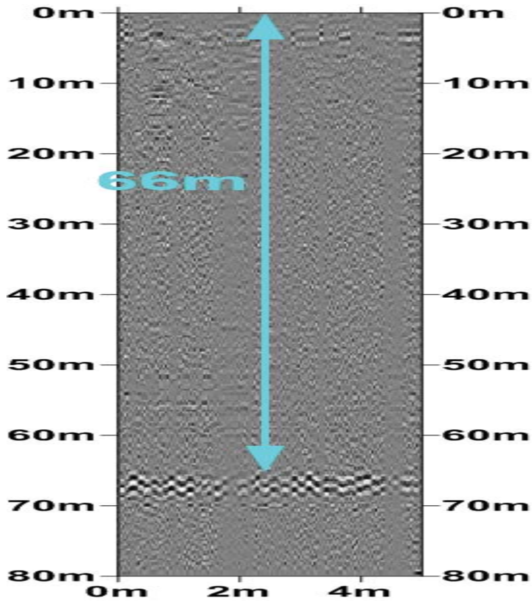


Figure 6: MineVue data along 7th Rise of 2nd X-Cut at K. B. Colliery, BCCL

The seventh underground site was surveyed using MineVue radar system along 11th level between 14th & 15th Dip at K.B. Colliery, BCCL. The interpreted radar data indicates a waterlogged mine gallery at a distance of 54 m from the coal face (Figure 16) and this is also being by mine part-plan as shown in Figure 17.

The last site was selected on the surface along PCC Road over 18th Seam at Aralgoria, Bhagabandh Colliery, BCCL for delineation of mine galleries from surface. MineVue radar survey was carried out over 18th Seam at Bhagabandh Colliery. The interpreted radar results indicate that there are underground

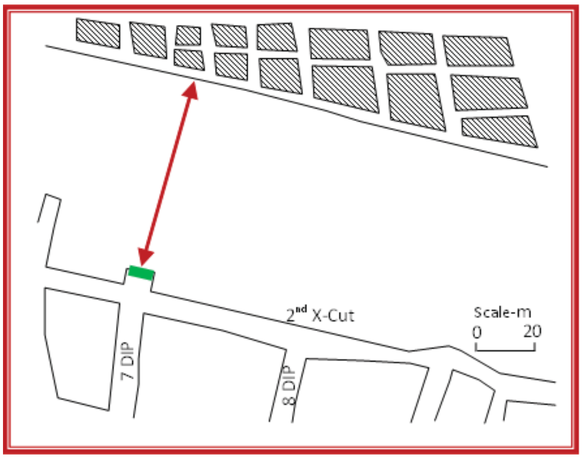


Figure 7: Radar traverse along 7th Rise of 2nd X-Cut at K.B. Colliery, BCCL.

galleries at the depth varied from 20 to 50 m from the surface as shown in Figure 18. This is also confirmed by mine part-plan shown in Figure 19.

The analyses of recorded data and subsequent

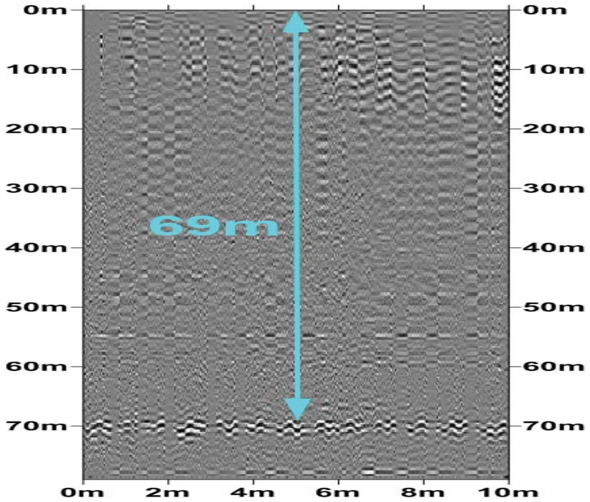


Figure 8: MineVue data along 2nd X-Cut between 7th & 8th Dip at K. B. Colliery, BCCL.

output were verified with existing data base of the respective mines. The followings are the capabilities and limitations of the specially designed and developed GPR system for Indian coalmines:

- The technology developed in this project, namely “MineVue”, is the world’s longest range and lowest frequency shielded radar system ever made, the first of its kind designed specifically for gaseous underground coal mines. It represents the cutting edge technology in Ground Penetrating Radar.

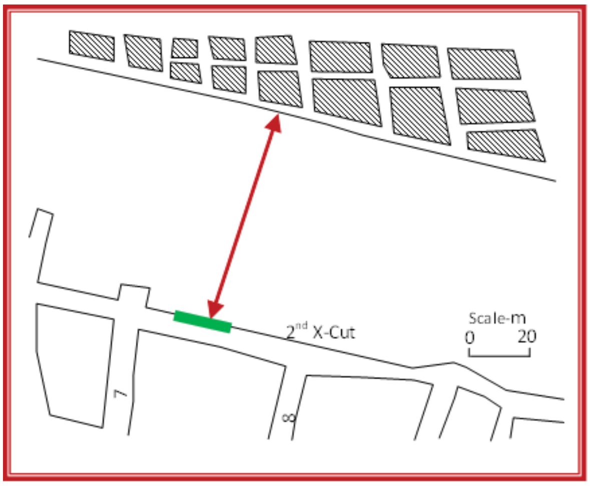


Figure 9 : Radar traverse along 2nd X-Cut between 7th & 8th Dip at K.B. Colliery, BCCL.

MineVue system has two versions; one ATEX-version and another Non-ATEX version. The ATEX-version will be used in gaseous underground coalmines and Non-ATEX-version will be used in non-gaseous coalmines and also from the surface to collect the data. ATEX-version has been certified for intrinsic safety by the British Intrinsically Safe Testing Authority (BASEEFA), U.K. and also by CSIR-CIMFR, Dhanbad for Indian Standard IS-5780:2002 (IEC 60079-11:2007).

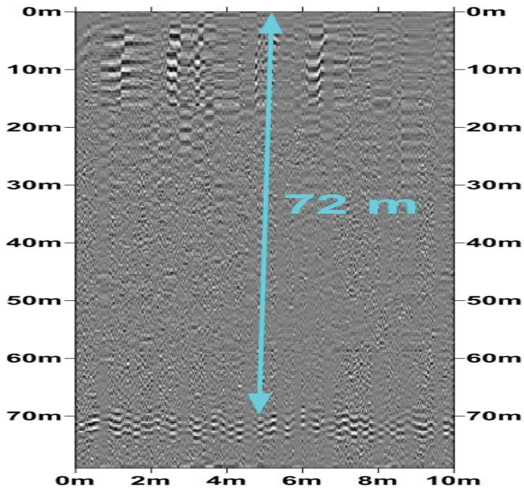


Figure 10: MineVue data along 2nd X-Cut between 8th & 9th Dip at K. B. Colliery, BCCL.

- This is the first low frequency (40 MHz) shielded MineVue system having real time stacking of 64000 for better quality of data collection and for best possible accuracy ±10%. The accuracy was also verified by the

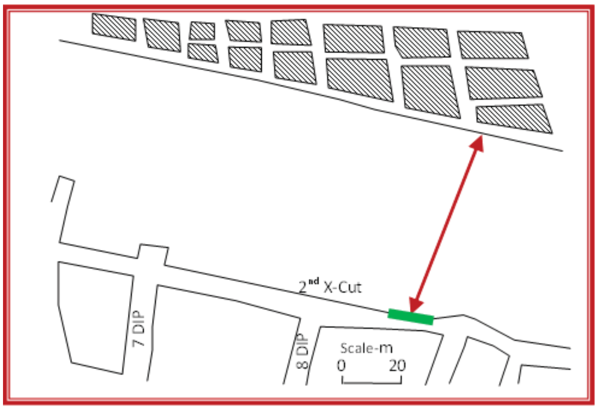


Figure 11: Radar traverse along 2nd X-Cut between 8th & 9th Dip at K.B. Colliery, BCCL.

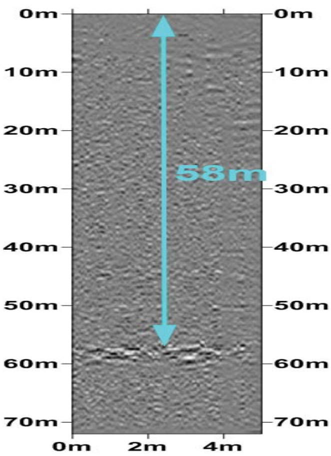


Figure 12: MineVue data along 11th Rise of 2nd X-Cut at K. B. Colliery, BCCL.

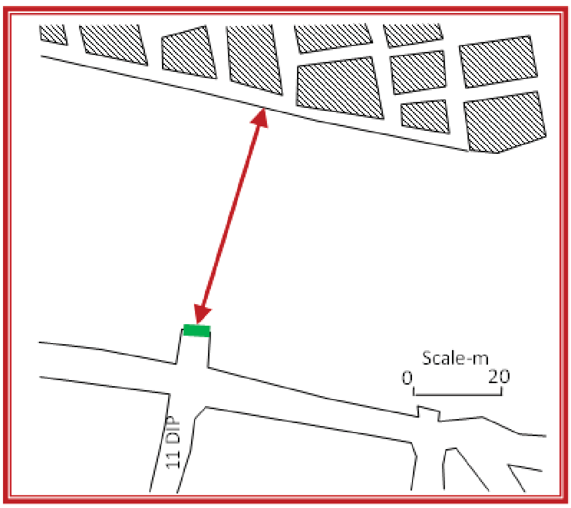


Figure 13: Radar traverse along 11th Rise of 2nd X-Cut at K.B. Colliery, BCCL.

concerned mine management while comparing the interpreted MineVue survey results with actual data available with concerned mine. The technology was found to be satisfactory fulfilling the project objectives.

- For enhanced accuracy of the results, GPR system should be in good contact with the wall on flat surface, since energy leaks from under the shield in air gaps and the leaked energy can bounce from walls and cause interference.
- GPR survey gives excellent results in underground coal mines where there are no rail tracks (haulage road) and power lines in the survey areas. Presence of these creates poor survey environment because the leaked energy

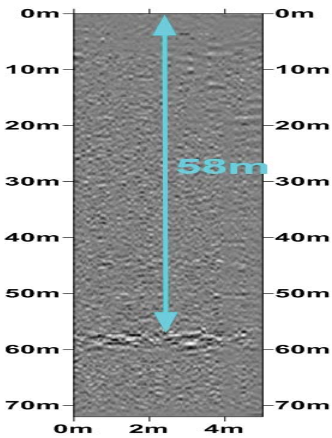


Figure 14: MineVue data along 13th Rise of 2nd X-Cut at K. B. Colliery, BCCL.

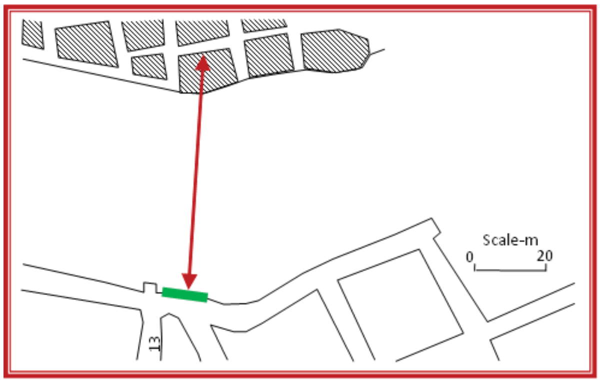


Figure 15: Radar traverse along 13th Rise of 2nd X-cut at K.B. Colliery, BCCL.

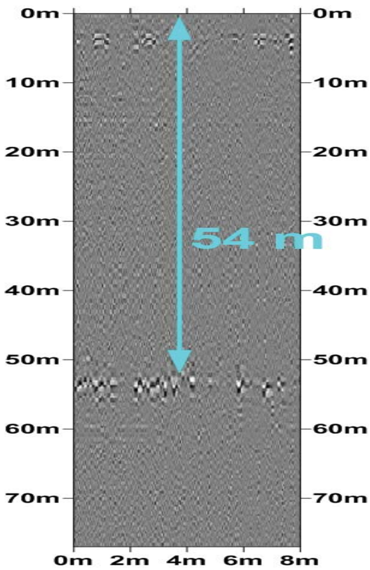


Figure 16: MineVue data along 11th Level between 14th & 15th Dip at K. B. Colliery, BCCL.

flows along metal and cause interference.

- Low frequency antenna of 40 MHz was used to penetrate up to 60 m and having resolution of 1 m. The 40 MHz antennas must be 1.2 m wide and separated by 0.5 m for getting the required depth of penetration. Wavelength of 40 MHz in air is 7.5 m. Shield must be minimum of 1/5 wavelength long and 1/6 wavelength wide, a logical technical requisite for better performance. Thus, size of the 40 MHz shielded antenna must be 1.5 m X 1.2 m. This limitation caused in designing and development of somewhat bigger size GPR system.

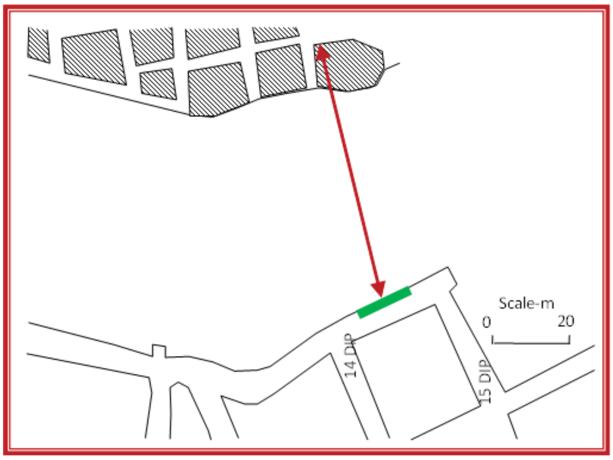


Figure 17: Radar traverse along 11th level between 14th & 15th Dip at K.B. Colliery, BCCL.

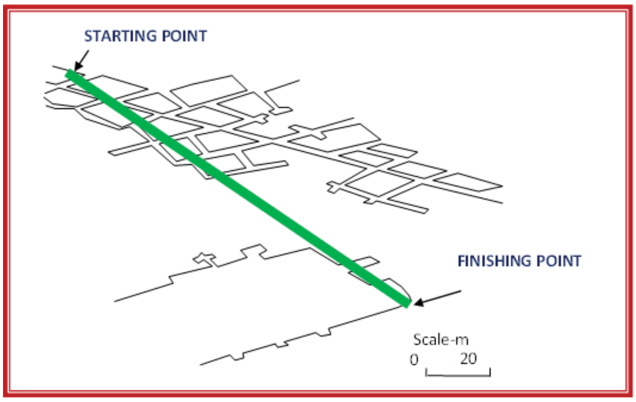


Figure 19: Radar traverse on the surface over 18th Seam at Aralgoria, Bhagabandh Colliery, BCCL.

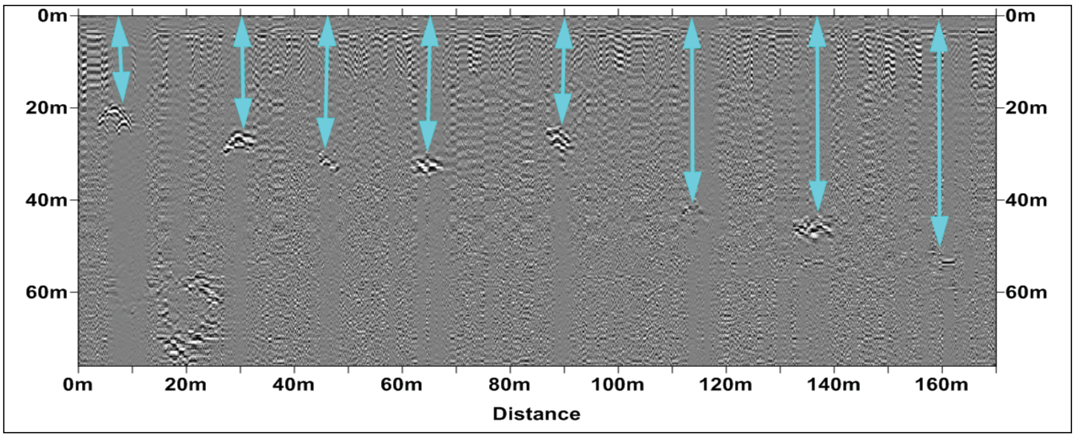


Figure 18: MineVue data on the surface over 18th Seam at Aralgoria, Bhagabandh Colliery, BCCL.

MineTech, Volume 33 No 1, P 15-18 Mar , 2012

Rapid volumetric analysis of excavated in-situ overburden in Opencast Mines using ALTM

DEFINITION OF THE PROBLEM

Overburden (OB) removals is an integral part of an opencast mining operation required for extracting the coal locked under the earth. The increase in coal production of Coal India Ltd. (CIL) in the last two decades has almost three folds from 144.70 million tones in 1988-89 to 403.70 million tonnes in 2008-09. By the end of XII Plan (year 2016-17) the total coal production of CIL is envisaged to be about 658 million tonnes, out of which 85% of the coal production will be only from opencast mine. About 610 million cubic meters of overburden was excavated during the year 2008-09 which will substantially increase in future due to emphasis on coal production by opencast mining. With increase in production, requirement of measuring of coal and OB volume with fast pace became inevitable. The OB excavation programme plays a major role in planning of coal mining activities. Rapid and accurate periodic measurement of OB removal is necessary for effective monitoring and operational planning of the opencast mines.

Currently Electronic Total Station (ETS) based conventional ground survey method is being used for measurement of the OB volume, which is time taking and also has limitations. Besides this, conventional method requires a team comprising of both skilled and semi skilled manpower. Due to constraints of infrastructures both requisite manpower (Surveyors) and survey equipments, it is difficult to measure the OB volume on monthly basis in all such mine producing coal 1 million tonne per year (MTY) and above. Therefore, to cope up the existing workload of OB measurement, it is warranted to evolve a new technique to measure the OB in time-cost effective manner on regular monthly basis.

Keeping the above in view, a proposal titled "Development of Methodology for Rapid Volumetric Analysis of Excavated In-Situ Overburden Integrating High Resolution Satellite, Airborne Laser Terrain Mapper (ALTM) and Terrestrial Laser scanner (TLS) data supported with ETS through Digital Photogrammetric Technique" was approved in 18th meeting of CIL R&D Board held on 01.07.2006 at Kolkata to develop the time and cost effective technology for OB measurement in coal mines.

PRESENT STUDY

The advent of new generation, high resolution, stereoscopic satellite data and Light detection and ranging (LiDAR) technology has opened a new vista in the field of remote sensing for mapping and measuring the earth features with the help of Digital Photogrammetric technique. Since the study was to be carried out for the first time in coal mining sector for OB measurement using multi sensors from different platforms; the efficacy and accuracy of sensor/platform needs to be assessed and duly validated in various coal mining conditions before introducing the same on routine basis for OB measurement in coal mining industry.

SCOPE OF WORK

Remote sensing provides a quick and relatively inexpensive means of gathering information from places not easily accessible. CARTOSAT-I satellite data in conjunction with ALTM, Terrestrial Laser Scanner and ETS data acquired over pilot study area, i.e. Belpahar OC, Ib Valley coalfield, & Gevra OC in Korba coalfield. About 8 to 10 target points are established around both the mines, so that same could be identified by satellite as well as ALTM. Three dimensional coordinates of these target points were determined using Global Positioning System (GPS) and used for Geo-referencing. Digital Terrain Model (DTM) of both the mines are generated based on the data acquired during December 2007 and December 2008. Volume of OB was computed by subtracting the DTM of two cut-off dates.

The research work were carried out by CMPDI, Ranchi

Table-1 : Excavated OB volume based on ETS Vs. ALTM and Satellite data of Dec.2007 and Dec.2008 in million cu.m.

Sl. No.	Sensors	Belpahar OC	Gevra OC
1.	Electronic Total Station (ETS)	2.597	5.460
2.	Airborne Laser Terrain Mapper (ALTM)	Height 750m = 2.652 1250m = 2.701 2000m = 2.618	Height 750m = 5.385 1250m = 5.357 2000m = 5.289
3.	CARTOSAT-I Satellite	5.609	Satellite data not available due to cloud cover

Table - 2: Excavated OB volume based on ETS Vs. Terrestrial Laser Scanner data of March-2009 (at 10 days intervals) in million cu. m.

Sl. No.	Sensors	Part of Belpahar OC	Part of Gevra OC
1.	Electronic Total Station (ETS)	0.0591	0.0268
2.	Terrestrial Laser Scanner (TLS)	0.0598	0.0272

Since such study has been carried out for the first time in coal mining sector for OB measurement using different sensors onboard different platform, therefore; a methodology needs to be developed to synergize the use of multi sensored data for accurate and rapid in situ OB measurement. The efficacy and accuracy of each sensor/platform has been assessed and duly validated in different coal mining conditions. The most suitable technology amongst the above would be proposed to introduce on routine basis for measuring the OB in time-cost effective manner on regular basis.

STUDY AREA

To test the efficacy the stereoscopic satellite, ALTM and Terrestrial Laser Scanner for volume computation, it was proposed to select one small and one large opencast coal mine having single and multiple seam quarry for pilot study. Accordingly, Belpahar OC in Ib Valley coalfield and Gevra OC in Korba coalfield were selected as test site for the present study.

DATA ACQUISITION

ALTM

ALTM data acquisition was carried out by National Remote Sensing Centre (NRSC), Hyderabad using ALS-50 system integrated with Digital Camera (DC) onboard Superking Beech-300 aircraft. ALTM data was acquired over the Belpahar and Gevra OCs at the height of 750m, 1250m and 2000m AGL to determine the most suitable height for volume measurement. ALTM data was acquired in December 2007 and December 2008. Digital photography was also carried out simultaneously with ALTM survey. About 10 field targets of size 3m x 3m painted in black & white colour were placed around the mine and x, y & z coordinates

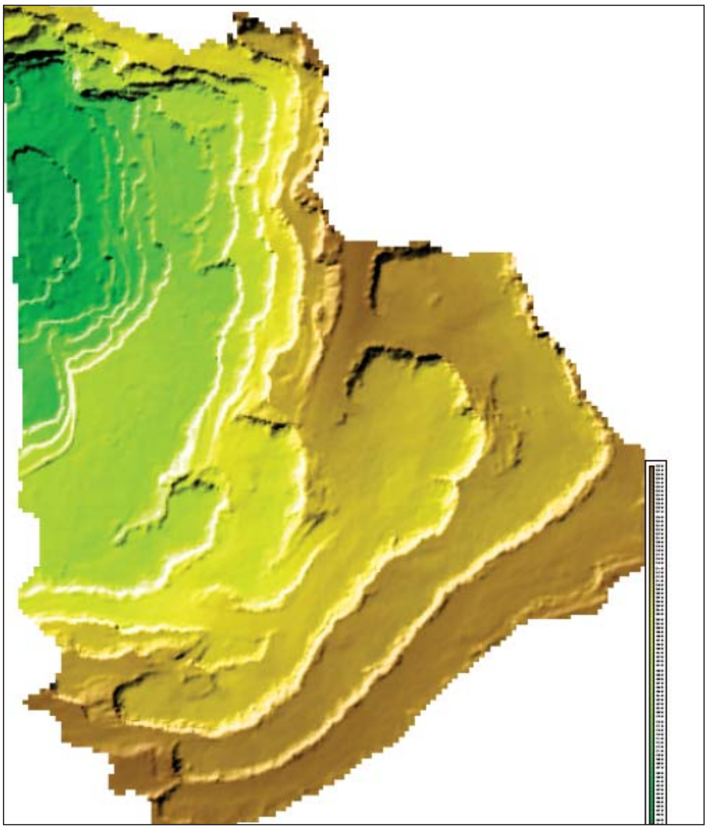


Fig-1: DTM of Gevra OC based on ALTM data of Dec.2007 from the height of 1250m.

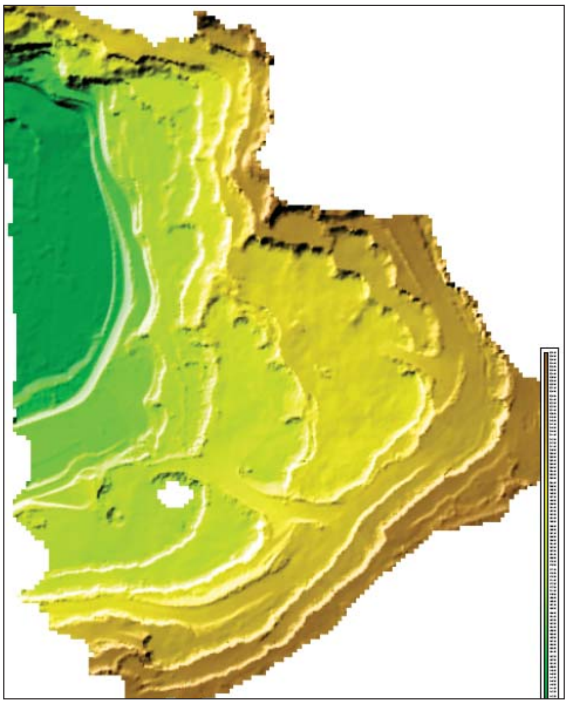


Fig - 2: DTM of Gevra OC based on ALTM data of Dec.2008 from the height of 1250m.

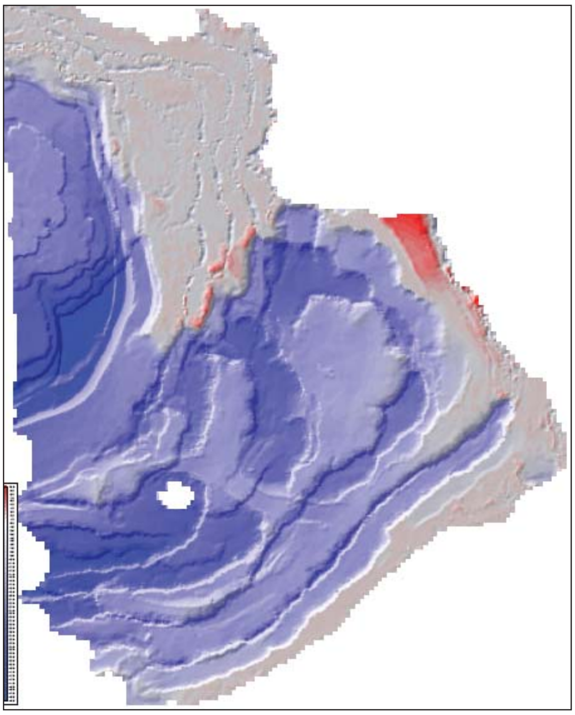


Fig-3: Differential DTM of Gevra OC based on ALTM data of Dec.2007/08 from the height of 1250m.

of the targets were determined using GPS.

Satellite

CARTOSAT-I satellite was programmed to acquire the stereo data of Belpahar and Gevra OCPs concurrently with ALTM data acquisition. Belpahar satellite data was acquired. However, Gevra satellite data could not be acquired because of the cloud cover over the area on the date of ALTM data acquisition.

Terrestrial Laser scanner

TLS data acquisition simultaneously with ALTM and satellite could not be made because TLS could not be procured during the ALTM survey. On receipt of TLS in the month of March 2009, data acquisitions for two spells were carried out both in Belpahar and Gevra mines. ETS survey was also carried out simultaneously for result validation.

DATA PROCESSING

Satellite, ALTM &TLS data was processed using Leica Photogrammetric Suit (LPS), Terrascan and RiSCAN PRO/Cyclone software respectively. DTM for two spell were generated and volume was computed using 'Difference Model'. ETS data was also processed using LISCAD software and excavated volume was computed based on DTM as well as cross-section method. DTM surfaces derived from ALTM survey carried out during year 2007 and year 2008 in Gevra OCP are shown in Fig.1 & 2. Differential DTM is shown in Fig.3

RESULT EVALUATION

Excavated volume of OB measured by different sensors in Belpahar & Gevra mines are given in Table-1 and Table-2.

It is observed that variance in the OB volume derived by ETS and ALTM is 0.80% in Belpahar and 1.3% in Gevra, whereas variance in ETS & TLS ranges between 1.18% to 1.40%. In case of Satellite, variance in the volume in respect to ETS is 215% because of poor vertical accuracy (4.00m)

CONCLUSION

A pilot study was carried out for rapid and accurate measurement of excavated in situ overburden in Belpahar OCP in Orissa and Gevra OCP in the State of Chattisgarh. CARTOSAT-I stereo satellite data, ALTM as well as TLS are used for acquiring the data for both the mines.

Methodology for processing the digital data for excavation measurement was developed under this project and result was validated against the ETS derived OB volume in both the mines. Study reveals that Terrestrial Laser Scanner is much faster for data acquisition as well as volume computation in comparison to ETS. TLS survey reduces 75% time and 50% manpower with respect to conventional ETS survey.

ALTM survey requires Ministry of Defence (MoD) clearance, which takes about 6 to 8 months time. Though the ALTM data acquisition being the airborne sensor is very fast and accuracy is also high, but availability of ALTM in India is very poor at present, hence it may not possible to get the ALTM survey on demand at present.

The spatial resolution of CARTOSAT-I is 2.5m and accuracy in the vertical direction (Z) is 4.0m, therefore, the volume derived from the satellite DTM is not matching with ETS data. However, in near future, when Z accuracy of new generation of satellite will improve, then satellite based volume computation will be the time-cost-effective solution for rapid OB measurement.

RECOMMENDATION

Based on the result of this study, it is recommended that:

- Terrestrial Laser Scanner should be used on routine basis for measuring the excavated volume of the overburden in opencast coal mines using the methodology developed under this project.
- For rapid and accurate measurement, total excavated volume should be measured and volume of coal excavated from the mine should be deducted from the total excavation volume to determine the volume of excavated overburden. The data for coal volume may be supplied by the project authority. Total excavation measurement may not have any ambiguity about the position of roof and floor of coal seam, for which surveyor is depending on the input from the project authority.
- ALTM based OB volume measurement may be considered to be taken up when number of service provider would be available for this survey in the country.
- Satellite based measurement for total excavation will be the most suitable time-cost effective method, which may be used on regular basis in future after getting the better spatial resolution stereo data.
- Further study needs to be carried out with higher resolution satellite data to determine the total excavation volume in mining area before using the same on routine basis.

MineTech, Volume 33 No 1, P 19-27 Mar , 2012

Integrated Communication System to communicate and locate trapped underground miners

INTRODUCTION

Need for Robust Communication Systems for emergency, productivity, efficiency and optimal utilization of resources.

Field Trial Introduction

As part of Science & Technology Grant from the Ministry of Coal, under the supervision of CMPDIL(HQ) Mining Electronics department, a field trial project was conducted to study the application of these technologies in Indian mining conditions. For conducting the study initially the Central Saunda Colliery was selected and then the system had to be relocated to neighbouring Bhurkunda Collieries' Lower Semana Mine due to adverse conditions at Central Saunda Collieries.

Due to its accident history, the Bansgarha seam of Central Saunda Colliery of Central Coalfields Limited (CCL) was selected to field trial a robust communication system comprising of Ultra Low Frequency (ULF) Through the Earth (TTE) Messaging system (implemented as Phase I) and ImPact Digital Wireless Network based Tracking (implemented as Phase II) with two-way digital wireless telephony. Phase III will provide unique value-add by creating "Location Aware Messaging", whereby an underground miner can be sent messages based on his location (that is updated in real-time on the Mine's surface control center computer system).

PHASE I

EMERGENCY COMMUNICATION: FAULT TOLERANT MINE WIDE THROUGH-THE-EARTH (TTE) COMMUNICATION SYSTEM

Surface Antenna

Challenges that required addressing included the Central Saunda Colliery's Bansgarha seam's multiple "surface fires" prohibiting any cable antenna placement in trenches in some areas. The alternate option of having the antenna cable on poles could not be utilized due to rampant theft in the area. All the above factors were incorporated in deciding the best path for ULF system antenna run for maximum signal coverage in underground working area coverage.

Due to Central Saunda's history of accidents caused due to underground disasters, it was selected to host the *Through-The-Earth* communication system where the 3000m surface antenna with a loop diameter of 600m providing approximate 1.8Sq. Km. mine wide coverage area was deployed taking into consideration following on-ground conditions, including surface fire, housing colonies, other restrictions caused by terrain conditions.

Besides, the placement of expensive and sensitive Head-end equipment in a secured, dust-free, air conditioned environment is required to be located inside a room in the Project Office campus. Furthermore, the concerned room had to be remodeled to suit the manufacturer's recommendation for an air conditioned, "dust-free" area and a separate PEDCALL application operator area.

Field testing and observation

Through The Earth Messages were sent every hour to the supervisors who were equipped with the *Integrated Communications Cap Lamp* (ICCL) when going to the underground as part of their daily duties. It was noted and verified that all messages that were sent from the surface control center were received by the supervisors in the underground.

Research project under implementation by CMPDI, Ranchi in association with Adcept Technologies Pvt. Ltd, Kolkata.

Through The Earth Messaging System redeployment at Bhurkunda Mines' Lower Semana Mines

Due to surface fire and considerable subsidence at the Project Office at Central Saunda Collieries' Project Office, the control center had to be relocated. is 372 Hz. Also the new LED based cap lamps that enhanced the light for miners by several factors and increased battery life of the ICCLs, were introduced in this phase. The miners who have experienced the new generation ICCLs, have received the LED light's performance in great spirit.

