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ORIGINAL PAPER

Shallow cover over coal mining: a case study of subsidence at Kamptee Colliery, Nagpur, India

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Abstract Shallow land cover over old underground workings at Kamptee Colliery has led to the development of ground collapse, with three crown hole subsidences recorded in a 10 year period. As the land above the workings has been developed, it was considered that for safety purposes areas with less than 15 m of competent rock should be established. The paper discusses the Multi-electrode Resistivity Imaging (RI) and Ground Penetrating Radar (GPR) undertaken over an area of 800 m × 200 m, which indicated that where a competent cover was present it was very thin.

Keywords Overburden cover · Subsidence · Collapse · Crown hole · Coal mining

Résumé Un recouvrement de faible épaisseur au-dessus des travaux souterrains des Houillères de Kamptee est à l'origine d'effondrements du sol, avec la formation de trois cuvettes d'affaissement en dix ans. Pour des raisons de sécurité par rapport aux projets d'aménagement de surface, il fut décidé de délimiter les zones présentant un recouvrement de terrains compétents de moins de 15 m d'épaisseur. L'article présente les techniques d'imagerie de résistivité multi-électrodes (RI) et du radar géologique (GPR) mises en œuvre pour réaliser cette cartographie sur une surface de 800 m × 200 m. Elles ont montré que, lorsqu'une couverture compétente était présente, elle était de faible épaisseur.

Motsclés Recouvrement · Subsidence · Effondrement · Cuvette d'affaissement · Mine de charbon

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Introduction

The Kamptee colliery in the Nagpur area of central India (Fig. 1) is an old coal mine worked by Western Coalfield Limited (WCL). Until 1999 underground working took place, although currently open cast methods are used. In all there are five coal seams present in the leasehold area. Above the mined area there are residential developments and associated infrastructure.

During the last 10 years there have been three occasions when crown holes have reached the surface. The last was at 1100 h on 7 August 2003 and damaged some of the colliery buildings. The subsidence area was 8 m in width and 30 m in depth. Thereafter, the old plans of the underground workings were analysed and it was found that there was considerably less surface cover where the collapse had occurred.

A geophysical investigations was undertaken to establish where workings were present within 15 m of the surface. The area investigated was 800 m along the strike and 200 m wide in the dip direction. Within this area there were 170 buildings.

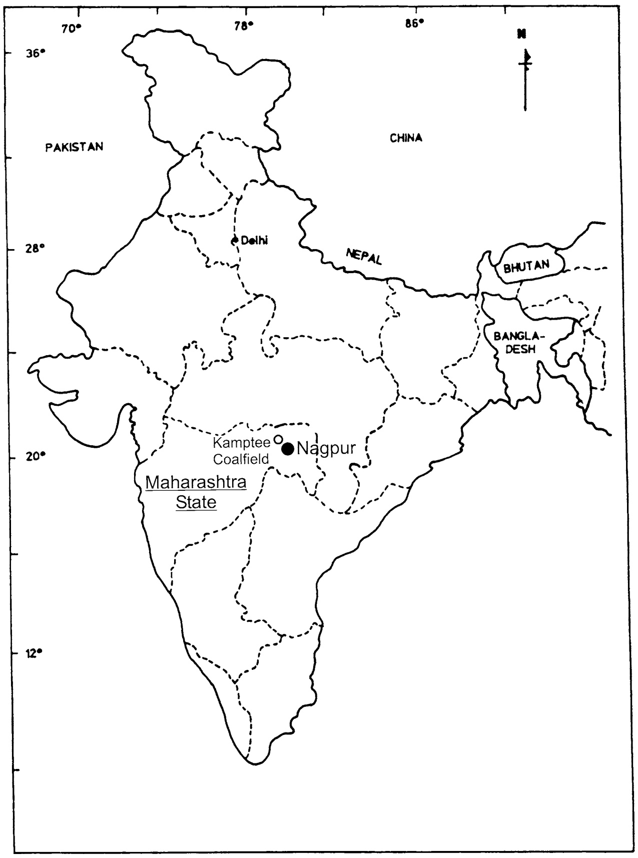

Fig. 1 Location map of the study area

The site

The study area is centred on latitude 21°15″N and longitude 79°12″E, some 25 km north west of Nagpur. The area has an almost flat topography with elevations ranging in the order of 300 m asl. The gentle southerly slope is towards the Kanhan River, which controls the drainage of the area.

