MineVue radar for delineation of abandoned mine galleries

Abandoned mine workings frequently occur beneath many urban areas in India and other parts of the world. On a site due to be developed, if abandoned mine workings are suspected, it is essential that they are accurately located and suitable remediation measures taken to make them safe. A properly procured, supervized and interpreted site investigation should be undertaken to fully characterize the ground conditions.

Where a mineral (e.g. a coal seam) of workable thickness occurs at shallow depth (i.e. within about 30–60 m of rockhead), it should be assumed that it has been worked at some time, although this may not have been in a systematic way. Even if there are no mine plans or records of past workings, the ground investigation should be planned on the assumption that mining has taken place until it is possible to prove otherwise. In particular, the location of subsurface voids due to mineral extraction is of prime importance in this context. In other words, an attempt should be made to determine the number and depth of mined horizons, the extraction ratio, geometry of the layout, and the condition of any old pillar and stall workings. The sequence and type of roof rocks may provide some clue as to whether void migration has taken place and if so, its possible extent. Of particular importance is the state of the old workings. Careful note should be taken of whether they are open, partially collapsed or collapsed, and the degree of fracturing, joint dilation and bed separation in the roof rocks should be recorded, if possible. This helps provide an assessment of past and future collapse that is obviously important.

Unfortunately, it is often the case that the extent, age and condition of old abandoned workings are poorly documented, or unknown. Even when former mine workings have been recorded, the plans are often incomplete and inaccurate. Therefore, it may not be possible to determine their precise location accurately in all situations. Furthermore, old abandonment plans rarely show information about the condition of the workings, such as whether the mine openings have been stowed to reduce the risk of collapse, or the type of support systems used. In fact, sometimes in India mine plans may be misleading showing shafts and adits in areas where a mineral was not mined. Considering the above, a new Ground Penetrating Radar (GPR) system named MineVue radar has been developed having depth of penetration of 60 m subject to geo-mining conditions of Indian coal mines. MineVue radar surveys were carried out at East Basuria and Tetulmari Collieries for delineation of mine galleries from the surface in underground coal mines. Delineated mine galleries were confirmed using concerned mine plans.

To prove barrier or parting and delineation of mine galleries by conventional surveying are arduous and time consuming, while proving the same by means of long bore holes, 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 20 years in an effort to replace exploratory drilling. 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 different types of civil engineering problems, some of which were similar to the problems of the mining industry. Geophysical methods can give better but indirect solutions after delineating different geotechnical problems in the mining areas[1,2]. Among the geophysical methods, GPR is the most feasible technique for shallow workings barring some limitations[3].

GPR technique depends on the emission, transmission, reflection and reception of an electromagnetic (EM) pulse. Depending on geological conditions of the area, it can produce continuous high-resolution profiles of the subsurface rapidly and efficiently[4–6]. GPR is also used for delineation of underground structures[7,8]. Nowadays, GPR is significantly used in identifying and locating subsurface features such as cavities, conduits, fractures and buried caves[1,9]. From the literature survey it can be concluded that presently no GPR system is commercially available to penetrate 50–60 m in coal.

Considering the above facts, the Central Institute of Mining and Fuel Research, Dhanbad had undertaken a study (funded by the Ministry of Coal, Government of India) to provide plausible solution to the long pending safety issue of Indian mining industry. The ‘MineVue’ radar developed in this study is the world’s longest range radar system having depth of penetration of 60 m and lowest frequency (40 MHz) shielded radar system designed specifically for underground coal mines. The primary aim of the GPR system is to delineate the mine galleries up to 60 m from the surface and in underground coal mines to avoid inundation hazard and other related mining problems for the safety of the mine managements and other mining machineries used in underground coal mines. This correspondence deals with the study of GPR survey on the surface to delineate mine galleries in underground coal mines.

As mentioned earlier, GPR depends on the emission, transmission, reflection and reception of an EM pulse perpendicular to the ground surface. A very short time impulse is generated at a very high frequency (25 MHz–1 GHz) and radiated by an antenna called a transmitter. When the signal encounters an anomaly, it is reflected and picked up by a receiver, which transmits it to a graphic recorder. The waves reflected by anomalies on the subsurface are observed successively with regular movement of the antenna along each profile. The data are presented as a ‘time section’. A record shows the total travel time for a signal to pass through the subsurface, reflect from an inhomogeneity, and return to the surface. The two-way travel-time is measured in nanoseconds (1 nsec = 10^{-9} sec).

Determining the depth to a reflector involves using the following basic equations

$$D = T \cdot V/2, \quad (1)$$

$$V = C/\sqrt{\varepsilon}, \quad (2)$$

where D is the depth to the reflector (m); T the two-way travel time (nsec), C the velocity of light in free space (0.30 m/nsec), ε the relative dielectric permittivity, a dimensionless ratio and V is the electromagnetic wave velocity (m/nsec).

