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Delineation of coal barrier thickness in underground coal mines to mitigate inundation hazards – case studies

Disaster due to inundation is one of the major threats of coal mines. Sudden heavy inrush of high volume of water from the unapproachable and unknown waterlogged workings in underground mines is defined as inundation. 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 many coal producing countries and may occur in future until a suitable tool to investigate barriers thickness is in regular use. Directorate General of Mines Safety (DGMS) has stipulated that a safety barrier thickness of not less than 60 m must be maintained between abandoned workings and contemporary mine developments. It has been estimated that a large number of underground coal mines in India are under threat of adjacent unknown waterlogged mine workings. Therefore, evaluation of barrier thickness up to 60 m is essential to prevent mine disasters due to inundations.

Considering the above facts, a new GPR system named MineVue radar is developed having depth of penetration of 60 m subject to geo-mining conditions of Indian coal mines first time in the world. Final trial of the developed MineVue radar system was done at the Kachhi Balihari colliery of Bharat Cocking Coal Limited (BCCL), Dhanbad. The validation of GPR data in the known mine sites were done with accurate existing mine-plans to establish the reliability and confidence of mine operators, policy makers and safety personnel.

Key words: *Inundation, MineVue, GPR, barrier, old workings.*

Introduction

Disaster due to inundation is one of the most hazardous incidents that take place in a mine. The problem of detecting abandoned colliery workings and evaluation of barrier thickness appears to be specific to this country. A review of previous works on the subject in the geophysical literature, did not offer any effective solution to this problem. Earlier attempts made in India met with only nominal 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. Unknown dimension of barrier pillars and not-knowing precise location of adjacent old workings are the primary stumbling block, adversely affecting the production and safety in underground mines. Mine safety and planning need to be sensitized, 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 challenge to researchers and mine operators. Where barriers have been breached, the inrush of water under pressure often resulted into the loss of life and equipment (Jha, P. et al, 2004).

One of the major causes of disaster in underground mines is inundation due to accidental connection with old waterlogged workings. Old workings are usually not approachable and often the old mine plans available for such workings are not accurate enough to indicate the exact thickness of barrier existing between the earlier and present workings. 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 equipment. In coal mining countries this type of disaster has occurred and may occur in future until a suitable tool to investigate barriers thickness is in regular use. Inter-mine barrier is an effective means to prevent transfer 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. As per Directorate General of Mines Safety (DGMS) (Tech) Circular No.5 of 2003 (Recommendations of Bagdigi Court of Inquiry), connection between adjoining old water logged workings and current workings may likely to take place due to eating away of the prescribed coal barrier between the two. DGMS has stipulated that a safety barrier thickness of not less than 60 m must be maintained between abandoned workings and contemporary mine developments (Ralston and Jonathan, 2000) as shown in Fig.1. It has been

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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 prevent mine disasters due to inundations.

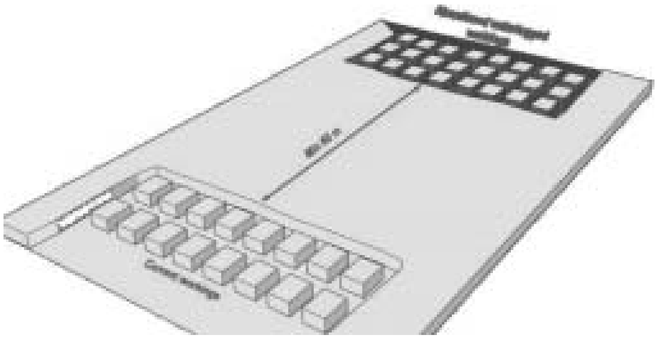

Fig.1 Illustration of current workings approaching abandoned waterlogged workings

