# Applications of Ground Penetrating Radar—A Comprehensive Case Study

**P. Senthil, Alex Varughese, Hari Dev, and S. L. Gupta**

**Abstract** Ground penetrating radar (GPR) is used to obtain subsurface information based on the properties contrast in the medium. GPR is generally employed for detecting underground utilities and can be used for applications such as subsurface stratigraphy, archaeology, forensics and detecting reinforcements. In this paper, comprehensive case study on GPR covering applications of four cases in utility detection for trenchless drilling and excavation; two cases in depth of rock for estimating constructing materials and foundations; and two cases in dam health monitoring are discussed. Penetration depth and resolution depend on frequency of EM waves generated by antenna. The use of different frequency antenna for each application is emphasised. Methodology adopted for GPR scanning upstream vertical face of dam and downstream face of dam was given. GPR was effectively employed to locate utility, estimate depth of overburden, and thickness of masonry and its homogeneity in the old ageing dams.

**Keywords** GPR applications · Dam health monitoring · Utility survey · Antenna frequency · Depth to bed rock

## 1 Introduction

Ground penetrating radar (GPR) survey is non-invasive geophysical techniques for locating the buried objects. It is also extensively used in geological application (delineation of bed rock profile), dam health monitoring (i.e. to investigate the continuity of medium), civil engineering (roads, bridges and reinforcement scan), archaeology and forensics applications. GPR survey produces two-dimensional section of subsurface without any drilling or trenching. Large area can be covered in short time with

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use of GPR survey. It can be used for the following three major civil engineering applications.

(a) Underground utility survey
(b) Delineation of bed rock profile
(c) Dam health monitoring / diagnostics investigation.

## 2 GPR—Principles

GPR is a technique based on the principles of RAdio Detection And Ranging (RADAR) to measure the location and size of targets buried in visually opaque material [1]. GPR injects electromagnetic waves (EM), typically in the range of 25–2500 MHz into the medium, from transmitting antenna. When EM wave encounters the interface of other medium having contrast in electrical properties, part of wave gets reflected back to the receiver antenna and remaining is transmitted into deeper medium. The radar system will measure the time elapsed between transmission and arrival of waves. In reality, the GPR (antenna) is moved along a profile and time elapsed is recorded with short intervals. Unit of measurement for travel time in GPR is “nanoseconds”. Continuous record of signals produces two-dimensional subsurface section along a profile. Subsurface velocity of EM wave is to be estimated and given as input for determining the depth of objects having contrast in electrical properties.

The penetration depth and resolution of GPR depend on the electrical properties of medium and antenna frequency used. The penetration depth of EM waves in ice medium is maximum; i.e. few hundred metres, whereas in clayey soil, the penetration depth is limited to few centimetres only.

$$\text{Interface depth} = \text{two} - \text{way travel time} \times \text{velcoity}/2 \tag{1}$$

Generally, the range of two-way travel time setting required varies from 10 to 500 ns. Relative permittivity of the subsurface material (soil, rock, concrete or any other) governs the velocity of electromagnetic wave. Relative permittivity ($E_{\text{rm}}$) is the ratio of the permittivity of the material ($E_{\text{m}}$) divided by the permittivity of air ($E_{\text{o}}$), or

$$E_{\text{rm}} = E_{\text{m}}/E_{\text{o}} \tag{2}$$

Relative permittivity for air and water is 1 and 81, respectively. EM velocity in material is determined from the following equation:

$$\text{Velocity through medium} = \text{EM wave velocity in air}/\sqrt{E_{\text{rm}}} \tag{3}$$

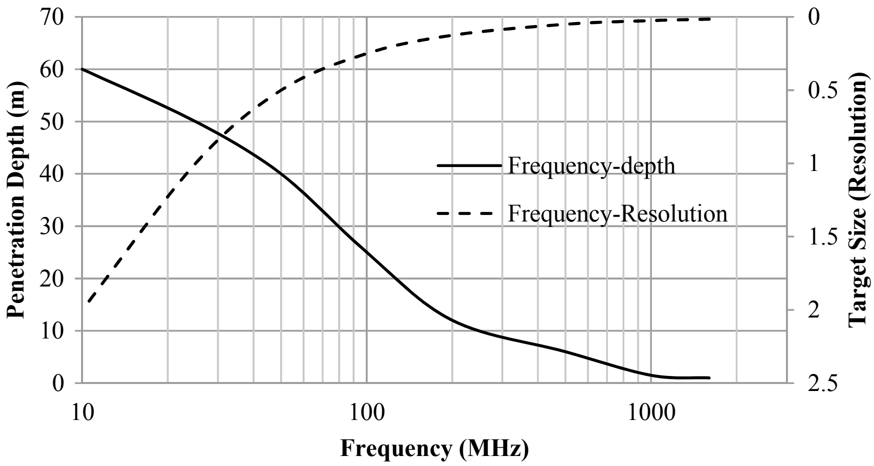


**Fig. 1** Frequency-resolution-penetration depth chart (penetration depth is also affected by the medium where GPR survey is employed)

EM wave velocity in air and water is 0.305 m/ns and 0.034 m/ns, respectively. The values of relative permittivity and EM wave velocity for selected materials can be found in Davis and Annan [2].