Figure 1: Through The Earth Messaging System at Central Saunda Collieries' Bansgarah seam.

Figure 2: Phase II Control Center in Saunda D CollieryServing Bhurkunda Collieries' Lower Semana Mines

Figure 3: Phase I TTE Headend installation at Central Saunda

A new 5000m surface antenna (with a loop diameter of 800m) providing approximate 3.2Sq. Km. coverage was deployed taking into consideration following on-ground conditions, including surface fire, housing colonies, other limitations due to terrain conditions. The system is to provide coverage to the Bansgarha seam's underground working area at the depth of 150m. The modulated carrier will propagate through the Earth giving useable signal strengths up to 0.75 to 3km away. The frequency used for transmission of PED messages

Field testing and observation

Through The Earth Messages were sent every hour to the supervisors who were equipped with the Integrated Communications Cap Lamp (ICCL) when going to the underground as part of their daily duties. It was noted and verified that all messages that were sent from the surface control center were received by the supervisors in the underground. In this case, it was observed that messages were received through the earth when supervisors travelled to Hathidari mines

Figure 4: Through The Earth Messaging System re-deployed at Bhurkunda Collieries' Lower Semana Mines

(another seam)! Hence, multi-seam messaging was demonstrated by this installation.

Benefits of Through the Earth Messaging System

In case of Mine accident/disaster due to explosion, roof fall, fire or inundation, miners get trapped with no means of communication with rescue team on surface. Since there is no system presently deployed for two-way communication for trapped miner location tracking. If systems that allow messaging from surface to underground miners through-the-earth (TTE) using a surface antenna are not deployed for emergency evacuation, rescue operations become extremely difficult, at best predictive, and sometimes even impossible, causing loss of lives. Having the Through the earth messaging system means that:

- Evacuation messages can be sent to people underground no matter what has happened underground as we do not depend on any underground antenna or other cabling that would be damaged in any major incident.
- The warning to evacuate can also say where the incident is, and recommended way to evacuate from the part of the mine the person is in.
- If people are trapped they can be updated with information on rescue attempts, for e.g. where borehole are being drilled, etc.
- The trapped people can be told that sensitive seismic sensors and listening devices are being set up and then told when to hit the roof so the signal can be picked up on the sensors, confirming they are alive and in addition to their whereabouts.
- PED is useful to the mine's day to day operation as well.

For all these reasons PED has been installed in almost 200 mines around the world including countries like Australia, USA, China, Canada, South Africa, South American countries.

TTE PAGING SOFTWARE - THE OPERATOR INTERFACE

The computer which is running PEDcall TTE Paging software controls the Transmission System. The PEDcall software provides the interface from the operator to the system in a simple and efficient manner.

The operator inputs information, such as the destination and the message content, then the PEDcall software will encode this information. Encoding of

Figure 5: Through The Earth Ultra Low Frequency Emergency Messaging System

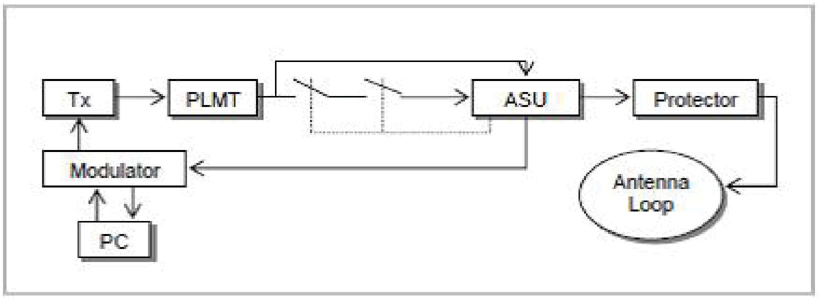


Figure 6 : TTE Paging Transmission System block diagram

the destination and message uses advanced encryption methods to eliminate any chance of invalid information being transmitted. These encryption methods also ensure the receivers can decode the call screen information precisely in adverse signal conditions. PEDcall software enables messages to be sent to individuals, predefined: groups or broadcasted simultaneously to all receiving units. PEDcall can be accessed using configured clients over a local area network, enabling messages to be sent from multiple computers. PEDcall also has the ability to operate ControlPEDs and BlastPED Receivers. PEDcall uses an ODBC compliant database, allowing third party applications to directly connect to PEDcall and send messages. This means that PEDcall can be used by people with little or no computer experience once they have been trained.

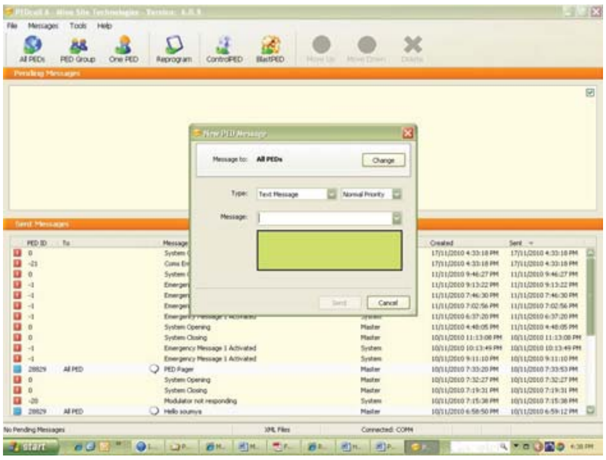


Figure 7: PEDcall screen

TTE PAGING MODULATOR

TTE PAGING Modulator: The Modulator Unit is a stand alone unit that connects to the PC through a standard RS-232 Com Port. The output signal is a 0-20 mA Current Loop. The output is usually connected to the Transmitter by a twisted pair, though optic fibre or

Figure 8: Modulator

radio links can be used if necessary. The PED External Modulator is connected to the PEDcall Computer via the serial port. This provides the interface to the Transmitter.

TTE PAGING ULF TRANSMISSION HEAD-END

TTE PAGING ULF Transmission Head-end: The TTE PAGING Head-end is mounted in a 19" Rack Cabinet and is connected to the incoming 0-20 mA Current Loop. The main role of the Head-end is to boost the signal into a high power output capable of driving up to 250 volts at 5 amps into a large loop antenna. The Transmitter within the Head-end utilizes an efficient technique to achieve this role on continuous basis, it is also protected from thermal overload and short circuit conditions. The Head-end also contains Antenna Safety Unit and Loop Matching Transformer to optimize signal quality and safety. Each Head-end can drive one loop antenna, therefore if a large mine requires two loop antennas, then two transmitters will be connected. The output from the TTE PAGING Head- end feeds into the Surface Loop Antenna.

Figure 9 :TTE PAGING ULF transmission headend

ANTENNA SAFETY UNIT

The Antenna Safety Unit (ASU) is one of the modules within the TTE PAGING Head-end. The ASU offers Earth Leakage and Open Circuit protection. It also monitors the output voltage. Should a fault occur the software will detect it and display a message on the PC, during a fault the messaging system is disabled.

The ASU offers selectable Earth Leakage (Ground Fault) protection and also Impedance Monitoring. In this way, some unsafe condition that may occur will result in the shutdown of the system. Any voltages will be completely removed from the Loop Antenna.

TTE PAGING LOOP MATCHING TRANSFORMER

The TTE PAGING Loop Matching Transformer (PLMT) is located within the Head-end and is designed to optimize transmitter output into the antenna. The PLMT is inserted between the transmitter and loop antenna. To ensure the best results are achieved the PLMT is customized for each installation.

PLMT Unit shown in rear view of PED Headend Cabinet

Figure 10: PLMT Located at base of PED Headend Cabinet

TTE PAGING PROTECTOR

PED Protector integrated into Marshalling Unit

Figure 11: Protector Unit is integrated into the Marshalling Unit

The TTE PAGING Protector is located within the Head-end and is a surge protection device. The unit is installed immediately before the loop antenna, hence any surges (e.g. those induced by lightning) on the antenna will be diverted and therefore minimize the risk of damage to the other transmission system components. The Surge Protector is integrated into the Marshalling Unit.

SURFACE LOOP ANTENNA

A site survey was undertaken and after carefully studying the physical terrain and taking into confidence the CCL surveyor's recommendations the following antenna layout plan has been made for the mines. The Loop Antenna is buried on the surface, the antenna cable is specially made and is heavily insulated for direct earth burial. The Surface Loop Antenna layout is critical to system performance. The layout will determine the range of signal line transmission. Generally, the larger the loop (up to a maximum of 12 km) the better the coverage will be. The Loop Antenna carries current and, due to this current flow an electromagnetic field is created around the Loop Antenna. This field appears as concentric bands radiating off the cable. The concentric pattern ensures signal is present inside, above, below and off the edge of the loop. Due to the signal radiation pattern, one centrally located loop can cover an average size mine. Surface loops are most desirable, due to the infrastructure being on the surface rather than underground. The Loop Antenna layout is critical to system performance. The layout will determine the range of signal transmission. Generally, the larger the loop the better the coverage will be.

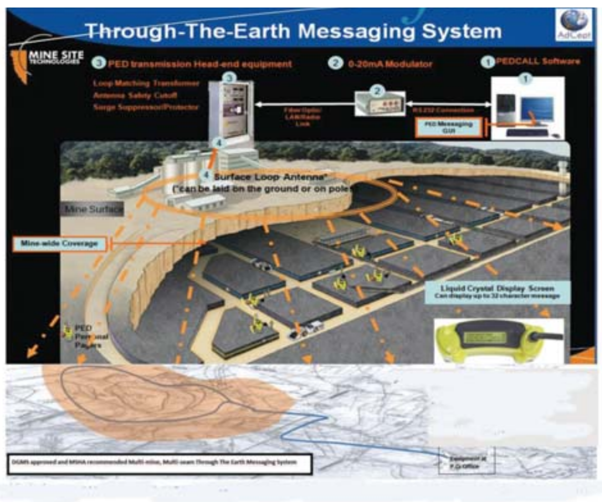


Figure 12: Surface loop antenna

PHASE II

TRAPPED MINER LOCATION WITH TWO-WAY VOICE COMMUNICATION TO AND FROM HAZARDOUS UNDERGROUND COAL MINES TO ANYWHERE IN THE WORLD

The constant push for productivity and safety improvements has driven the development and adoption of more advanced automation, remote monitoring and control systems. ImPact Digital wireless tracking system's principal design criteria incorporates standards based protocols on a ruggedized platform, i.e. the Wireless Network Switch (WNS') are designed specifically for the arduous underground environment in terms of physical packaging, electronic design and connecting to fibre and power. Physically, and in the practicality of installation and maintenance, the ImPact WNS' are vastly superior. These WNS' integrate fast switch to facilitate hub/branch configuration or to switch between access cards based on data priority (e.g. VoIP packets assigned priority for QoS performance). Notable feature is that these operate on touch voltage (15.1 VDC) – certified to be Intrinsically Safe. While the Fiber Optic interface allow us to maximize WNS' spacing targeting 600m separation [802.11b/g] based on minimum signal propagation of 300m in typical 4m x 5m openings.

The control center for the Bhurkunda Mines project is located at Saunda D project office almost 5 Km away. Hence fiber connectivity was made between the surface control center and the underground network. This fiber has survived the summer heat and worst thunderstorms of Jharkhand.

Digital networks have allowed the convergence of many applications onto a single communication backbone in general industry. The opportunity for a similar consolidation of communication infrastructure has driven the introduction of IP based networks into underground mines. This convergence of technologies is discussed together with the experience in coal mines of the implementation of new applications, including Wi-Fi devices, such as intrinsically safe VoIP Telephones and RFID Tracking.

Providing reliable voice and data communication that is flexible and durable enough for underground mining operations, has been a challenge — until now. Advanced connection technology today makes it simple and economical to couple fiber optic networking with an integral power source for truly flexible wireless access.

Like most above-ground applications, subterranean mining operations not only face a profusion of network communications issues, but also exceptional economic ones. There is the inherently harsh environment, the need to frequently relocate communications access points, and potential for soaring maintenance costs in addition to the critical need of providing unbroken mobile people and equipment, especially within a very rugged environment.

The ImPact Digital Wireless Network System was deployed per the suggestion of the mine management to provide coverage in the main tunnel and working zones. The Tracking software at the surface control center, displays the last known location of the miners carrying either the ICCL cap lamps (with integrated RFID) or self-contained RFID tags. The records are stored in the database for future analyses. This system will help the Project office to know the last known location of all miners carrying the ICCLs or Tags.

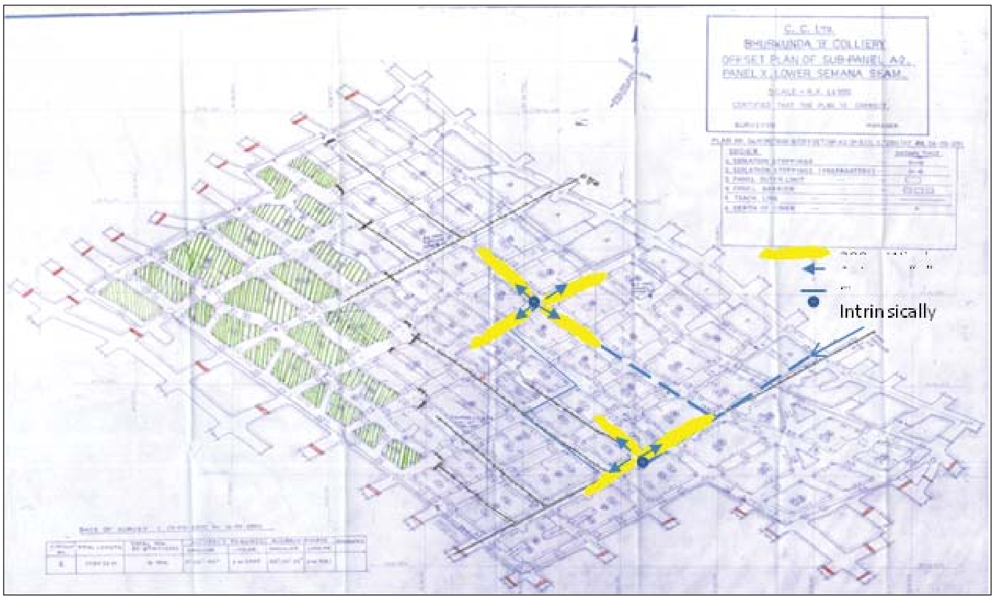


Figure 13: Underground Wireless Network for Tracking and Two-way Voice over IP

FIELD TESTING AND OBSERVATION

Tracking System

Figure 14: ImPact Wireless System for Underground Coal Mines

THE TWO-WAY VOICE OVER IP COMMUNICATION SYSTEM

The ImPact Digital Wireless Network System was deployed per the suggestion of the mine management to provide coverage in the main tunnel and working zones. Two wireless phones are being taken to the underground by the supervisory staff and they can call each other or the surface control center and have communication with digital clarity.

We further enhanced the system to integrate the underground mine network to the outside world using a GSM gateway. As a result of this, calls with digital clarity can now be made from underground to any number on the surface and vice-versa.

The system's robustness was tested for over 7 months now of continued operations in the underground in the heat, humidity and harsh conditions.

Wireless backbone for hazardous underground coal mines

The ImPact Digital System complements our other communication technologies, ensuring a mine's overall communication system not only meet their safety requirements, but enable optimum productivity from all their mining assets.

Mine Site Technologies' I.S. ImPact 802.11 Wireless Network Switch (WNS) provides the mining industry with a high throughput and robust communications infrastructure to support the deployment of general IP applications with a focus on mobile data solutions that are implemented over the ImPact Wireless LAN. The ImPact WLAN is standards based and Wi-Fi compliant.

Voice over Internet Protocol (VoIP) Wireless Phones

Mine Site Technologies' MinePhone handsets offer a simple and robust solution for Voice over Internet Protocol (VoIP) communications in mining environments. The handset allows users to make and receive VoIP phone calls from any area of the mine covered by the wireless network and includes mine specific functionality including Push To Talk (PTT), emergency alarms and a battery life designed to last an entire shift. The handset is IEEE 802.11b/g (Wi-Fi) compliant and uses Session Initiation Protocol (SIP) for both voice calls and text messaging. The units can be configured using the on screen menu system or via a web browser simplifying system deployment.

RFID Tracking

The ImPact tracking system is a cost-effective method of asset and personnel tracking, ensuring that the whereabouts of underground staff is always known, and that assets can be quickly located, particularly at shift changes.

Active RFID tags are carried by personnel or attached to assets such as vehicles and other implements. These tags are detected by strategically placed digital tag readers, typically installed at section entries, load points ore passes, draw points, and refuge bays. Location and movement data can be monitored and tracked, in real time, throughout the mine and presented in list format or as overlays on mine plans and maps. The application software provides users with a customizable viewer and powerful sorting, filtering, and searching tools, with comprehensive logging and extensive report generating facilities.

Call Management Platform for Surface Control Center

Software based IP PBX is proposed which replaces a proprietary hardware PBX / PABX. IP PBX has been developed specifically for Microsoft Windows or Linux and is based on the SIP standard, making it easier to manage and allowing you to use any SIP

March/April 2012

Technology Update

Two-way Digital Wireless Telephony over High Speed Wireless Infrastructur

Intrinsically Safe System for Hazardous Underground Coal Mines

Mine Site Technologies' MinePhone handsets offer a simple and robust solution for Voice over Internet Protocol (VoIP)

Intrinsically Safe MinePhone

communications in mining environments. The handset allows users to make and receive VoIP phone calls from any area of the mine covered by the wireless network and includes mine specific functionality including Push To Talk (PTT), emergency alarms and a battery life designed to last an entire shift.

Voice Over IP (VoIP) —Next generation wireless telephony for hazardous underground coal mines

- Digital wireless telephony now installed in a hazardous coal mine in India.
- It is now possible to make a phone call from anywhere in the world to a miner in the underground and vice versa.

Possible benefits:

1. Reduced downtime of equipment
2. Personnel in underground can now contact management on surface in case of any emergency/ advice/report, etc.
4. Eliminating the feeling of alienation of underground miners by remaining in touch with the outside world- Improved moral of underground workers
5. Productivity and efficiency improvement – now you can deploy network based environmental monitoring, automation systems.

Intrinsically Safe Wireless Infrastructure

The Mine Site Technologies Intrinsically Safe Wireless Network Switch is the heart of a scalable, high-speed, communications system for both underground and surface operations. Designed to cope with time-sensitive, high-bandwidth applications and enabling functionality such as VoIP, IP video streaming, control system management, mobile data

Intrinsically Safe Wireless Network Switch

acquisition, real-time vehicle diagnostics, and asset / personnel tracking right to the coal face. The ImPact Wireless Network Switch provides a quantum leap forward from traditional technologies by delivering improvements in reliability, bandwidth, data quality, system capacity and support for open standards. It also addresses the challenge of power distribution in an underground environment.

phone (software or hardware). A software-based IP PBX / PABX offers many benefits:

- Easier to install & manage via web-based configuration interface
- Far less expensive to purchase and expand than a hardware-based PBX / PABX
- Improve productivity with presence, desktop based call control and extension management
- No need for separate phone wiring – phones use computer network, easy hot desking!
- Delivery mobility by allowing employees to work from home using a remote extension
- Choose between popular IP hardware phones or softphones - no vendor lock in
- Receive & make calls via the standard PSTN using VoIP Gateways or cards

CONCLUSION

A must have for Emergency Evacuations besides daily messaging to underground miners

The most basic requirement of a post-tragedy communication system is to provide a communication link between the surface personnel and underground miners after a fire, explosion, or inundation. The emergency communication system should be robust to make the system more fault-tolerant and be part of a mine's routine system, rather than an entirely separate system, to better ensure that it will properly function when an emergency occurs. In India, research unfolds the cause-wise fatalities in disasters (in CIL). Refer to figure 15.

In case of Mine accident/disaster due to explosion, roof fall, fire or inundation, miners get trapped with no means of communication with rescue team on surface. Since there is no system presently deployed

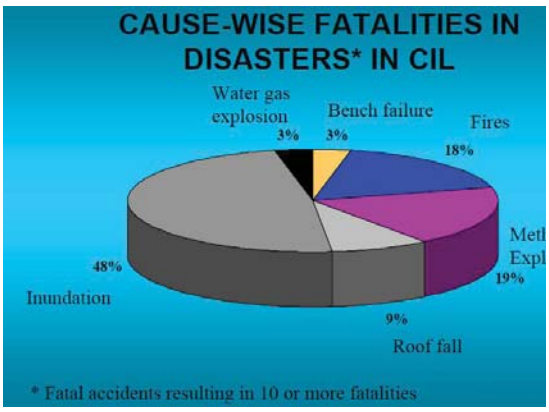


Figure 15:Cause of fatalities in Underground coal mines in India

for two-way communication for trapped miner location tracking. If systems that allow messaging from surface to underground miners through-the-earth (TTE) using a surface antenna are not deployed for emergency evacuation, rescue operations become extremely difficult, at best predictive, and sometimes even impossible, causing loss of lives. Having the Through The Earth messaging system means that:

- Evacuation messages can be sent to people underground no matter what has happened underground as we do not depend on any underground antenna or other cabling that would be damaged in any major incident.
- The warning to evacuate can also say where the incident is, and recommended way to evacuate from the part of the mine the person is in.
- If people are trapped they can be updated with information on rescue attempts, for e.g. where borehole are being drilled, etc.
- The trapped people can be told that sensitive seismic sensors and listening devices are being set up and then told when to hit the roof so the signal can be picked up on the sensors, confirming they are alive and inaddition to their whereabouts.
- PED is useful to the mine's day to day operation as well.
- For all these reasons PED has been installed in almost 200 mines around the world including countries like Australia, USA, China, Canada, South Africa, South American countries.

With the two-way Digital Wireless Voice Communication system we find that the workers stay happier by staying in touch - As mining projects spring up in increasingly remote areas of the world, feelings of isolation can become quite common throughout an onsite workforce. Calls to mine management at CCL HQ, CMPDIL HQ and to all official mobile numbers of Project Office are now possible from the underground. Similarly, anyone on the surface, intending to contact personnel in the underground, can dial the gateway phone number and the personnel's wireless phone's extension. One key to retaining employees facing long periods of separation is to provide convenient communications to the outside world.

Field studies on the application of Lignite Humic Acid on various crop responses in different Agro-climatic conditions

HUMIC ACID - AN ORGANIC CROP ENERGIZER

The tropical soils are low in organic matter content under intensive farming. The use of high analysis fertilizers has brought out self reliance in the food production; however, the soil fertility has declined and the productivity has become stagnant. The indiscriminate use of chemical fertilizers enhanced the microbial degradation of soil organic matter resulting in the decrease of soil organic carbon.

Maintenance of soil organic matter at a satisfactory level is very important to sustain higher crop yields under Indian farming conditions. Though, the traditional organic manures played a crucial role in maintaining soil fertility, the agriculture based on organic manure alone is not target oriented; besides organic manure is also not available in adequate quantities. Hence, it has become quite imperative to apply organic matter through other alternative sources to enrich the soil with humic substances. In this context, the role of humic acid, obtained from coal and lignite (brown coal), has assumed a greater importance. Humic acid based fertilizers are quite popular in abroad and these fertilizers are being manufactured by USA, South Africa and Greece and sold in trade names like Aactosol, Neogen, Fytomon, Phytormon, Veto liquid, Humotrel and Anthormon. In India, the estimated lignite deposits are about 29,000 million tonnes. Out of this, about 91% (26,115 million tonnes) is available in Tamil Nadu. The Neyveli lignite is rich in humic acid and Neyveli Lignite Corporation, Pvt. Ltd. is engaged in extraction of humic acid from lignite and the test material is in the form of water soluble potassium humate.

OBJECTIVES

Though the availability of material is in plenty, the knowledge on its beneficial effects is lacking. Hence an effort has been made by TNAU in collaboration with NLC to study the effect of humic acid on crops yield, quality and soil health with the following objectives:

- To study the influence of lignite humic acid on soil properties
- To find out the effect of lignite humic acid on certain important crops under different agro-climatic zones.
- To assess the extent of fertilizer saving by supplementing nutrient requirements through lignite humic acid.
- To test verify the results and conduct field demonstrations for final recommendations.

Characteristics of lignite potassium humate

The products of decomposition processes of organic matter are humic substances. They are thought to be formed by microbial, enzymatic and chemical transformations of plant and animal residues. They possess chemically reactive groups which may influence plant growth directly or indirectly. The characteristics of the potassium humate are studied in detail. Potassium humate of lignite is a dark coloured substance, soluble in water and varies in chemical properties. The high CEC indicates that this material is having profound affinity to the adsorption of cationic species and the high organic carbon is the cause for its marked influence on soil physical properties, sequestration and biological activities.

Humic acid on yield of crops

Field experiments were conducted to study the influence of humic acid on yield of major food crops, commercial and vegetable crops in different agro-climatic zones of Tamil Nadu. For all the crops, the response was studied initially with and without NPK. Based on the results of experiments, the treatments which performed better were selected for test verification trials to derive definite conclusions on the effect of humic acid in various crops.

Paddy

The findings of the experiments on paddy in different agro-climatic zones showed that the application of humic acid (HA) increased the grain yield to the tune

Research work carried out by Neyveli Lignite Corporation, Neyvelli in association with Tamil Nadu Agricultural University Coimbatore of 950 kg ha^{-1} over control. The combined application of HA through soil + foliar spray + root dipping showed relatively higher yield than application of HA separately. Adoption of the technology comprising soil application of HA @ 10 kg ha^{-1} + 0.1% foliar spray + 0.3% root dipping along with 100% NPK produced

higher yield of grain and straw (Table 1. Increasing the level of humic acid beyond 20 kg ha^{-1} has not produced appreciable increase in yield.

Sugarcane

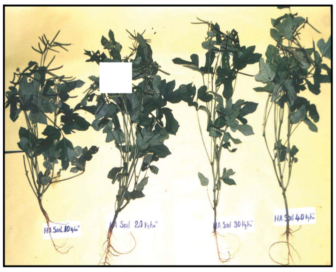
The experimental results proved that appreciable increase in cane yield could be obtained with the

application of HA over control. Growth attributes such as number of millable canes, single cane weight and number of nodes were also favourably influenced by HA application (Table 2). Soil application of humic acid @ 20 kg ha^{-1} along with 100 % NPK was observed to be best for getting higher cane yield to the tune of 5.4 - 24.7 t ha$^{-1,}$ with a net return of Rs. 4,500 to 19,500 per hectare and improved quality characteristics of juice viz., juice %, brix %, purity % and CCS %.

Groundnut

The results obtained from experiments on groundnut indicated that the application of HA increased the yield of pod to the extent of 511 kg ha^{-1} over control (Table 3). Soil application of HA 20 kg ha^{-1} with 100% NPK was found to be the best when compared to other treatments in enhancing pod yield, shelling percentage, crude protein and oil content.

Pulses



The findings of the experiments on pulses (green gram and black gram) revealed that the grain yield was increased from 107 - 252 kg ha^{-1} by the application of HA over control. Basal application of 20 kg HA ha^{-1} + 0.1% FS along with 75% NP recorded higher grain yield over 100% NP at all locations (Table 4). The quality characteristics viz. protein and methionine contents were also improved by the soil application of HA. Nutrient uptake by crop was well pronounced in treatments receiving soil application of 20 kg HA with 100% NP, followed by 75% NP fertilizers.

Cotton

Application of 100 % NPK along with soil application of 30 kg HA ha^{-1} was found to be optimum for obtaining higher kapas yield and better quality of cotton. Crop, growth rate, net assimilation rate and relative growth rate were also positively influenced by the HA. Cotton fibre quality such as fibre fineness, bundle strength, and elongation percentage were

Table 1: Effect of humic acid on grain yield of rice at different locations

Sl. No.	Location & Soil type	Variety	Grain yield (kg ha^{-1})		% increase	BCR
			100% NPK	100% NPK + 10 kg HA ha^{-1} + 0.1% FS + 0.3 %RD		
1	TNAU, Wet land Noyyal series	ADT 36	4363	4795	9.9	1.59
2	ARS, Bhavanisagar lrugur series	ADT 36	4212	4752	12.8	1.57
3	AC &RI, Killikulam ManakaraI series	ASD 16	3677	4500	22.4	1.49
4	AC&RI, Madurai Madhukkur series	ADT 36	3296	3933	19.3	1.30
5	TRRI, Aduthurrai Kalathur series	ADT 39	4900	5850	19.4	1.94
6	ARS,Pattukottai Madhukkur series	ADT 39	4015	4610	14.8	1.53
7	TRRI, Aduthurrai Kalathur series	ADT 39	4180	4520	8.1	1.50
8	Farmers field, Killikulam	ADT 43	5164	5347	3.5	1.77
9	Manakarai senes Farmers field,	ADT 39	6107	6360	4.1	2.11
10	Kattuthottum Farmers field, Paiyur	ADT 39	5120	5620	9.8	1.86
11	Farmers field, Ambasamudram	ADT 36	5220	5510	5.6	1.83
12	Farmers field, Trichy	BPT 5601	4750	5512	16.0	1.83

HA - Humic acid; FS - Foliar spray; RD - Root dipping; BCR - Benefit Cost Ratio

Table 2: Effect of humic acid on cane yield of sugarcane at different locations

Sl. No.	Location & Soil type	Variety	Cane yield (t ha^{-1})		% increase	BCR
			100% NPK	100% NPK + 20 kg HA ha-l		
1	Farmers field, Gobi-Irugur series	CO 86032	105.3	110.7	5.1	1.88
2	Farmers field, Attur - PN palayam series	Co V 92102	102.6	127.3	24.1	2.17
3	Farmers field, Molapalayam - Irugur series	CO 353	96.4	102.2	6.0	1.74
4	Farmers field, Attur - PN palayam series	CoC 90063	114.9	.138.3	20.4	2.35
5	SRS, Cuddalore - Gadillum series	CoC 98061	95.1	102.4	7.7	1.74

Table 3: Effect of humic acid on pod yield of groundnut at different locations

Sl. No.	Location & Soil type	Variety	Pod rield (kg ha^{-1})		% increase	BCR
			100% NPK	100%NPK + 20 kg! HA ha^{-1}		
I	RRS – Vridhachalam - Vallam series	VRI2	1964	2475	26.0	2.64
2	Farmers field, Pollachi - Irugur series	JL24	1729	2200	27.2	2.35
3	Farmers field, Kakapalayam - Irugur series	VRI2	1737	2100	20.9	2.24
4	RRS - Vridhachalam - Vallam series	VRI2	1868	2130	14.0	2.27
5	Farmers field - Virdhachalam Vallam series	VRI2	1733	2008	15.9	2.14

Table 4: Effect of humic acid on grain yield of pulses at different locations

Sl. No.	Location & Soil type	Variety	Grain yield (kg ha^{-1})		% increase	BCR
			100% NP	75 % NP + 20 kg HA ha^{-1} + 0.1 % FS		
Green gram						
1	Farmers field, Sundapalayam, Somayanur series	VBN GG2	862	1114	29.2	2.84
2	Farmers field, Kalipalayam, Irugur series	VBN 1	694	838	20.7	2.13
Black gram						
3	Farmers field, Alanthurai Irugur series	VBN3	740	945	27.7	2.36
4	Farmers field, Alanthurai Irugur series	TMVI	812	990	21.9	2.48
5	Farmers field, Madurai Madhukkur series	TMVI	746	853	14.3	2.13
6	Farmers field, Alanthurai Irugur series	CO5	654	765	17.0	1.91

Table 5: Effect of humic acid on kapas yield of cotton at different locations

S. No.	Location & Soil type	Variety	Kapas yield (q ha^{-1})		% increase	BCR
			100% NPK	100% NPK + 30 kg HA ha^{-1}		
1	TNAU, Coimbatore PN palayam series	MCU 12	21.7	26.8	23.5	2.68
2	TNAU, Coimbatore PN palayam series	MCU 12	19.3	24.0	24.4	2.40
3	Farmers field, Rasipuram	RCH2	26.4	30.7	16.3	3.07
4	Farmers field, Coimbatore	RCH2	27.2	31.4	15.4	3.14

improved with HA application. Soil application of HA @ 30 kg ha^{-1} along with 100 % NPK increased kapas yield to the tune of 4.2 -5.1 q ha^{-1} with a net return of Rs. 11,000 to 14,000 per hectare (Table 5).

Tomato

Soil application of HA @ 20 kg ha^{-1} with 100 % NPK boosted the yield of tomato by 16 % over no HA treatment. Higher content of N, P, K, Ca and Mg was found in fruits which received HA @ 20 kg ha^{-1}. Application of HA resulted in maximum leaf area index, and chlorophyll a and b content of tomato leaves. Humic acid addition produced better quality fruits by increasing the total soluble solids, titratable acidity, sugar and protein contents of fruits with a reduction in starch content. A dramatic increase in ascorbic acid, lycopene and pectin contents of fruits was also observed in treatment receiving HA @ 20 kg ha^{-1} along with 100 % NPK.

Onion

Application of HA showed synergistic effect on added inorganic fertilizers. Yield attributes such as number of bulbs per plant, bulb girth were maximized by soil application of HA @ 20 kg ha^{-1} with 100 % NPK. The highest bulb yield of onion was recorded with 20 kg HA ha^{-1} as soil application along with 100 % NPK. The quality parameters like TSS, ascorbic acid, pyruvic acid, total sugar and crude protein contents of onion bulb were also improved by application of 20 kg HA ha^{-1} along with 100 % NPK.