The proving of barrier or parting by conventional surveying is arduous and time taking, while proving the same by means of long boreholes, drilled by safety boring machines, requires special machines, skilled operators and adequate arrangements at the colliery. Various government agencies in India have experimented with a number of geophysical methods over the last 30 years in an effort to supplement or replace exploratory drilling. Ground penetrating radar (GPR) technology has shown the greatest potential to provide rapid a priori information ahead of a working face and can provide redundant data with better reliability for prediction of barrier thickness. Since the 1970s, GPR has been used extensively mainly in solving a different types of civil engineering problems, some of which were alike the problems of the mining industry. Geophysical methods can give better but indirect solutions after delineating different geotechnical problems in the mining areas (Momayez et.al., 1996; Cook, 1975). Among the geophysical methods, GPR, barring some limitations is the most feasible technique for shallow workings (Singh, 2003) and for delineation of barrier thickness in underground coal mines to check inundation hazard. Depending on geological conditions of the area, it can produce continuous high-resolution profiles of the surface rapidly and efficiently (Benson, 1995; Beers and Haeni, 1989). Nowadays, the GPR is significantly used in identifying and locating subsurface features such as cavities, conduits, fractures and buried caves (Momayez et al., 1996; Grasmueck, 1996).

Methodology

GPR technique depends on the emission, transmission, reflection and reception of an electromagnetic pulse. Depending on geological conditions of the area it can produce continuous high-resolution profiles of the subsurface rapidly and efficiently. The GPR is also used for delineation of underground structures (Singh and Chouhan, 2000 and 2002). In recent times, the GPR is significantly used in identifying and locating subsurface features such as cavities, conduits, fractures and buried caves (Momayez et al., 1996; Grasmueck, 1996). From the literature survey it is known that presently no GPR system is commercially available to penetrate 50-60 m in coal today. The biggest limitation of available GPR today is that they are not built for the mining industry and its geo-environmental parameters. This would also not solve the problem of inundation as the question of evaluating the barrier thickness up to 60 m with better accuracy is still not available.

Under a mega project funded by the Ministry of Coal, Government of India, a new GPR system named MineVue having depth of penetration of 60 m subject to geo-mining conditions of Indian coal mines is developed first time in the world. The developed radar system has following special characters:

(a) First intrinsically safe GPR in the world for coal mines,

(b) First low-frequency (40MHz) shielded radar in the world,

(c) First shielded real-time sampling radar in the world,

(d) First single-board radar in the world (transmitter, receiver and console unit are all on one small circuit board,

(e) Deepest penetrating shielded radar in the world.

During the final trial of the developed MineVue radar system, one coal mine namely Kachhi Balihari colliery of Bharat Cocking Coal Limited (BCCL) was selected. Radar survey was carried out along seven sites (over seven underground panels) in this mine using MineVue system as shown in Fig.2. During the survey, MineVue radar was simply dragged on the coalface so that electromagnetic waves can penetrate in the coal seam and after reflection from any geological homogeneity like fault, slip etc. reflect back on the surface of the coal seam. The reflected waves were recorded on a handy data logger having blue-tooth facility as shown

Fig.2 Illustration of survey procedure in underground coalmines using MineVue radar

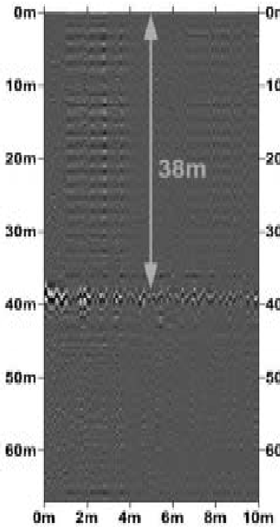

Fig.3 MineVue data along 1st X-cut between 3 and 4 dip at K.B. colliery, BCCL

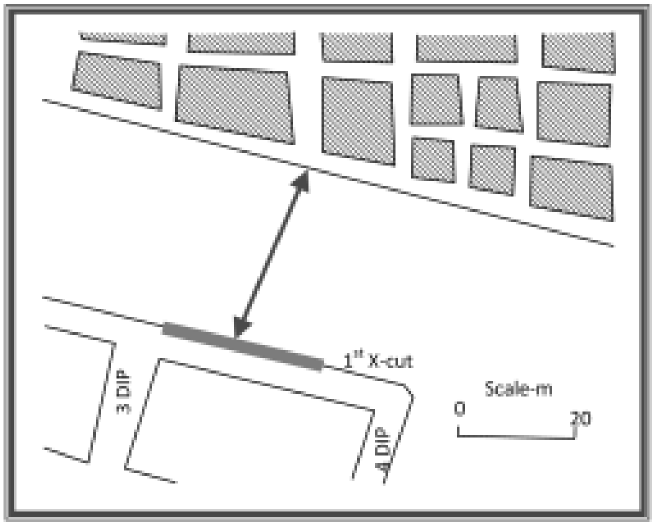

Fig.4 Radar traverse along 1st X-cut between 3rd and 4th dip at K.B. colliery, BCCL