Six profiles (RR1, AA1, BB1, CC1, DD1 and D2D3) were selected for the Resistivity Imaging survey and two profiles (GG1 and G2G3) for the GPR survey (Fig. 2).

Geo-mining details of study site

The underground colliery was started in 1954 and abandoned in 1999. It is overlain by a thick mantle of black cotton soil, medium and coarse grained sand with quartzites and metamorphosed pebbles and boulders.

The Kamptee Colliery is in the Lower Gondwana Formations and being a basinal structure has a 'horse-shoe' shape aligned in a N-W direction. The coal seams proved in six boreholes are indicated in Fig. 3. Bore-hole P indicates the presence of eight coal seams which have been numbered II, III (two seams), IV (two seams) and V (three seams). Seam 1, known to occur elsewhere in the Middle Barakars Formation, is not present in the study area.

The dip varies between 1 in 5 and 1 in 6 (circa 10°). It was observed in nearby open pit workings that there is no competent cover over seam III.

Scrutiny of the old mine plans indicates seams II, III, IVB, VA and VB have been worked and are partly backstowed in the area under investigation.

Geophysics

Figure 4 shows the Wenner-Schlumberger (WS) profiles along traverse AA1 and CC1, giving the measured apparent resistivity pseudosection, the calculated apparent resistivity pseudosection and the inverse model resistivity.

In traverse AA1, a high resistivity zone of more than 136 Ω was recorded at chainage 150–180 m at a depth of 25–30 m, indicating the presence of seam IV (BH K30, Fig. 3). The low resistivity material (<59 Ω) overlying seam IV represents soils and loose sandstone. A high resistivity zone is also shown in CC1 (>53 Ω) between chainage 90–95 m at a depth of 38 m, corresponding to seam II at 37.2 m depth in BH K24. The overlying low resistivity zone is again due to soils and loose sandstones.

Ground Penetrating Radar surveys were carried out in the subsidence areas and over the underground workings (GG1 and G2G3, Fig. 2). Traverse GG1 was 243 m long and divided into three sections: 0–80 m (the guest house), 80–160 m and 60–243 m (damage zone). As can be seen from Fig. 5, the radar signatures for section I (0–80 m) indicate the strata are disturbed to a depth of 30 m. Some cavities were indicated at a depth of 10 m at chainages 12 and 35 m. The formation of these cavities is likely to be related to the underground development of the seams shown in BH K31. The strata in this zone are very weak and friable with no hard strata present.

Traverse G2G3 (Fig. 6) starts at the colony (along line AA1 line) and ends close to a subsidence (chainage 245 m). The radar signatures show various disturbed and less disturbed strata in the first two sections (chainages 0 to 120 m). Between chainages 120–160 m the strata is relatively undisturbed to a depth of 10 m, below which it is very disturbed. Cavities are present at chainages 95, 105, 123 and 150 m, at depths varying from 5 to 8 m. This is due to void migration associated with seam III which has no competent cover (see BHs

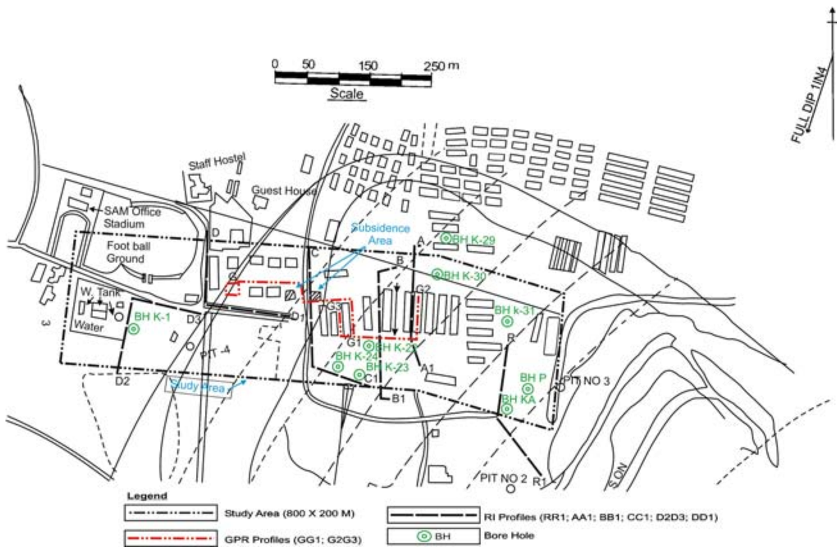

Fig. 2 RI and GPR profiles over study area (Kamptee Colliery)