Tea

The foliar spraying of HA @ 0.25 to 2.00 % was given to tea after every picking. Foliar spraying of

HA @ 0.50 % showed marked increase in green leaf yield of tea over higher concentration of HA and control. Quality parameters of made tea viz., theofillin, theorubigin, total liquor colour, caffeine, highly polymerized substances, aroma and ..flavour and polyphenol content of green tea were improved with HA application.

Maize

Application of different levels of HA along with 100 % NPK significantly :influenced the grain yield of

maize. Besides marked increase in yield attributes of maize viz., cob length, number of filled grains and 100 grain weight was observed. The highest grain yield was registered in be treatment receiving 100 % NPK and HA @ 20 kg ha^{-1} which out yielded by 16 % over control.

Benefits of humic acid

- Improves soil physical properties.,
- Holds exchangeable plant nutrients.
- Increases moisture holding capacity of the soil,
- Forms complexes with phosphorus and micronutrients, which are easily assimilable by

the plants and thus increase the efficiency of mineral fertilizer utilization,

- Helps the plants to overcome adverse pH condition of problem soils,
- Increases the permeability of plant membranes thereby enhancing the uptake of nutrients more efficiently,
- Stimulates seed germination and improves seed viability.,
- Aids in uninterrupted growth of various groups of beneficial microorganisms,
- Stimulates plant enzymes and hormones and
- Aids in root formation.

Recommendations

Based on the experimental results and cost analysis, the following recommendations can be made for getting higher crops yield and quality, besides improving the soil fertility.

- Rice : 100% NPK + 0.1 % FS + 0.3% RD + 10 kg HA ha-l .
- Pulses: 75 % NP + 20 kg HA ha-l +0.1 % FS
- Groundnut: 100% NPK + 20 kg HA ha-l
- Sugarcane: 100% NPK + 20 kg HA ha-l .
- Cotton: 100% NPK + 30 kg HA ha-l
- Onion: 100% NPK + 20 kg HA ha-l .
- Tomato: 100% NPK + 20 kg HA ha-l

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MineTech, Volume 33 No 1, P 34-42 Mar , 2012

Development and use of Fly ash based Pesticides

LARGE SCALE PRODUCTION OF BACTERIAL MOSQUITOCIDAL TOXIN(S)

Mass production of an indigenously isolated Bacillus thuringiensis var. israelensis (VCRC B17) was undertaken in a pilot scale bioreactor (100 L capacity) equipped with accessories and automatic control systems for dissolved oxygen, pH, antifoam, impeller speed, aeration rate and temperature. The fermentor was filled with 60 L production medium containing 2% soya powder and mineral nutrients with pH adjusted to 7.2. The fermentor was sterilized in situ at 121˚C for 30 min. and fermentation was carried out under the following conditions: temperature 30˚C, stirrer speed 150 rpm, dissolved oxygen (DO) 30% saturation, 10% antifoam agent. Fermentation was terminated after completion of spore crystal complex formation as observed under a microscope, which usually occurs after 24 h.

Mass production of biopesticide in a Fermentor (100 l)

The sporulated culture broth was harvested using a continuous flow centrifuge and the biomass was used for making into formulations. Thirty five batches of biocide have been produced and each batch was subjected to quality control tests against mosquito larvae under laboratory conditions.

Continuous centrifuge for separation of bacterial cell mass

DEVELOPMENT OF BACTERIAL FORMULATIONS USING FLY ASH AS A CARRIER

Preparation of Fly ash material and particle size selection

The lignite fly ash was received from Neyveli Lignite Corporation Limited, Neyveli, India. It was powdered using the ball grinder at the Department of Agriculture, Annamalai University, Chidambaram. The flyash powder was sieved to obtain particles of size ≤25 microns, which was used for the preparation of formulations. Three to four types of formulations were attempted, so that, the most suitable formulation(s) could be selected for the field use.

Water Dispersible Powder (WDP) formulation

Formulations were prepared with sixteen different ratios of active ingredient, fly ash, binding agents and dispersants.

Slow Release Floating Formulation (BR)

Slow release floating formulations namely briquettes (BR) of different shapes (cylindrical, half spherical etc) were prepared using different proportions of active ingredient, binding agent, floating agent and fly ash.

Research work carried out by VCRC, Puducherry in association with Neyveli Lignite Corporation and Annamalai University, Tamilnadu.

Slow Release submerged granular formulation (GR)

Preparation of slow release submerged formulation namely granules (GR) was standardized using different ratios of active ingredient, fly ash, binding agents and hardening solutions.

Water dispersible powder

Briquette formulation

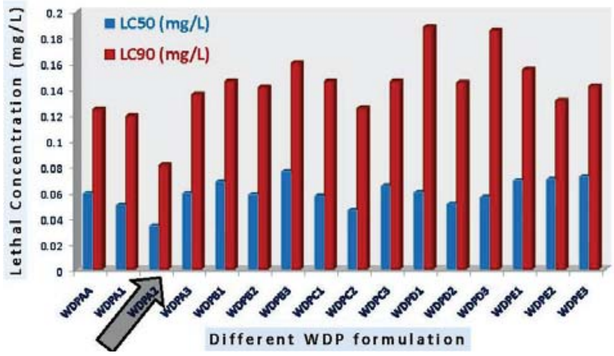
Granular formulation

LABORATORY EVALUATION OF THE FORMULATIONS AGAINST IMMATURE STAGES OF MOSQUITOES

Water Dispersible Powder (WDP) formulation

Range-finding bioassays were performed for all the WDP formulations against third stage larvae of Culex quinquefasciatus, the vector of lymphatic filariasis (Fig. 1). The most effective WDP formulation (WDPA2) was selected and bioassay was carried out against three major mosquito species namely, Cx. quinquefasciatus, vector of filarial parasite, Anopheles stephensi, malaria vector and Aedes aegypti, vector for Dengue and Chikungunya viruses (Table 1). The

Testing of WDP formulation against immatures of mosquitoes



Formulation	Mosquito species	LC_{50} (mg/L)
WDPA2	*Culex quinquefasciatus*	0.034
	Aedes aegypti	0.035
	Anopheles stephensi	0.107

spores released from the formulation were found to be concentrated at the upper layers of the water column. The residual activity of the formulation was found to last for 72 hours.

Slow Release Floating Formulation (BR)

Slow release floating formulation was tested in circular cement tanks with a capacity of 40 L and a surface area of $0.27m^2$. The granules were applied at 0.25 g,0.5 g, 0.75 g and 1 g/m^2. Mortality of the larval stages was noticed from 5^{th} day onwards in the tanks treated at all doses which increased to 87.1, 90.4, 94.6 & 99.5% at doses, 0.25, 0.5, 0.75 & $1g/m^2$ respectively. By 6^{th} week the mortality in 0.25 g/m^2 treatment came down to 79.6% and slow decline to 77.6%. In the tanks treated at 0.5, 0.75 & 1 g/m^2, 79.1%, 95% & 99% mortality of the larvae was maintained for upto 9 weeks respectively. The experiment was terminated due to disintegration of the briquettes. A single treatment of 1.0 g/m^2 was able to provide 99 % mortality for upto 9 weeks. Hence, for large scale field trials, $1.0g/m^2$ is recommended for use in clean water habitats like pools, fountains, water storage containers, etc.

Evaluation of BR formulation against Aedes aegypti in cement tanks

Slow Release Granular Formulation (GR)

Slow-release Granular formulation (GR) has been standardized using various ingredients and tested in lab against Aedes aegypti. This formulation has been found to release toxin in a slow manner and 100% mortality was observed for a period of 6 weeks, at 15 mg/ 500 ml under laboratory conditions.

CONDUCTING TOXICOLOGICAL STUDIES ON THE FLYASH BASED MOSQUITOCIDAL FORMULATIONS FOR TESTING THEIR SAFETY TO MAMMALS AND NON-TARGET ORGANISMS

Safety to mammals

Biopesticidal formulations developed for mosquito control need to be safe to human beings and non-target organisms that are commonly found in association with mosquito larvae in aquatic habitats.

Hence safety of the formulations on mammalian systems was carried out at International Institute of Biotechnology and Toxicology (IIBAT), Padappai, Kancheepuram Dt., Tamil Nadu. The toxicological studies done for WDP, BR and GR formulation by IIBAT were as follows:

- Acute oral toxicity/pathogenicity in Wistar rats (certificate given by IIBAT with respect to WDP formulation given below)
- Acute dermal toxicity/pathogenicity in New Zealand white rabbits
- Primary skin irritation in New Zealand white rabbits

The studies showed that all the formulations were safe to mammals.

Safety to non-target organisms

The WDP formulation when tested at 10 times the dose used for obtaining 90% kill in mosquito larvae, was found to be safe to Crustaceans namely Ostrocods, Cyclops and Daphnia, mosquito predatory insects namely Notonectids, Diplonychus, mayfly nymphs, and water beetles, mosquito predatory fishes namely Gambusia and Poecilia, snails and tadpoles.

FIELD EVALUATION OF THE BIOPESTICIDAL FORMULATIONS

WDP formulation

Small-scale field trials in natural breeding sites

Preliminary evaluation of the Water Dispersible Powder (WDP) formulation carried out in polluted habitats of Pondicherry & Cuddalore, namely cesspits and drains to arrive at the optimum dosage of the WDP formulation which can be used for the large scale field trial at Neyveli. The cesspits were treated at the dosages of 0.5, 1.0 and 1.5 g/m^2 and 80-90% mortality was noticed within 24 hours of treatment among the larval stages and within 48 hours of treatment among the pupal stages of Culicine species. Among the dosages tested, 1 & 1.5g/m^2 gave the same level of control. Hence, 1.0 g/m^2 (10 kg /hectare) was recommended for large-scale field studies.

Recording larval and pupal density of mosquitoes in cesspits

Observation for presence of immature stages of mosquitoes in cesspits

Recording pH and temperature of polluted water in cesspits

Satellite picture of the area selected at Block 21, Neyveli LigniteCorporation Limited, for testing of WDP formulation

Large-scale field trials at Neyveli

Survey of mosquito breeding habitats

A detailed survey of the mosquito breeding habitats in 19 locations of Neyveli, Tamil Nadu was undertaken during 2007 to record the mosquito species prevalent in these areas, to analyze the water quality of the various mosquito breeding sites, presence of insecticide residues & insecticides used in various field sites were also collected at this time. This information helped us in deciding the bacterial agent to be used in the preparation of flyash based formulations and also the types of formulations which will be appropriate for use in these areas.

In 2010, all the habitats breeding C. quinquefasciatus, the vector of filariasis, in one block of Neyveli Township, Block 21 were enumerated and GIS locations were recorded. Cesspits, unlined drains and tar storage tanks were found to harbor this species. Preparation of the WDP's was done on a large scale for 4-5 rounds of testing in various mosquito breeding sites in this block. The WDP was applied at 10 kg/ hectare in these sites. In this way the cess pits and tar tanks received a total of 4 and 5 rounds of continuous spraying. However, the drains started overflowing due to unprecedent rains which occurred on the 7th day of initiation of the trial, l, and therefore only 2 rounds of spraying could be done in this habitat.

Observation of mosquito immatures prior to spraying of WDP

Dead mosquito larvae in cesspits sprayed with WDP

Cesspits

At 24 h post-treatment, the density of late instars was brought down by 95% further increased to 99.3% on day 3 and 86.6% on day 5, after which the population started buiding up (Fig. 2). The same trend of reduction and resurgence was observed with all the 4 rounds of spray. In case of pupal stages, by day 1 only 63.1% reduction was noticed which reached 100% by 3rd day. By day 5, only a slight increase in the pupal population was noticed. Reduction of >90% was maintained throughout the 4 rounds of spray.

Spraying of WDP in different mosquito breeding habitats

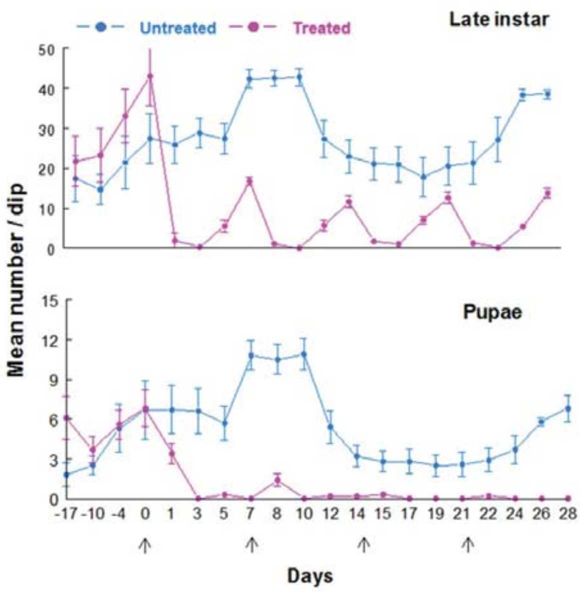


Fig. 2: Efficacy of fly ash based WDP on the immatures of Culex quinquefasciatus in cesspits

Drains

At 24 hr after treatment, the density of late instars was brought down by100% (Fig. 3). The population started resurging by 3rd day and by 7th day; the population reached half the pretreatment level. The percent reduction noticed during the II nd round of spray was lesser than that noticed during the Ist round. The results of the IIIrd round of spray could not be followed due to unprecedent rains during this time. With the pupal stages, by day 1 only 79.8% reduction was noticed. However, this reached 100% by 3rd day and there was no recruitment of pupae throughout the study period in the drains.

Tar storage tanks

Almost complete mortality of late (99%) instar stages was noticed by 24 hr of treatment (Fig. 4). The late instars were maintained at 0 level upto 5th day after which resurgence was noticed, resulting in IV instar stages by 14th day. The II and III round of spray were done at 7 days interval while the V round of spray was done at 9th day. With all the treatments, there was a 100% decline of late instar stages for upto 3 days, followed by a slow buildup of the population. Among the pupal stages, even though a slight decline

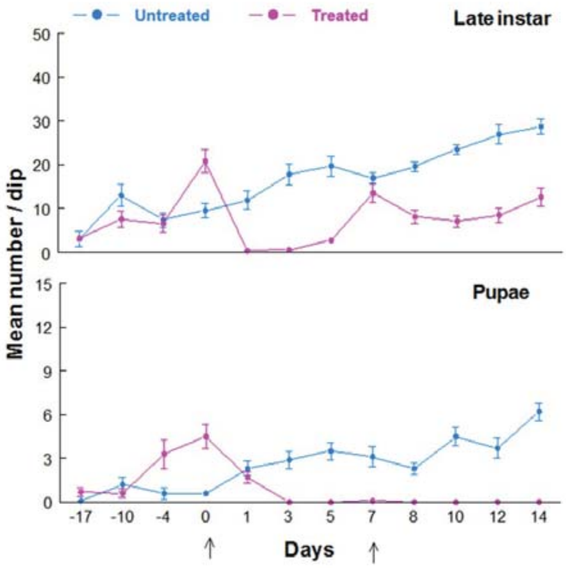


Fig. 3: Efficacy of fly ash based WDP on the immatures of Culex quinquefasciatus in drains

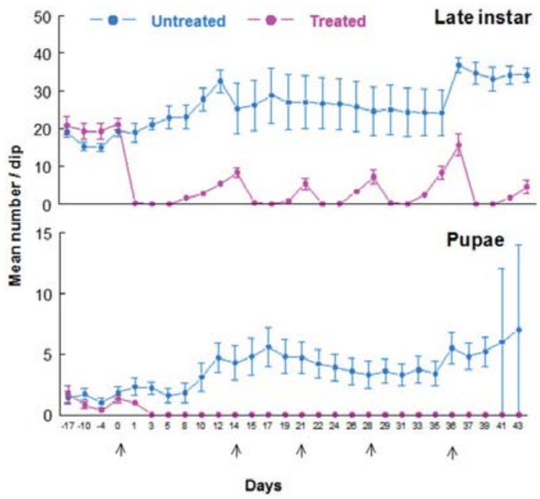


Fig. 4 : Efficacy of fly ash based WDP formulation against the immatures of Culex quinquefasciatus in tar storage tanks

Spraying of WDP in different mosquito breeding habitats

in the population was noticed by 1st day,100% control of pupal recruitment was observed throughout the 43 days observation of this habitat.

The reduction in the immature population was seen up to 5 days regardless of the habitat treated and by 7th day IV instar larval stages could be seen in the habitats, thereby necessitating the application of the WDP once a week to prevent pupal formation and adult emergence.

Slow Release Floating Formulation (BR)

The Slow-release floating briquette formulation was tested against Culex quinquefasciatus in less polluted water habitats, e.g., disused wells. Fifteen wells were treated with briquettes at doses of 1g, 2g and 3g/m-2 respectively, having 5 replicates for each dosage while five wells were left untreated. In the late instar stages, 54.8%, 87.1% and 96.1% reduction was noticed by 6th day which increased to 88.3%, 95.2% and 95.1% by 14th day (Fig. 5). Reduction of >80% was maintained for upto 19 days, after which the population started building up, although a reduction of 46 %, 73.4 % and 73.7% was noticed on the 28th day in the above treatments.

As seen with the late instar stages, pronounced reduction in the pupal stages was noticed only by 6th day. At 1g, 2g and 3g/m-2 respectively, the reduction was 64.6, 81.5 and 96.2%. This level of reduction was almost maintained for upto 19th day after which the pupal population started building up. As 2g and 3g/m^2 have yielded 90% reduction upto 14th day, 2g/ m^2 is recommended for large scale field trials.

Slow Release Granular Formulation (GR)

Slow-release Granular formulation was tested in simulated field conditions (circular cement tanks), against Aedes aegypti. The granules were applied at 0.5 g, 1 g, 1.5 g and 2 g/m2.

Complete mortality of the larval stages was noticed for up to 3 weeks in the tanks treated at 0.5 and 1g/m2 respectively (Fig. 6). By 5th week the mortality in these treatments came down to 57 and 65% respectively. In the tanks treated at 1.5 and 2g/m2 respectively, 100% mortality of the larvae was maintained for up to

Monitoring of mosquitoes after WDP treatment by VCRC & Health, TA, NLC officials and Demonstration of activities done at Block 20 by Director, VCRC to Administrative, Health and CARD, NLC officials

Evaluation of BR formulation on the immatures of Culicines in wells

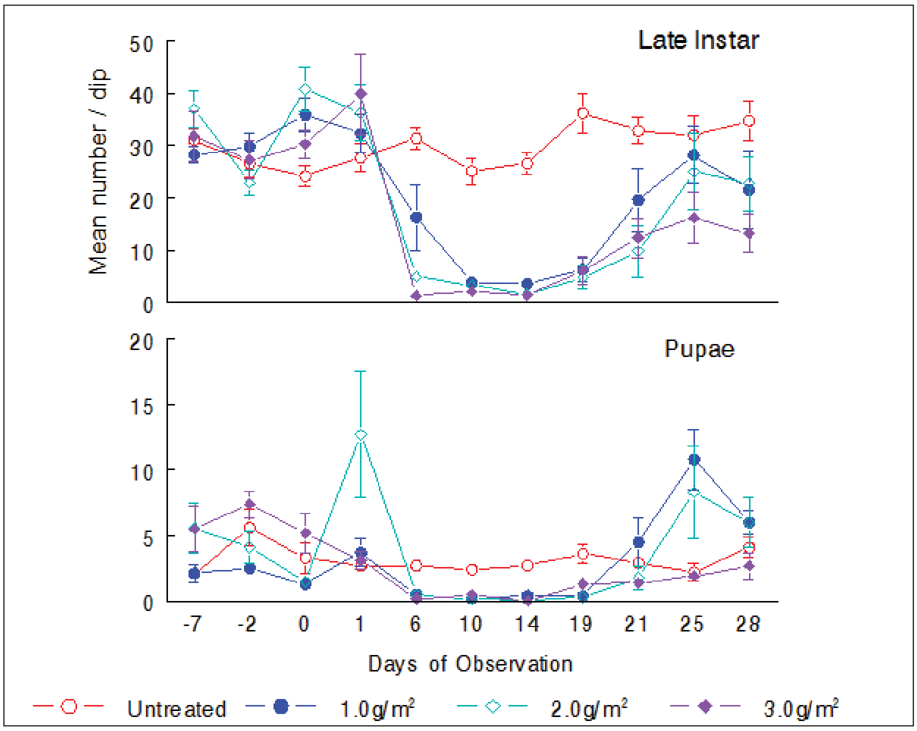


Fig. 5 : Efficacy of fly ash based slow-release floating formulation (BR) on the immatures of Culicines in wells

Evaluation of GR formulation against Aedes aegypti in cement tanks

5 weeks after which there was a slow decline in the release of the toxin, resulting in 40 and 58% mortality at the above doses by 7th week.

A single treatment of 1.5 and 2 g/m2 respectively was able to provide 100% mortality for upto 5 weeks. Hence, for large scale field trials in habitats like tree holes, discarded tyres, water storage containers etc. 1.5g/m2 is recommended.

Dissemination of the knowledge on the use of Flyash based biopesticides to public

Safety week 2010 was organized by Neyveli Lignite Corporation at Neyveli. The fly ash based pesticides developed in this project viz., Water Dispersible Powder, Slow- release briquettes and Slow-release Granular formulations were exhibited and details regarding its usage was demonstrated to public. The vector borne diseases transmitted by mosquitoes like filariasis, dengue and malaria and their breeding habitats were exhibited by way of posters, display boards, models, etc. to create awareness about the surrounding places to the public and the ways to protect & treat the breeding sites with the help of biopesticides developed in this project.

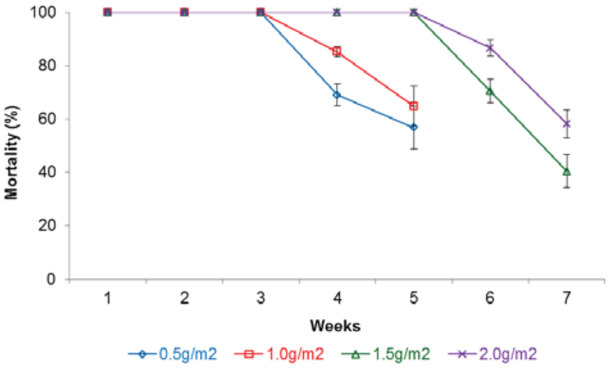


Fig 6: Efficacy of fly ash based slow-release granular formulation (GR) on the immature stages of Aedes aegypti in simulated conditions (cement tanks)

In the project proposal submitted to CMPDIL during 2006, five activities were listed by VCRC, Puducherry & all these have been completed successfully. The performance of the fly ash based mosquito pesticide was demonstrated at Neyveli to the officials of Administrative Section, Neyveli Lignite Corporation, Health Department and Centre for Applied Research and Development, Neyveli.

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Characterisation of rock and explosive parameters for optimal explosive energy utilisation in opencast mines

BACKGROUND AND OBJECTIVE

In order to achieve blast optimisation for a given geo-mining condition, the knowledge of target rock and the explosives characteristics are very important. The complexity of the modern explosives system requires that its various technical aspects be systematically investigated to parameterise their effects on the overall blasting performance. Without technical information on the basic energy release characteristics of the explosives, it is not possible to design blasts with a large degree of certainty in the outcome. Presently, the industrial explosives and accessories used by Coal India Limited has touched a whopping figure of Rs.1500 Crores. The demand of commercial explosives is scaling new heights in the Indian mining industry. In the present scenario of burgeoning demand of coal, a synergistic approach integrating the knowledge of rock-explosives interactions will play a pivotal role for achieving optimal explosives energy utilisation with enhanced opencast productivity.

Knowledge of rock mass characteristics provides suitable guidelines to blast designers to correlate rock mass characteristics with certain explosives properties. Since, there is no elaborate guideline available to choose suitable explosives for particular rock characteristics, a thorough study and research was felt necessary for formulation of such guidelines. The objectives of the study are enumerated below:

1. Effect of detonator timings and delay sequences on blast vibration.
2. Effect of initiation mode on the release of explosives energy.
3. Energy release characteristics of explosives and their effect on blast results.
4. Effect of sympathetic pressure on energy release and VOD in the receptor explosives.
5. To establish the relationship between rock geotechnical properties and the explosives properties.

WORK DONE

Under this coal S&T project, five experimental locales were selected in consultation with respective subsidiaries of Coal India Limited and Neyveli Lignite Corporation. The extensive field experimentation was carried out at Umrer project of Western Coalfields Limited, Sonepur Bazari project of Eastern Coalfields Limited, Jayant project of Northern Coalfields Limited, Kusmunda project of South Eastern Coalfields Limited and Mine-I & II of Neyveli Lignite Corporation Limited.

In order to understand the role of concentrated or distributed cast boosters in the blast hole loading configuration on energy release and release rate characteristics, the field experiments were carried out at Kusmunda project, Sonepur Bazari project, Jayant project and Umrer project of Coal India Limited. In order to understand the effect of density gradient on energy release characteristics, static pressure gauges were lowered inside the blast holes at different heights before charging the holes with bulk explosives column at Jayant project and the pressure head was measured. Scattering in initiation system is presently, a common phenomenon affecting the blast performance significantly.

In order to understand the effect of detonator timing and delay sequences on blast vibration, the field experimentation was carried out at Jayant project, Kusmunda project, Sonepur Bazari project, Umrer project of Coal India Limited and Mine-II of Neyveli Lignite Corporation. In order to characterise the rock mass multi channel analysis of surface waves has been carried out at Umrer OCP, WCL. The dynamic properties of rock mass was determined by Split Hopkinson Bar Technique (SHPB) for Indian sandstone, shale and coal samples for first time for Indian rock and coal samples.

Research work carried out by CMPDI , Ranchi in association with CIMFR, Dhanbad.

Effect of detonator timings and delay sequences on blast vibration

It is technically desirable to use precise detonators with accurate delay timings to achieve desired blast results in terms of improved fragmentation, lower level of vibration and air overpressure. Precise surface and down-the-hole delay timing affects explosives energy utilisation and precise timing would help in achieving desired blast results. Scattering in initiation systems is presently a common phenomenon in Indian manufacturers which affects the blast performance significantly. Delay timing is primarily, provided using delay element made up of pyrotechnic composition placed between the ignition system and the primer charge. Initiation system made with pyrotechnic delay compositions has inherent scattering in their delay timings and affects the blast vibration significantly.

In order to understand the effect of detonator timing and delay sequences on blast vibration, the field experimentation was carried out at Jayant project, Kusmunda project, Sonepur Bazari project, Umrer project and Mine-II of NLC.

Effect of initiation mode on the release of explosives energy

Cast Boosters are used as priming systems to initiate or activate the detonation of the explosives column in the blast hole so that there should be sufficient run-off of the velocity of detonation(VOD) in the blast hole. In order to understand the role of concentrated or distributed cast boosters in the blast hole loading configuration on energy release and release rate characteristics, field experiments were carried out at Kusmunda project, Sonepur Bazari project, Jayant project and Umrer project. In the concentrated boosters loading, the required boosters were placed at one location at sub-grade level as shown in Figure 1 (a). In the practice of distributed boosters, the boosters were placed at more than one location as shown in Figure 1 (b). The concentrated booster in a blast hole always delivered significantly higher in-the-hole VOD of explosives as compared to distributed booster charging configuration.

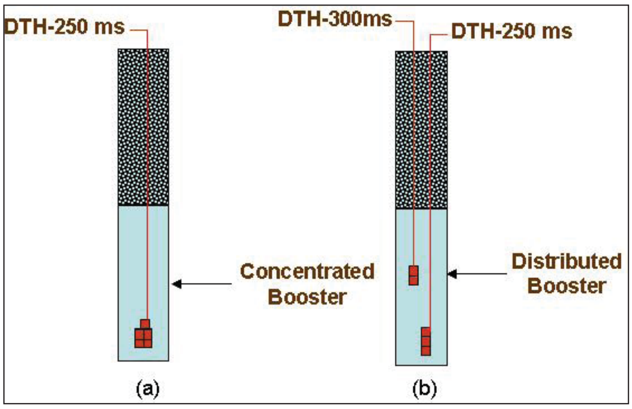

Figure 1: Cast booster distribution inside the blast hole

Energy release characteristics of explosives and their effect on blast results

The in-the-hole VOD of an industrial explosives is dependent on explosives charge diameter and borehole diameter. The diameter vs. VOD curve provides a fundamental guide to the rate of energy conversion and energy release within the detonation head on the interaction of explosives with the confining medium.

The in-the-hole VOD of explosives was measured by deploying the Multi-channel Data acquisition system named DataTrap-II manufactured by M/s MREL, Canada. It essentially measured change in the resistance of the VOD probe cable suspended in the charged hole during detonation. As the detonation wave travels along the explosives column, it consumes the probe which decreases the electrical resistance in linear manner and was measured by DataTrap-II.

The measured in-the-hole VOD of explosives at Umrer project, Kusmunda project and Mine I & II of NLC for different borehole diameter but for identical explosives composition of same particle size, density, viscosity and loaded into bore hole with same degree of confinement was analysed critically.

Role of density gradient inside a borehole

The density gradient in a charged borehole plays a pivotal role in explosives performance as energy and energy release characteristics are primarily dependent on density. When explosives is loaded in a borehole, a positive density gradient exists inside the charged borehole. The detonation pressure exerted by an explosives column on the borehole is directly proportional to density of explosives column in the borehole. If the density of the explosives column is very low, they become sensitive to the detonating cord which begins to initiate the explosives column before the detonation of the primer cartridge. On the other hand, if the density is kept very high, they become insensitive and not detonable. The limit density is called “Death Density’. When the explosives column reaches the death density, it loses its sensitivity and it no longer behaves like explosives or a detonable source.

In order to understand the role of density gradient, digital static pressure gauges having digital read out units were used at Jayant project. The static pressure gauges were lowered inside the blast holes at different heights before charging the holes with bulk explosives column. When the explosives column was charged, the pressure gauge read out unit displayed the pressure head at different depth in blast hole.

Role of viscosity on explosives energy

Viscosity is the internal resistance of the explosives material to flow and is the measure of flowing characteristics of the explosives matrix. The viscosity is primarily, flowing characteristics of the explosives product. Any explosives material should be pumpable so that it can be poured into the borehole very easily. During field experimentation, explosives sample was collected in beaker without disturbing the basic emulsion matrix and viscosity of premix/ basic matrix was determined with the help of Brook field Viscometer. By selecting the suitable spindle, the viscosity was determined in field at ambient temperature. The viscosity of the emulsion matrix varied from 40,000 cps to 1,30,000 cps for the explosives products available during experimentation. The in-the-hole VOD of explosives and run up length of explosives column for explosives products having different viscosity was determined.

Effect of sympathetic pressure on energy release and VOD in the receptor explosives

Decking is a technique that enables the blaster to divide the explosives in a blast hole into two or more locations. Decking is used primarily for the following purposes:

- to give confinement of explosion gases where a soft seam or void is encountered
- to give a better energy utilisation
- to cope up with vibration constraints and reduce the explosives weight per delay

The reason for minimal deck thickness is to ensure that sympathetic detonation and/or cross propagation between charges does not occur. The minimal deck thickness will also ensure that there is no pressure desensitisation of explosives in upper decks due to detonation of explosives column of lower decks or adjacent boreholes arising out of pressurisation of nearby detonated boreholes. There is significant effect of pressure desensitisation on energy release in the receptor explosives column resulting into change in the measured in-the-hole VOD in receptor explosives column.

The pressure desensitisation in receptor explosive column may be classified as follows:

- Sympathetically initiate the detonator (i.e. instantaneous detonation)
- Sympathetic desensitisation of upper decks
- Sympathetic detonation of upper deck
- Pressurise the detonator in the booster and thereby increase its firing time
- The pressurisation may result into density increase or fall of sensitivity of explosives column in adjacent boreholes

In order to understand the role of decking on pressure desensitisation in a borehole deck thickness was varied from 4D to 12D between the upper and bottom explosives charge columns where D shows the borehole diameter (mm). The in-the-hole VOD of the explosives column in top deck explosives column and bottom deck explosives column was measured by Datatrap-II with the help of VOD probe cable of high resistivity i.e. 10.8 Ω /m.

When the deck thickness was not optimum, detonation of bottom explosives column affected the top explosives column as recorded by DataTrap-II i.e. top deck got detonated prior to the designed time delay between top and bottom explosives columns due to pressurisation. When the deck thickness was optimum, the top and bottom decks were monitored as independent events. The in-the-hole VOD of explosives plot vividly showed the actual time delay between the decks along with the in-the-hole VOD of explosives values of top and bottom explosives columns. Figure 2 shows the typical in-the-hole VOD of explosives plots recorded in both the explosives columns in the

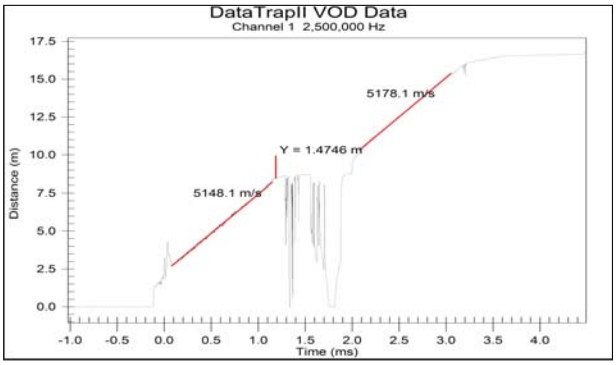

Figure 2: In-the-hole VOD of explosives plot recorded at Umrer project

blast hole (bottom charge and top charge) at Umrer project,WCL.