the selected sites at Kacchi Balihari colliery of P.B. area, BCCL. Kachhi Balihari (K. B.) colliery, P.B. area of BCCL, Dhanbad is situated at 1.5 km from Kerkend railway station and 1.0 km from N.H.-32 Road (Pootkee). The uppermost seams (XVIII and XVII) are depillared and exhausted, which may contain water. The underlying XVI seam, 112 m vertically below from the surface which is mostly depillared and partly standing on pillars and only pumping is being done from XVI seam. The next underlying XV seam, 6.55 m thick, is developed by bord and pillar method and presently being depillared. In working XV seam, only strata water and stowing water accumulated in main sump, which is pumped out at surface by regular pumping. GPR surveys were carried out in XV seam at seven locations in this underground mine for delineation of barrier thickness.

in Fig.2. After that, data processing was done using reflex software after downloading the collected data from data-logger to computer.

The validation of GPR data in the known mine sites were done with accurate existing mine-plans to establish the reliability and confidence of mine operators, policy makers and safety personnel.

Location of sites and mining details

Experimental sites were selected for the experimentation using developed MineVue radar system during the final trial of the developed radar system. Selection of sites was based on the availability of the suitable locations with known geological conditions, thickness of barrier, size of the galleries (Dry and Waterlogged) and known mine plans for the verifications of the GPR data. Final trials were carried out at the selected sites at Kacchi Balihari colliery (continued above)

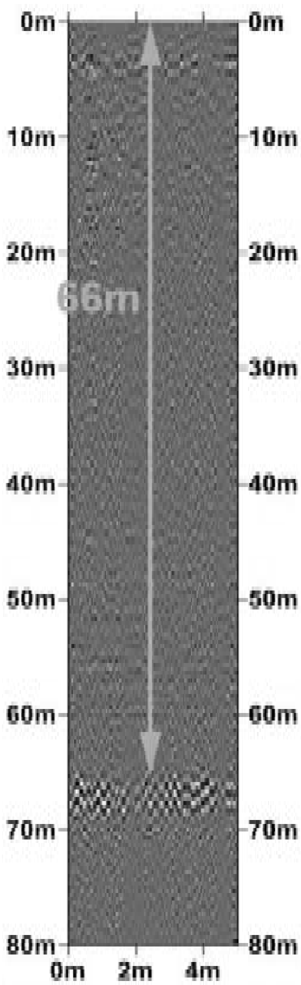

Fig.5 Minevue data along 7th rise of 2nd X-cut at K. B. colliery, BCCL

Data analysis and interpretation

Final trials of the developed MineVue system were conducted at the proposed mine sites along seven panels of underground coal mine at Kachi Balihari colliery of P. B. Area, BCCL in the presence of mining officials of BCCL, CMPDIL, S&T Division and DGMS, Central Zone. Seven underground panels were selected and surveyed at K. B. colliery with MineVue to detect the thickness of the barriers/panels.