K22 and K24, Fig. 3). Between chainages 160–245 m, which includes the area parallel to the AA1 line, roadside and damaged buildings (Fig. 4a), the strata are weak and disturbed to chainage 175 m. A cavity is indicated 8 m below the surface at chainage 202 m. It is known that below 30 m extensive extraction took place from the coal seams indicated in Fig. 3.

Summarising the geophysical information,

1. There are many underground voids, which may develop into crown holes by void migration. These areas are not safe for human habitation.
2. The geophysical profiles are consistent with the borehole information and indicate there are no competent bands above seams II and III to a depth of 30 m.
3. The GPR signatures indicate some voids in the overlying strata at depths of 5–10 m from the surface. These voids may extend upwards by void migration and appear as crown holes in the future. A survey in India has indicated that such crown holes can develop between 7 days and 27 years after mining/depillaring (CMRI 2002).

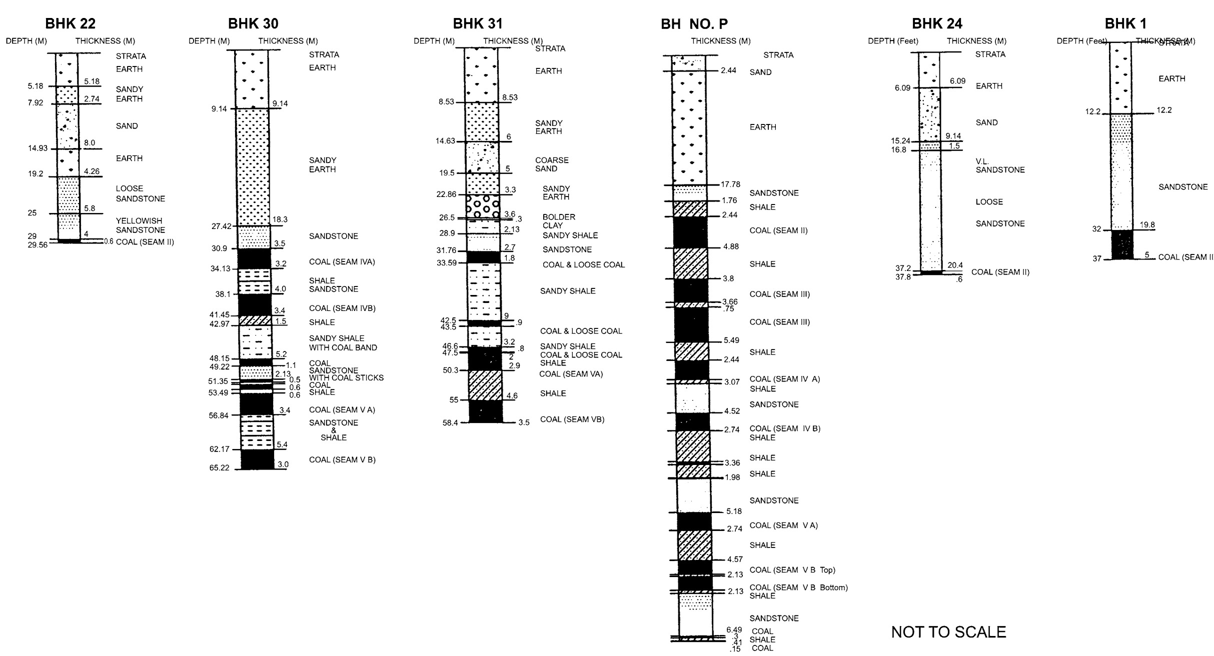

Fig. 3 Borehole logs at Kamptee Colliery over old underground workings

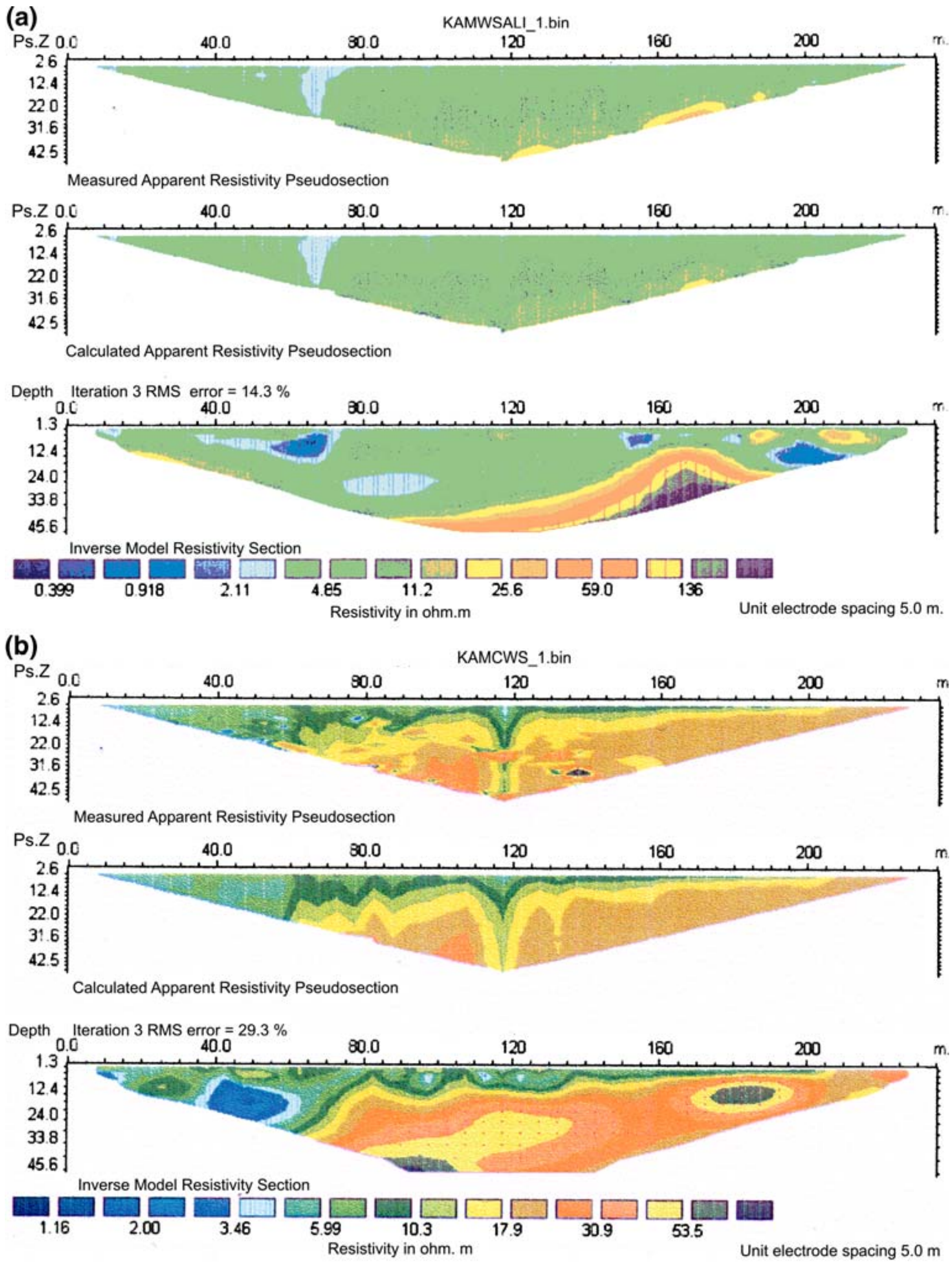

Fig. 4 **a**, **b** Wenner–Schlumberger configuration inverted resistivity section along the traverse AA1 and CC1

Based on this, the colliery management have been advised that for safety reasons, residents in the dangerous zone where no competent cover is present should be evacuated.

Understanding the phenomenon of potholing

Table 1 summarises some research results for Indian coal mines.