The depth of penetration depends on the following parameters[4,5]: pulser voltage of the emitter, emitted wave frequency, electric properties of subsurface materials (dielectric and conductivity) and moisture content.

The conductivity of the ground imposes the greatest limitation on the use of radar probing in site investigation. In other words, the depth to which radar energy can penetrate depends upon the effective conductivity of the strata being probed. This, in turn, is governed chiefly by the water content and its salinity. Furthermore, the value of effective conductivity is a function of temperature and density, as well as the frequency of the electromagnetic waves being propagated. The least penetration occurs in saturated clayey materials or when the pore water is saline.

The 'MineVue' radar used in the present study for surveying (40 MHz frequency and depth of penetration of 60 m) is shown in Figure 1. GPR survey is used on the surface in two mines, namely East Basuria and Tetulmari Collieries, Bharat Cocking Coal Limited (BCCL), Dhanbad for delineation of mine galleries in underground coal mines. Delineated mine galleries are confirmed by the concerned colliery surveyors using mine plans.

Figure 1. MineVue radar survey on the surface in coal-mining areas.

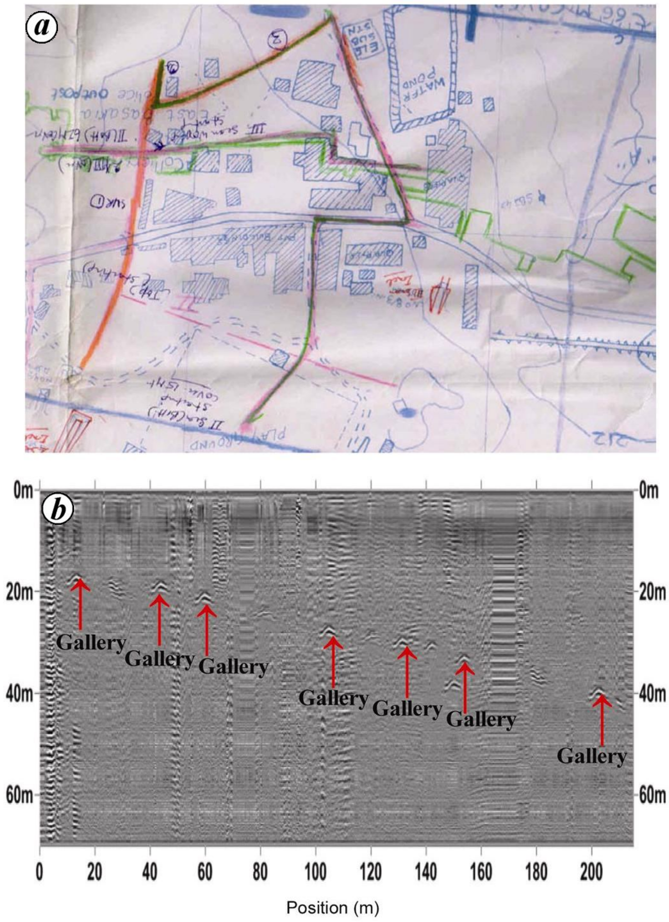

Figure 2. Location of MineVue radar profiles (***a***) and MineVue data acquired from the surface (***b***) at East Basuria Colliery.

East Basuria Colliery: This is situated in the eastern part of Jharia Coalfield, at a distance of 7 km from Dhanbad station, 2.5 km west of Bhuli township on the Bhuli–Loyabad DB road. The present East Basuria Colliery was formed after amalgamation of four separate units, viz. East Basuria Section, Tikmani–Gareriya Section, Central Gareria Section and Gopal Gareria Section. The leasehold of East Basuria Colliery is about 348.59 acres (141 ha). Kusunda–Tetulmari (KT) link line of Eastern Railways passes along southeast to northwest of the Colliery. Ekra Jore flows from north to south and passes along the eastern boundary of the Colliery. This Colliery is surrounded by Gondudih Colliery (east), Nichitpur Colliery (west), Barron Area (north) and Sendra-Bansjora Colliery (south). There are nine seams (X, IX, VIIIA, VIII, VII, V/VI, IV, III and II). All the seams from II to X are outcropping within the leasehold of the mine. GPR survey was carried out on the surface over seams II and III using the MineVue radar system.

Figure 2 *a* shows a map of the locations of the three survey lines during the February, 2011 trials of MineVue radar. The use of radar from the surface to detect coal workings requires the radar signals to penetrate through the surface soils, and the overburden geology to image individual tunnels at significant depth. Excellent results were achieved by MineVue during the surface trials at East Basuria Colliery, which were confirmed by the concerned mine plan (Figure 2 *a*). Figure 2 *b* depicts an example of MineVue data, showing detected galleries as hyperbolae, at depths varying from 18 to 40 m.

