

## Stabilization of old unapproachable workings of XIII seam in Kari Jore using ground penetrating radar

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The ground penetrating radar (GPR) system is used for solving problems like detection of underground voids that cause the instability of different surface features and structures at shallow depth in an unapproachable area. Seam XIII, which was developed on the boundary of Kushunda-Industry Collieries of Bharat Coking Coal Limited (BCCL) at shallow cover around Kari Jore is now on fire on either side of Jore and unapproachable. The main objective of this paper is to explore the actual underground strata conditions using GPR so that underground strata should be stabilized by hydraulic sand stowing and coal can be extracted safely and economically from this area.

### 1 Introduction

The ground penetrating radar (GPR) was first proposed as video pulse radar system by Melton<sup>1</sup>; but the first practical video pulse radar system was introduced for tunnel detection as the Geodar system<sup>2</sup>. After that, so many research organizations were involved in this type of the system for doing better modifications. Moffatt *et al.*<sup>3</sup> of Ohio State University had earlier used this system to detect a variety of geological structures. Somewhat later development was a pipe detector system that was patented by Young and Caldecott<sup>4</sup>. This system has been successfully employed to resolve structural features in both soil and bedrock<sup>5,6</sup> and to locate buried pipes and cables<sup>7</sup>. Investigations were also concentrated on assessing the feasibility of GPR for detecting coal beds<sup>8</sup>, granular deposits and sea-ice thickness in permafrost regions<sup>9</sup>. Some past studies have also confirmed the usefulness of GPR for delineating tunnels<sup>10,11</sup> and abandoned mines<sup>12</sup> in granitic and limestone rock masses. Application of the GPR technique for geological mapping was also reviewed<sup>13</sup>. Similarly, this technique had been proved to be very useful in mapping contaminant migration<sup>14</sup>, saltwater intrusion<sup>15</sup> and permafrost<sup>16</sup>. Several GPR studies have been conducted in underground mines for the detection of cavities and adjacent tunnels<sup>17,18</sup>. Other applications include the detection of geological features such as faults, dykes, fractures, lithologic boundaries, water pockets, clay seams and other

discontinuities. In the New Brunswick Coal mine in Minto, GPR was used along with core log data to map and construct a 3-D block of a section of the bench showing the relative position of different layers overlying the coal seam<sup>19</sup>. In India, a Canadian team (Laval University, Quebec, Canada) had conducted GPR study first time along with an Indian team (Central Mine Planning & Design Institute Ltd. and Mining Geological & Metallurgical Institute of India) for identification and delineation of abandoned, unknown and unsurveyed underground colliery workings in Raniganj coalfield in 1995 (Ref.20). This survey was also done in 1997 for detection of old unapproachable working area below Jharia town in India<sup>21</sup>.

Jharia coalfield, the main source of prime coking coal in India, covers an area of 450 km<sup>2</sup> and contains 40 coal horizons. Prime coking coal seams lying at shallow depth were mined indiscriminately without considering the safety and conservation aspects by the erstwhile owners. The indiscriminate coal extraction results in leaving of small/undersized stooks below different surface features and structures. This causes sudden subsidence following crushing of the undersized stooks, outbreak of fires and inundation of workings. Seam XIII was developed on Kushunda-Industry colliery boundary of the Bharat Coking Coal Ltd. (BCCL) below and north-east side of Kari Jore at shallow cover (Fig.1). The XIII seam is also on fire on the either side of Kari Jore. Unless this fire is

restricted, the overlying strata may collapse in Kari Jore. This phenomena can also happen following weathering of shallow cover and time dependent deformation of stooks. Thus, there is a possibility of drowning of other nearby workings of Industry as well as of Kushunda, Ena, Kustore and Alkusa collieries of the area in future. Considering the seriousness of the problem, this unapproachable patch was stabilized hydraulically with sand through boreholes drilled in the bed and on the embankment. But, the volume of sand filled in was  $147 \text{ m}^3$  against expected value of  $1900 \text{ m}^3$ . Therefore, it was decided to conduct GPR survey for locating underground voids/strata conditions below the Jore bed and below the embankment so that the underground strata should be stabilized with hydraulic sand stowing.