A number of workers in both India and other parts of the world have considered the relationship between the worked thickness and the depth of overburden as an indicator of the likelihood of crown hole collapse. As the void migration takes place mainly through stress release due to the mining, blocks of expandable material, such as mudrocks, will fall and the void will migrate upwards. As the fallen material will have a significantly greater volume than in the in situ state (referred to as bulking) a rising void will choke itself when the height of the overburden is in the order of ten times the mined cavity. However, if for any reason the bulked material is moved by either water or due to a steep dip in the

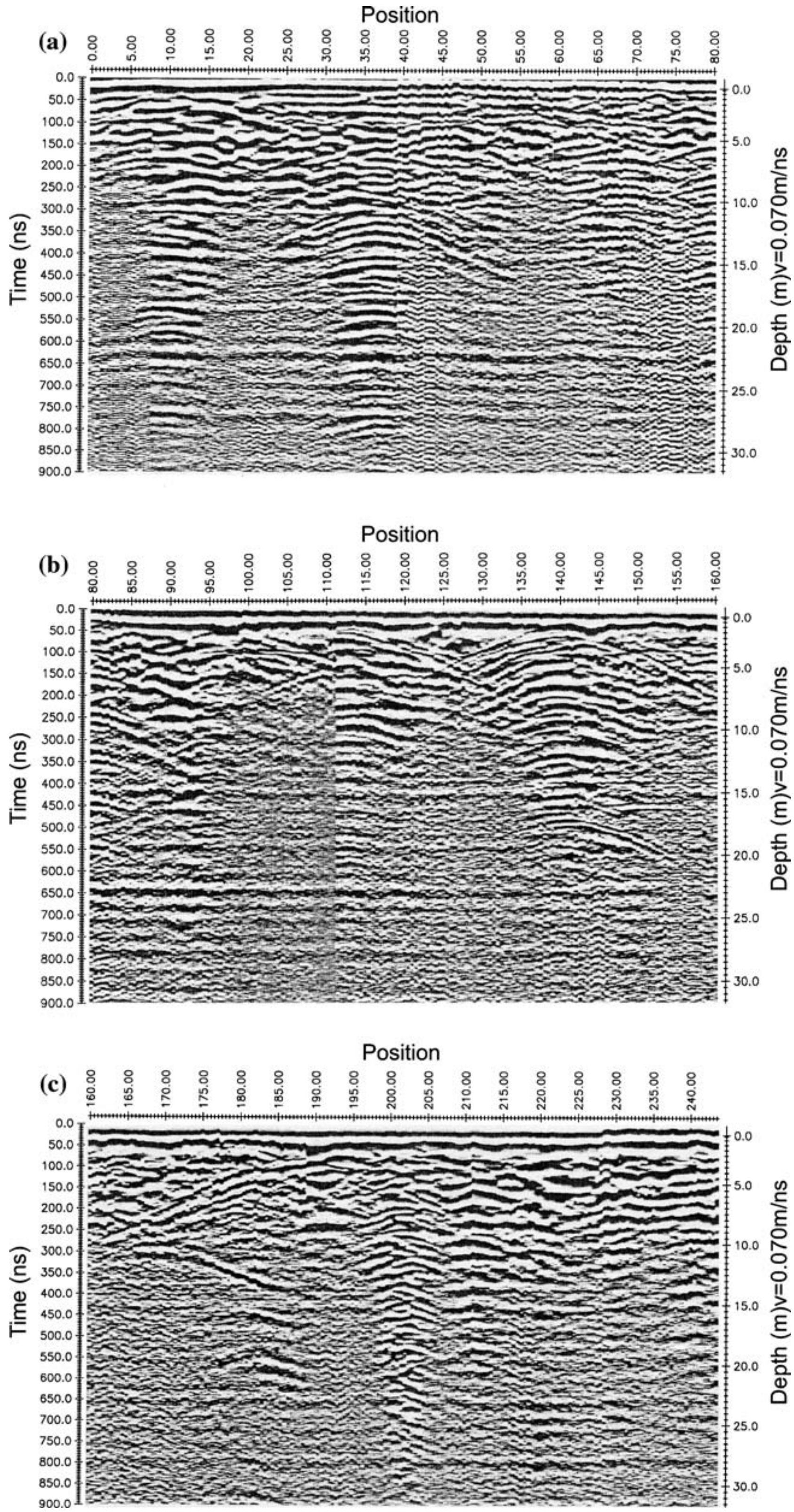

Fig. 5 GPR signatures along the Profile GG1

seams, then the void may migrate significantly more than ten times the worked thickness before bulking will inhibit further migration.