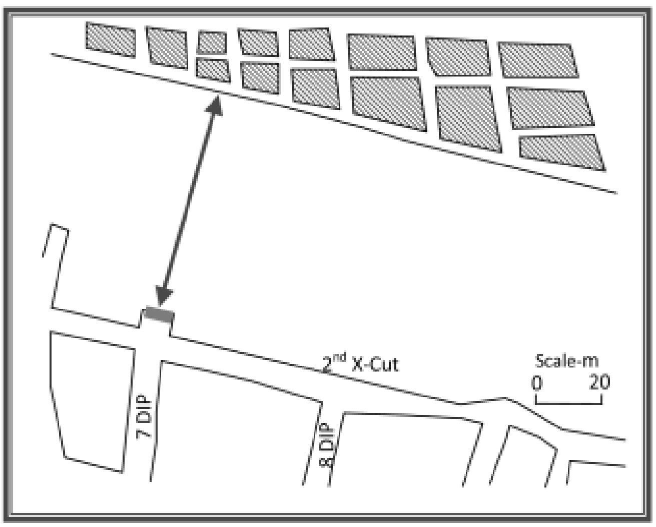

Fig.6 Radar traverse along 7th rise of 2nd X-cut at K.B. colliery, BCCL

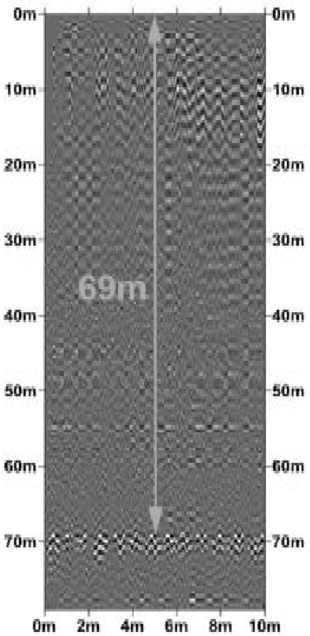

Fig.7 MineVue data along 2nd X-cut between 7th and 8th dip at K.B. colliery, BCCL

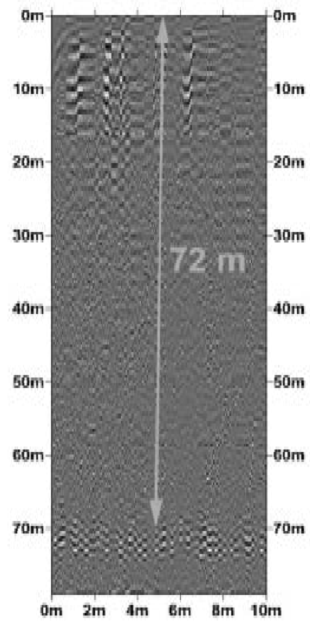

Fig.9 MineVue data along 2nd X-cut between 8th and 9th dip at K.B. colliery, BCCL

Radar data from the first site, located along 1st X-cut between 3 and 4 dip at K. B. colliery, BCCL clearly shows a dry tunnel at approximately 38 m from the wall, as shown in Fig.3. The mine part-plan shown in Fig.4 agrees with this interpretation.

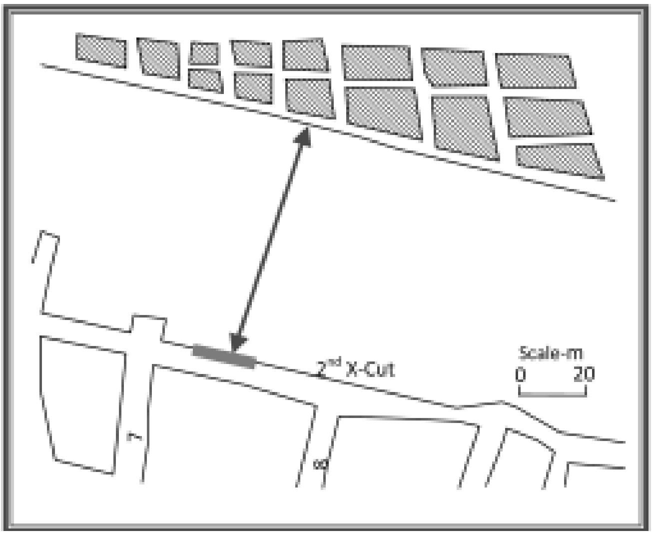

Fig.8 Radar traverse along 2nd X-Cut between 7th and 8th dip at K.B. colliery, BCCL

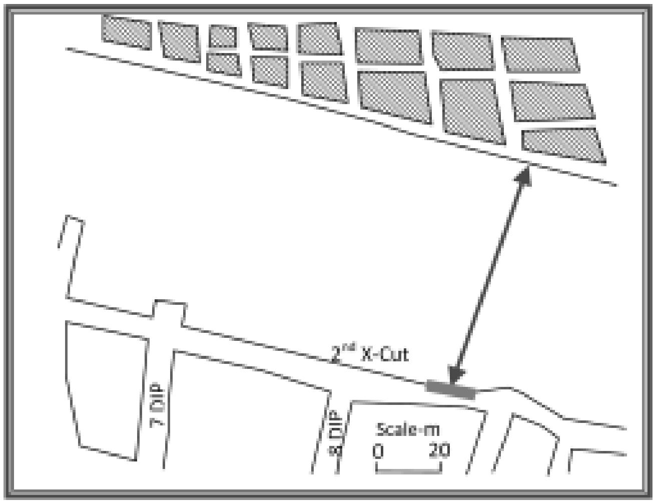

Fig.10 Radar traverse along 2nd X-cut between 8th and 9th dip at K.B. colliery, BCCL