## 2 Methodology

In this area, a 50 MHz frequency antenna is used for carrying GPR survey. For this survey, reflection and common mid-point (CMP) techniques are used. First, CMP survey is carried out for calculating the velocity of EM waves in this area. The velocity of EM waves is found to be  $0.07 \text{ m/ns}$ , and the depth of penetration of EM waves is found to be 17 m. Reflection surveys are carried out along the sections A-A1 and B-B1 and along C-C1 in the riverbeds (Fig. 1).

## 3 Analysis of GPR data

The types of GPR signatures have been established after conducting GPR survey and correlating with borehole data in coal mining area. According to this, it is assumed that thick black lines (reflected radar signature) are indicating solid strata and absence of thick black lines are indicating water bearing strata with clay; because EM waves are absorbed and highly attenuated in water and, therefore, there is no reflected signature, as shown in Figs 2-4. It is clear from Fig. 2 that there is a solid layer up to 1 m depth from the surface throughout the section. This represents alluvial soil. At the surface positions of 28 m and 33 m in Fig. 2, there is a weathered solid layer up to the depth of 13 m and below it loose filling materials are present under water-saturated conditions. At the surface position of 26 m, there is a weathered solid layer (breakage lines / discontinuous layer) up to the depth of 10.5 m and after that similar type of a clay layer with some loose filling materials are present along with water-saturated zone. At the surface position of 17 m, solid weathered layer starts from the depth of 1 m and continues up to the depth of 10 m and after that a clay layer is present along with some filling materials and water bearing strata. At the surface position of 8 m, there is a solid weathered layer starting from the depth of 1m and ending at the depth of 11 m. In this case, clay layer