Relationship between rock geotechnical properties and explosives properties

Rock breakage by explosives involves the action of an explosives and the response of the surrounding rock mass within the realms of energy, time and mass. The rock properties are uncontrollable variables comprising of many parameters viz. geology, strength, structural discontinuities, state of weathering of rock mass, etc. It is very difficult to quantify a blast as good or bad on any one single parameter but there are number of parameters which characterises the blast results to be defined a good blast or a bad blast. A good blast may be defined which yields the following outputs:

- Optimum fragmentation
- Optimal muck pile displacement
- Optimal muck pile profile with ease of digging
- Lower level of ground vibration generation
- Lower level of air overpressure generation
- Non ejection of flyrock
- Practically no back or over break
- No misfires, etc

In order to achieve the above objectives, selection of suitable explosives is very pertinent. The strength of the rock is an important criterion for selecting the explosives for achieving desired / optimum fragmentation in consonance with the loading equipment in use. In order to meet the optimum fragmentation, the explosives characteristics plays a pivotal role with due regard to environmental nuisances i.e. vibration, flyrock and air over pressure. The determination of these parameters by direct or laboratory methods is very costly, time consuming and difficult, as the samples tested do not usually include discontinuities and the lithological changes of the rock mass from where they were taken. Geophysical technique such as seismic survey method was used at Umrer project to characterise the rock mass using Multi Channel Analysis of Surface Waves (MASW) system. The design of any blast is strongly influenced by the rock mass characteristics. The rock mass shows spatial variations and need to be monitored to allow corresponding changes to blast design to be incorporated. Seismic survey by MASW can characterise the overburden strata for improving blasting efficiency. The MASW system with its various components is shown in Figure 3.

Data acquisition system

The seismic data collected using the MASW technique for surface wave analysis are generally

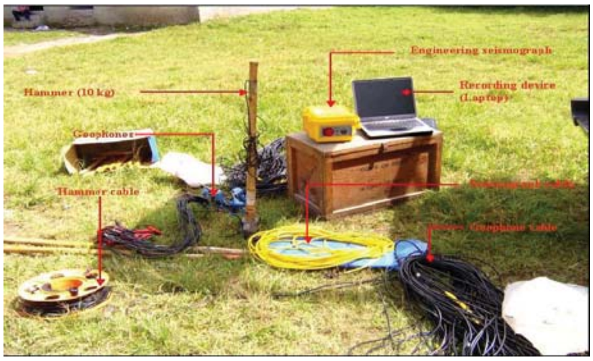

Figure 3: Various components of the MASW system

broadband (i.e. 4 Hz to 64 Hz), with offsets designed based on target dimensions and depths. Standard Critical Meet Points (CMP) roll-along techniques are used in conjunction with 24-channel recording systems. The data acquisition methodology is shown in Figure 4. The arrangements of geophones and seismic source for a survey are shown in Figure 5. The preliminary wave trains trend obtained by MASW system is shown in Figure 6.

Velocity profiles for rock mass characterisation

The seismic raw data was generated in the field and was stored in a lap-top computer connected to Geode while surveying. The raw data collected in the field was

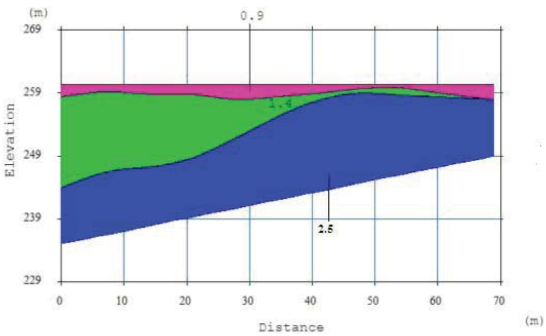

Figure 7: V_p profile of major cluster of layers of overburden bench at Umrer project.

analysed by software known as 'Seismic Imager'. The processed data generated V_p profile of rock strata up to a depth of 25 m from the surface. The overburden strata were divided into 10 layers initially by MASW system and the velocity profiles was varying from 0.9 km/s to 2.5 km/s from top to bottom sandstone layers. The typical P-wave velocity profiles of the overburden bench at Umrer project was smooth layered for generalisation of rock mass characterisation into three

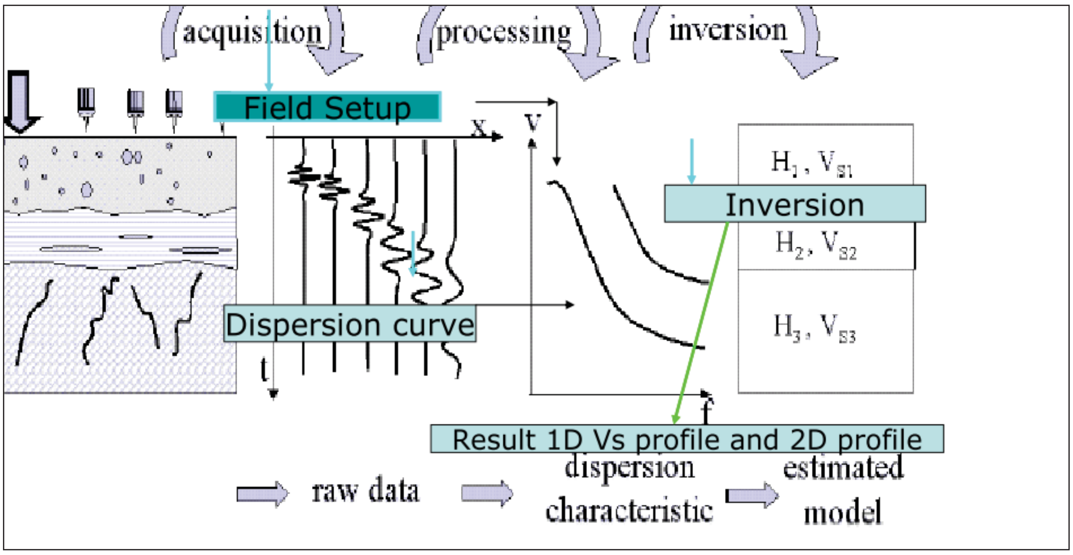

Figure 4: Data acquisition methodology.

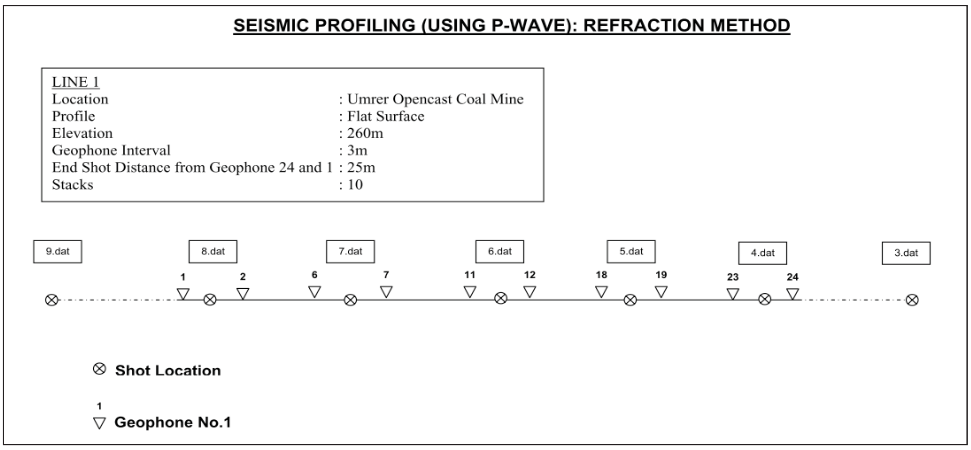

Figure 5: Layout of position of geophones and shot location (seismic source).

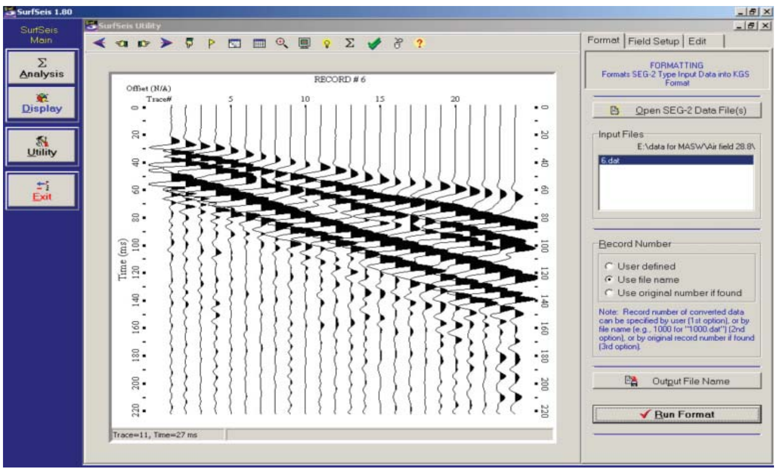

Figure 6: Preliminary wave trains trend obtained by MASW system at Umrer project.

main layers. The V_p profiles of soft rock, medium hard and hard rocks are shown in Figure 7.

It is evident from Figure 7 that the P -wave velocity of top layer is 0.9 km/s whereas the P -wave velocity of middle layer is 1.4 km/s and bottom layer is 2.5 km/s respectively. Thus, it can be concluded that overburden rock mass can be classified into three main layers as shown in Figure 7 for characterisation of rock mass.

Methodology for explosive selection for given rock mass

The acoustic impedence, Z for any material is defined as:

$$Z = \rho \times V_p$$

Where,

Z = acoustic impedence,

P = density of material,

V_p = Sonic velocity of material

The rock impedence (Z_1) may be approximated by product of rock propagation velocity and rock density whereas explosives impedence (Z_2) may be approximated by the product of detonation velocity of explosives and its density. In order to maximise the transfer of explosives energy to the rock mass, the impedence of the explosives should be close to that of the rock mass. When the impedence of the explosives is close to that of the rock mass, explosives energy is better transmitted to the target rock. Under such condition the maximum pressure transmitted to the rock is nearly equivalent to the detonation pressure generated inside the pressurised borehole. When the impedence of the rock is less than the impedence of the explosives, then the major part of the explosives energy transmitted to rock mass will be reflected back as tensile wave and will be responsible for breakage of the rock.

The minimum / limiting condition can be expressed as:

$$Z_1 = Z_2$$

The Rock_Impedence matrix and Explosives_ Impedence matrix is calculated using the following formula in MATLAB R 2007 b.

$$[Rock\_\text{Im}\,pdence] = [Rock_{Sonic\_velocity}] \times [Rock_{density}]$$

$$[Explosive\_\text{Im}\,pdence] = [Explosive_{Inhole\_VOD}] \times [Rock_{density}]$$

The desired minimum VOD of explosives has been computed by matching or equalising the rock impedence and explosives impedence matrix. Figure 8 shows the minimum in-the-hole VOD of explosives required by each layer for yielding optimum fragmentation.

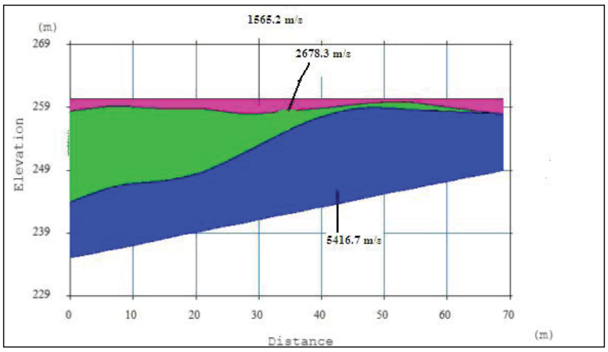

Figure 8: VOD of explosives profile of major cluster of layers of overburden bench at Umrer project.

It is evident form the graph that in-the-hole VOD of explosives for the top layer, middle layer and bottom layer is 1565.2, 2678.3 & 5416.7 m/s respectively.

Determination of Dynamic Tensile Strength by Split Hopkinson Bar

Technique (SHPB)

Accurate measurements of dynamic fracture parameters are pre-requisite for understanding fracture mechanism and also useful for rock fragmentation in blast engineering applications. The Split Hopkinson Bar Technique (SHPB) was applied to investigate fracture mechanism of rock and coal to determine the dynamic properties of rock at different loading rates.

Figure 9: Rock samples prepared for SHPB test.

Determination of dynamic properties by SHPB

The dynamic properties of rock samples have been ascertained by Split Hopkinson Bar Technique (Brazilian) by making rock and coal specimen samples with NX size diameter and maintaining a length and diameter ratio as 0.5. In this report, a modified SHPB technique and Brazilian test method was used to test the dynamic tensile strength of coal, shale and sandstone samples. Under this test different kinds of loading rate were tested to investigate the relationship between

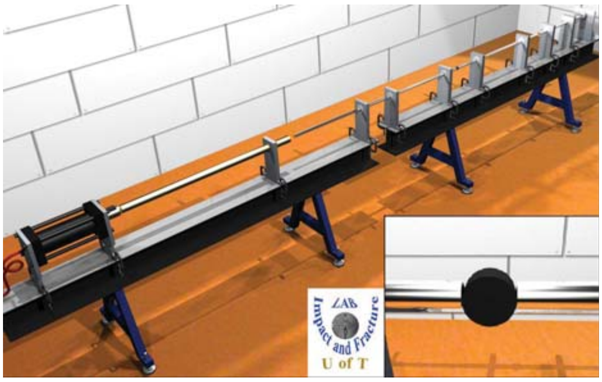

Figure 10: SHPB testing facility at University of Toronto, Canada for determination of dynamic properties of rock samples

tensile strength & dynamic loading rate and dynamic tensile strength was compared with static test results. The numbers of samples prepared were 100 and were sent to Lassonde Institute of Geosciences, University of Toronto, Canada for determination of dynamic tensile strength of rock samples as shown in Figure 9. The SHPB testing facility is shown in Figure 10.

CONCLUSIONS

1) It was observed that concentrated booster loading in blast hole explosive loading configuration has higher energy release and release rate as compared to distributed booster loading in blast hole explosive loading configuration. The percentage increase in in-the-hole VOD of explosives due to concentrated booster configuration was up to 13.4 percent in comparison to distributed booster configuration. The explosives column under 10 m can be safely initiated by single point priming i.e. concentrated booster priming instead of multiple point priming increasing time and cost advantages to the operating mines.

2) There exists positive and significant relationship between in-the-hole velocity of detonation (VOD) of explosives and borehole diameter. The relationship between in-the-hole VOD of explosives and drill diameter may be approximated for Indian geo-mining scenario. The in-the-hole VOD of explosives reaches fairly constant value after reaching a limiting/threshold diameter of 311 mm. The minimum diameter for steady state detonation velocity for large diameter non-permitted and bulk explosives product may be approximated as 83 mm.

3) The study revealed that when the explosives density reaches the dead pressed density i.e. 1.25-1.30 g/cc, it no longer behaves like an explosives as the detonation characteristics changes to deflagration characteristics. The viscosity of an emulsion matrix for high energy release should be between 40000 cps to 80000 cps.

4) In order to understand the role of decking on pressure desensitisation in a borehole, deck thickness was varied from 4D to 12D between the upper and bottom explosives charge columns where D represents the borehole diameter (mm). The study revealed that the optimal deck thickness between decked explosives columns to obviate any chance of occurrences of pressure desensitisation inside a borehole may be approximated to 10D. The cast booster should be positioned at a distance of 4D from the floor of the blast hole. The observed actual time delay between decks in case of affected/punctured deck shows that pressurised wave front originated from bottom deck travelled with the sonic velocity to affect the stemming and initiate detonation of top explosives column before the designed delay. Under such circumstances the maximum explosives charge per delay of designed blast event and actual blast event will vary significantly and the vibration characteristics will get affected. The pressurisation may even result into change in explosives detonation characteristics of top explosives column arising out of pressurisation of bottom explosives column. When the deck thickness is optimum then both the top and bottom explosives column detonates as independent event and there is not much change in the measured in-the-hole VOD of explosives in top and bottom explosives column.

5) The study revealed that the scattering in delay detonators affects the explosives charge weight per delay for any blast design. There is significant impact of detonator timing and delay sequences on blast vibration characteristics and will influence the blast performance and energy utilisation in rock fragmentation. The relationship between change in maximum explosives weight per delay and scattering percentage for any blast design is random in nature. It is technically difficult to forecast or predict the change in vibration characteristics for any blast design due to change in scattering percentage. Use of electronic detonators will help in controlling the scattering in delay detonators and will have technical advantage over NONEL to minimize the blast induced vibration impact.

6) In order to characterise the rock mass multi channel analysis of surface waves has been used. An attempt has been made to classify the in-situ rock mass into three categories as soft formation, medium hard formation and hard formation. The P-wave velocity

range for soft formation, medium hard formation and hard formation will be 500-1500, 1500-2200 and more than 2200 m/s respectively and is shown in following table.

Type of rock mass formation	P-wave velocity range (m/s)
Soft formation	500 - 1500
Medium hard formation	1500-2200
Hard formation	> 2200

7) By matching the explosives impedence with rock mass impedence, the in-the-hole VOD of the explosives for soft, medium hard and hard formation has been computed for the first time for Indian geo-mining scenario. The in-the-hole VOD of explosives for soft formation, medium hard formation and hard formation will be 3000±150, 4000±200 and 5000±250 m/s respectively and is shown in following table.

Type of rock mass formation	In-the-hole VOD of explosives range (m/s)
Soft formation	3000±150
Medium hard formation	4000±200
Hard formation	5000±250

The soft formation in upper benches may be blasted using low strength emulsion/slurry explosives product having in-the-hole VOD of explosives in the range of 3000±150 or by pouring mechanically mixed ANFO made up of low density thermally stabilised and water resistant ammonium nitrate prills. Use of low strength explosives product in softer formation will have techno-economic advantages. The use of low VOD explosives product in softer formation will reduce the environmental nuisances (viz. vibration, air overpressure and flyrock problems) and give cost advantages to the mines. Under such scenario, the blast performance will be enhanced with improved energy utilisation. Use of high strength explosives products for medium hard and hard formation will enhance blast performance by proper explosives energy utilisation in rock fragmentation.

8) The study also revealed that dynamic tensile strength of rock and coal is much higher as compared to the static tensile strength of rock and coal respectively. The dynamic tensile strength of Indian coal samples was found to be 1.5 times higher than the static tensile strength with increasing dynamic load whereas, the dynamic tensile strength of Indian sandstone was found to be 3 times higher than static tensile strength with increasing dynamic load.

A technical guideline formulated and proposed will help the opencast mine management, practising blasting engineers, researchers and working contractors to select suitable explosives for any rock mass by matching the rock impedance with explosive impedance for achieving optimal explosives energy utilisation in rock fragmentation.

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Effect of delay timing, total charge and direction of initiation on blast induced ground vibration

ABSTRACT

A study was conducted at four open-pit mines to investigate the effect of delay timing, total amount of explosives detonated in blast round and direction of initiation on the magnitude of blast induced ground vibrations. Extended seismic arrays were used to identify the vibration characteristics within 25 m of the blasts and also as modified by the propagating media at distances up to 6500 m. In total, 215 blasts were performed and 1512 vibration data were recorded in order to achieve the objectives of the study. The depths of blastholes varied from 5.5 to 42 m. The explosive charge weight per delay fired in a blast round varied widely from 33 to 24,800 kg. Similarly, the total charge weight in a blasting round also varied from 100 to 1,98,400 kg. The existing practice of 8 ms delay interval for charge separation of two detonations was found inadequate. The 8-ms delay criterion is not holding good at low frequency site because the wavelengths are simply too long to constructively cancel out the waves. The hole depths are longer and, sometimes, require 10-15 ms to fully detonate the whole column of the explosives. The delay intervals between the rows for dragline benches should be 10-18 ms/m of effective burden and for shovel benches the optimum delay interval should be 8-13 ms/m of effective burden. Hence, based on the investigation it has been recommended that the minimum delay interval of 17 ms between the holes in a row should be adopted.

Blasts at shovel benches with higher amount of explosives generated higher level of vibrations at near field compared to those which were detonated at the same bench face with lower amount of explosives, though the blast design and explosives parameters were kept identical. The explosives detonated in a delay in both sets of blasts were also similar in weight. The similar trends were observed at dragline benches. In some instances, the vibrations recorded were more than 70 % higher at various scaled distances when the total charge was about 1.5 times higher. The study confirmed that the impact of total charge was up to 8-10 m/kg$^{1/2}$ scaled distances in shovel benches, whereas for dragline benches it was up to 15 m/kg$^{1/2}$ scaled distances. It is concluded that bottom initiation system generates less vibration in comparison to top initiation system. The reductions in vibrations were observed up to 36.2 % by changing the mode of initiation of blastholes from top initiation to bottom initiation. The fragmentations got improved and the efficiency of the operating heavy machineries was also enhanced in handling the blasted materials where bottom initiations were practised. Noise generations were also comparatively low with bottom initiation system.

INTRODUCTION

A great improvement in blasting technology occurred with the application of delayed blasting in 1950's. The use of delay blasting is now practised for not only reducing vibration, but also obtaining better fragmentation, throw and muck pile profile. Presently, 8 ms criterion is a well known and applied rule for defining "separate" charges for predicting blast vibration amplitudes. However, the genesis of this criterion is not well understood.

In most of blasting, attempts are made to control vibration levels by restricting the amount of explosives detonated at any instant of time (delay interval less than 8 ms). The blast design must also ensure that enough explosive is detonated within a given volume of rock to sufficiently fragment it for removal. When blasting location is close to structures, the design must reduce the amount of explosive detonated at any one delay while holding the amount detonated per volume of rock constant. The total amount of explosives in blast round should also be in compliance control of vibration with stipulated limit.

Research work carried out by CIMFR, Dhanbad.

The place of primed booster is important in ascertaining maximum strain at a particular place. How are the vibrations generated as a function of delay intervals, both nominal (designed) and actual? How can the frequency and amplitude of vibration be influenced by initiation delay control? How do these vibrations propagate and change character as function of distance and geometric relationships between a given direction and orientation? The answer to these questions gained through studies of this type will provide blasters with the tools to modify or adjust blast design for desired impacts along with information on the productivity and practicality of such changes.

With these in view a study was taken-up to investigate the impact of delay timing, total charge and direction of initiation on blast induced ground vibration. Under this programme, four opencast mines were selected. The experimental sites were Jayant and Nigahi projects of Northern Coalfields Limited, Sonepur Bazari project of Eastern Coalfields Limited and Kusmunda project of South Eastern Coalfields Limited.

PROPAGATION & PREDICTION OF BLAST VIBRATION

Anyone who detonates a blast or who is nearby a blasting site realises that ground vibration and airblast are simply parts of the process. Many investigators have studied ground vibrations generated from blasting and they have developed different relationships to predict the vibrations at distances from the source. The concept of scaled distance is generally used for blast vibration prediction. Scaled distance is defined as the actual distance (R) of the vibration measuring point from blasting face divided by some power of the maximum weight of the explosive per delay (Q_{max}). Different researchers have suggested different values of exponent.

Currently, the most widely accepted norm of single measurement of ground vibrations which has the potential for damaging structures, is the peak particle velocity (PPV). It is defined as the highest speed at which an individual earth particle moves or vibrates as the waves pass a particular site. Many predictive equations have been proposed to compute explosive weight per delay to attain the specific level of peak particle velocity. Singh (2002) concluded that USBM predictor equation is better than any other predictor models suggested by different investigators in Indian context. The equation considers cylindrical explosive geometry for long cylindrical charges, and suggests that all linear dimensions should be scaled with the square root of the explosive's weight in a delay. The equation is as follows:

$$v = K \cdot \left(\frac{R}{\sqrt{Q_{max}}} \right)^{-b}$$

where,

v = peak particle velocity (mm/s)

K, b = site constants to be determined by regression analysis

R = distance of the measuring transducer from the blasting face (m)

Q_{max} = maximum weight of explosive per delay (kg)

Factors affecting ground vibration

The factors influencing ground vibrations caused by blasting are listed below:

1. local geology and rock characteristics
2. distance between the explosion site and structure
3. basic design parameters i.e. bench height, burden, spacing, hole depth, subgrade drilling, charge length, stemming length, etc.
4. blast face condition
5. air decking/decoupling
6. type of explosives
7. quantity of explosives in a delay
8. total quantity of explosive in a blasting round
9. delay timing
10. direction of initiation

Out of these, the first two are uncontrollable, rest being controllable. Many of these variables are interrelated. Several researchers have addressed the controllable factors based on their rock formations, available explosives and blasting accessories. The three important variables i.e. delay timing, total explosives detonated in a blasting round and direction of initiation have been addressed in detail in this report.

Effect of delay timing on blast vibration

Delay interval is the difference in firing timings between two groups of holes. In rock blasting the effective delay interval is important from vibration and fragmentation points of view. The prediction of vibration effects largely depended on delay accuracy. Not only is the accuracy of the delay is important, but the choice of delay interval is equally important (Wheeler, 1997).

The idea of delays is to create phase shifts, sufficient for destructive interference between vibrations from adjacent delays, not to separate the wavelets in time. 8 ms criterion is a well known and applied rule for defining "separate" charges for predicting vibration. Though the criterion of 8 ms delay interval for separation of overlapping of waves is widely used, its efficiency has been questioned by many researchers. Wiss and Linehan (1978) suggested a nominal time between successive delays interval of 17 ms to eliminate the summing effect of the vibration. Oriard and Emmert (1980) tested different delay interval between holes in a row shots. The shots initiating 5 and 9 ms delays showed little difference in vibration levels. Shot using 17 ms delays and more showed lower vibration levels than the shorter delays. Anderson (1989) stated that "the 8 ms criterion, have we delayed too long in questioning it?" and suggested that 8 ms delay interval is not appropriate to separate the overlapping of waves. Siskind et al., (1989) concluded that based on charge weight per 8 ms delay, decking appeared to be ineffective in reducing vibration amplitude and actually produced higher vibration at a given scaled distance. Chiapetta (1998) recommended that without using proper delay intervals in blasting operation, good looseness for subsequent loading and hauling operations cannot be obtained.

Effect of total charge weight in a blast round on vibration

One of the important blast design parameters that affect amplitude of vibration is maximum amount of explosive detonated in a blast round. It is explosive weight per delay usually presented as "kg per delay". Siskind (1994) on personal communication confirmed that total charge weight detonated in a round has significant effect on vibration amplitudes. Singh and Vogt (1998) investigated and reported that there is significant effect of total explosive fired in a blasting round on magnitude of vibrations at closer distances from the blast source.

Effect of direction of initiation on blast vibration

The position along the hole at which the priming occurs changes the explosive performance and affects the resultant amplitude of vibration at the structure concern. Kopp and Siskind (1986) reported that the orientation of blast and direction of initiation has a noticeable effect on the magnitude of vibration. Wiss and Linehan (1978) reported that the variation of the seismic and overpressure amplitudes with the direction of blast is probably attributable to a phasing addition of the respective energy pulses. Phasing addition is a function of the effective delay interval relative to an instrument position. Milles (1994) used the down the hole initiation with short delay detonators which improved fragmentation whilst at the same time minimises ground vibrations. Singh and Vogt (1998) found that the PPV measured in the flank opposite to the initiation was almost double the PPV measured in the flank at the initiation end.

EXPERIMENTAL SITES AND BLASTS DETAIL

Location and geology of the experimental sites

Experimental sites were Sonepur Bazari project, Jayant project, Nigahi project and Kusmunda project. The rock formations of all the four projects varied widely.

Sonepur Bazari project

Sonepur Bazari project is located in the eastern part of Raniganj coalfields. It is well connected by rail and roads. In the project area, four coal seams viz. R-IV, R-V, R-VI and R-VII are mainly exposed. Presently, seams R-V and R-VI are being extracted by opencast method of mining.

Jayant project

Jayant project is located in the Singrauli coalfields. The project is well connected by rail and roads. It is situated on a high plateau ranging from 300-500 m above mean sea level. The rocks are of Gondwana formation having coal bearings of Barakars within it. Three coal seams viz. Purewa top, Purewa bottom and Turra are being mined out. The thicknesses of these seams are 5-9, 9-12 and 13-19 m respectively. The parting thickness between Purewa bottom and Purewa top seams is 17-32 m whereas it is 52-59 m between Turra and Purewa bottom seams.

Nigahi project

Nigahi project is also situated in Singrauli coalfield. It stands out as a hilly plateau with elevations of about 400–450 m above mean sea level. The rocks are of lower Gondwana formation. There are three coal seams namely Turra, Purewa (bottom) and Purewa (top), the thicknesses of which are 13-17, 11-12 and 7-9 m respectively.

Kusmunda project

Kusmunda project is located on the western bank of Hasdeo river in the central part of Korba coalfields in the district of Korba in Chhattisgarh state. It is having a flat terrain with minor undulations. The area of the project is covered generally by soil/sub-soil. The upper Kusmunda seam incrops below a cover of 6-31 m in an elliptical fashion and overlies lower Kusmunda seam after sandstone parting of 65 to 75 m. The area constitutes a doubly planging anticlinal trend. The lower Kusmunda seam is composite in western part of the property but the same splits into two sections viz. lower Kusmunda (top split) and lower Kusmunda (bottom splits) eastwards. One oblique set of faults strike across the anticlinal axis, while the other set of faults appear to strike parallel to the anticlinal axis. The the overall grade of coal is F.

Instrumentation and measurement techniques

The ground vibrations produced by blasting were monitored by deploying 8-12 seismographs simultaneously at various locations. These were namely BlastMate III and MiniMate plus (made in Canada by M/s Instantel Inc.), SSU 3000 LC (made in USA by M/s Geosonics Inc.) and Mini-Seis (made in USA by M/s White Industrial Seismology).

EXPERIMENTAL DETAILS

Studies were carried out with the existing blast designs practised in the mines as well as with modified blast designs to achieve the objectives of the S&T project. Signature blasts were also conducted to investigate the nature of wave transmitting medium and delay intervals. Brief details of field investigations are as follows.

Sonepur Bazari project

The field investigations were conducted at shovel and dragline benches. The drill diameters were 260-270 mm for shovel benches and 270 mm for dragline bench. The hole depths, burden and spacing ranged between 7.5-18.8 m, 5.0-7.5 m and 6-8 m respectively for shovel benches whereas for dragline benches these were between 22.8-34m, 8-9 m and 8-10 m respectively. The number of holes detonated was between 1-60 and 15-49 for shovel and dragline benches respectively. The explosive detonated in a blast round varied widely. It was between 300-20,921 kg for shovel benches and 19,326-45,808 kg for dragline benches. The explosive detonated in a delay (more than 8-9 ms) was between 100-550 and 935-2,400 kg in shovel and dragline benches respectively. The blasts were initiated with detonating fuse as well as Nonel initiating system. The vibration monitoring stations were between 25 and 960 m from the site of blasting. The number of blasts conducted with varying blast designs was 57 and vibration data recorded at various locations were 321.

Jayant project

The field investigations were conducted at shovel and dragline benches. The drill diameters were 250-270 mm for shove benches and 260-310 mm for dragline benches. The hole depths, burden and spacing ranged between 11-28.5 m, 5.5-9 m and 6.5-11 m for shovel benches whereas for dragline benches these were 28-40 m, 9-10 m and 10-12.5 m respectively. The number of holes detonated was between 1-119 and 25-97 in shovel and dragline benches respectively. The explosive detonated in a blast round varied widely and it was between 325-1,45,137 kg in shovel benches and 50 kg, 250-1,97 kg, 407 kg in dragline benches. The explosive detonated in a delay (more than 8-9 ms) was 325-12,000 kg and 1,980-7,790 kg in shovel and dragline benches respectively. The blasts were initiated with detonating fuse as well as Nonel initiating system. The vibration monitoring stations were between 10 m and 6500 m from the site of blasting. The blasts performed with varying designs were 69 and vibration data recorded were 465.

Nigahi project

The field investigations were conducted at shovel and dragline benches. The drill diameters were 260-270 mm for shovel benches and 310 mm for dragline benches. The hole depths, burden and spacing varied from 9.5-19 m, 6-10 m and 6.5-11 m for shovel benches whereas for dragline benches these were between 38-42 m, 10-10.5m and 12-13 m respectively. The number of holes detonated was between 1-52 and 59-64 in shovel and dragline benches respectively. The explosive detonated in a blast round varied widely and it was between 635-36,000 kg in shovel benches and 1,53,561-1,98,400 kg in dragline benches. The explosive detonated in a delay (more than 8-9 ms) was 590-6000 kg and 17,470-24,800 kg in shovel and dragline benches respectively. The blasts were initiated with detonating fuse as well as Nonel initiating system. The vibration monitoring stations were between 20 m and 6500 m from the site of blasting. The blasts conducted with varying blast designs were 35 and vibration data recorded were 305.

Kusmunda project

The field trials were conducted at shovel and coal benches. The drill diameters were between 260 and 270 mm for shovel benches and 160 mm for coal benches. The hole depths varied from 6.2 -17.7 m for shovel benches and 5.5-9 m for coal benches. The burden was in the range of 5.5- 7.5 and 4-6 m for shovel and coal benches respectively. Similarly, spacing ranged between 6-9 and 4-6.5 m for shovel and coal benches respectively. The number of holes detonated was between 1-84 and 9-51 for shovel and coal benches respectively. The explosive detonated in a blast round varied widely and it was between 100-23,335 kg. The

Table 1: Summarised blast details of all the four experimental sites.