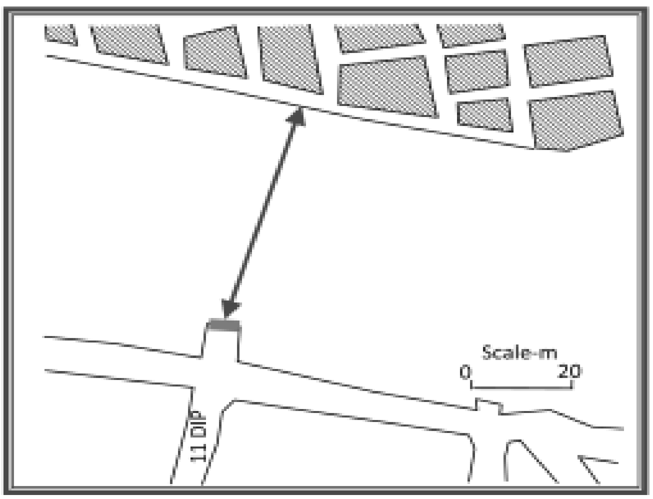

Fig.12 Radar traverse along 11th rise of 2nd X-cut at K.B. colliery, BCCL

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 a distance of 66 m from the coalface (Fig.5), which is also being confirmed by the mine plan shown in Fig.6.

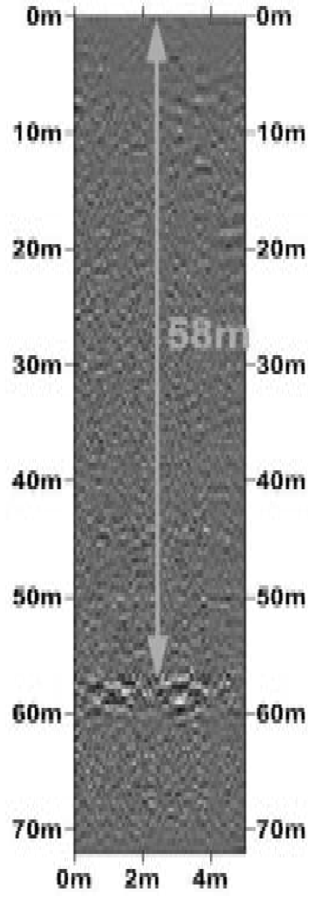

Fig.11 MineVue data along 11th rise of 2nd X-cut at K.B. colliery, BCCL

The third site was surveyed along 2nd X-cut between 7th and 8th dip at K.B. colliery, BCCL. Radar data indicates that waterlogged gallery/tunnel may be there at a distance of 69 m from the coalface (Fig.7), which is being confirmed by surveyor's part-plan as shown in Fig.8.

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

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 (Fig.11). This is confirmed by part-plan as shown in Fig.12.

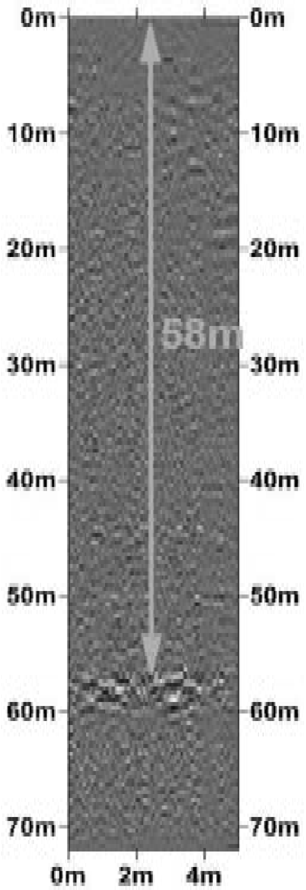

Fig.13 MineVue data along 13th rise of 2nd X-cut at K.B. colliery, BCCL

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 (Fig.13) and is also being confirmed by mine part-plan as shown in Fig.14.