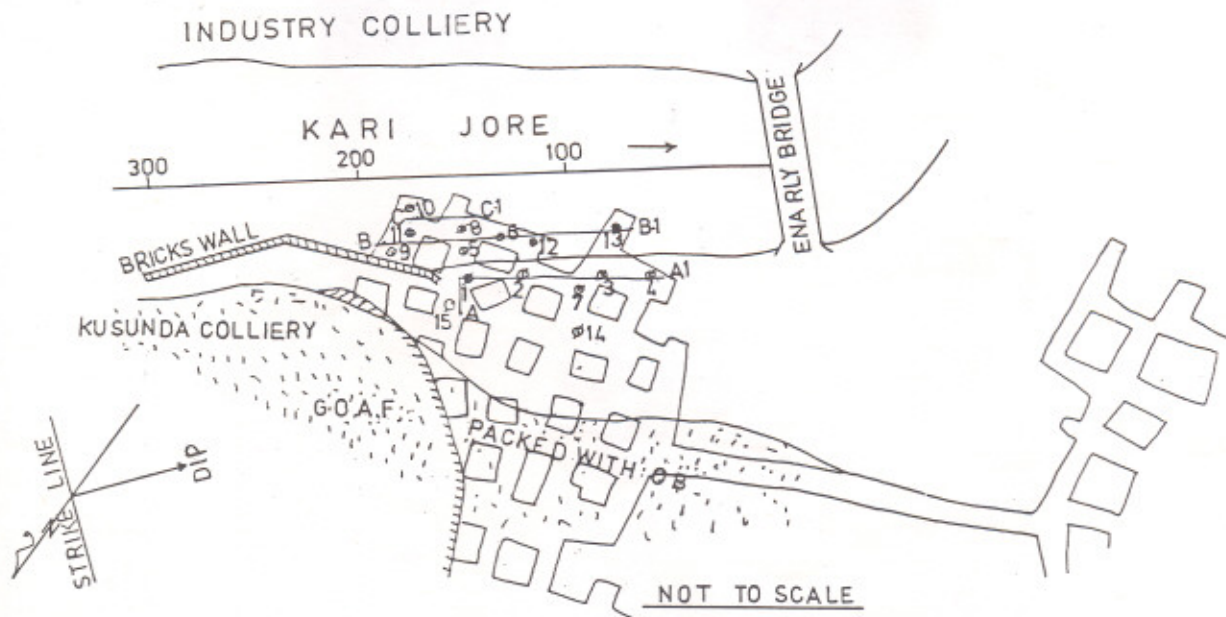


Fig. 1—Location of GPR survey sites at Kari Jore

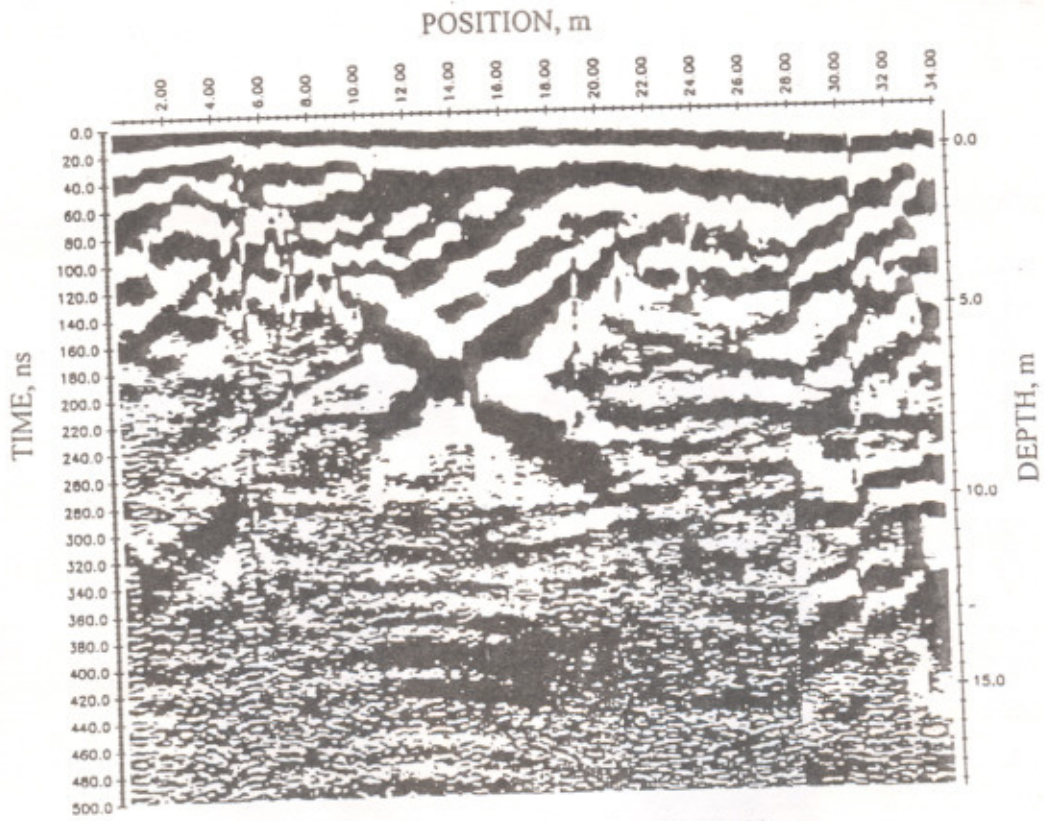


Fig. 2—Radar signatures along the section A-A1

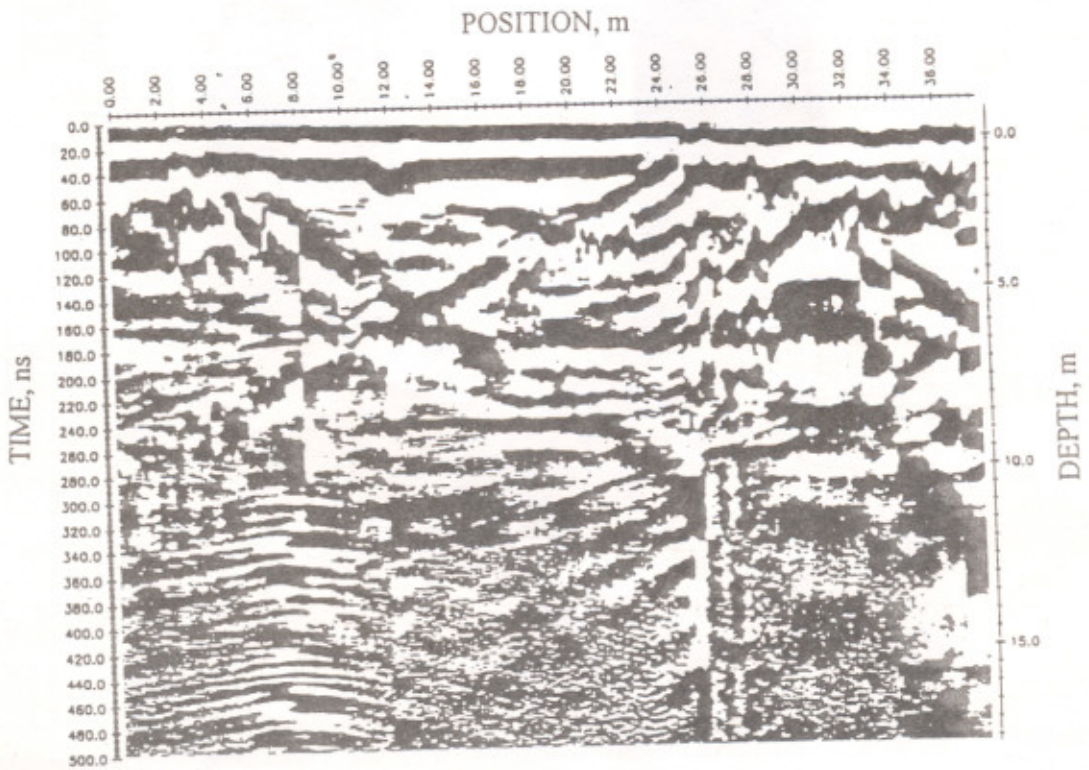


Fig. 3—Radar signatures along the section B-B1

starts from the depth of 6 m along with some loose materials and water bearing strata. In the beginning (surface position = 0 m) a discontinuous weathered layer continues up to the depth of 6 m and after that water-saturated loose materials is present. In this section, boreholes 15, 1, 2, 7, 3 and 4 are intersected at 0, 8 m, 17 m, 26 m, 28 m and 33 m surface positions, respectively.

Figure 3 represents the radar signatures along the section B-B1 lying in the riverbed. At 5 m surface position, weathered layer starts from the depth of 1m and ends at the depth of 4.5 m and after that loose filling materials and water-saturated zone are noticed. There is a continuous weathered layer along with some loose materials starting from the depth of 1m to

5.5 m at 13 m surface position. In this case also, there is a water-saturated zone with loose materials below 5.5 m depth cover. At the surface positions of 25 m and 28 m, a discontinuous weathered solid layer starts from the depth of 1 m and ends at the depth of 7.5 m, and after that loose materials and water-saturated zone are recorded. At 36 m surface position, a weathered solid layer starts from the depth of 1m and continues up to the depth of 10 m and after that solid lines indicate a solid layer along with water-saturated zone. Boreholes 9, 8, 6, 12 and 13 are also drilled at 5 m, 13.5 m, 24.5 m, 28 m and 37 m surface positions, respectively.

Figure 4 shows the radar signatures along the section C-C1 in the river bed. In this section, disturbed weathered layers (breakage/discontinuous solid lines) start from the depth of 1 m and continue up to the last along with some loose filling materials and water-saturated zone. Boreholes 10 and 11 are also drilled in this section of investigation.