Name of the project	No. of blasts	No. of PPV data recorded	Range of total explosive weight detonated (kg)	Range of explosive weight per delay detonated (kg)	Range of PPV monitoring distances (m)	Range of recorded PPV (mm/s)	Range of principal frequency (Hz)
Sonepur Bazari	57	321	300-48,440	100-2,400	25-960	1.67-265.4	2.5-85
Jayant	69	465	325-1,97,407	325-12,000	10-6,500	0.925-208	3.3-83
Nigahi	35	305	635-1,98,400	590-24,800	20-6,500	2.01-288.76	2.8-64
Kusmunda	54	421	100-23,335	33-3,770	25-760	1.18-253	2.9-85.3
Total	215	1512	100-1,98,400	33-12,000	10-6,500	0.925-288.76	2.5-85.3

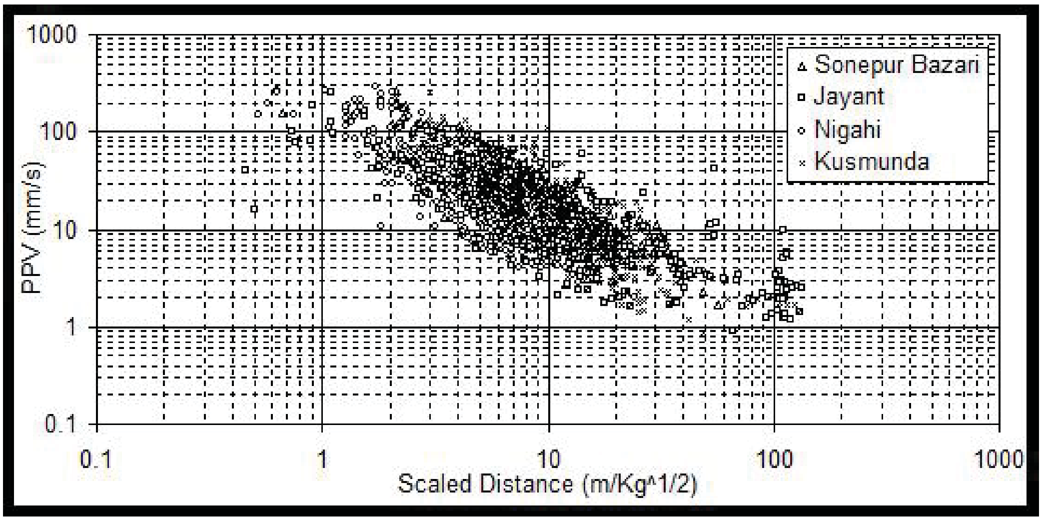


Figure 1: Plots of vibration data recorded at all the four experimental sites at their respective scaled distances.

explosive detonated in a delay (more than 8-9 ms) was 33-3,770 kg. The blasts were initiated with detonating fuse as well as Nonel initiating system. The vibration monitoring stations were between 25 and 760 m from the site of blasting. The blasts conducted with varying blast designs were 54 and vibration data recorded were 421.

The summarised details of experimental blasts conducted at all the experimental mines are presented in Table 1. The vibration data recorded at the entire experimental site are presented in Figure 1 for their respective scaled distances. The frequencies of the blast wave recorded up to 1600 m at all the four experimental sites are presented in Figure 2. The principal frequencies recorded between 1600 and 6500 m were below 10 Hz at all the four experimental sites.

EFFECT OF DELAY TIMING ON GROUND VIBRATIONS

Experiments with varying delay intervals

To investigate the impact of delay interval on blast vibration, the trial blasts were conducted at Sonepur Bazari, Nigahi and Kusmunda projects. Nine sets (eighteen blasts) of experiments were performed by providing delay intervals of 8 and 17 ms between two detonations. The number of holes detonated in a blast was two, three and six. For each set of experiment, blast design and explosive parameters such as bench face, hole diameter, hole depth, burden, spacing, density of explosives, weight of explosives in each holes were kept identical. The Nonel tubes, MS connectors and cord relays of same batch were used to avoid the scattering of timing in delay element. The influence of geology

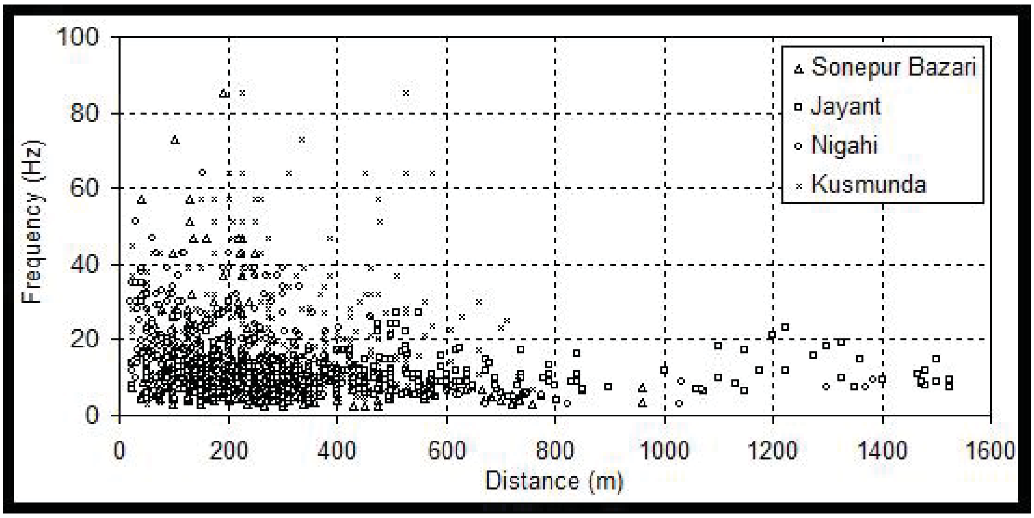


Figure 2: Plot of principal frequency recorded at various locations upto 1600 m from all the experimental sites.

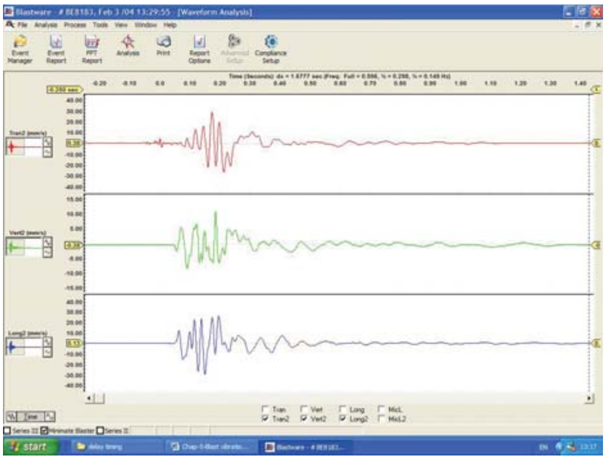


Figure 3: Blast wave signature recorded at 165 m from the blast face at Nigahi project when six holes were detonated by a delay interval of 8 ms.

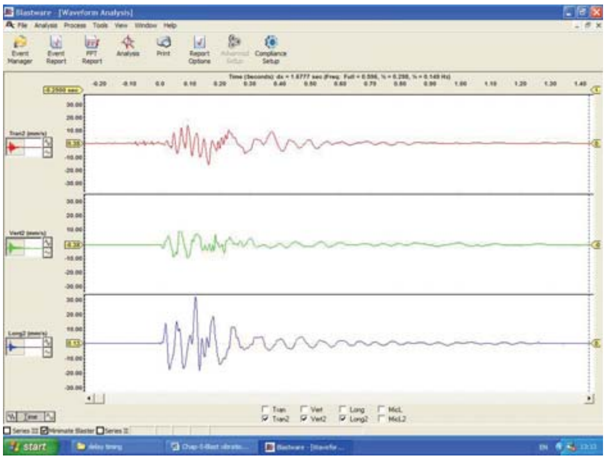


Figure 4: Blast wave signature recorded at 165 m from the blast face at Nigahi project when six holes were detonated by a delay interval of 17 ms.

and transmitting medium of blast wave was also kept identical by putting vibration monitoring transducers at similar distances in each set of experiments for the same bench with adjoining faces. The only variations were in delay timing between two detonations i.e. 8-9 ms for the first blast and 17 ms for successive blast. The delay element of 8 ms was not readily available, so the rearrangements of delay sequence of 8-9 and 17 ms between the two detonations were made.

Interpretation of recorded wave signatures and vibration data

The blast vibrations were recorded at 6-11 locations in an array for each set of experiments. The nearest vibration monitoring point to the blast face was only at 25 m. The vibration results confirmed that the delay interval between the two detonations of 17 ms produced lower vibration compared to that of 8-9 ms. The blast wave signatures recorded from 8-9 ms delay interval depicted shorter persistence of vibration with higher amplitude (Figure 3), whereas 17 ms delay interval

Table 2: Reduction of vibration with 17 ms delay interval between two detonations compared to 8 ms.

Set No.	Location of blast	Hole depth (m)	No. of holes	Burden x spacing (m x m)	Explosives per hole (kg)	Explosives per delay (kg)	Total explosives weight (kg)	Monit-oring distance (m)	PPV (mm/s) with delay interval 8 ms	PPV (mm/s) with delay interval 17 ms	Reduction in PPV in (%)
Sonepur Bazari Project											
1.	1st o/b bench	13.0	2	6.0 x 7.5	300	300	600	60	25.1	19.3	23.1
								85	22.3	16.8	24.7
								110	21.4	13.2	38.3
								135	12.7	8.78	30.9
								160	11.1	7.01	36.8
								185	8.76	5.24	40.2
								210	7.83	4.56	41.8
								235	4.33	3.15	27.3
								260	3.92	3.07	21.7
								285	3.91	3.08	21.2
Kusmunda Project											
2.	Top o/b bench	7.0	2	4.0 x 7.0	100	100	200	25	102.0	80.5	21.1
								50	43.8	29.7	32.2
								75	18.7	14.5	22.5
								100	10.2	7.5	26.5
								150	8.23	5.86	28.8
								175	7.05	5.21	26.1
								200	4.05	3.17	21.7
								225	4.03	3.06	24.1
								250	2.32	1.79	22.8
3.	4th o/b bench	13.4	2	6.0 x 9.0	275	275	550	100	40.1	31.1	22.4
								140	32.2	24.1	25.2
								200	30.1	22.8	24.3
								250	14.9	10.6	28.9
								275	11.9	9.34	21.5
								325	9.56	5.5	42.5
Nigahi project											
4.	Top o/b bench	16.5	6	8.0 x 9.0	590	590	3540	40	288.8	212.0	26.6
								60	154.0	120.3	21.9
								90	86.5	63.9	26.1
								120	58.5	43.1	26.3
								140	43.3	31.4	27.5
								165	38.7	29.6	23.5
								190	26.9	20.7	23.0
								220	22.3	14.9	33.2
								265	13.6	10.0	26.5
5.	Top o/b bench	18.5	3	10.0 x 10.0	740	740	2220	40	211.0	165.2	21.7
								70	106.0	65.6	38.1
								100	40.0	27.0	32.5
								130	31.7	23.5	25.9
								190	22.9	16.2	29.3
								250	20.2	12.9	36.1
								280	13.8	10.23	25.9
								310	9.22	6.12	33.6

Table 3: Reduction of vibration with 25 ms delay interval between two detonations compared to 17 ms.

Set No.	Location of blast	Hole depth (m)	No. of holes	Burden x spacing (m x m)	Explosives per hole (kg)	Explosives per delay (kg)	Total explosives weight (kg)	Monitoring distance (m)	PPV (mm/s) with delay interval 17 ms	PPV (mm/s) with delay interval 25 ms	Reduction in PPV in (%)
Nigahi Project											
1.	Top overburden bench	18.5	3	10.0 x 10.0	740	740	2220	40	165.2	155.7	5.7
								70	65.6	60.31	8.1
								100	27.0	25.5	5.6
								130	23.5	22.1	6.0
								190	16.2	15.81	2.4
								250	12.9	12.34	4.4
								280	10.23	9.43	7.8
								310	6.12	5.72	6.6
2.	Top overburden bench	16.5	6	8.0 x 9.0	590	590	3540	40	212.0	200.6	5.4
								60	120.3	111.5	7.3
								90	63.9	58.9	7.7
								120	43.1	40.12	6.9
								140	31.4	29.0	7.6
								165	29.6	28.54	3.6
								190	20.7	19.3	6.8
								220	14.9	14.3	4.1
								265	10.0	9.26	7.4

between all the six holes produced lower vibration and a little bit higher persistence compared to 8-9 ms delay interval (Figure 4). The representative details of design parmeters and corresponding recorded vibrations are given in Table 2..

The studies with a number of experiments by changing the blast design confirmed that the vibrations produced were more when delay interval of 8 ms was provided between two consecutive detonations compared to those of 17 ms delay interval. The comparative assessments were also made by firing blast rounds with 17 ms and 25 ms delay interval between two consecutive holes (Table 3). The recorded

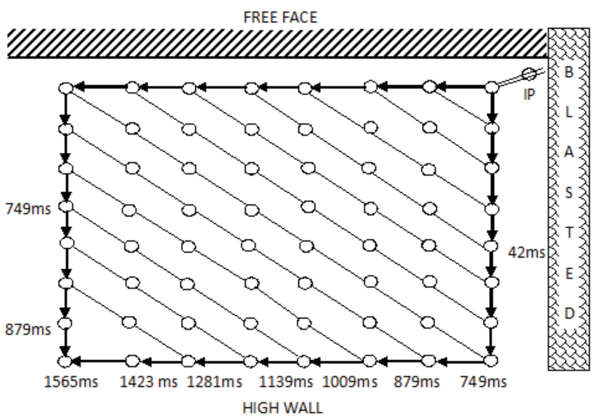


Figure 5: Blast layout of dragline blast at Nigahi project.

vibration data revealed that 25 ms delay interval reduced vibration but only by maximum of 8 %.

The near field monitoring (at 200 m) at dragline bench of Nigahi project was carried out to record the blast wave signatures. As the blast holes were 42 m deep, it was not adequate to provide 8 or 17 or 25 ms delay interval between two detonations. The time to detonate the explosives from the bottom of the blast hole requires sufficient time (8 to 15 ms depending upon the hole depths and type of initiation device i.e. DF or Nonel tube). So, the delay interval was designed based on the swelling of rock mass. The blast layout is shown in Figure 5. The firing of holes were carried out row-by-row (15 rows having 64 holes) providing sufficient relief time. The blast wave signature also confirmed that there was no overlapping of waves and clearly 15 detonations in the waveform were recorded (Figure 6).

All the vibration data recorded from above mentioned experiments have been plotted for respective scaled distances (Figure 7). It is evident from the Figure that blasts with 8 ms delay interval between the holes generated higher vibration compared to those with delay intervals of 17 and 25 ms. Vibrations generated from 17 and 25 ms delay intervals between two detonations in a row were very close to each other. The muti-hole blasts confirmed the similar trends.

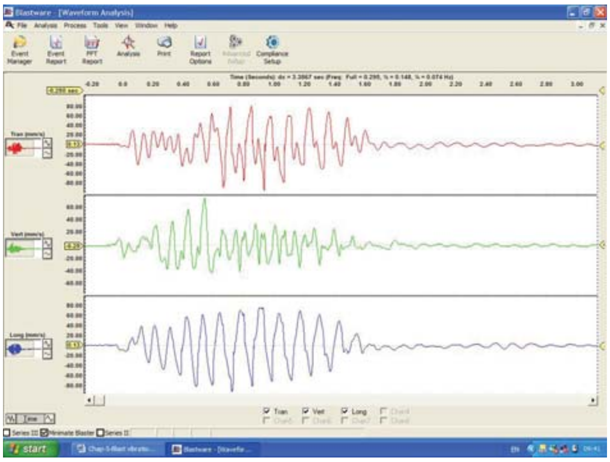


Figure 6: Blast wave signature recorded at 200 m from the dragline blast face at Nigahi project when 64 holes in 15 rows were detonated row-by-row by a delay interval of 42-142 ms.

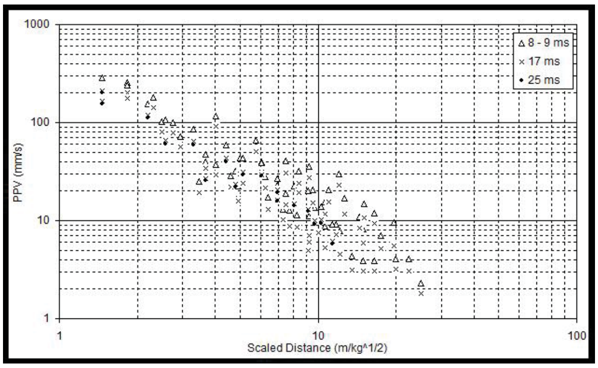


Figure 7: Plots of PPV recorded at its corresponding scaled distances keeping delay intervals of 8-9, 17 and 25 ms between holes.

DELAY INTERVAL OPTIMISATION

Persistence of vibration

The characteristics of blast vibration waves in a particular transmitting media were studied by conducting signature blasts at various benches of each experimental site. The damping characteristics of the waves were also analysed. It was observed that the persistence of vibrations, due to dragline blasts, were up to 15 seconds in the structures at far off distances. Twenty six dragline blasts were performed at Jayant and Nigahi projects and vibrations were monitored simultaneously at 8-12 locations. The impacts of persistence of vibrations in various structures situated at 2 to 6.5 km from the blasting sites were studied. A dragline blast conducted at west section of Jayant project vibrated the Morwa house at 5.5 km from the blasting site more than 10 seconds (Figure 8). The number of holes detonated were 62 and total explosive detonated was 1,79,292 kg. The maximum charge weight per delay was 5784 kg. There were 16 rows and the designed duration of the blast was 2184 ms.

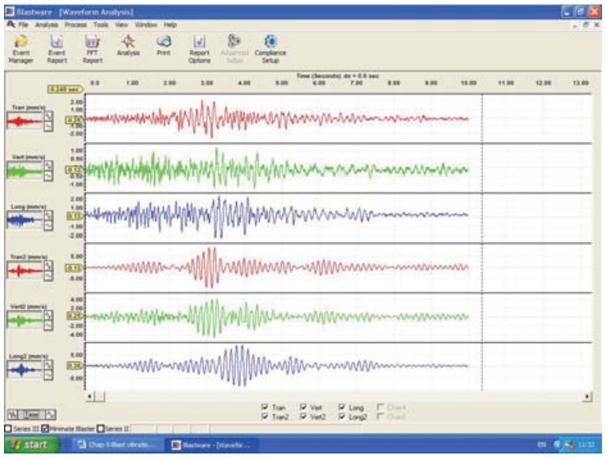


Figure 8: Blast wave signature recorded at Morwa house at 5.5 km from the blasting site.

Signature vibration

The time histories of signature blasts were taken as a tool to optimise the delay timing between the holes in a row and between the rows. The vibration characteristics of a signature blast performed at the 6th bench of west section of Jayant project is shown in Figure 9.

The frequency spectra of the signature blasts were analysed. Linear superposition of the waves were done to simulate the waveform characteristics. The simulated blast design confirmed that very long delay

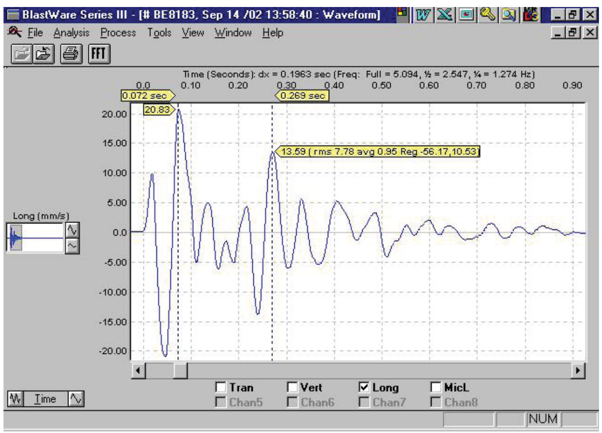


Figure 9: Time history of the signature blast in longitudinal direction at the 6th bench of west section of Jayant project.

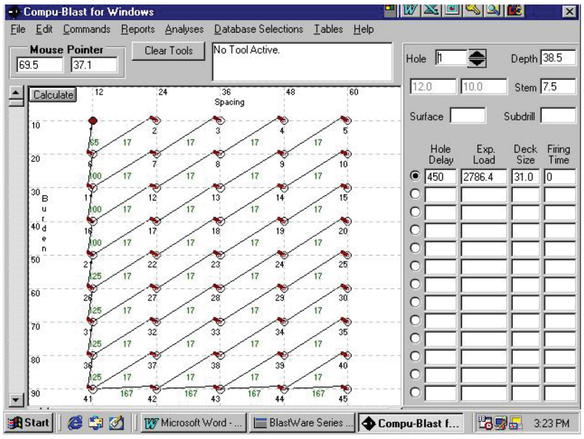


Figure 10: Optimised delay interval between rows in the experimented blast design at dragline bench,West section, Jayant project.

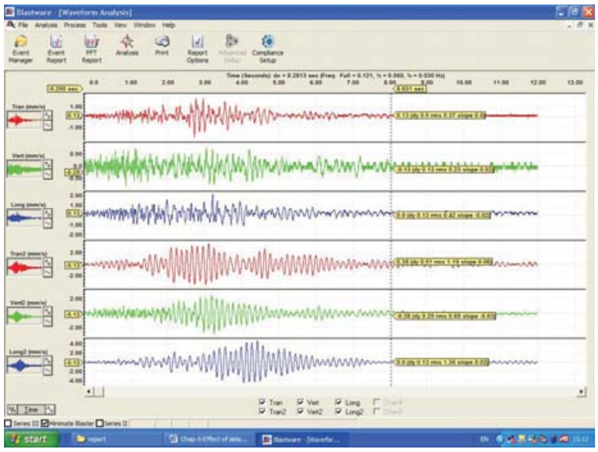


Figure 11: Blast wave signature recorded at Morwa house due to optimised delay timing.

intervals between the rows were provided which caused structures to vibrate for longer period. The analyses further concluded that the minimum time needed to start the movement of rock face was 3.5-4 ms/m of effective burden. The delay timing of 15-27 and 13-23 ms/m of effective burden at east section and west section of Jayant project were in practice. The designed duration of blast was 1801 and 2184 ms at east and west sections of Jayant project respectively. Based on the analysis of signature records, the blast designs were experimented. The optimised delay interval in the blast design is shown in Figure 10. The number of holes detonated at west section of Jayant project was 45 and 1,25,372 kg of SME explosive was distributed in the holes. There were 9 rows and designed duration of the blast was 1533 ms. The charge weight per delay was 2,990 kg. The recorded persiustance of vibration at Morwa house was 8 seconds and the amplification of vibration in the structure was only 2.18 times (Figure 11).

DETERMINATION OF EFFECTIVE DELAY INTERVALS

Dragline blasts

The blast vibration data recorded from dragline blasts at Jayant and Nigahi projects were grouped together for analysis. The data recorded were 235 from 24 blasts. Both the projects followed diagonal firing for taking advantages of two free faces. The firing of single hole, two holes, three holes and sometimes row-by-row was the practice of both the mines. Such four groups were identified for analysing and thereafter optimising the delay interval between the two detonations. These groups were having delay interval of 5-9.9, 10-13.9, 14-18 and 18.1-26.3 ms/m of effective burden. The vibration data were plotted for all the four groups of delay interval separately and the propagation equations were established. These equations were then used for prediction of vibration at various scaled distances. Further computational exercise was carried out by plotting vibrations for a range of scaled distances for each group of delay interval together and shown in Figure 12. It is evident from it that delay timing of 10.0-13.9 ms/m of effective burden produced lower vibration amplitude up to a scaled distance of 45 m/kg$^{1/2}$. For higher scaled distances the delay timing of 14-18 ms/m of effective burden resulted into lower generation of vibration.

Shovel bench blasts

The typical blast designs experimented are illustrated in Figures 13-15. Attempts were made to keep the same delay interval between the rows for a

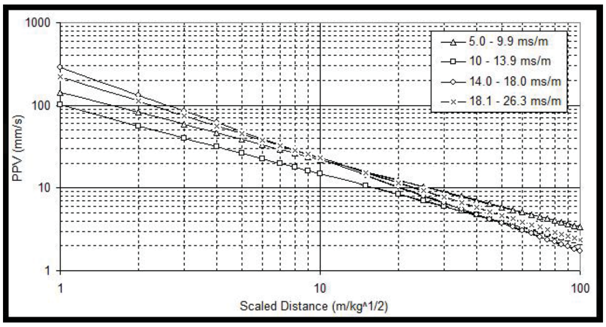


Figure 12: Plots of predicted PPV data for respective scaled distances at different delay intervals between rows for dragline benches.

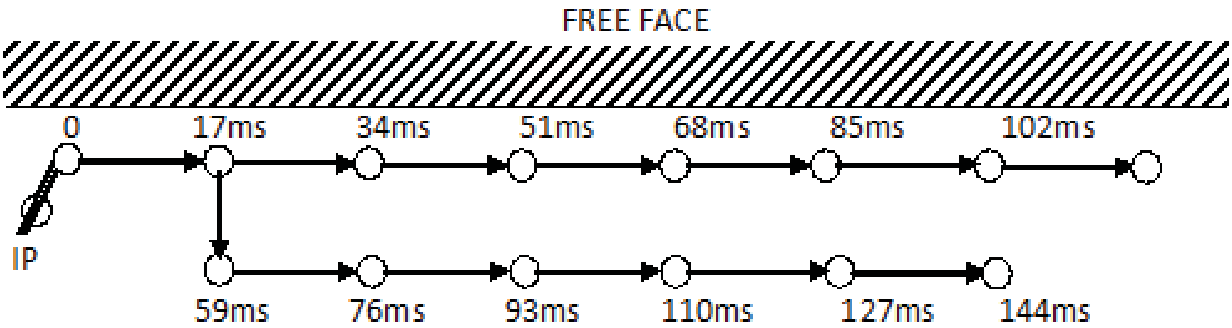


Figure 13: The typical blast design with 42 ms delay interval between rows performed at first overburden bench of Sonepur Bazari project.

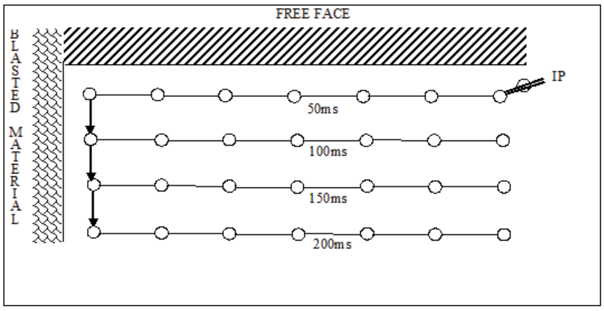


Figure 14: The typical blast design with 50 ms delay interval between rows performed at fourth overburden bench of Kusmunda project.

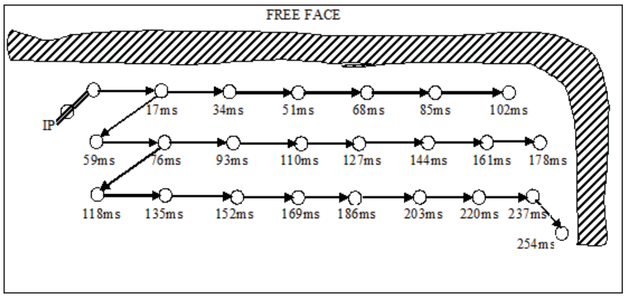


Figure 15: The typical blast design with 59 ms delay interval between rows performed at third overburden bench of Sonepur Bazari project.

number of experimental blasts and vibrations were monitored at 8-11 locations simultaneously for a blast. The multi-holes and multi-rows blasts were also experimented. Vibration analyses were carried out for the delay intervals of 42, 50, 59, 75 and 100 ms.

The similar exercise of analysis was also carried out for blasts of shovel benches. The blasts conducted were of different delay interval between the rows. The effective delay timing was computed which was between 6-12.5 ms/m of effective burden. The effective delay intervals were grouped in five sets of data i.e. 42 ms (6.0-7.0 ms/m), 50 ms (7.1-8.3 ms/m), 59 ms (7.4-9.0 ms/m), 75 ms (8.3-11.4 ms/m) and 100 ms (11.1-12.5 ms/m) between rows for the hole depths of 12-20 m. These delay intervals were maintained for a set of experiments. The recorded data for each set of delay intervals were grouped separately for statistical analysis and best fit predictor equations were established.

The established equations were used for prediction of vibration at various scaled distances. The effect of these five groups of delay interval on the intensity of vibration were analysed from the data collected. The PPV data recorded for their respective scaled distances are presented in Figure 16. The further computational exercise was carried out by predicting vibrations for a range of scaled distances for each group of delay interval and are plotted in Figure 17. It is evident from Figure that delay timing of 8.3-11.4 ms/m of effective burden produced lower vibration amplitude up to scaled distance of 20 m/kg$^{1/2}$. For further higher scaled distances the delay timing of 11.1-12.5 ms/m of effective burden resulted in to generation of lower vibration levels.

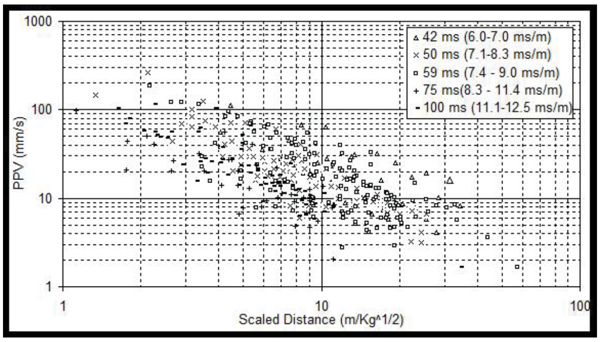


Figure 16: Plots of recorded PPV data with their respective scaled distances with varying delay intervals between the rows for shovel benches.

EFFECT OF TOTAL AMOUNT OF EXPLOSIVE DETONATED ON GROUND VIBRATIONS

Experimental details

To investigate the impact of total amount of explosives detonated in a blast round on ground vibration, 140 blasts were performed. The experimental set-up was made in such a way that two rounds of blast having identical blast design parameters were performed with varied total weight of explosive in each round at the same bench. The make of explosives, charging pattern and charge weight per delay were also similar. The variations were only in total amount of explosives detonated in a blast round. In all 70 sets of such blasts were performed at the four experimental mine sites. Vibrations were monitored in an array at 7-11 locations. Photograph 1 depicts the experimental blasts conducted with lesser explosives weight in a blast round, along with a second blast face ready to be detonated with higher amount of explosives.

Photograph 1: Two blasts were performed at the same bench with only variation in amount of total explosives detonated in the respective blast rounds.

In addition to above mentioned blasts, experimental trials were also carried out by detonating a single hole only with 100 kg of explosives and monitoring of vibrations at 11 locations from 25 to 250 m at an interval of 25 m. At the same blast-face two holes were charged with 100 kg of explosives in each hole and detonated by providing a delay interval of 17 ms. Again, vibrations were monitored at similar locations from 25 to 250 m. Thus, the charge per delay in the latter blast was 100 kg similar to single hole blast but the total charge was 200 kg. The vibrations recorded at five locations nearer to source of blasting were higher in second round of blast compared to the first one, but at locations further away the monitored vibrations were almost similar in both blasts. Layouts of a few blasts experimented to investigate the influence of total explosive weight on the magnitude of vibration are depicted in Figures 17-19.

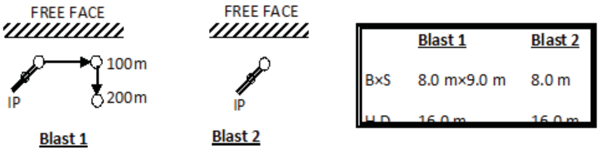


Figure 17. Layouts of two blasts performed at a shovel bench of Jayant project with only variation in amount of total explosives detonated in the blasts.

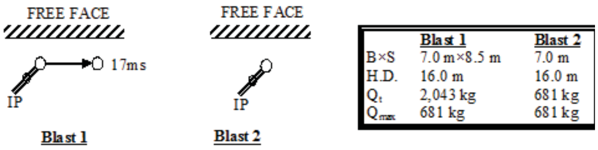


Figure 18: Layouts of two blasts performed at a shovel bench of Nigahi project with only variation in amount of total explosives detonated in the blasts.

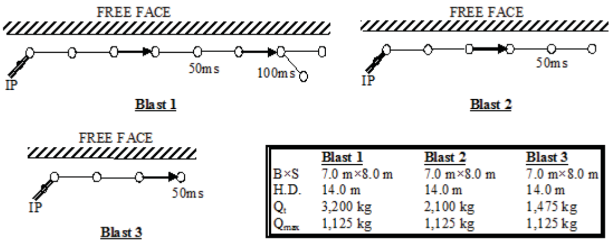


Figure 19: Layouts of three blasts performed at a shovel bench of Kusmunda project with only variation in amount of total explosives detonated in the blasts.

Results of vibration monitoring

The blast wave signatures recorded at various locations for each set of experiments indicated that in blasts where higher amount of explosives were detonated higher level of vibrations were generated in near field to the blast face in comparison to the blasts in which lower amount of explosives were detonated, although the charge weight per delay, delay intervals and blast design as well as explosive parameters were kept identical. The persistence of vibrations was of shorter durations in the case of latter.