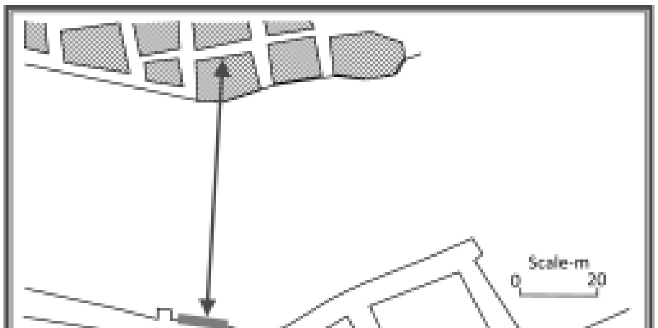

Fig.14 Radar traverse along 13th rise of 2nd X-cut at K.B. colliery, BCCL

The seventh underground site was surveyed using Minevue radar system along 11th level between 14th and 15th dip at K.B. colliery, BCCL. The interpreted radar data indicates a waterlogged mine gallery at a distance of 54 m from the coalface (Fig.15) and this is also being confirmed by mine part-plan as shown in Fig.16.

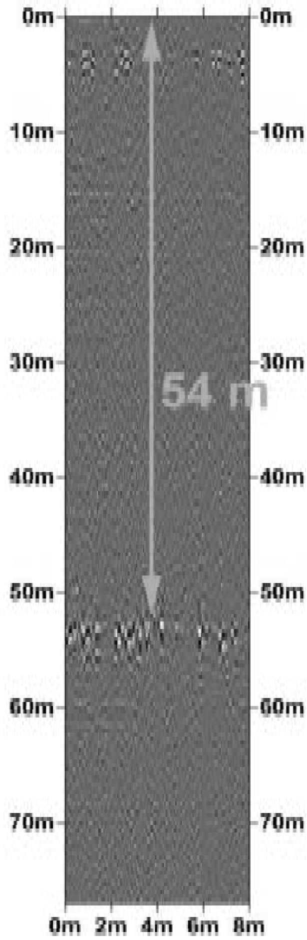

Fig.15 MineVue data along 11th level between 14th and 15th dip at K.B. colliery, BCCL

Conclusions

Under this programme of study, a new GPR system named MineVue radar has been developed having depth of penetration of 60 m in underground coal mines of India. Extensive trials were carried out for the development of GPR for the penetration of 60 m. The newly designed system was rigorously utilised in collection of data. The analyses of recorded data and subsequent output were verified with existing data base of the respective mines. The following conclusions are drawn and the limitations of the GPR are also enumerated below:

- 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

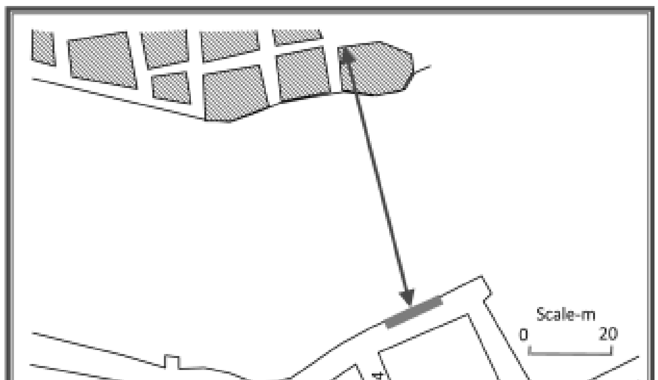

Fig.16 Radar traverse along 11th level between 14th and 15th dip at K.B. colliery, BCCL

- After final trials with developed MineVue system at Kacchi Balihari (K.B.) colliery of BCCL in the presence of the experts and representatives from various mining and mine regulatory agencies, it was concluded that the developed MineVue radar system is capable to delineate barrier thickness of 60 m against the inaccessible workings (waterlogged/dry).

- 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 concerned mine management while comparing the interpreted MineVue survey results with actual data available with concerned mine.
- 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 create poor survey environment because the leaked energy flows along metal and cause interference.

Acknowledgement

The author would like to thank the mine management of Kachhi Balihari colliery of P.B. area, B.C.C.L., Dhanbad for presenting the opportunity and necessary facilities to conduct final trial of the developed MineVue radar system.

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