Lower-frequency (≤ 100 MHz) antenna gives higher penetration depth but lower resolution and higher frequency antenna (≥ 500 MHz) give lower penetration depth but high resolution. The typical frequency-depth-resolution plot is shown in Fig. 1.

## 3 Underground Utility Survey

Following are the typical examples where GPR was employed for detection of underground utilities including water supply line, sewer, cavity, cable and tunnels. GPR survey will facilitate in taking preventive action so that these utilities may not cause hindrance during construction. In general, antenna frequency used for the utility detection purpose was 300 MHz.

### *3.1 Four Crossings at New Delhi*

Mahanagar Telephone Nigam Ltd. (MTNL) proposed to lay communication cables across important crossings in New Delhi using trenchless technology in 1998. It was essential to locate underground utilities at that location in order to lay cables at convenient depth. Due to heavy traffic during day time, the filed work was carried out

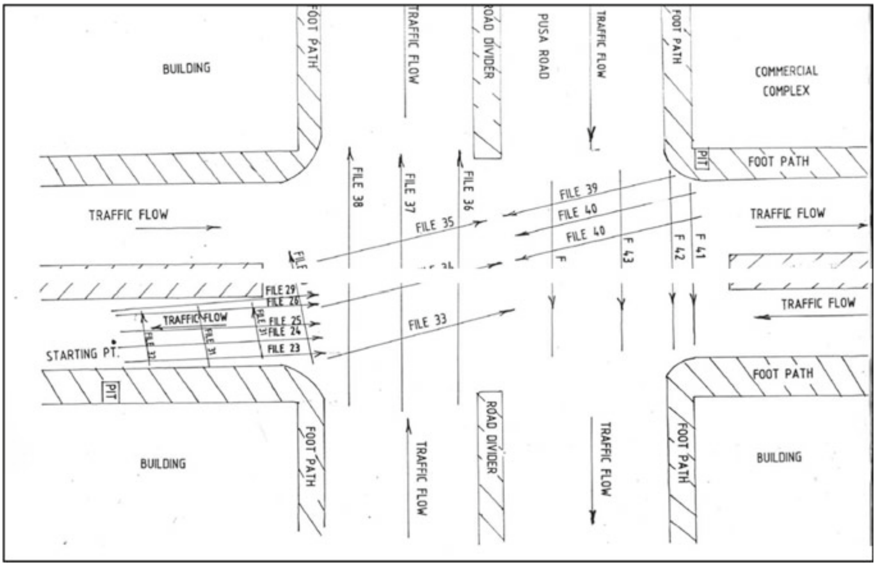


**Fig. 2** GPR survey map of four crossing at Pusa Road, Delhi

during night time [3]. A 300 MHz antenna was employed for scanning of underground utilities at following locations:

(a) **Puchkuian road**: Overall 20 profile lines were surveyed including 9 lines across the road and remaining along the road.
(b) **Pusa road**: Overall 20 profile lines were surveyed including 9 lines across the road. The profile map is shown in Fig. 2.
(c) **DB Road**: Total 15 profile lines were surveyed.
(d) **Park street**: Total 12 GPR lines were surveyed including 4 lines across the road.

Based on GPR survey, 2 m depth of clear zone was identified for carrying out cabling work.

## *3.2 Punjabi Bagh Crossing*

Public Works Department, Delhi, took up construction work of flyover at Punjabi Bagh crossing, New Delhi. GPR survey was conducted using 300 MHz antenna to find out utilities upto 3.5 m below ground level at crossing before excavation [4].

Based on GPR survey, the presence of pipes at a depth between 0.5 and 1.5 m was detected and mapped for taking precautionary measures during excavation.