The experiments conducted in successive trial blasts also resulted into similar trends. The plots of vibrations data recorded at various locations from both the blasts performed to quantify the impact of total charge on blast vibration are depicted in Figures 20-23. The trends of the figures indicate that there is significant

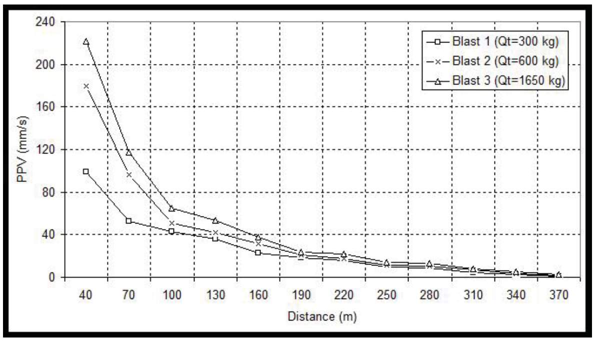


Fig. 20 : Effect of total amount of explosive detonated in a blast on ground vibration recorded from detonation of three blasts at shovel bench of Sonepur Bazari project

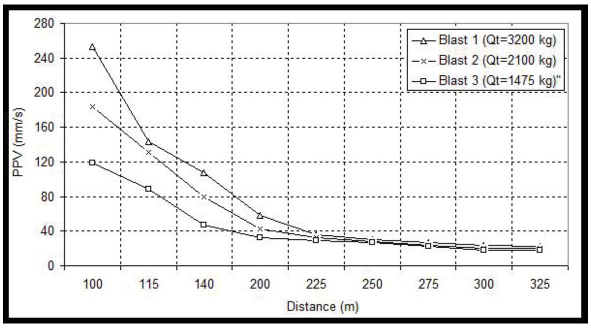


Fig. 23: Effect of total amount of explosive detonated in a blast on ground vibration. The vibration data recorded from detonation of two blasts at shovel bench of Kusmunda project

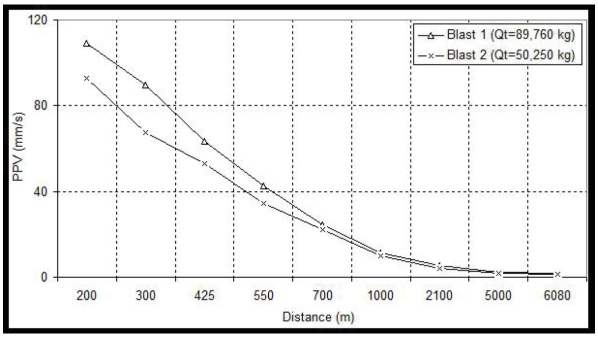


Fig. 21: Effect of total amount of explosive detonated in a blast on ground vibration data recorded from detonation of two blasts at dragline bench of Jayant project

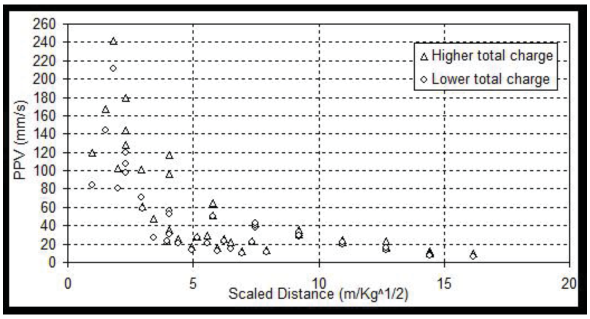


Figure 24: Plot of PPV recorded fromsingle hole and double holes detonations against their respective scaled distances

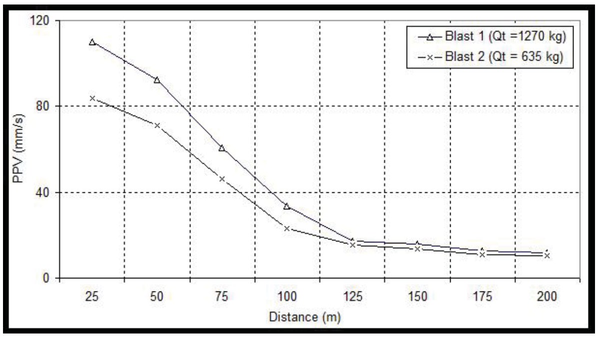


Fig. 22: Effect of total amount of explosive detonated in a blast on ground vibration.The vibration data recorded from detonation of two blasts at shovel bench of Nigahi project

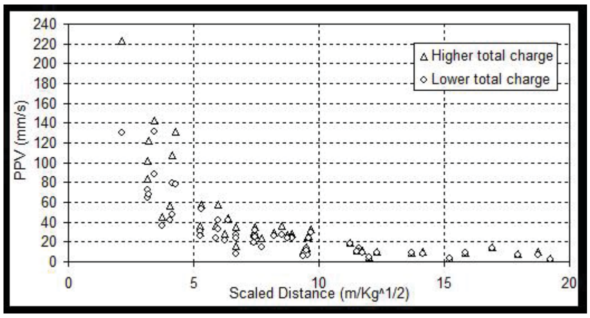


Figure 25: Plot of PPV recorded from production blasts for a set of experiments in shovel benches against their respective scaled distances

influence of the total amount of explosives detonated in a blast round on generation of vibrations.

The analysis of recorded vibration data indicated that the impact of total amount of explosives detonated in blast-round was significant in near fields. It was very essential to quantify the range of their influence. The PPV recorded from a single hole and double holes detonations are ploted against their respective scaled distances and shown in Figure 24. It is evident from this figure that the effect of total explosives detonated in a blast round has influence up to 4-5 m/kg$^{1/2}$ scaled distances. Similarly, the PPV recorded from production blasts are ploted for a set of experiments in shovel benches against their respective scaled distances and are presented in Figure 25. The plot reveals that the effect of total explosives detonated in a blast round has

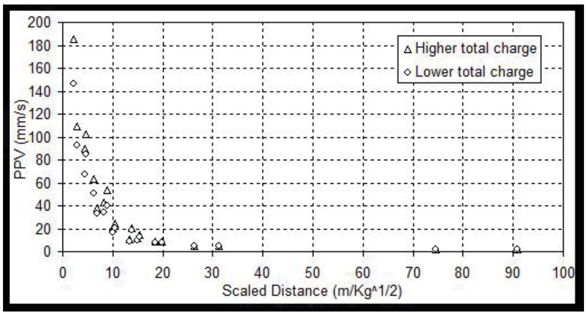


Figure 26: Plot of PPV recorded for a set of experiments against their respective scaled distances

influence up to 8-10 m/kg$^{1/2}$ scaled distances. Similar analyses of recorded PPV from dragline blasts were carried out. The plot of PPV for a set of experiments are presented in Figure 26 against their respective scaled distances. The analyses of data indicate that the effect of total explosives detonated in a blast round has influence up to 15 m/kg$^{1/2}$ scaled distances.

EFFECT OF DIRECTION OF INITIATION ON GROUND VIBRATIONS

Indian mines are still using detonating cords/fuse for initiation of boosters in the blast holes. There are a number of reasons for this practice being followed by mining industry.

Experimental details

The field studies at all the experimental sites were carried out to investigate the influence of top and bottom initiation on the generation of ground vibration and subsequent fragmentation and recovery of the blasted material. The blast design as well as explosive parameters were kept identical. The variations were only in detonation systems i.e. with detonating cords/ fuse and Nonel tubes with bottom initiation. Blast vibrations were monitored at similar locations for each set of experiments. Figure 27 depicts the details of signature blasts performed at Jayant project with top as well as with bottom initiations. Vibrations were monitored at 10 locations in both the blasts.

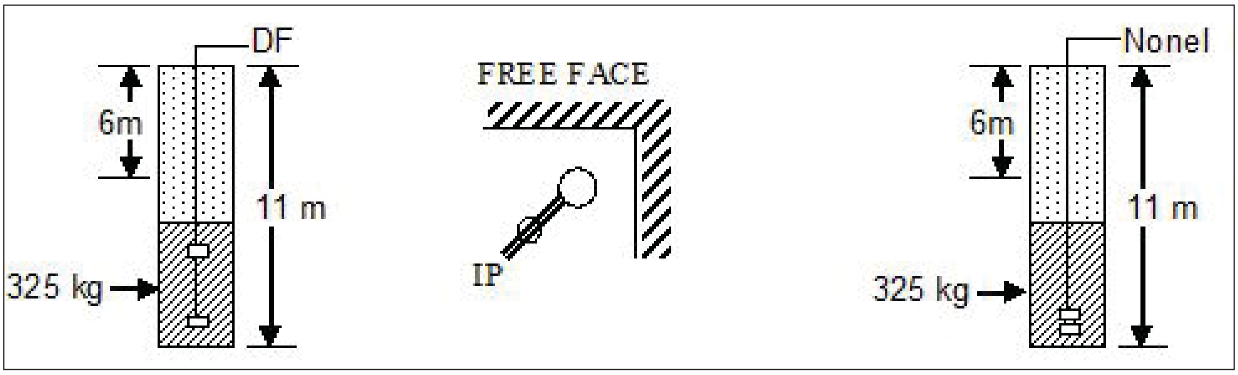


Figure 27: Blast design layout with charging pattern for signature blast detonated by DF and Nonel initiation system at Jayant project.

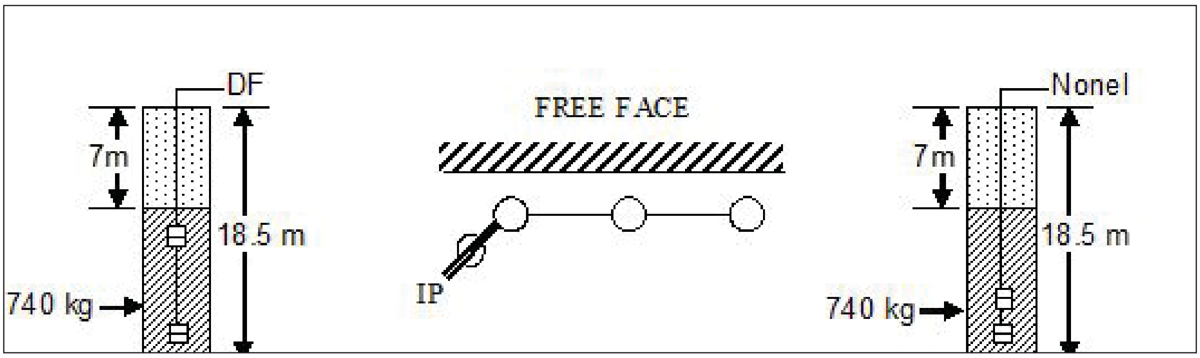


Figure 28: Blast layout and charging pattern for three holes detonated by DF as well as by Nonel initiation system at Nigahi project.

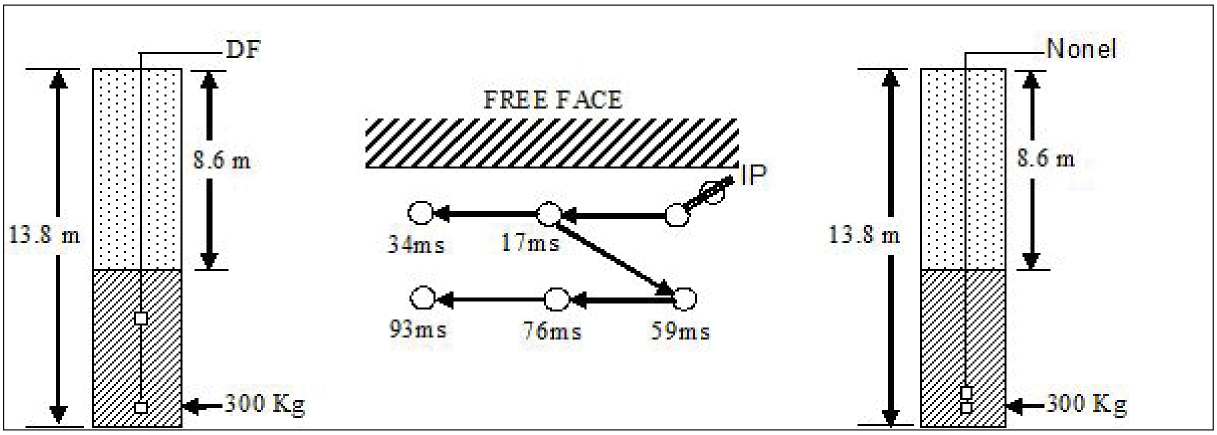


Figure 29: A typical blast layout conducted at 1st bench of Sonepur Bazari project for both the initiation systems.

The impact of initiation sequences was also studied by detonating three holes instantaneously at Nigahi project. Two rounds of experiments were performed. The holes were drilled up to 18.5 m deep in both the blasts. Burden, spacing, make of the explosives and other blast design and explosives parameters were kept identical. The variation was only in initiation mode (Figure 28). Vibrations were monitored at 9 locations in both the blasts.

Similarly, the experiments were conducted with six holes at Sonepur Bazari (Figure 29) and Nigahi projects. The blasts performed with seven holes for the same purpose at Kusmunda project were also documented. The experiments were further extended and performed with production blasting. The vibrations recorded due to bottom initiation were always found lower than those with top initiation system. A few sets of experimental details and recorded PPV are presented in Table 4.

VIBRATION SIGNATURES AND FRAGMENTATION ANALYSES

The analyses of blast waveforms recorded from bottom initiation system indicated that persistence of vibration was comparatively lower than that with top initiation system. Vibration due to bottom initiation was further reduced with increase in depth of holes. In case of signature blasts, the reduction in PPV varied from 11.7–15.6 % when the depths of holes were 11 m. Similarly, the reductions in vibrations were between 9.3-30 %, when depths of holes were up to 20 m. At dragline blast of Jayant project the reduction in vibrations was between 12.7-36.2 %. The graphical presentation of reduction in vibrations due to bottom initiation system compared to top initiation is shown in Figure 30. The vibration monitoring location was fixed at 250 m for all sets of experiments of varying blasthole depths of 7.5, 11, 19 and 33 m.

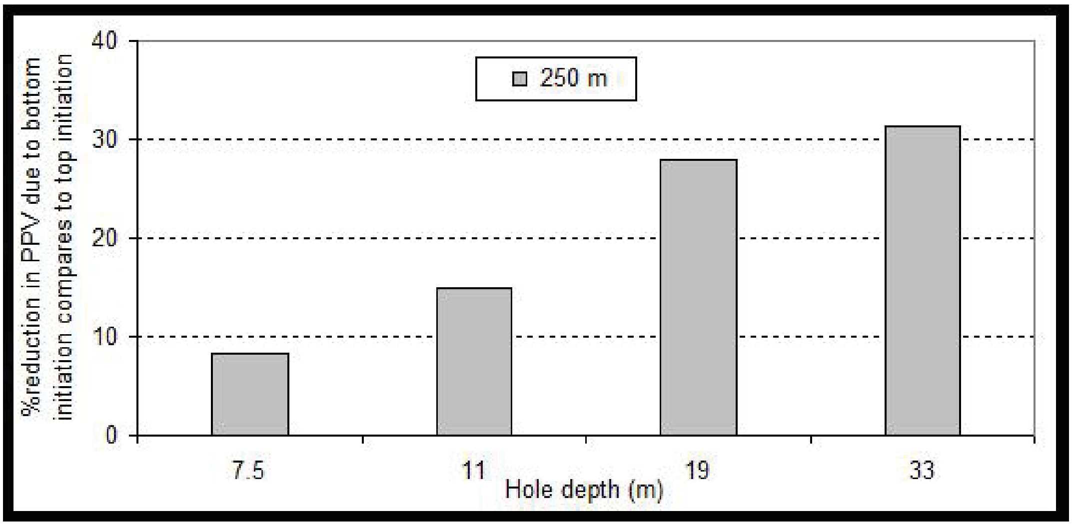
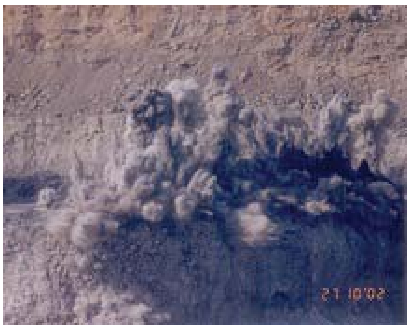


Figure 30: Reduction in PPV due to bottom initiation from that of top initiation for different depths of holes (vibrations were monitored at 250 m for each sets of experiments).

Table 4. Reduction in vibration due to bottom (Nonel) initiation system over top (DF) initiation system.

Set No.	Location of blast	Hole depth (m)	No. of holes	Burden × Spacing (m × m)	Explosive weight per delay (kg)	Total explosive weight (kg)	Monitoring distance (m)	Peak particle velocity (mm/s)		Vibration reduction due to bottom initiation (%)
								DF	Nonel	
1	2	3	4	5	6	7	8	9	10	11
1.	3rd bench of Sonepur Bazari project	14	10	6 × 7	350	3205	40	265.4	200	24.6
							65	124	88.2	28.9
							95	78.34	59.4	24.2
							125	60.9	52.9	13.1
							155	40.3	32.4	19.6
							180	30.9	22.8	26.2
2.	3rd bench (East) of Jayant project	19	22	8.75 × 9.75	4445	19,195	225	51.7	41.9	19.0
							275	37.5	27	28.0
							375	21.2	17.1	19.3
							425	17.9	14.8	17.3
							475	14.9	11.3	24.2
							575	8.57	6.95	18.9
							625	8.48	6.52	23.1
3.	Dragline bench (West) of Jayant project	33	50	10.0 × 12.5	4680	1,14,386	200	101	64.4	36.2
							250	82.9	57	31.2
							300	75.2	54.4	27.7
							400	50.4	38.8	23.0
							450	37.6	28.8	23.4
							500	28.4	20.3	28.5
							800	14.6	11.1	24.0
							2500	1.81	1.58	12.7
4.	Top bench (East) of Nigahi project	18.5	3	10 × 10	740	2220	60	123	110	10.6
							90	55.3	41.6	24.8
							120	36.5	28.6	21.6
							150	33.8	25	26.0
							180	24.5	18.6	24.1
							210	18.6	14.5	22.0
							240	17.9	12.9	27.9
							270	16.0	11.2	30.0
							300	7.22	6.55	9.3
5.	Top bench of Kusm-unda project	7.5	1	Burden 3.5	100	100	25	53.1	46.6	12.2
							50	25.3	22.1	12.6
							75	15.9	14.2	10.7
							100	8.52	7.81	8.3
							125	5.94	5.14	13.5
							150	5.39	4.95	8.2
							175	4.82	4.12	14.5
							200	2.93	2.25	23.2
							225	2.35	2.01	14.5
							250	1.94	1.78	8.2



Photograph 2: Rock movement and venting of gases in top initiation at Kusmunda project.

Photograph 3: Rock movement and excellent fragmentation due to bottom initiation at Kusmunda project.

Fragmentation and recovery of blasted materials also improved in case of bottom initiation. The fragmentation due to top initiation was coarser than that resulted due to bottom initiation system. The operating efficiency of the dragline was monitored while mucking of blasted materials with DF and Nonel initiation system. The blasts performed with Nonel initiation system improved the efficiency of dragline operation. The bucket filling time was reduced by 8 %. The high speed camera was deployed for motion analysis of the blasts detonation sequences. The premature escape of gaseous energy was observed with top initiation of blasts (Photograph 2). The bottom initiation resulted into lower escape of gaseous energy, fewer generations of flyrocks and optimum muck pile for shovel loading (Photograph 3).

CONCLUSIONS AND RECOMMENDATIONS

The persistence of vibration in the structures is dependent upon the duration of blasts. Attempt should be made to keep the blast duration less than 1500 ms. The propagating medium of blast wave is responsible for generation of low frequency blast wave.

The existing practice of 8 ms delay interval for charge separation of two detonations is not adequate. The minimum delay interval of 17 ms between the holes in a row should be adopted. The 8-ms delay criterion is not holding good at low frequency site because the wavelengths are simply too long to constructively cancel out the waves. The hole depths are longer and sometimes requires 10-15 ms to fully detonate the whole column of the explosives. The delay intervals between the rows for dragline benches should be 10-18 ms/m of effective burden and that for shovel benches it should be 8-13 ms/m of effective burden. These delay intervals will provide adequate burden relief for each row and will improve fragmentation and will reduce vibration.

Blasts, where higher amount of explosives is used, generate higher level of vibrations in near field to the blast face in comparison to blasts with lower amount of explosives. In production blasts at shovel benches the impact of total charge is felt up to 8-10 m/kg$^{1/2}$ scaled distances whereas for dragline benches it is up to 15 m/kg$^{1/2}$ scaled distance.

Bottom initiation system generates less vibration in comparison to top initiation system. Vibrations due to bottom initiation further reduced with increase in depths of hole. Fragmentation improves where bottom initiation is practiced resulting into increase in efficiency of the heavy machinery in handling the blasted materials. Noise generation is also comparatively low in case of bottom initiation system.

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Treatment of Acid Mine Drainage through Constructed Wetlands–A Case Study

ABSTRACT

The occurrence of acid mine drainage (AMD) in Indian coal mines is limited to north eastern coalfields and a few mines located in the states of Madhya Pradesh and Maharashtra. In the past, treatment of AMD was tried using active treatment technology for neutralization by chemical treatment but it was not found to be cost effective.

With a quest to provide a simple and cost effective AMD treatment technology, a project using passive treatment technology in Indian coal mines was undertaken in an underground coal mine in Chhindwada District in the State of Madhya Pradesh. The mine water was characterized as follows: pH 2.90; dissolved oxygen (DO) 2.1 mg/l; the ferrous ions (as Fe) < 0.1 mg/l, the ferric ion (as Fe) concentration 9.7 mg/l; manganese (as Mn) 20.2 mg/l, aluminum (as Al) 11.7 mg/l and total acidity (as $CaCO_3$) was observed to be 326 mg/l.

An experimental horizontal flow anaerobic constructed wetland was designed to treat 25 m^3/day of AMD with unit acidity loading rate of 3.5 grammes acidity/m^2/day. The locally available plant Typha latifolia was selected for the wetland due to its greater tolerance towards AMD and lesser build up of toxicity. Typha latifolia was transplanted in the wetland at a density of 10 plants/m^2.

A performance evaluation revealed significant increase in pH (from 2.90 to 5.60), noticeable decrease in acidity from 326 mg/l to 110 mg/l (66.25%) and reduction in concentrations of iron, manganese and aluminum. The post-treatment pH reached the acceptable level of regulatory standards in India. The results are encouraging for use of passive treatment technology for AMD in Indian coal mines.

Keywords: *AMD, passive treatment, Typha latifolia, acidity, pH*

INTRODUCTION

Coal is the most important and abundant fossil fuel in India. It accounts for 55% of the country's energy need as per an assessment made by Ministry of Power, Government of India. The country's industrial heritage was built upon indigenous coal.

Commercial primary energy consumption in India has grown by about 700% in the last four decades. The current per capita commercial primary energy consumption in India is about 350 kg oil equivalent/year (kgoe/year). Driven by the rising population, expanding economy and a quest for improved quality of life, energy usage in India is expected to rise to about 450 kgoe/year. Considering the limited reserve potential of petroleum and natural gas, eco-conservation restriction on hydro-electric projects and geo-political perception of nuclear power, coal will continue to occupy center-stage of India's energy scenario.

With hard coal reserves of around 285.86 billion tonnes as of 1st April, 2011, of which 114 billion tonnes are proven, Indian coal offers a unique fuel source to domestic energy market for the next century and beyond. Hard coal deposits are spread over 27 major coalfields. They are mainly confined to eastern and south central parts of the country. The lignite reserves stand at a level around 36 billion tonnes, of which 90% occur in the southern State of Tamil Nadu.

Coal India Limited

Coal India Limited (CIL) as an organized state owned coal mining corporation which came into being in November 1975 with the government taking over private coal mines. With a modest production of 79 million tonnes in the year of its inception, CIL today is the single largest coal producing company in the world. Operating through 81 mining areas, CIL is an

Research work carried out by CMPDI, Ranchi

apex body with seven wholly owned coal producing subsidiaries and one mine planning and Consultancy Company spread over eight provincial states of India and current annual production stands at 430 millions tonne per year. CIL also fully owns a mining company in Mozambique christened as 'Coal India Africana Limitada'. The company produces around 81.1% of India's overall coal production; meets to the tune of 40% of primary commercial energy requirement of the country; commands nearly 74% of the Indian coal market; feeds 82 out of 86 coal based thermal power plants in India; accounts for 76% of total thermal power generating capacity of the utility sector; supplies coal at prices discounted to international prices; insulates Indian coal consumers against price volatility and makes the end user industry globally competitive.

Indian coal is generally low in sulfur content and devoid of trace metals. The occurrence of acid mine drainage (AMD) is limited to some mines in north-eastern coalfields (NEC), western coalfields (WCL), south eastern coalfields (SECL) and in northern coalfields (NCL). An example of the coal properties in non-AMD and AMD generating areas is provided in Table 1.

Table 1: Coal Properties in Indian Coalfields

Sl. No.	Parameters	Value range (Ramgarh Coalfields)	Value range (Pench Coalfields)*
1	Moisture	3.7-5.5%	2.8-7.2%
2	Ash	14.0-19.3%	15.4-21.6%
3	Volatile Matter	31.1-34.7%	30.2-32.9%
4	Fixed carbon	44.5-47.6%	40.5-46.3%
5	Gross calorific Value	6040-6500 kcal/kg	5535-6210 kcal/kg
6	Carbon	61.7-65.9%	57.2-61.3%
7	Hydrogen	3.8-4.2%	3.6-3.9%
8	Nitrogen	1.2-1.3%	1.2-1.4%
9	Sulfur	0.4-1.0%	0.7-2.2%
10	Carbonates	Trace-1.04%	0.08-0.17%
11	Phosphorus	0.105%	0.006-0.029%

** Coalfield having occurrence of AMD*

Sulfur content observed in some of the AMD prone coalfields are given in Table 2.

Table 2: Sulfur content in AMD prone coalfields in CIL

Sl. No.	Name of the Coalfield	Range of sulfur content (on air dried basis)
1	Pench-Kanhan Coalfield	0.4-2.2%
2	Churcha Coalfield	0.4-1.1%
3	North-Eastern Coalfields	1.0-7.7%
4	Gorbi	0.4-2.5%

The wastewater in the coal mines are generated from various sources viz. mine working, workshop, coal handling plants etc. Among these, the AMD generated from the under ground mine workings and opencast mines have the highest pollution potential and are difficult to treat. The situation warrants treatment of acid mine water to make it potable for public use or for safe discharge to the natural water system.

In view of the regulatory requirement of Government of India, efforts have been made in the past to treat the AMD through conventional treatment methods of neutralization. Since the recurring expenses were quite high, it required immediate attention so that a simple and cost effective treatment system could be developed to prevent pollution to natural streams due to discharge of AMD.

PRESENT STUDY

Treatment of acid mine drainage using plant species through constructed wetlands (using geochemical and microbiological processes) has been successfully undertaken in western countries. Based on the experience gained in those countries, a project was undertaken to ascertain treatability of AMD using plant species in an Indian mining area. The project was carried out in Kanhan Area of India. The mines in the Kanhan Area have a long history of occurrence of AMD from underground mines.

Objectives of the study

The objective of the study was to develop a simple and cost-effective passive treatment system to treat the acid mine drainage from the coal mines. The target was to improve the water quality to the point that it conforms to regulatory requirement for discharge or could be utilized for potable use after giving further treatment.

Mechanism of AMD Formation

Acid mine drainage occurs when mining activity brings sulfidic rock into contact with surface water or ground water. Under oxidizing conditions and facilitated by acido-philic bacteria, pyrite–containing rock produces sulfuric acid and dissolved iron. These acidic waters may then dissolve other metals contained in the rock, resulting in low-pH, metal bearing water. Much of the AMD worldwide is commonly thought to be associated solely with coal mining but AMD is also a large problem where sulfides in geologic materials are exposed in highway construction, metal mines and other deep excavations.

There are many types of sulfide minerals which contribute to AMD problems when exposed to oxygen and moisture. Table 3 provides list of important metal sulfides which form acid upon exposure to oxidizing conditions.

Table 3: Important Metal Sulfides which form sulfuric acid upon exposure to oxidizing conditions and bacteria

Sl. No.	Name	Chemical Formulae
1	Pyrite	FeS_2
2	Marcasite	FeS_2
3	Pyrrhotite	Fe_xS_x
4	Chalcosite	Cu_2S
5	Covellite	CuS
6	Chalcopyrite	$CuFeS_2$
7	Molybdenite	MoS_2
8	Millerite	NiS
9	Galena	PbS
10	Sphalerite	ZnS
11	Arsenopyrite	FeAsS

Acidity levels, metal composition and concentration depend on the type and amount of sulfide mineral and the presence or absence of alkaline materials.

In coalfields when sulfides are present, the oxidation of iron disulfides and subsequent conversion to acid occur through several reactions. The following four chemical equations reflect those processes-

$$FeS_2 + 7/2\, O_2 + H_2O = Fe^{2+} + 2\, SO_4^{2-} + 2\, H^+ \quad (1)$$

$$Fe^{2+} + 1/4\, O_2 + H^+ = Fe^{3+} + ½\, H_2O \quad (2)$$

$$Fe^{3+} + 3\, H_2O = Fe\,(OH)_3 + 3\, H^+ \quad (3)$$

$$FeS_2 + 14\, Fe^{3+} + 8\, H_2O = 15\, Fe^{2+} + 2\, SO_4^{2-} + 16\, H^+ \quad (4)$$

The rate of pyritic oxidation depends on numerous variables such as reactive surface area of pyrite, form of pyritic sulfur, oxygen concentration, solution pH, catalytic agents, flushing frequencies and the presence of Acidithiobacillus bacteria. Water is essential for the chemical reaction. The rate of pyrite oxidation increases with water vapor pressure until at 100% relative humidity; the rate becomes equal to that for immersed pyrite. It has been suggested that water may not necessarily be a reactant; it may act as a medium for the transfer of oxidation products from reaction sites in view of the fact that the rate of the oxidation reaction increases as the concentration nears saturation state.

Passive Treatment Systems

Mechanisms of AMD treatment within wetlands listed in their approximate order of importance include: 1) formation and precipitation of metal hydroxides, 2) microbial sulfate reduction forming metal sulfides, 3) organic complexation reactions, 4) exchange with other cations on negatively-charged sites, and 5) direct uptake by living plants. Other mechanisms include neutralization by carbonates, attachment to substrate materials, adsorption and exchange of metals onto algal mats, and microbial reduction of dissolved Fe^{3+} and Fe hydroxides to furnish energy for metabolism of microbes.

The way in which a wetland is constructed ultimately affects how water treatment occurs. Initially, two construction styles were: 1) "**aerobic**" wetlands consisting of *Typha* and other wetland vegetation planted in shallow (<30 cm), relatively impermeable sediments comprised of soil, clay or mine spoil, and 2) "**anaerobic**" wetlands consisting of *Typha* and other wetland vegetation planted into deep (>30 cm), permeable sediments comprised of soil, peat moss, spent mushroom compost, sawdust, straw/manure, hay bales, or a variety of other organic mixtures, which are often underlain or admixed with limestone. In aerobic wetlands, treatment is dominated by processes in the shallow surface layer. In anaerobic wetlands, treatment involves major interactions within the substrate.

Design of AMD Treatment System

The following criteria were taken into account when designing the AMD treatment system, i.e. constructed wetlands.

- Physico-chemical characteristics of mine water
- Discharge rate of AMD

Table 4: Quality of mine water prior to treatment

Sl. No	Characteristics	Mine Water Quality		
		Sample-1	Sample-2	Sample-3
1	pH	4.16	3.11	3.21
2	Dissolved Oxygen (DO), mg/l	2.1	2.1	2.1
3	Ferrous ion (as Fe), mg/l	<0.1	<0.1	<0.1
4	Ferric ion (as Fe), mg/l	7.4	9.7	2.2
5	Manganese (as Mn), mg/l	3.6	20.2	5.3
6	Aluminium (as Al), mg/l	1.3	11.7	2.5
7	Total acidity (as $CaCO_3$ eq), mg/l			
	a. at pH 3.7	--	125	--
	b. at pH 8.3	30	326	49

Table 5: Coal Mine's Effluent Standards of India

Particulars	Prescribed limits
pH	5.5-9.0

Table 6: Monitoring of pH for 1st Week

Sl. No.	Date of sampling	pH at inlet	pH at outlet	
			At the water level (Aerobic zone)	At the root zone (Anaerobic zone)
1	06.10.2010	2.90	3.00	4.31
2	07.10.2010	2.93	3.04	4.31
3	08.10.2010	2.80	2.93	4.30
4	09.10.2010	2.90	3.13	4.32
5	10.10.2010	2.87	3.12	4.32
6	12.10.2010	3.08	3.20	4.32
7	13.10.2010	2.88	3.11	4.32

Table 7: Monitoring of pH for 2nd Week

Sl. No.	Date of sampling	pH at inlet	pH at outlet	
			At the water level (Aerobic zone)	At the root zone (Anaerobic zone)
1	18.10.2010	2.90	3.12	4.36
2	19.10.2010	2.93	3.04	4.49
3	20.10.2010	2.70	2.93	4.52
4	21.10.2010	2.92	3.13	4.62
5	22.10.2010	2.72	3.05	4.78
6	23.10.2010	3.18	3.22	4.82
7	24.10.2010	2.43	3.11	4.96

Table 8: Monitoring of pH for 3rd and 4th Week

Sl. No	Date of sampling	pH at inlet	pH at outlet	
			At the water level (Aerobic zone)	At the root zone (Anaerobic zone)
1	26.10.2010	2.85	4.05	5.01
2	29.10.2010	2.95	4.10	5.10
3	08.11.2010	3.02	4.03	5.12
4	11.11.2010	2.95	4.13	5.32

- Treatment technology options
- Availability of land
- Cost of treatment

Quality of Mine Water

As a first step in the project, historical monitoring data were reviewed to ascertain the general characteristics of the mine water at the study site. The analyses revealed the quality of mine water as shown in Table-4.