Where migration has taken place in strata where sandstones occur such that with pillar failure a temporary bridging structure is created, then a sudden col-

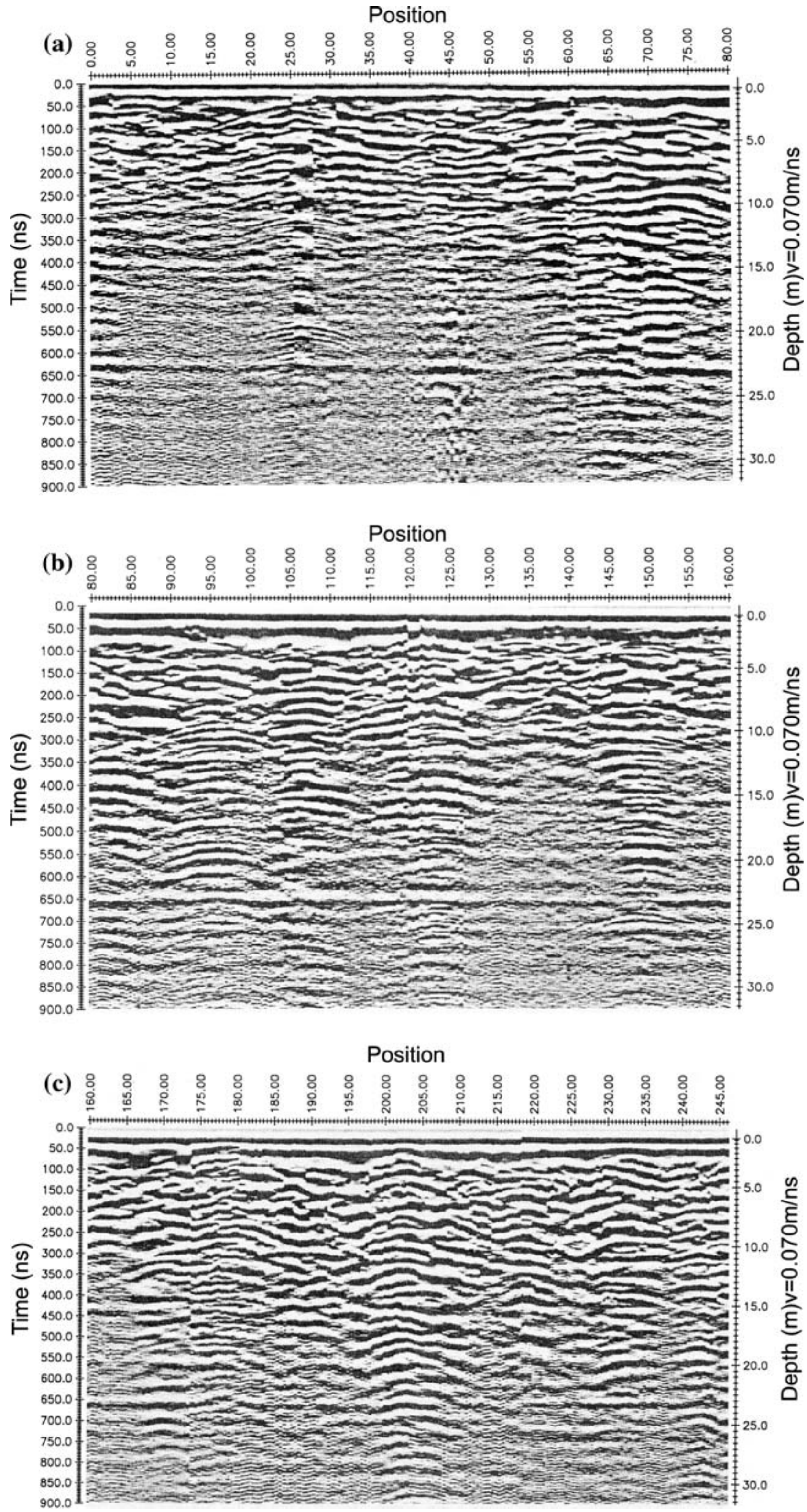

Fig. 6 GPR signatures along the Profile G2G3

lapse of the ground over a significant area may occur, e.g. that described at Bathgate, south west of Edinburgh, UK (Carter Jarman and Sneddon 1981; see also Singh 2000; Stathum and Treharne 1991; Hunt 1980)