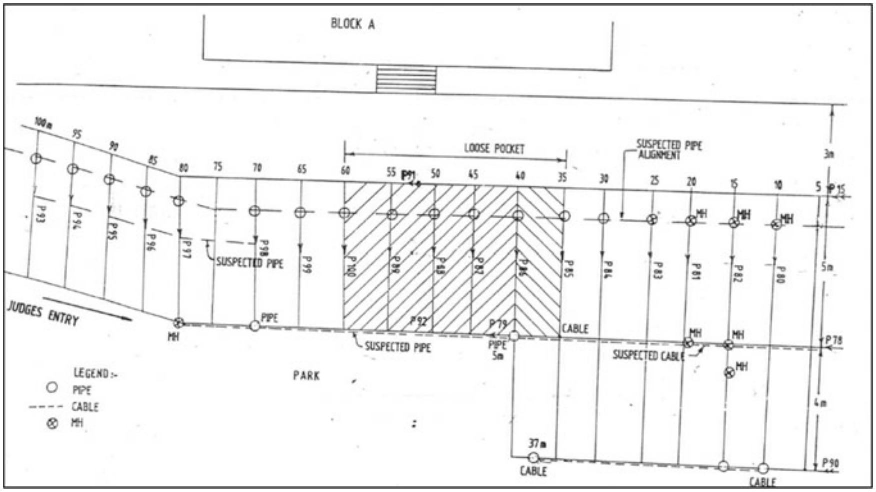


**Fig. 3** GPR survey map of underground parking at Delhi High Court

### *3.3 Underground Parking at Delhi High Court*

GPR survey was conducted at the construction site of basement parking for additional court building at Delhi High Court, New Delhi. GPR was towed manually in grid pattern of 10 × 5 m with target depth of 5 m. Twenty-four profile lines covering 328 m total length were surveyed. A loose pocket from 35 to 60 m (P85–P100) as shown in Fig. 3 was detected at 4.5 m depth from ground level. A pipe passing along road at a depth of 1.6 m was also detected [5].

### *3.4 Construction Site of Boys Hostel "D", IIT Delhi*

GPR survey was carried out at boys Hostel "D" site near existing Satpura hostel in the premises of IIT, Delhi. The land was fairly even, and the number of manholes was existed in the survey area. Monostatic 300 MHz antenna was used for underground utility survey [6].

GPR was towed manually at 5 m interval in both the directions forming 5 × 5 m grid. Total of 25 profile lines covering 850 m length of survey were carried out at the site. On perusal of GPR records, sewer line passing parallel to the boundary wall of DG shed and water reservoir were detected at 4 m depth. Also, an electrical cable passing at 0.6 m below was detected, and the same was visible at point of excavation.

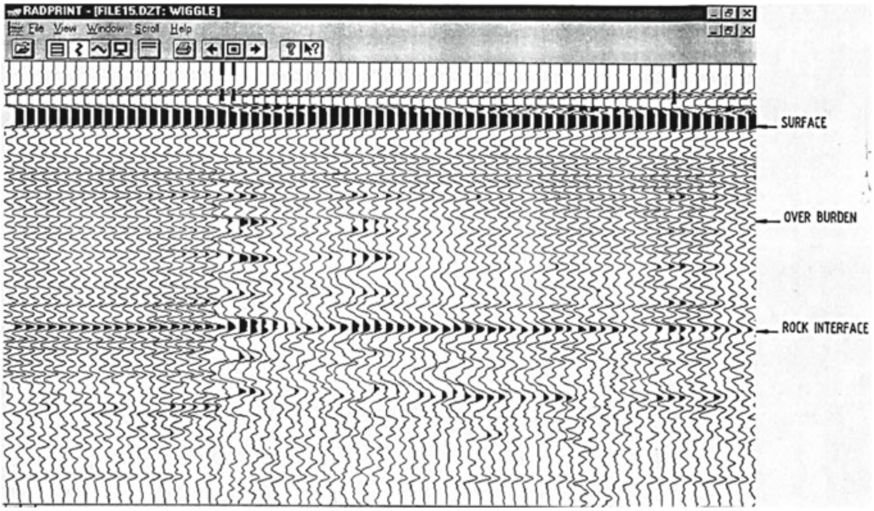


**Fig. 4** GPR wiggle trace showing bedrock in Asena quarry area survey

# 4 Delineation of Bed Rock

## *4.1 Tehri Project, Uttrakhand*

Tehri Dam is the highest dam in India, i.e. 260.5 m high earth and rock fill dam built across Bhagirathi River, a tributary of Ganga River. It has created submergence of 42 km$^2$ with storage capacity of 3450 MCM. The water stored is being served for irrigation, water supply and hydro power generation.