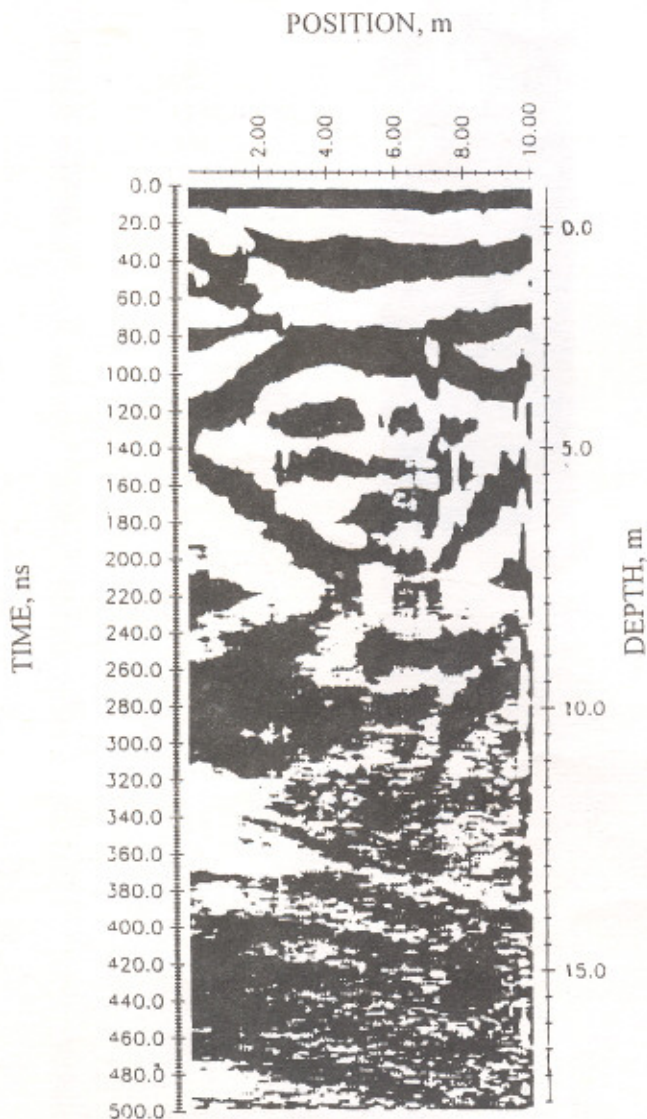


Fig. 4—Radar signatures along the section C-C1

#### 4 Analysis of boreholes data

Colliery management drilled 15 boreholes to stabilize the old unapproachable workings of XIII seam. Out of 15 boreholes, seven boreholes numbered as 1, 2, 3, 4, 7, 14 and 15 are located on the embankment, whereas remaining eight boreholes (Nos. 5, 6, 8, 9, 10, 11, 12 and 13) lie directly in the river bed. Boreholes 3, 10, 11 and 13 could not be joined to the workings. Voids were stowed with sand hydraulically with the help of boreholes 1, 2, 4, 5, 6, 7, 8 and 12. The total volume of sand consumed for stowing is 147 m<sup>3</sup> as against 1900 m<sup>3</sup> anticipated volume.

The depth of old unapproachable workings of XIII seam varied between 4.3 m and 7.3 m in the river bed, whereas it was 6.1-12.2 m from the embankment of Kari Jore. The thickness of alluvium varied between 0.5 m and 1.5 m and between 3.0 m and 3.7 m in the river bed and on the embankment, respectively. The gap at the top of the workings of XIII seam in different boreholes was 0.07 m-0.3 m. Table 1 depicts the gap and volume of sand stowed in different boreholes.

#### 5 Discussion

Signatures of the GPR indicate that there are no voids along all the sections A-A1, B-B1 and C-C1. But, overburden strata (above XIII seam workings) are weathered in almost all the cases, as there are no

Table 1—Status of boreholes

B.No.	Gap m	Quantity of stowed sand m <sup>3</sup>	Remarks
1	0.10	30	Stowed
2	0.30	40	Stowed
3	—	—	Not joined
4	0.13	25	Stowed
5	0.15	20	Do
6	0.15	7	Do
7	0.08	5	Do
8	0.08	10	Do
9	0.30	—	Not stowed
10	—	—	Not joined
11	—	—	Do
12	0.23	10	Partly stowed
13	—	—	Not joined
14	0.15	—	Not stowed
15	—	—	Not stowed

continuous lines along all the three sections after 1 m depth from the surface.

The depth of workings in the river bed varied between 4.3 m and 7.3 m, whereas it was between 6.1 m and 12.2 m from the embankment of the Jore. The thickness of alluvium in the river bed varied between 0.5 m and 1.5 m, and the thickness of weak weathered formation in the river bed was found to be between 3.6 m and 6.6 m. This thin parting is weathered and weak. Fires were also noticed close to the river bed on either side of it. Therefore, river beds are not likely to sustain the load of the water in Kari Jore during rainy season due to 3.6 m-6.6 m weathering and overburdening with weathered and weak strata and fire on either side of Kari Jore.

## 6 Summary and conclusions

Geo-radar investigations carried out in Kari Jore river bed and on the embankment to assess the voids in old unapproachable workings of XIII seam led to the following conclusions :

(i) The overburden thickness in the river bed varied between 4.3 m and 7.3 m, whereas it was between 6.1 m and 12.2 m on the embankment.

(ii) The thickness of alluvium in the river bed was 0.5-1.5m.

(iii) The overburden strata having 3.6 -6.6 m thickness above old abandoned workings of XIII seam was weak and weathered.

(iv) Fire has reached close to the river bed from

north-east side (Kushunda colliery) and south-west (Industry colliery) of the Kari Jore.

(v) Considering the weathered overburden having 3.6 m - 6.6 m thickness above old abandoned workings of XIII seam and a close fire at the top of its development, it is recommended to fill up this shallow workings with sand/gravels after digging and cement in the river bed and construct an embankment so that possibility of inundation due to XIII seam can be avoided in future.

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