Obviously the nature of the overlying geology and the stability of the land surface are important considerations in the potential development of surface failures. In some mining areas it is known that the size of

Table 1 Summary of subsidence phenomena based on studies in the coal mines of India

Properties of potholes	Statistical data	Remarks
Location percentage	33% - over development workings of coal mines 62% - over depillaring areas of coal mines. 6% in other areas	CMRI data based on 34 case histories of Indian coal mines
Shape of the potholes	Nearly circular	
Diameter of potholes	1.5–30 m	
Depth of potholes	2.0–26.5 m	
Depth of underground workings	15.7–63.0 m	30 occurrences between the depth range of 10–40 m. 4 occurrences between 40–70 m depth range
Seasonal effect	41% during rainy season 54% during dry season	Cases of pot-holing during rainy season: dry season = 14:20 (Total thirty four cases)
Physico–mechanical properties of adjoining strata	Compressive strength = 2.8–9.0 MPa Tensile strength = 0.3–1.0 MPa	In coal mines adjoining strata or overburden consist of sandstone, which could be fine, medium or coarse grained

The data given in table are compiled from pothole studies in the coal mines of India. (CMRI 2002; Singh and Singh 1998; Singh 2000)

the collapse is related to the geological discontinuities, whether they are faults or joints. In other cases it is believed that collapses have occurred where marginally stable areas have become de-stabilised due to seismic tremors.

There is always concern when infrastructure or properties are constructed above underground mining when the workings have followed specific seams rather than semi-vertical loads. Many old workings used a pillar and stall system, such that voids may exist for many years albeit they are steadily migrating upwards. Bruhn Magnuson and Gray (1981), writing on the Pittsburg coalfield, state ‘‘Unless total extraction has been achieved, there is no identifiable height above an abandoned mine that ensures a site total freedom from subsidence, nor necessarily a reduction in severity of damage. An increased interval above mine level, however, seems generally associated with a reduced frequency of subsidence.... Unless total extraction has been achieved, there is no identifiable time after mining when the threat of subsidence is clearly past, and there appears little assurance that subsidence will be limited to a single episode.... Although the specific cause of subsidence above an abandoned mine is not often determined, it is apparent that in some cases activities by man have hastened the onset of subsidence if not initiated it.’’

In view of the above, it is prudent to taken some precautionary measures where mining has been undertaken in the past, as long term support is unlikely to have been provided at that time or subsequently. Often the area can be stabilised by infilling the voids by grout, see for instance Evans and Hawkins (1981).

Conclusions

Interpretation of the GPR traverses (GG1 and G2G3) and RI sections (AA1 and CC1) shows that in the study area the overburden cover is less than 15 m and there are many underground voids which may develop as crown holes in the future (Fig. 7).

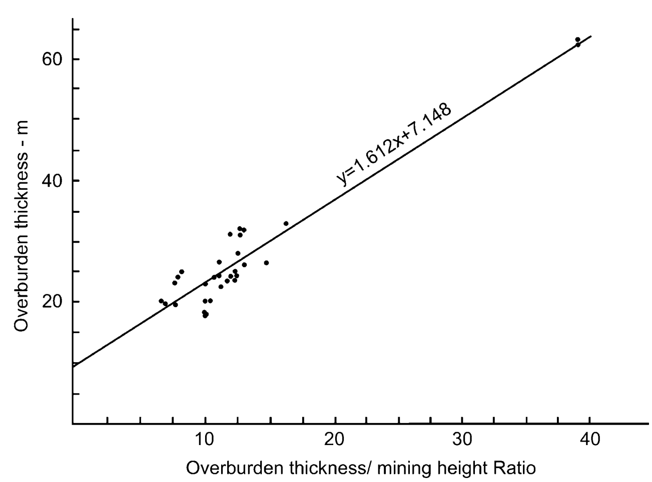

Fig. 7 Relationship between overburden thickness (*h*) and mining height (*m*)

In the Indian context, ready-to-use guidelines for subsidence prediction based on scientific and engineering judgment are urgently required.

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