GPR survey was conducted using 80 MHz antenna in Asena quarry for the assessing the overburden thickness [7, 8]. This quarry was proposed to obtain rip–rap material. GPR survey was conducted for five profiles at different locations for a total length 130 m. The quarry area was 22,000 m$^2$ (200 m $\times$ 110 m) between EL 950.0 and 1100.0 m. The depth of overburden in the estimated was 18 m, and in some portion, it ranged from 12 to 18 m. GPR wiggle trace for one profile is shown in Fig. 4.

The quantity of rip–rap material was estimated based on the GPR survey at Asena quarry site.

## *4.2 Ganvi Hydroelectric Project, Himachal Pradesh*

Ganvi Hydroelectric Project generates 22.5 MW by utilising 7.25 m$^3$/s discharge of River Ganwi, a tributary of River Sutluj. GPR was used during construction of this project to estimate the depth to bed rock at anchor blocks in the penstock alignment.

The diameter and length of the penstock are 1.4 m and 600 m, respectively. GPR survey along with seismic refraction survey was carried out for determining bed rock profile.

GPR survey carried out on sloping terrain and bed rock profile along penstock alignment was mapped for locating foundation of anchor blocks [9].

## 5 Dam Health Monitoring/Diagnostics Investigation

GPR survey also employed to identify cracks, cavities and damages in the dam body. The survey can predict the stratigraphy of the dam body material based on properties contrast. Case studies of GPR surveys in diagnostic investigations of old dams are presented below. Apart from GPR, geophysical methods like seismic refraction survey, resistivity imaging and tomography techniques can be employed for dam diagnostics investigations [10].

### *5.1 Mulla Periyar (Baby Dam)*

The Periyar Reservoir Project was designed and executed by Col. John Pennycuick to divert west flowing River Periyar to the east to extend irrigation in the Vaigai basin. The main dam is solid masonry gravity dam 56.64 m height and 366 m length. Adjacent to main dam, in order to plug the saddle, a baby dam of 16 m height, 75 m length also constructed with rubble masonry.

GPR survey was carried out on the dam body to locate the presence of voids/cavities, if any, in the structures using 80 MHz (on dam top), 300 MHz (downstream face) and 500 MHz (upstream face) frequency antennas [11].

**Top of dam**: 80 and 300 MHz antenna were utilised for conducting GPR survey on dam top with 2 m interval along dam axis. The depth of observation was 18 m.

**Upstream face of dam**: A total of 24 survey lines using 500 MHz antenna were conducted on downstream face at regular intervals. The GPR profiles lines are shown in Fig. 5.

**Downstream face of dam**: Antenna with 500 MHz frequency was tied with the coir rope and pulled from bottom to top, ensuring proper contact with upstream face of dam. The observations were made at 5 m interval initially. Further, dam was scanned using 500 MHz antenna at 2 m interval. Total of 24 survey lines using 500 MHz antenna conducted on downstream face at regular intervals.

The GPR survey indicated absence of any cavity on the dam body. Further, integrity and homogeneity of dam were ascertained. The thickness of masonry on upstream face varied from 1.25 m (top) to 1.75 m (bottom); whereas on downstream face, it varied from 1.75 to 1.5 m in slope portion and 1.25–1.0 m in vertical portion.

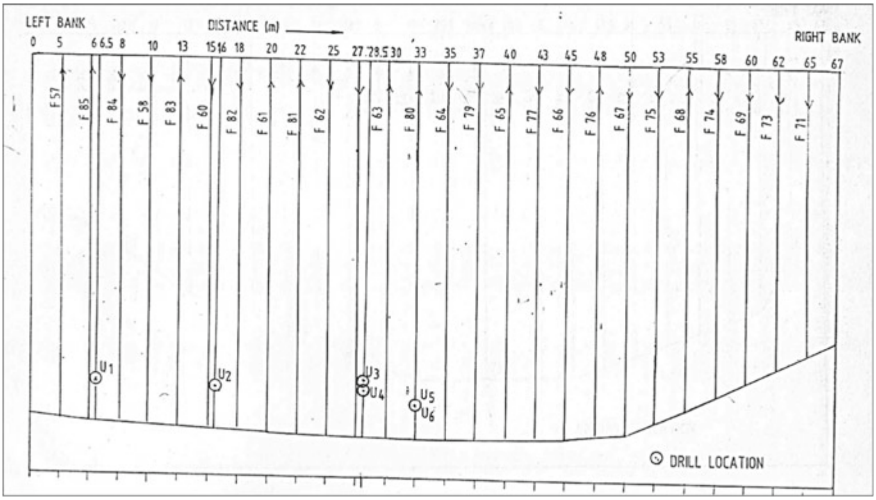


**Fig. 5** GPR profile lines in upstream face of Baby dam (Mulla Periyar), Tamil Nadu

## *5.2 Lower Jhelum H.E. Project*

The Lower Jhelum Project components includes dam, water conductor system of 8750 m length and power house housing three turbine of 35 MW each. The dam is built across River Jhelum in Baramullah District of J&K is located on the Jhelum River at Gantamulla in Baramullah District of Jammu and Kashmir. Power generation at this project was stopped due to sudden collapse of trash rack. It was suspected that collapsed piers might have damaged the upstream face of dam.