The analysis result revealed that the mine water was net acidic with moderate metal concentrations.

Discharge Rate of AMD

The quantity of mine water being pumped from the mine incline was estimated to be 550 m^3/day on an average basis.

Pollution Load in the Mine Water

Considering the availability of land nearby the mine, a hydraulic loading of 25 m^3/day only was utilized in the design of the treatment system. Based on the characteristics of the mine water, the acidity load of the effluent was estimated as under:

Maximum acidity load = 326 mg/l x 25 kl per day
= 8150 gms / day

Effluent Standards

Current Government of India standards for effluent discharge from coal mines into rivers or streams or onto land, are summarized in Table 5:

Optional Parameters: *All other parameters indicated in the general standards for discharge of environmental pollutants under Schedule-VI, shall be in addition to the effluent standards specified as above.*

Selection of the Treatment Process

It is evident from the data provided in Table 4 that the AMD contains high concentrations of ferric ions, aluminum and manganese. The pH is well below 4 and acidity is high (326 mg/l). The flow chart decision tree shown in Figure 1 was used to identify an optimum treatment process for the mine water. An anaerobic wetland was deemed to be the best alternative.

Total acidity load considered for treatment = 8150 g / day
Given a unit loading rate of acidity = 3.5 g acidity/m^2/day
The capacity of the anaerobic wetland would need to be = 8150 / 3.5= 2328.57 or approximately 2500 m^2
So two cells each of area 1250 m^2 would be sufficient to treat the water. Each cell would be of dimension 50 m x 25 m.

The wetlands were designed to maintain- 0.15 m depth of water over 0.60 m of substrate. The substrate consisted of permeable sediments containing peat moss, spent mushroom compost, sawdust, straw/ manure, over 0.30 m thick layer of limestone.

Several studies in USA report on the effects of different plant species in wetlands treatment systems. Early in the development of treating AMD with constructed wetlands, Sphagnum was the predominant wetland species. Sphagnum has a well-documented capacity to accumulate iron (Fe). However, it was found that saturation of Sphagnum moss with Fe could occur within one growing season. Some have indicated that metal retention over the long term is limited in some wetlands because organic matter inputs by wetland plants are limited. Many of the original constructed wetlands in USA were vegetated with Sphagnum but few remained effective. Cattails (Typha) have been found to have a greater environmental tolerance than Sphagnum moss. One of the reasons is that cattails do not accumulate metals into their tissues through uptake. Keeping in view the greater tolerance towards AMD and lesser build-up of toxicity, Typha latifolia was selected for treatment of AMD through wetlands. Density of Typha latifolia in the constructed wetland was kept at 10 plants / m^2.

RESULTS AND DISCUSSION

Performance Evaluation

For performance evaluation of the wetlands, the following water quality monitoring frequency was undertaken:

- Daily at inlet and outlet (for pH only) for the initial two weeks
- Twice weekly at inlet and outlet (for pH only) for two weeks
- Three fortnightly samples: (for comprehensive analysis as per general standards for discharge of environmental pollutants as per Schedule-VI specified by Ministry of Environment & Forests, Government of India.

The monitoring results for pH are provided in Tables 6 to 9. These results indicate increase in pH level upto 5.60 in the initial three months of wetland operation.

The mine water and treated samples were collected for comprehensive analysis as per general standards for discharge of environmental pollutants as contained in Schedule-VI specified by Ministry of Environment & Forests, Government of India to ascertain the overall quality of treated water and also to ascertain the efficacy of iron, manganese, aluminum and acidity removal by wetland.

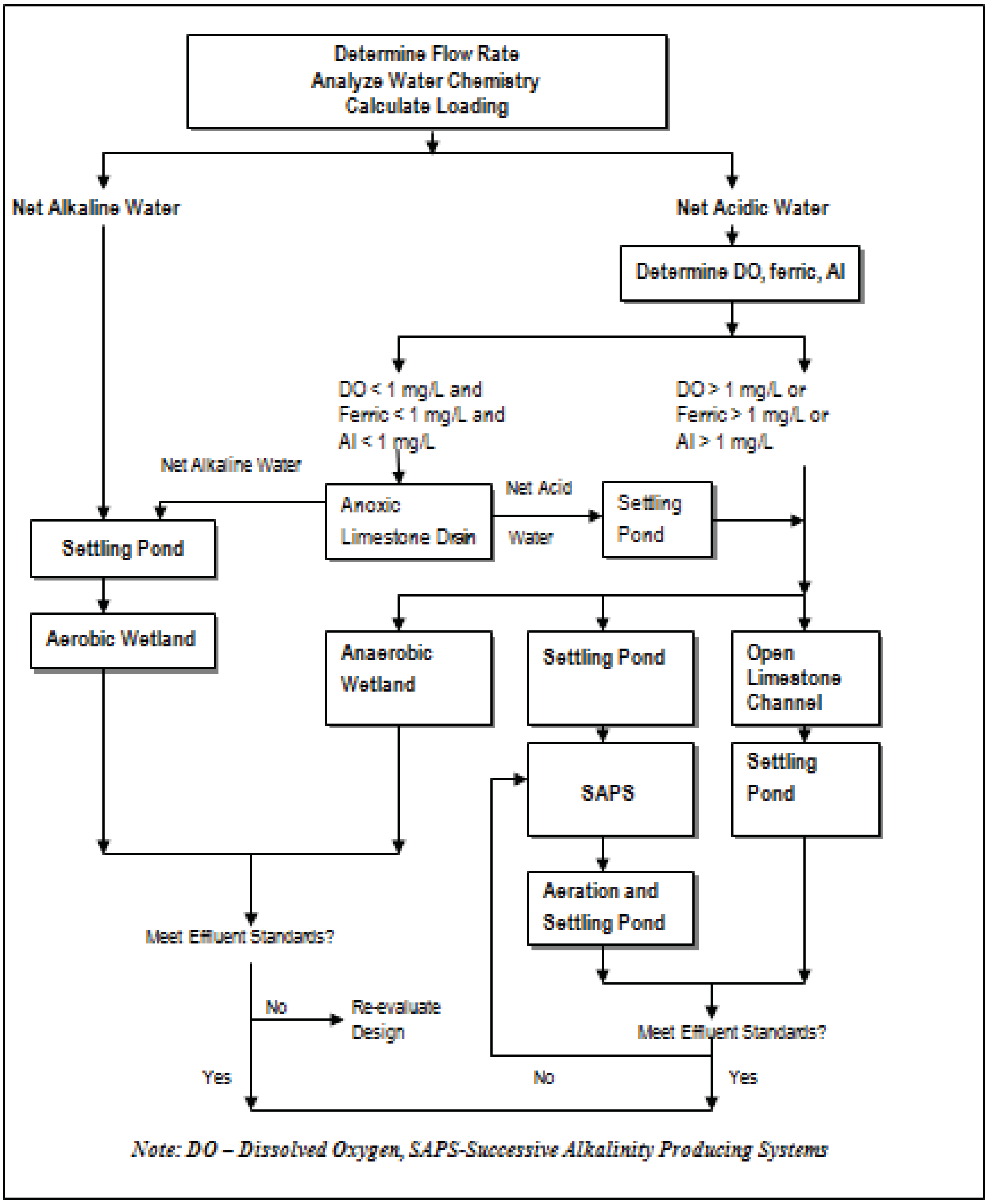

Figure 1: Flow chart for selecting passive treatment systems under various conditions

A schematic AMD treatment system is provided in Figure 2.

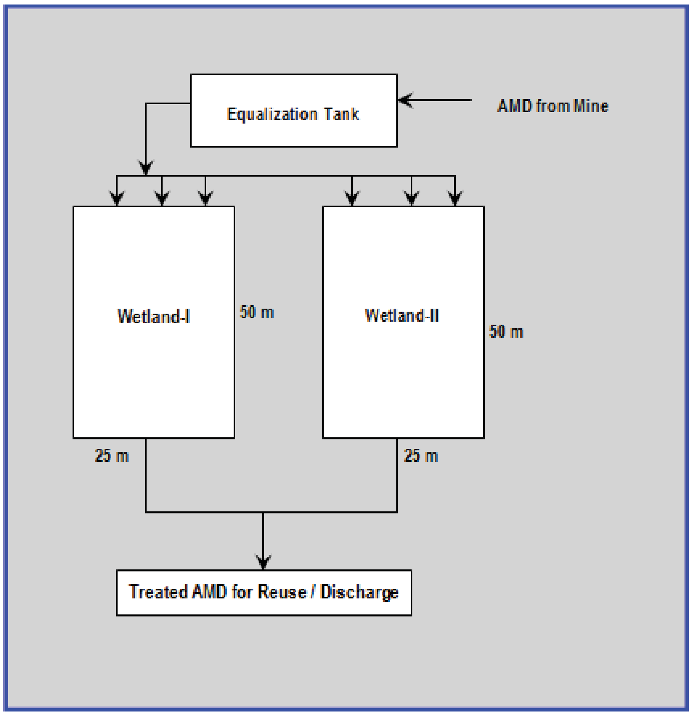

Figure 2: Scheme for AMD Treatment through Constructed Wetlands

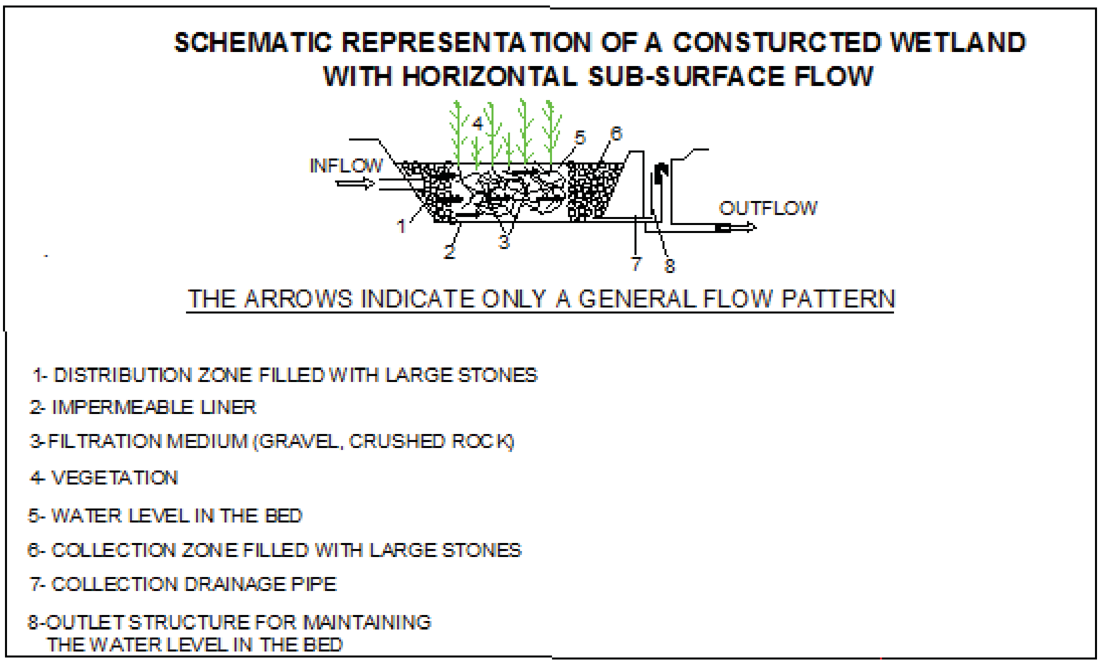

Figure 3: Schematic representation of constructed wetlands

Figure 4: Wetland bed under preparation

Figure 5: View of the wetland

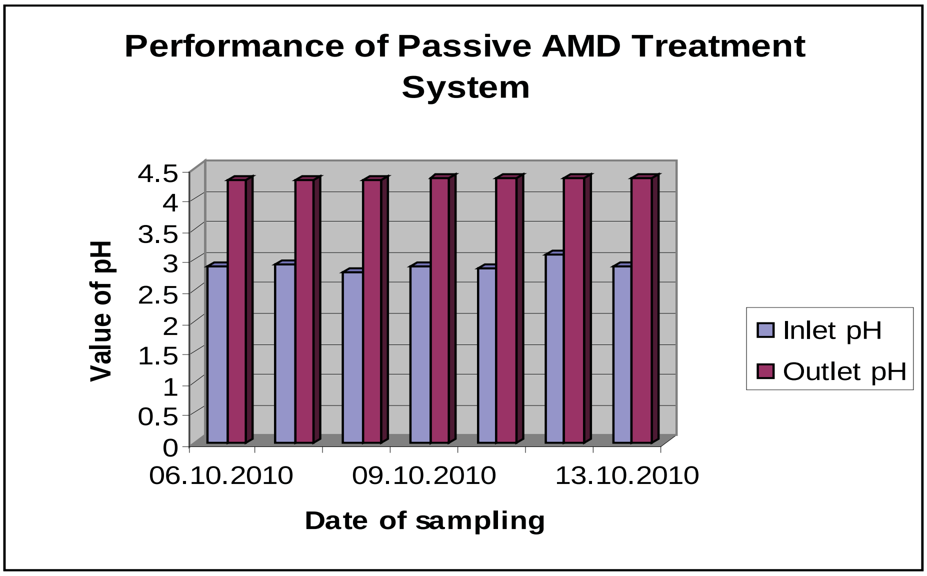

Figure 6: Performance of AMD Treatment System (1st Week)

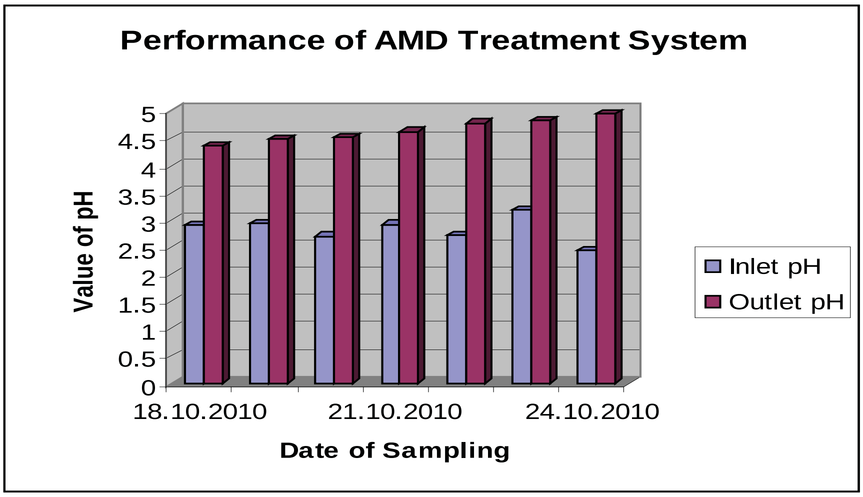

Figure 7: Performance of AMD Treatment System (2nd Week)

Table 9: Fortnightly Monitoring of pH

Sl. No.	Date of sampling	pH at inlet	pH at outlet	
			At the water level (Aerobic zone)	At the root zone (Anaerobic zone)
1	20.11.2010	3.01	4.12	5.48
2	08.12.2010	2.93	4.35	5.51
3	28.12.2010	2.90	4.34	5.60

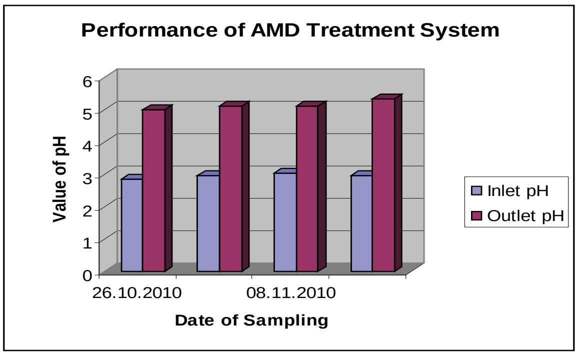

Figure 8: Performance of AMD Treatment System (3rd and 4th Week)

Table 10: Improvement in mine water quality

Sl. No.	Characteristics	Mine Water Quality	
		Influent Quality before treatment	Treated Effluent Quality after 3 months
1	pH	2.90	5.60
2	Dissolved Oxygen (DO), mg/L	2.10	2.20
3	Iron (as Fe), mg/L	9.7	2.40
4	Manganese (as Mn), mg/L	20.2	18.0
5	Aluminum (as Al), mg/L	11.7	6.6
6	Total acidity (as CaCO3), mg/L	326.0	110.0
8	Total Chromium (Cr), mg/L	1.0	0.6
9	Zinc (as Zn), mg/L	1.0	0.8

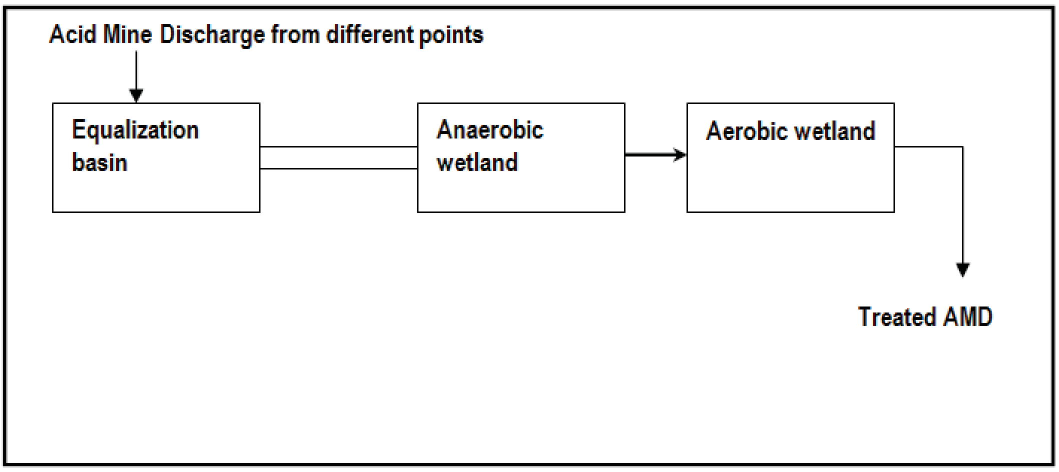

Figure 9: Suggested Flow sheet for AMD Treatment through Constructed Wetlands

OBSERVATIONS

The analysis report for the pH indicates that constructed wetland using the plant Typha latifolia is quite effective in Indian coal mines in improving the level of pH in acid mine drainage. The increase in pH level from 2.90 to 5.60 occurred within initial three months of the operation of the wetlands. Substantial reductions in acidity, iron, manganese and aluminum concentrations were also observed as indicated in Table 10.

The improvement of acid mine discharge quality after three months of wetland operation is summarized in Table 10 . There is noticeable reduction in acidity and some metallic ions like iron, manganese, aluminum and chromium. The bio-remediation treatment through anaerobic constructed wetlands shows acid mine drainage quality improves after treatment and can be discharged onto land or into surface water bodies as per the Indian regulatory standards. The cost of design and construction of treatment system was around US $ 80000. This is a cost effective method of treatment and recurring cost is almost insignificant. The process does not require skilled supervision and maintenance.

The result of this study indicate that the wetland treatment process improved the water discharging from an Indian coal mine so that it may now meets the regulatory standards for discharge into inland water. However, the treated acid mine water discharge needs further physico-chemical treatment for making it fit for potable use. The treatment system may comprise one softening unit using lime soda process and coagulation with alum. The water should then be subjected to filtration and disinfection through chlorination.

CONCLUSION

i. Based on the preliminary results of this study it may be concluded that constructed wetlands containing the plant Typha latifolia improve mine water quality by increasing the pH level of the acid mine drainage from 2.90 to 5.60.
ii. Significant reductions in acidity as well as concentration of iron, aluminum and manganese were also observed.
iii. The constructed wetlands provide a simple treatment system for acid mine drainage from coal projects. The wetland system is almost maintenance free and does not require skilled operation and maintenance.
iv. This process is simple, easy to operate, requires less recurring expenses and no skilled supervision.
v. In order to achieve further improvement in treated water quality, a combination of two or more wetlands can be provided in series. An aerobic wetland can be provided after the anaerobic wetland to further improve the quality of treated water. The suggested typical flow-sheet for AMD treatment is shown in Figure 9.

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Standardisation of blast vibration damage threshold for the safety of residential structures in mining areas

ABSTRACT

A study was conducted to evaluate the effect of blast produced ground vibration due to open-pit blasting on damage potential to the residential structures and to determine the safe levels of ground vibration for the safety of residential structures and other buildings in mining areas. Under this project, three types of test structures were constructed at two experimental sites namely Sonepur Bazari Project of Eastern Coalfields Limited and Kusmunda Project of South Eastern Coalfields Limited. The structures were (a) Single room mud house with Raniganj tiles, (b) Single storey two room unit of brick and mud with cement plaster and Raniganj tiles and (c) Double storey three room RCC structures. Two old houses were also selected for the study.

The impacts of 341 blasts conducted at the aforesaid mines were monitored at the structures and 1871 blast vibrations data were recorded on or near the structures. Frequencies of blast vibration were determined directly from the vibration time histories and by real time spectral analysis. The natural frequencies of the test structures were in the range of 6-14.8 Hz. Frequency spectra analysis of recorded vibration data revealed that the maximum concentration of vibration energy was in the range of 3.3-9.2 Hz. The incoming vibrations thus had frequency in the range of natural frequency of the structures, thereby causing resonance in the structures and hence amplification of vibration within the structure. The recorded amplification of vibration in the structures was between 1.74 and 5.21 times.

The cosmetic cracks in the brick-mud house were detected at peak particle velocities between 51.6 and 56.3 mm/s. The RCC structure of ground floor experienced cosmetic cracks at PPV level of 68.6 to 71.3 mm/s, whereas the cosmetic cracks at first floor were detected at PPV levels of 71.2 to 72.2 mm/s. The minor damage in the mud house was detected at PPV levels of 55.0 to 56.1 mm/s, whereas in brick-mud house it was recorded at PPV levels of 81.0 to 89.7 mm/s. The RCC structure at ground and first floor experienced minor damage at PPV levels of 104 mm/s and 98.3-118 mm/s respectively. The major damage was recorded in mud house at PPV levels of 87.1 to 104 mm/s. The brick-mud house experienced major damage at PPV level of 99.6 to 113.0 mm/s. Major damage was recorded in RCC structure at the ground floor at PPV of 122 mm/s, whereas the first floor experienced major damage at PPV level of 128.9-161 mm/s. Despite these high observed values, the threshold limit of vibrations for different type of structures has been recommended, significantly, at a lower level.

Research work carried out by CIMFR, Dhanbad

INTRODUCTION

Ground vibrations due to blasting are a potential problem for the mining and construction industries, the public living near the mining activities and the regulatory agencies responsible for setting safety and environmental standards. Questions frequently arise about blast vibration effects and specifically about whether vibrations can or could have caused cracking and other damage in residential and other structures. The answer depends primarily on vibration levels and frequencies and to a lesser degree on site and structure specific factors.

The surface mines, which were planned earlier to be away from residential areas, are now approaching to those areas. The vibrations generated due to detonation of explosives may cause damage to structures and annoyance to their residents in the vicinity of these mines. The Indian mining industry needs realistic design levels and also practical techniques to safe guard the structures in its periphery. At the same time, mines safety control agencies responsible for blasting and explosives need reasonable, appropriate and technologically established and supportable blast vibration damage criteria on which to base their regulations.

In view of long pending needs of the Indian mining industry, a study was conducted at Sonepur Bazari Project of Eastern Coalfields Limited and Kusmunda Project of South Eastern Coalfields Limited.

The objectives of the study were to document the level of vibration causing damage to the structures and subsequently to propose damage criteria for the safety of residential structures found in mining areas.

PROPAGATION AND PREDICTION OF BLAST VIBRATION

Anyone who has detonated a blast or who has been present around the blasting area understands that ground vibration and airblast are simply a part of the process. Many investigators have studied ground vibrations generated from blasting and they have developed different relationships to predict the vibrations at distances from the source. The concept of scaled distance is generally used for blast vibration prediction. The scaled distance is defined as the actual distance (R) of the vibration measuring point from the blasting face divided by some power of the maximum weight per delay (Q_{max}) of explosives. Different researchers have suggested different values of exponent.

Currently, the most widely accepted concept of single measurement of ground vibration for prediction of potential damage to structures is the peak particle velocity (PPV). It is defined as the highest speed at which an individual earth particle moves or vibrates as the waves pass a particular site. Many predictive equations have been proposed to compute explosive weight per delay to attain the specific level of peak particle velocity. Singh (2002) based on the analyses of 572 vibration data collected from 24 opencast mines in India concluded that USBM predictor equation is the best among the predictor models suggested by different investigators in Indian context. The equation considers cylindrical explosive geometry for long cylindrical charges, and is suggested that all the linear dimensions should be scaled with the square root of the explosive's weight in a delay. The corresponding equation is of the following form:

$$v = K \cdot \left(\frac{R}{\sqrt{Q_{\max}}} \right)^{-b}$$

where, v = peak particle velocity (mm/s)
K, b = site constants to be determined by regression analysis
R = distance of the measuring transducer from the blasting face (m)
Q_{max} = explosive's maximum weight per delay (kg)

Existing blast vibration standards

Different countries have set their own standards on the basis of their extensive field investigations carried out in their mines for several years. There is a plethora of standards available world-over based on various aspects of ground vibrations e.g. amplitude, peak particle velocity, frequency, acceleration, etc. An overview of the vibration standards implemented by various countries is presented in Tables 1-3.

EXPERIMENTAL SITES AND BLASTS DETAIL

The experimental sites were Sonepur Bazari project and Kusmunda project. Sonepur Bazari project has four coal seams viz. R-IV, R-V, R-VI and R-VII. Presently, seams R-V and R-VI are being extracted by opencast method of mining.

Table 1: USA standard after Siskind et al. (1980).

Type of structures	Peak particle velocity (mm/s)	
	Frequency(<40 Hz)	Frequency (>40 Hz)
Modern homes, dry wall interior	18.75	50
Older homes, plaster on wood lath construction	12.5	50

Table 2: Australian standards (Ca-23-1967) (Just and Chitombo, 1987).

Type of structures	Maximum values
Historical building and monuments and buildings of special value	0.2 mm displacement for frequencies less than 15 Hz
Houses and low rise residential buildings, commercial buildings not included below	19 mm/s resultant PPV for frequencies greater than 15 Hz
Commercial buildings and industrial buildings or structures of reinforced concrete or steel construction	0.2 mm maximum displacement corresponds to 12.5 mm/s PPV at 10 Hz and 6.25 mm/s at 5 Hz

Table 3: Permissible peak particle velocity (PPV) in mm/s at the foundation level of structures in mining area (DGMS circular 7 of 1997).

Type of structure	Peak particle velocity (mm/s)		
	Frequency (< 8 Hz)	Frequency (8-25 Hz)	Frequency (> 25 Hz)
(A) Buildings/structures not belonging to the owner			
1. Domestic houses/structures (Kuchcha, brick & cement)	5	10	15
2. Industrial buildings	10	20	25
3. Objects of historical importance and sensitive structures	2	5	10
(B) Buildings belonging to owner with limited span of life			
1. Domestic houses/structures	10	15	25
2. Industrial buildings	15	25	50

The Kusmunda project is having a flat terrain with minor undulations. The area of the project is covered generally by soil/sub-soil. The upper Kusmunda seam in-crops below a cover of 6-31 m in an elliptical fashion and overlies lower Kusmunda seam after sandstone parting of 65 to 75 m. The seam generally has a dip ranging from 50^0 to 100^0 (1 in 5.6 to 1 in 11.5) and the overall grade of coal is F.

Test structures details

The locations for construction of test structures were decided estimating the advancement of the working benches in next 15 months. The minimum distance of about 400 m was planned at both sites from the nearest working bench at the time of completion of the construction of test structures. Three types of test structures were constructed at both the sites. The structures were (a) Single room mud house with Raniganj tiles, (b) Single storey two room unit of brick and mud with cement plaster and Raniganj tiles and (c) Double storey three room RCC structures.

Photograph 1: Single room mud house with Raniganj tiles at Sonepur Bazari Project.

Photograph 2: Single storey two room unit of brick and mud with cement plaster and Raniganj tiles at Sonepur Bazari Project.

Photograph 3: Double storey three room RCC structure at Sonepur Bazari Project.

Photographs 1-3 depict the constructed test structures at Sonepur Bazari Project. Test structures constructed at Kusmunda Project were also of similar types and attempt was made to use the similar construction materials at both the experimental sites.

Instrumentation and measurement techniques

Ground vibrations from blasting were typically measured with motion-sensing transducers attached to digital recorders. The peak particle velocity was measured simultaneously by deploying 6-12 seismographs in all the structures at various points. Those were namely BlastMate III and MiniMate plus, MiniMate Blaster, MiniMate DS-077 (made in Canada by M/s Instantel Inc.), SSU 3000 LC (made in USA by M/s Geosonics Inc.) and Mini-Seis (made in USA by M/s White Industrial Seismology).

Experimental details

The field trials were conducted at coal, shovel and dragline benches of Sonepur Bazari project. The drill diameters were between 160 and 270 mm. The hole depths varied from 4 to 33 m. The burden was in the range of 3 to 8.5 m. Similarly, spacing varied from 4 to 9.5 m. The number of holes detonated in a blast round varied from single hole to 60 holes. The explosive detonated in a blast round was from 100 to 44,800 kg. The explosive detonated in a delay was 50 to 1650 kg. The blasts were initiated with detonating fuse as well as Nonel initiating system. The distance of the test structures from the blasting face varied from 20 to 1800 m. The number of blasts conducted with varying blast designs was 182 and vibration data recorded at various locations and on the test structures were 1073. A propagation plot of recorded vibration data on the ground surface with their respective scaled distance is presented in Figure 1. The frequencies of the blast waves monitored at varying distances are plotted in Figure 2. The field trials were conducted at shovel and coal benches of Kusmunda project. The drill diameters ranged from 160-270 mm. The hole depths varied from 4-20 m. The burden was in the range of 3–8 m. Similarly, spacing was between 3.8 and 9 m. The numbers of holes detonated varied from single hole to 157 holes. The explosive detonated in a blast round varied widely and was in the range of 50-13,905 kg. The explosive detonated in a delay was 50-4,450 kg. The blasts were initiated with detonating fuse as well as Nonel initiating system. The distance of the test structures from the blasting face varied from 10 to 750 m. The blasts conducted with varying blast designs were 159 and vibration data recorded on the structures and in surrounding areas were 798. The propagation plot of recorded vibration data on the ground surface with their respective scaled distances are presented in Figure 3. The frequencies of the blast wave recorded at different distances are plotted in Figure 4. The recorded range of vibration, frequencies along with the amount of explosives detonated, etc., to achieve the objectives of the study is presented in Table 4.

Determination of natural frequency of the structures

The natural frequency of the structures is determined with the help of transfer function tool. The resultant transfer function is the ratio of two frequency spectra. One spectrum, the driving function, is computed from a waveform recorded with a transducer located outside a structure. The second spectrum, the response spectrum, is recorded with a transducer mounted inside the structure. The frequency, at which this resultant transfer function is maximum, is considered as natural frequency of the structure. The Photograph 4 shows the monitoring of response to blast vibration for the test structure made at Kusmunda project.

The structure's above ground parts tend to amplify horizontal ground motion with the amount of response dependent on the vibration frequency, natural frequency of structures and damping. The highest response is expected from the excitation at the structure's natural frequency. The amplification of vibrations in all the test structures was recorded. The plots of amplification recorded in the test structures at the corresponding ground vibration frequencies are presented in Figure 5.

The maximum level of amplification recorded at Sonepur Bazari Project was 5.21 times, whereas at Kusmunda Project it was 5.03 times. This high amplification factor was recorded at the second floor of the RCC structures at both the projects. The amplification factors with respect to frequencies of incoming vibration and the range of the natural frequency for each type of test structure have been presented in the Table 5.

BLAST VIBRATION EFFECTS ON STRUCTURES

An attempt was made to document the initiation of cracks due to blasting in the three types of structures constructed for the experimental purposes. Measurements were made in the structure produced by the ground borne vibration for assessment of potentially damaging blasts. Besides documentation of crack initiations, the continued study of about 20 months enabled to record the cosmetic cracks, minor damage and major damage to the structures due to blasting at

Table 4. Summarised blast details of both the experimental sites.

Name of the project	No. of blasts	No. of PPV data recorded	Range of total explosive weight detonated (kg)	Range of explosive weight per delay detonated (kg)	Range of PPV monitoring distances (m)	Range of recorded PPV (mm/s)	Range of dominant peak frequency (Hz)
Sonepur Bazari	182	1073	100-44,800	50-1,650	20-1800	0.31->254	2.38-38.5
Kusmunda	159	798	50-13,905	50 -4,450	10-750	0.38->254	2.13-39.8
Total	**341**	**1871**	**50 - 44,800**	**50 - 4,450**	**10-1800**	**0.31->254**	**2.13-39.8**

Table 5. Range of amplification of vibrations recorded at the test structures and their frequency range.