Tetulmari Colliery: This Colliery in the Sijua area, BCCL is situated about 0.5 km south of Tetulmari railway station of Grand-Chord line and about 15 km west of Dhanbad railway station. The Colliery is surrounded by Sendera Bansjora & Nichitpur Colliery in the east, Amalgamated Keshalpur & West Mudidih Collieries in the west, Non-coal-bearing area in the north and Mudidih

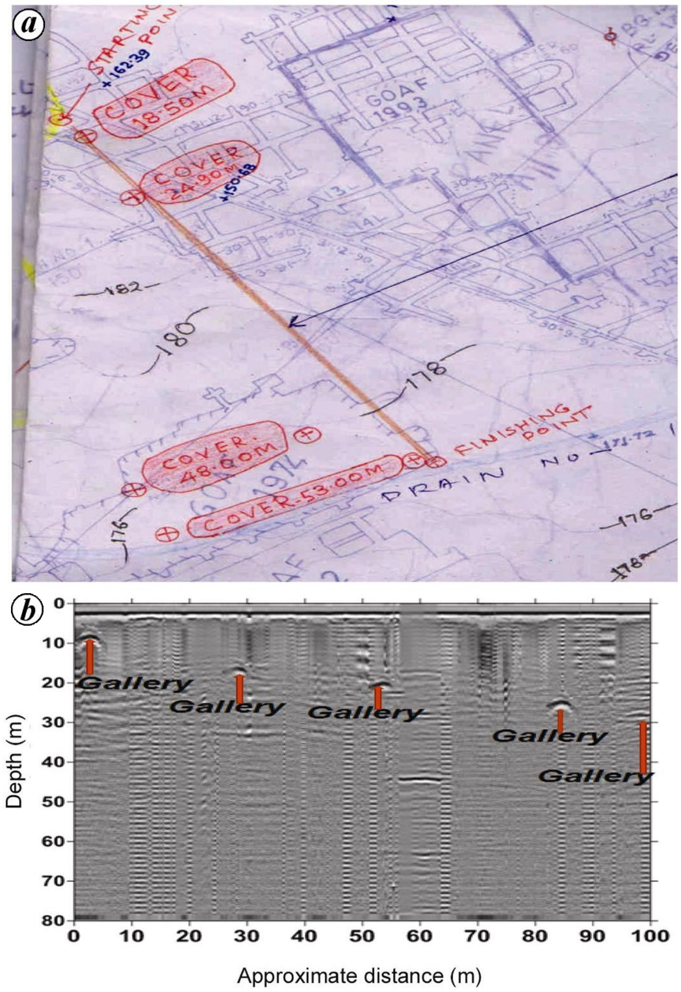

Figure 3. MineVue radar traverse (0–200 m) on the surface from Lamp-Room to near H.T. Line (***a***) and MineVue data from the surface (***b***) at Tetulmari Colliery.

Colliery in the south. Total coal reserve of this Colliery is 62.8 MT, having coal quality of Washery-IV and Grade-D. The Colliery was being worked by 18 different private mine owners before the take-over; these 18 small collieries were amalgamated in 1973. At present, total lease-hold area of the colliery is 3.17 sq. km. There are many different coal seams, starting from seams I to VIIIA and all are outcropping in the property. General gradient of seams are 1 in 8, except at the OCP patch where the gradient of the seam has changed to 1 in 4 due to strike fault. There are four numbers of dip-rise faults of 3.0, 4.5, 1.2 and 4.5 m, and one strike fault of 0–24 m throw occurring in the property.

GPR survey during experimentation was carried out on the surface over seams II and III using MineVue system, as shown in Figure 3 *a*. The radar survey was conducted at the surface at Tetulmari Colliery to detect galleries from the surface. The results of this survey are shown in Figure 3 *b*. Excellent results were achieved by MineVue during the surface trials at Tetulmari Colliery, which were confirmed by the concerned mine plan (Figure 3 *a*). Figure 3 *b* depicts an example of MineVue data, showing detected galleries, as hyperbolae at depths varying from 10 to 30 m.

MineVue radar is useful for delineation of mine galleries in underground coal mines from the surface without disturbing the ground features. MineVue survey results lead to the following conclusions: (i) MineVue detected galleries at depths varying from 18 to 40 m along the three survey lines at East Basuria Colliery and one survey line at depths varying from 10 to 30 m at Tetulmari Colliery. (ii) The delineated galleries at the two collieries were correlated and confirmed using the concerned mine plans.

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