GPR survey was conducted on upstream face of dam using 500 MHz antenna with penetration depth of 2 m [12]. The antenna was tied with coir rope and was pulled from bottom to top ensuring the proper contact with upstream face of dam. A total of 20 profile lines were scanned at spacing of 1.5/2.0 m interval. The photograph of GPR scanning on upstream face of dam is shown in Fig. 6. Based on the GPR survey, the presence of cavity or damaged portion was ruled out on the upstream face of dam.

## *5.3 Matatila Dam Project*

Matatila Dam is earthen dam with stone masonry having 6.3 km length built across the River Betwa. The project serves as multipurpose for water sully, irrigation and hydro power. The spillway section of length and height is 490 m and 45.7 m, respectively. The project installed capacity is 3 × 10.2 MW.

**Fig. 6** Photograph of GPR scan on upstream face of Lower Jhelum Dam

The GPR survey was carried out to demarcate leakage points in dam body around a water supply intake pipe of 35 cm diameter [13]. Total of 42 profile lines using 80 MHz frequency antenna were conducted across and along the dam axis. The GPR profile along with intake pipe alignment is shown in Fig. 7. No anomaly indicating leakage through dam body was detected.

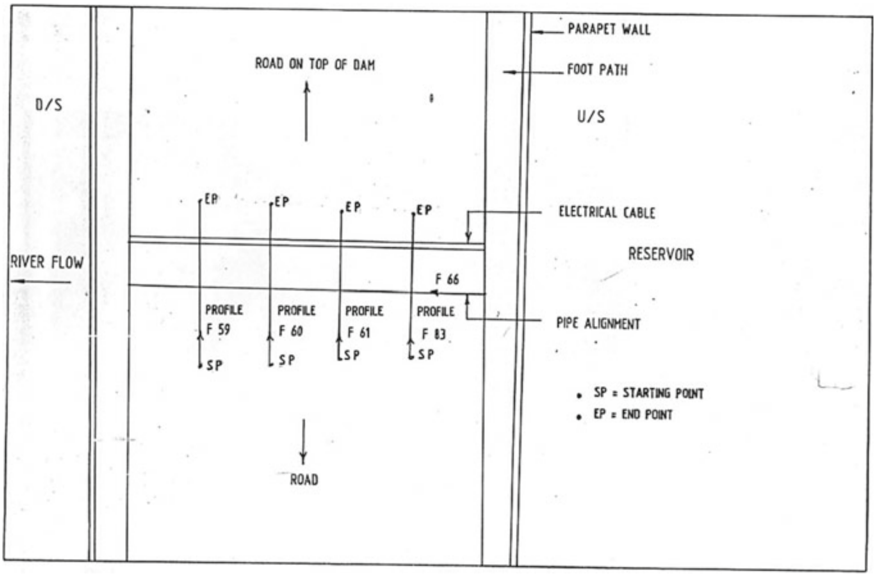


**Fig. 7** GPR profile lines in Matatila Dam, Jhansi, Utter Pradesh

## 6 Summary

Based upon the case histories of GPR applications in underground utility scan, delineation of bed rock profile and diagnostics investigations of old dams, the following are inferred;

- GPR survey can be used for detection of any buried utility for laying cable using trenchless technology and planning excavation for construction of new buildings. Mostly 300 MHz frequency antenna was used, and depth of investigation was less than 5 m.
- GPR can be employed for delineation of bed rock profile for locating foundation and also for estimating the quantity of construction materials. Generally, 80 MHz frequency antenna was used and depth of investigation was about 25 m.
- GPR was also successfully employed for finding the integrity and homogeneity of dam. The GPR investigations assisted in judging the thickness of masonry on upstream and downstream faces of old dams. The integrity of upstream faces of dam was scanned using 500/300 MHz frequency antenna with penetration depth of 3 m. Interior body of dam was scanned through 80 MHz frequency antenna, and the depth of investigation is about 20 m.

Overall GPR methods proved to be a successful tool in number of applications, and its use can be extended to all its civil engineering applications.

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