S. No.	Locations and type of structures	Range of amplification		Range of frequency contributing maximum amplification	Natural frequency of the structures [Hz]
		Minimum amplification (times)	Maximum amplification (times)		
Sonepur Bazari Project					
1.	RCC structure- Second floor	1.26	5.21	4.5 -11	6.38 - 9.88
2.	RCC structure- First floor	1.05	3.08	2.8 – 11.6	6.13 - 8.25
3.	Brick-mud structure	1.12	2.75	4.3 – 14.0	9.2 - 11.3
4.	Mud Structure	1.0	1.74	3.2 – 6.5	6.25-10.3
Kusmunda Project					
5.	RCC structure- Second floor	1.14	5.03	4.5-21.3	6.63-8.13
6.	RCC structure- First floor	1.12	2.95	2.5-24.3	6.25-7.88
7.	Brick-mud structure	1.11	2.63	5-20.3	6.0-14.8
8.	Mud structure	1.08	1.95	4.8-21.5	9.13-12.8

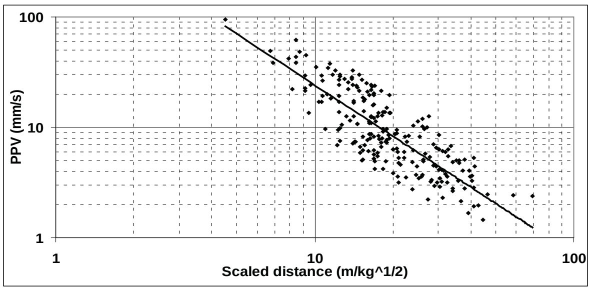


Figure 1: Propagation plots of vibration data recorded on ground surface near the foundation of structures with their respective scaled distances at Sonepur Bazari project.

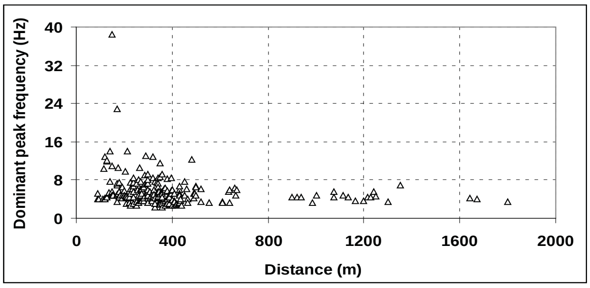


Figure 2: Plot of dominant peak frequencies recorded at various locations at ground surface at Sonepur Bazari project.

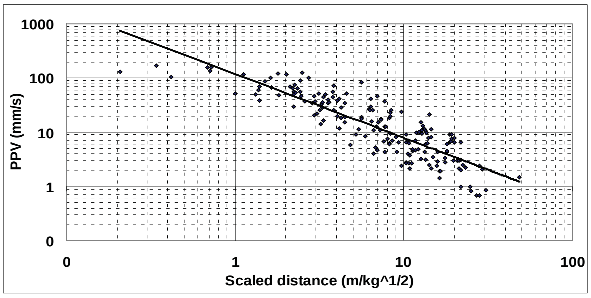


Figure 3: Propagation plots of vibration data recorded at ground surface near the foundation of structures with their respective scaled distances at Kusmunda project.

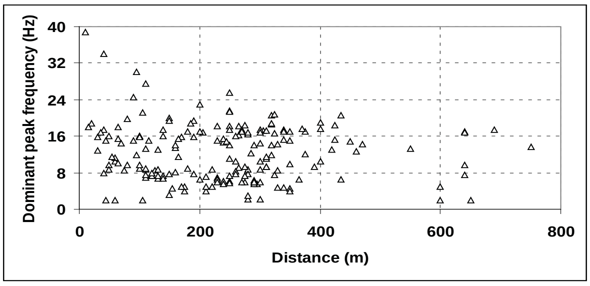


Figure 4: Plot of dominant peak frequencies recorded at various locations at ground surface level at Kusmunda project.

Photograph 4: Monitoring of response of the brick-mud structure with cement plaster to blast induced vibration at Kusmunda Project.

both the experimental sites.

Damage observed in structures and classification thereof

The brick-mud wall with cement plaster and RCC test structures were whitewashed with distemper so that the cosmetic cracks can be visually observed. The test structures were closely inspected visually and also by crack monitor gauges. Photographs were also taken with the help of digital and video cameras for the existing as well as newly formed cracks in the structures after each of the blasts. The level of damage in the test structures was influenced by peak particle velocity and its associated frequency. The effects of repeated blasting also played significant role in extending the existing cracks in the structures.

Based on the observed damages an attempt was made to classify them according to the peak particle velocity with associated dominant peak frequency.

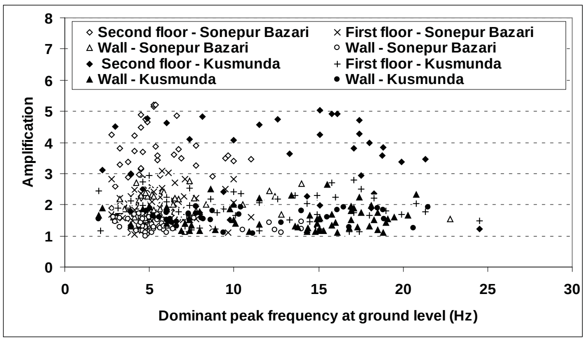


Fig 5: Amplification of vibration at all the test structures of Sonepur-Bazari and Kusmunda projects.

The damages were classified in four categories (Table 6). These are No damage, Cosmetic damage, Minor damage and Major damage. The level of vibration below the cosmetic damage level has been termed as No damage level and it has been considered as the threshold limit of vibration for the safety of residential buildings and other structures in mining areas.

Study of damage in the test structures at Sonepur Bazari project

The blast vibration monitoring on the newly constructed test structures was commenced on 10 January, 2004. The study continued upto 22 June, 2006. Attempt was made to record vibrations simultaneously in all the structures for a blast. The vibration impacts were monitored for all the major blasts conducted in the mine. A blast conducted on 06.10.2004 at third overburden bench with explosive weight per delay of

Table 6. Damage classification.

Uniform Classification	Description of damage
Threshold limit	Visually no crack/deformation in the wall of the structure due to blasting.
Cosmetic damage	Loosening of paint; small plaster cracks at joints between construction elements; initiation of hairline cracks, lengthening of old cracks.
Minor damage	Loosening and falling of plaster; cracks in masonry around openings near partitions; hairline to 3 mm cracks, fall of loose mortar/plaster.
Major damage	Cracks of several millimetres in walls; rupture of opening vaults; structural weakening; fall of masonry; detachment of bricks from the walls, etc.

800 kg and total explosive of 9750 kg caused cosmetic cracks in a small portion of the structures. The blast face was 245 m away from the test structures. The recorded vibration on the window of the brick-mud structure was 56.3 mm/s with dominant peak frequency of 6 Hz. The vibration recorded on the ground floor and first floor of the RCC structure was 47.8 and 71.2 mm/s respectively. The dominant peak frequency in the latter was 6.2 Hz. The Photograph 5 depicts the initiation of cosmetic cracks in the brick-mud and RCC structures.

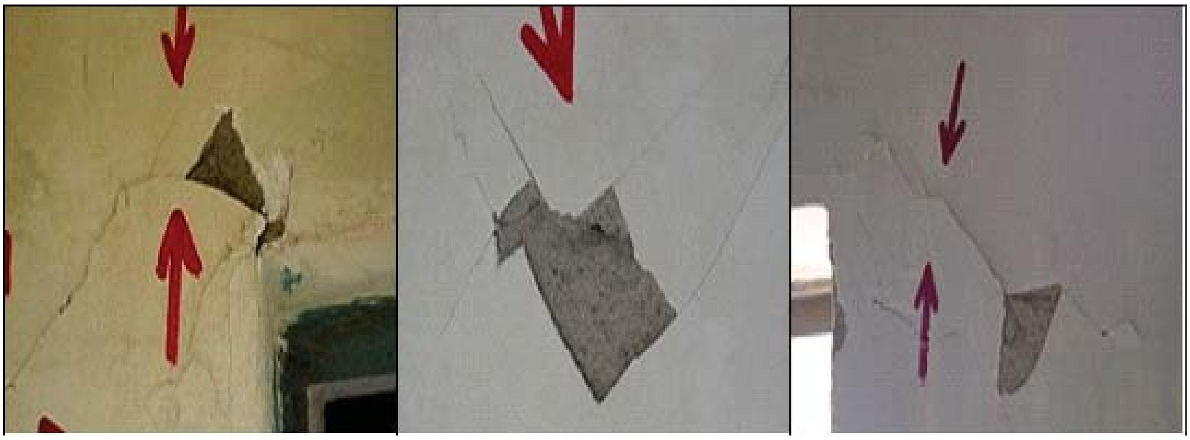
The monitoring of vibration was continued and elongation of cosmetic cracks was documented. The recorded vibrations after development of the cosmetic cracks were of lower magnitude, so there was no extension of cosmetic cracks. A blast conducted on 15.01.2005 at first overburden bench with explosive weight per delay of 800 kg caused minor damage in almost all the structures. The blast face was 175 m away from the structures and explosives detonated in the blast round was 5,970 kg. The recorded vibrations in the test structures were: mud house, 55 mm/s with associated dominant peak frequency of 4.38 Hz; wall of brick-mud house, 81.0 mm/s and dominant peak frequency, 5.0 Hz; RCC structure, first floor, 98.3 mm/s and dominant peak frequency, 5.6 Hz. The minor damage observed within the structures for the corresponding vibration and frequencies mentioned above is shown in Photograph 6.

The first major damage was recorded in almost all the

Photograph 5:The view of the cosmetic cracks developed in the brick-mud house and at the first floor of the RCC structures on 06.10.2004 at Sonepur Bazari Project.

Photograph 6. View of the minor damage at the first floor of the RCC structure at Sonepur Bazari Project.

structures on 12.08.2005 after an interval of 20 months of continued vibration monitoring in the structures. The blast face was only 105 m away from the structures. The blast conducted contained 4,420 kg of explosives in 23 holes and was detonated with explosive weight per delay of 400 kg. The recorded vibration level in the mud house was 87.1 mm/s with dominant peak frequency of 6.13 Hz and in brick-mud structure it was 99.6 mm/s with dominant peak frequency of 7.4 Hz whereas the first floor of RCC structure experienced the vibration of 128.9 mm/s with dominant peak frequency of 14.1 Hz. The damages observed in the respective structures are shown in Photograph 7. The major damage was recorded in all the structures except in the ground floor of the RCC structure. However, minor damage was developed in the ground floor of the RCC structure. The first floor of the RCC structure was badly damaged. The measurements of dislodgement of big plaster etc. were documented. It was recorded that when blast face was only 20 m from the structures (Photograph 8) the mud house collapsed totally but the brick-mud and RCC structures were standing with major damage in plaster.



Photograph 7: Views of the major damages at the first floor of the RCC test structure on 12.08.2005 at Sonepur Bazari Project.

Photograph 8: The view of the location of the test structure on 22.04.2006 indicating working benches at 20 m from structures at Sonepur Bazari Project.

Study of damage in the test structures at Kusmunda project

The continuous monitoring of four months did not show any deformation in the structures, although, 42 blasts were conducted and the blast face advanced from 435 to 256 m towards the test structures. The first cosmetic cracks were observed at vibration level of 51.6 mm/s with dominant peak frequency of 19.8 Hz monitored at wall of brick-mud structure. The blast was conducted at top shovel bench, 180 m away. The maximum explosive weight per delay and total explosive detonated in the blast were 2,600 and 5,100 kg respectively. The cosmetic cracks at the first floor of RCC structure was developed on 29.03.2006 at vibration level of 72.2 mm/s with dominant peak frequency of 17.3 Hz. The corresponding blast was performed at second bench, 135 m away from the RCC structure. Explosive detonated in the blast round was 2,330 kg and explosive weight per delay was also 2,330 kg. Some views of the cosmetic cracks at the first floor of the RCC structure are shown in Photograph 9.

Fifteen holes were drilled at 78 m from the test structures and were loaded with 4,500 kg of explosives. The blast was detonated with the maximum explosive weight per delay of 1,800 kg on 27.04.2006. All the test structures developed cosmetic or minor damage due to this blast. Vibrations were recorded simultaneously

this blast. Vibrations were recorded simultaneously on all the test structures. The mud house experienced vibration of 56.1 mm/s with peak dominant frequency of 21.1 Hz and suffered minor damage. The ground floor and the first floor of RCC structures developed cosmetic cracks and minor damage respectively. The corresponding vibration levels recorded was 68.6 mm/s with peak dominant frequency of 18.1 Hz on the ground floor and 118 mm/s with peak dominant frequency of

Photograph 9. Some views of the cosmetic cracks developed at the first floor of the RCC test structure on 29.03.2006 at Kusmunda Project.

on all the test structures. The mud house experienced vibration of 56.1 mm/s with peak dominant frequency of 21.1 Hz and suffered minor damage. The ground floor and the first floor of RCC structures developed cosmetic cracks and minor damage respectively. The corresponding vibration levels recorded was 68.6 mm/s with peak dominant frequency of 18.1 Hz on the ground floor and 118 mm/s with peak dominant frequency of 5.16 Hz on the first floor. Brick-mud structure also suffered minor damage. The vibration recorded was 89.7 mm/s with peak dominant frequency of 19.5 Hz. The Photograph 10 depicts the damage observed in the RCC structure.

Fifteen holes were drilled at 78 m from the test structures and were loaded with 4,500 kg of explosives. The blast was detonated with the maximum charge weight per delay of 1,800 kg on 27.04.2006. All the test structures developed cosmetic or minor damage due to

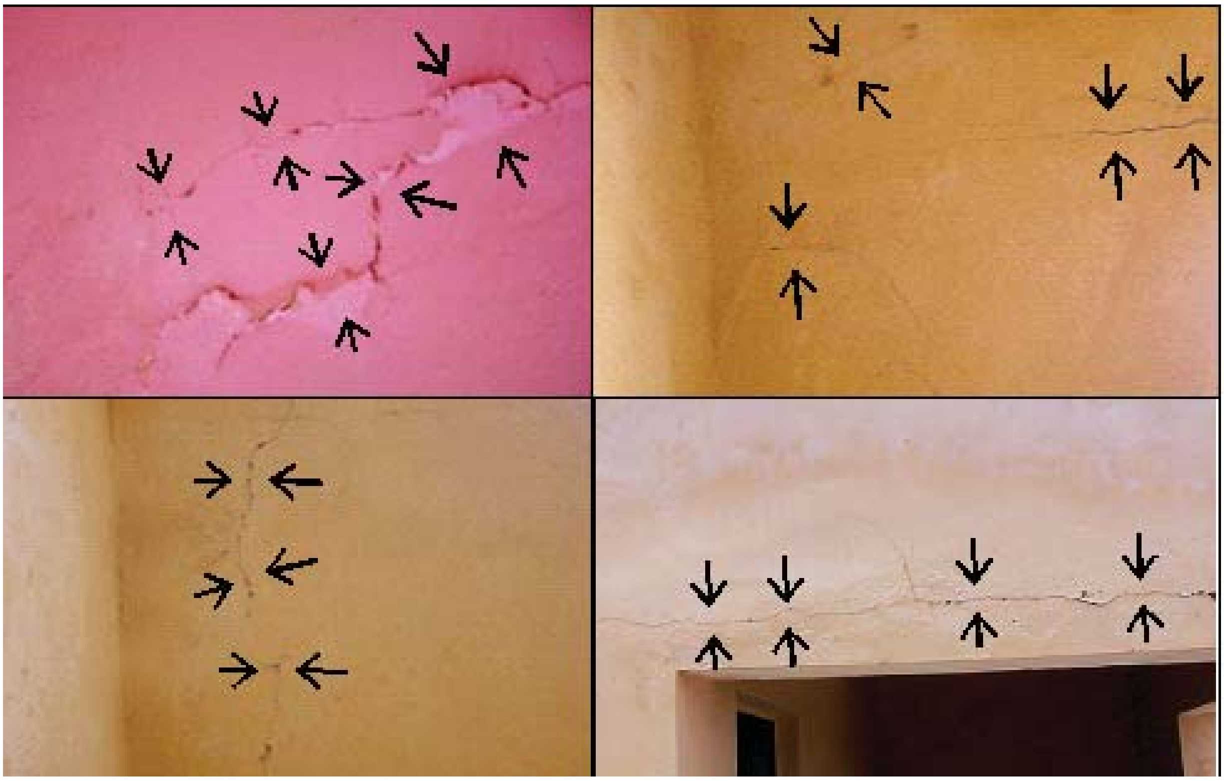
5.16 Hz on the first floor. Brick-mud structure also suffered minor damage. The vibration recorded was 89.7 mm/s with peak dominant frequency of 19.5 Hz. The Photograph 10 depicts the damage observed in the RCC structure.

As the blast face approached closer and closer to the structures, the monitoring of vibration revealed increase in vibration levels in the test structures. As a result, extension of minor damage was also observed in almost all the test structures. When the blast face was only 55 m away from the test structures, 53 holes were drilled and loaded with 11,907 kg of explosives. The blasting was conducted by detonating fuse keeping maximum explosive weight per delay of 3,890 kg on 10.05.2006. The major damage was noticed in all the structures. The vibration generated from the aforesaid blast on the first floor of the RCC test structure was 161 mm/s with dominant peak frequency of 14 Hz.

The damaged condition of first floor of RCC structure is shown in Photograph 11. The major damage found in the brick-mud structure due to the above mentioned blast conducted on 10.05.2006 was at the vibration level of 113 mm/s with dominant peak frequency of 7.5 Hz. Mud structure also developed major damage at PPV of 104 mm/s with dominant peak frequency of 18.9 Hz.

A blast was performed, when the face was only 35 m away from the structure (Photograph 12), with 22 holes loaded with 5,223 kg of explosives. The maximum explosive weight per delay was 2,750 kg. The major damage was developed in the ground floor of the RCC test structure. The recorded PPV was 122 mm/s with dominant peak frequency of 13.4 Hz.

Further, the mine management was requested to extend the blasting face to 10 m from the test structures to document the impact of heavy blasting on collapse characteristics of the structures. All the structures remained standing having major damage in their walls but did not collapse. Although the vibrations experienced by them were more than 254 mm/s. The recorded damage levels in all the test structures corresponding to peak particle velocity and its frequencies are presented in Table 7.

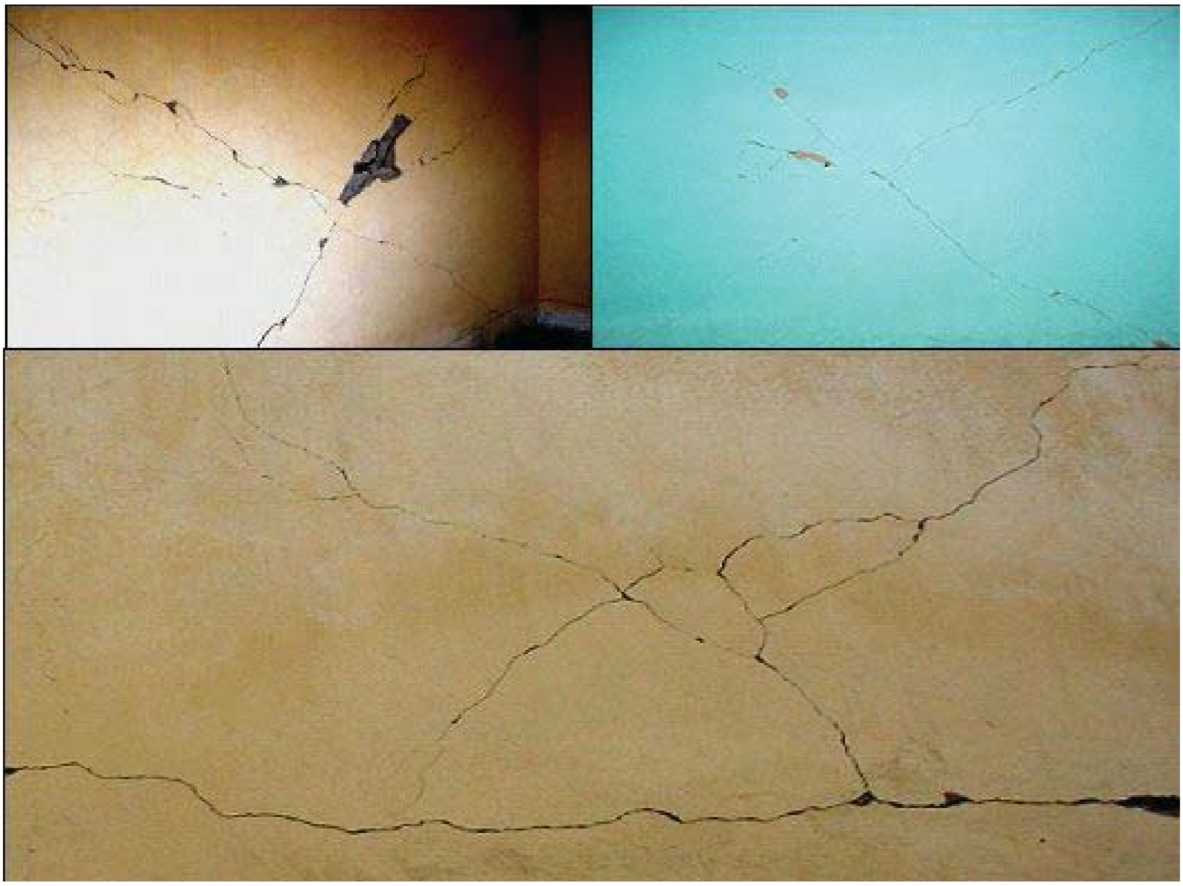


Photograph 10. Some views of the minor damages recorded in the first floor of the RCC test structure on 27.04.2006 at Kusmunda Project.

DISCUSSIONS AND CONCLUSIONS

The amplification of vibration recorded in the mud house at both the sites was in the range of 1.0 to 1.95 times. The corresponding excitation frequency was in the range of 3.2 to 21.5 Hz. The natural frequency of the mud houses was between 6.25 and 12.8 Hz. Similarly, the amplification of vibration recorded in the brick-mud house of both the sites was in the range of 1.11 to 2.75 times. The corresponding excitation frequency was from 4.3 to 20.3 Hz. The natural frequency of the brick-mud houses was between 6 and 14.8 Hz.

The amplification of vibration recorded in the first floor of RCC structures at both the sites was in the range of 1.05 to 3.08 times. The corresponding excitation frequency was from 2.5 to 24.3 Hz. The natural frequency of the first floor of the RCC structure was between 6.13 and 8.25 Hz. The amplification of vibration recorded in the second floor of the RCC structures was in the range of 1.14 to 5.21 times. The corresponding excitation frequency was in the range of 4.5 to 21.3 Hz. The natural frequency of the second floor of RCC structure was between 6.38 and 9.88 Hz. Normally, most of the structures have natural frequency less than 15 Hz. However, a few structures do have natural frequency upto 20 Hz. Figure 6 represents the range of natural frequencies of the 69 structures which recorded data revealed that the maximum concentration of vibration energy was in the range of 3.3-9.2 Hz. The structures studied had fundamental frequencies between 6 and 14.8 Hz. The incoming vibrations thus had frequency in the range of natural frequency of the structures, causing resonance of frequencies in the structures and hence amplification of vibration within the structure. This is the reason why the structures at



Photograph 11. Some views of the major damages developed in the first floor of the RCC structure on 10.05.2006 at Kusmunda Project.

were subjected to blasting vibration under this study as well as various previous studies in Indian mines.

The maximum amplifications occurred at resonance frequencies because of low differential responses. The frequencies below resonance did not show amplifications because there was no relative displacement and hence, no appreciable strain. The frequency of blast vibration recorded was less than 15 Hz in 94% of the recorded data. These low frequencies were perhaps due to the low-velocity surface layer (top soil) and the far-field monitoring locations. Frequency spectra analysis of higher floors vibrated with higher amplitudes than those closer to the ground. The recorded frequencies of ground vibration were categorised in three groups based on the response characteristics of the structures.

1. Low frequency (<15 Hz): The natural frequencies of structures studied were between 6 and 14.8 Hz. The maximum amplification of vibration was recorded in the dominant peak frequencies of 2.8 to 14 Hz.
2. Medium frequency (15-30 Hz): The frequency above the natural frequencies of the structures.

Photograph 12. A view of the blasting site at 35 m away from the structures at Kusmunda Project.

The moderate amplification of vibration was recorded in the structures.

3. High frequency (> 30 Hz): The frequency much higher than the natural frequencies of the structures. No amplification of vibration was recorded in the structures.

SAFE LEVEL OF GROUND VIBRATION

The researchers all over the globe have studied human response to ground vibration and conjured on a same opinion regarding the house owner's chief concern about their house. The house owners always remain under the fear that their houses could be or being damaged by the blast vibrations. The perceptibility levels of human being vary from person to person and also depend upon the age and health. The reported perceptibility level ranged from 2 to 19 mm/s depending upon the frequency of blast events. The perceptibility level of human beings is far below the threshold limit of vibration. The non-blasting sources also produce significant vibration levels such as movement of heavy vehicles, trains, etc. Environmental changes and human activities produce strains equivalent to 12-15 mm/s and even higher in some cases (Dowding, 1992; Siskind, 2000).

The cosmetic cracks were detected in brick-mud houses for PPV of 51.6 to 56.3 mm/s. The highest amplification of vibration was due to resonance recorded in the window of the brick-mud house was 2.75 times. Thus, it was estimated that the vibration near the foundation of the brick-mud structures was 18.76 mm/s which initiated cosmetic cracks in brick-mud house. Similarly, cosmetic cracks detected in RCC structures were due to PPV of 68.6 to 72.2 mm/s. The highest amplification of vibration due to resonance was 5.21 fold in the RCC structures. It was estimated that vibration near the foundation of the RCC structures was 13.16 mm/s which initiated cosmetic cracks in RCC structure. It was difficult to record the cosmetic cracks in the mud house.

The minor and major damages recorded in the mud house were for a PPV range of 55-56.1 and 87.1-104 mm/s respectively. The highest amplification of 1.95 times due to resonance was recorded in the window of the wall. The estimated vibration level near the foundation of mud house which might have caused minor and major damage was 28.2 and 44.6 mm/s respectively.

The minor and major damages recorded in the brick-mud houses were due to PPV of 81-89.7 and 99.6-113 mm/s respectively. The highest amplification of 2.75 times was recorded due to resonance in the window of the wall. Thus, the estimated vibration level near the foundation of brick-mud house which might have caused minor and major damage was 29.45 and 36.2 mm/s respectively.

The minor and major damages recorded in the RCC structures at ground and first floor were for PPV of 98.3-118 and 122-161 mm/s respectively. The highest amplification of 5.21 times was recorded due to resonance in the window of the wall. The estimated vibration level near the foundation of RCC structure which might have caused minor and major damage would be 18.86 and 23.41 mm/s respectively.

The cosmetic cracks found in the test structures due to blasting were for PPV of more than 50 mm/s. The vibrations measured outside and close to the structures of concern should have PPV of 18.76 for low rise houses and 13.16 mm/s for high rise structures, considering

Table 7. Details of damage levels at Sonepur Bazari and Kusmunda Projects

Type of structure	Cosmetic crack level (PPV) and dominant peak frequency (Hz)	Minor damage level (PPV) and dominant peak frequency (Hz)	Major damage level (PPV) and dominant peak frequency (Hz)	Maximum amplification of vibration in structure (times)
Sonepur Bazari Project				
Mud structure	-	55.0 mm/s, 4.38 Hz	87.1 mm/s, 6.13 Hz	1.74
Brick-mud structure	56.3 mm/s, 6 Hz	81.0 mm/s, 8.4 Hz	99.6 mm/s, 7.4 Hz	2.75
Ground floor of the RCC structure	71.3 mm/s, 5.0 Hz	No minor cracks	No major cracks	3.08
First floor of the RCC structure	71.2 mm/s, 6.2 Hz	98.3 mm/s, 5.6 Hz	128.9 mm/s, 14.1 Hz	5.21
Kusmunda Project				
Mud structure	-	56.1 mm/s, 21.1 Hz	104 mm/s, 18.9 Hz	1.95
Brick-mud structure	51.6 mm/s, 19.8 Hz	89.7 mm/s, 19.5 Hz	113 mm/s, 7.5 Hz	2.63
Ground floor of the RCC structure	68.6 mm/s, 18.1 Hz	104 mm/s, 6.0 Hz	122 mm/s, 13.4 Hz	2.95
First floor of the RCC structure	72.2 mm/s, 17.3 Hz	118 mm/s, 19.5 Hz	161 mm/s, 14.0 Hz	5.03

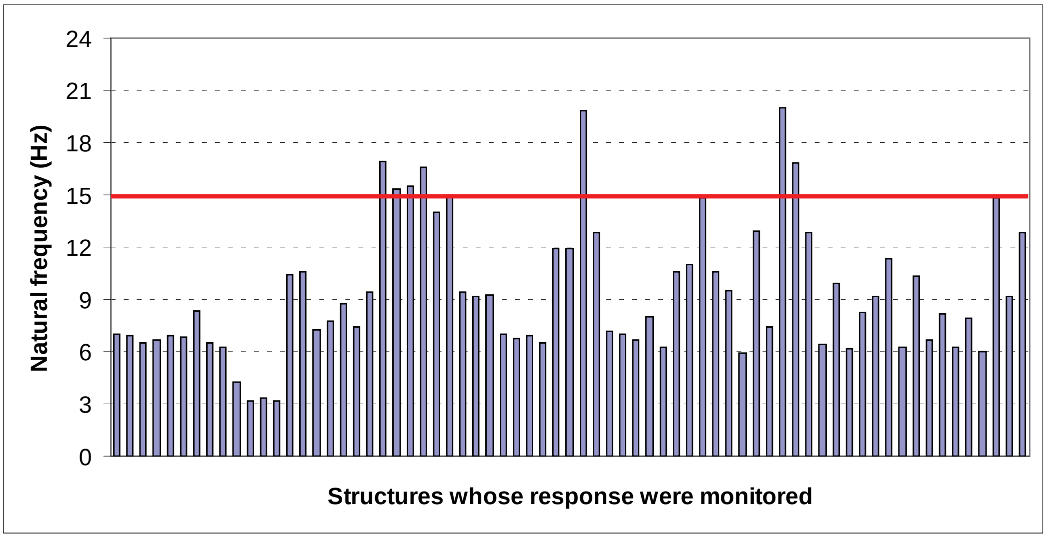


Figure 6. The natural frequency of structures found in the periphery of Indian mines.

Table 8. Recommended peak particle velocity (PPV) in mm/s at the foundation level of buildings/ structures in mining areas.

Type of structure	Peak particle velocity (PPV) in mm/s		
	Dominant frequency (< 15 Hz)	Dominant frequency (15-30 Hz)	Dominant frequency (> 30 Hz)
(A) Buildings/structures not belonging to the owner			
1. Domestic houses/structures (Kuchcha, brick-mud, brick-cement)	12	20	25
2. Industrial buildings	18	30	40
3. Objects of historical importance and sensitive structures	5	7	10
(B) Buildings belonging to the owner with limited span of life			
1. Domestic houses/structures	18	30	40
2. Industrial buildings	30	40	50

the resonance of frequencies, to cause cosmetic cracks. These levels of vibrations can be experienced by the houses/structures due to movement of residents in the house, temperature and humidity and upto some extent winds. The minor damage level recorded in mud house was at PPV of 55.0 mm/s. The mud house response characteristic to blast vibration was of meagre in nature. However, the recorded minor damage in the other brick-mud houses were due to PPV more than 81 mm/s for low rise house and 98.3 mm/s for RCC structures.

Despite these high observed values, the threshold limits of vibrations for different types of structures in mining areas have been recommended at a significantly lower level (Table 8). This is based not only on the structural response and actual observations of cracking/ damage in test structures from the blasts conducted at the mines but also considering the fact that these structures were newly constructed for the purpose of the study and therefore may have superior vibration resistance than similar but much older structures.

It should also be noted that these recommendations are based on repeated blasting effects on structures and therefore for limited span of blast loading on the structures the threshold vibration levels would be much higher than observed in this study. In view of these facts, the recommended threshold levels, although higher than current regulation, should be considered as very conservative.

RECOMMENDATIONS

The frequency of blast vibration recorded was less than 15 Hz in 94% of the recorded data. These low frequencies were perhaps due to the low-velocity surface layer (top soil) and the far-field monitoring locations. The structures studied had fundamental frequencies between 6 and 14.8 Hz. The incoming vibrations thus had frequency in the range of natural frequency of the structures, causing resonance of frequencies in the structures and hence amplification of vibration within the structure. This is the reason why the structures at higher floors vibrated with higher amplitudes than those closer to the ground.

The cosmetic cracks found in the test structures due to blasting were for PPV of more than 50 mm/s. The vibrations measured outside and close to the structures of concern should have PPV of 18.76 for low rise houses and 13.16 mm/s for high rise structures, considering the resonance of frequencies, to cause cosmetic cracks. The minor damage level recorded in mud house was at PPV of 55.0 mm/s. However, the recorded minor damage in the other brick-mud houses were due to PPV more than 81 mm/s for low rise house and 98.3 mm/s for RCC structures.

The threshold limit of vibrations for different type of structures has been recommended (Table 8) considering the safety and long term stability of the houses and other structures in mining areas. It is hoped that Directorate General of Mine Safety (DGMS) will consider modifying the existing technical circular 7 of 1997 regarding blast vibration by adopting the recommended threshold limit of vibration (Table 8) for the safety of building and other structures in mining areas.

References

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