Journal of Engineering Geology — *Volume XLIV, Nos. 1 & 2*
A bi-annual Journal of ISEG — *June & December 2019*

Applications and future of ground penetrating radar (GPR) as a near-surface geophysical technique: A review

Sinharay, Rajib K.
Associate Professor, Department of Petroleum Engineering,
Maharashtra Institute of Technology, Paud Road, Pune-411 038, Maharashtra, India.
E-mail: rsrism@gmail.com

Abstract

Ground Penetrating Radar (GPR) technology has grown rapidly in last two decades significantly increasing depth of penetration, resolution, speed of acquisition, advanced 3D modeling, precession of location etc. Numerous GPR surveys have been carried out nationally and internationally during this period and several works have been published in different journals and workshops. This review work on GPR technology shows that GPR has been successfully used almost in every possible near surface investigation including polar studies, geotechnical investigations, soil studies, land mine detection, tunnel surveys, monitoring active fault etc. High resolution GPR with both shielded and un-shielded antennas can be efficiently used in several river valley and hydroelectric projects to detect cavities below the concrete dam, seepage path of the canals, assessment the health of old concrete structures, mapping the fracture patterns, faults etc. GPR also have been used to detect the lineaments, lithological boundaries, active faults and very useful for geological characterization of the civil project sites. GPR also has proven its tremendous potential to study the glaciers, sub-glacial lakes, permafrost, crevasses, yearly snow depositional pattern etc. Presently the use of GPR for utility surveys has been increase many fold and tens of Indian companies are providing GPR services. Ease, speed, resolution, availability and scope has made GPR the most celebrated near-surface geophysical technique of the present decade. In future, we may expect few advanced features such as artificial intelligence (AI) for automatic 3D object mapping facilities, remote controlled surveys with robotics, significantly increased survey depth, 4D GPR surveys for hazard monitoring and real time alarming system etc.

1. Introduction:

Ground Penetrating Radar (GPR) is an active reflection electromagnetic (EM) profiling technique which sends EM waves into the subsurface as microwave pulses with frequencies commonly ranging from 10 MHz to 1.5 GHz and records the reflected signals using EM receivers (Figure 1). The amplitude and travel-time of the returned signals provide subsurface information with high resolutions. The two most important physical properties which impact the behavior of radar waves are the material's dielectric properties and its electrical conductivity. The velocity of the EM wave in a medium is determined by the dielectric constant of the medium whereas depth of penetration depends on the electrical conductivity. The arrival time and amplitude of recorded EM waves are analyzed to create sub-surface models across the profile.

Ground Penetrating Radar (GPR) technology has rapidly grown in last two decades having higher depth of penetration, better depth resolution, increasing speed of acquisition, precession of location etc. Numerous GPR survey have been carried out nationally and internationally during this period and several works have been published in different journals and workshops. This is a review work to identify the full potential of GPR as a near-surface tool for all possible applications.

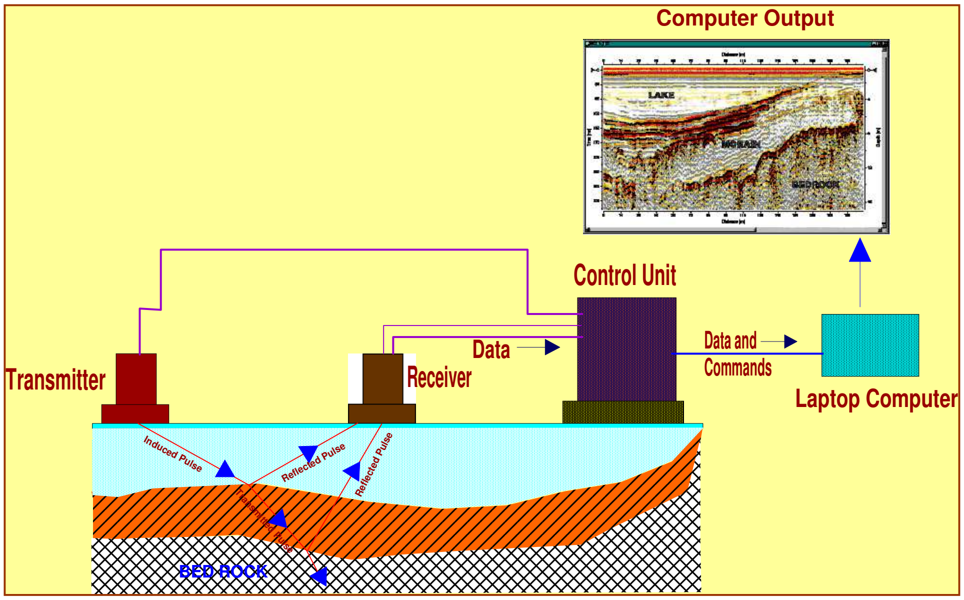

Figure 1 Basic GPR units and field set up for surveys

2. Evolution of GPR Technology:

Heinrich Hertz carried out some experiments in late 19th century which showed that radio waves are reflected by metallic objects. In early 20th century, Christian Holsmeyer used this radio echo technique to build a simple ship detection device. The first patent for continuous-wave radar to locate buried objects was submitted by Gotthelf Leimbach and Heinrich Lowy in 1910 (Wiki). Tuve and Breit (1925) used pulse radar to estimate the height of a conducting layer in the year 1925. A glacier's depth was measured using ground penetrating radar in 1929 (Stern, 1930).El Said tried to measure subsurface water table depth in 1956 using radio waves (El Said, 1956). One of the initial uses of radio echo was to study the polar ice caps (Bailey et al., 1964; Walford, 1964). During 1970s, the use of radio echo technique was extended to study underground coal seam mapping (Cook, 1973), salt deposit studies (Holser et al, 1972; Unterberger, 1978) and finally for lunar surface study in Apollo 17 lunar exploration programmes. During same time, Geophysical Survey Systems Inc. developed the first GPR and started selling it. Shortly OYO, Japan added another GPR with a commercial name “Georadar” which was commercially used and successful. In 1985, the first low frequency digital GPR technologies were reported by Davis et al. and pulse EKKO series of GPRs were developed. During 1980s, few GPR survey were carried out for nuclear waste disposal, road investigation, utility survey etc. During middle of 1980s, borehole GPR was developed by Swedish Geological Survey. However, during this time U.S. Environmental Protection Agency started using it to locate contaminated lands. The other application of GPR during this time was soil classifications for agriculture (Annan, 2001). The next phase of development of GPR technology started during 1990s and was rapid. Geophysical Survey Systems Inc. (GSSI) exhibited strong commercial success and was bought by OYO Corporation. Mala Geosciences was established from Swedish Geological Survey roots. Sensors & Software Inc. grew rapidly broadening its pulse

EKKO product line. Presently, these three companies are the leading GPR manufacturer and selling globally.

Presently the advanced GPRs are using very wide frequency bands with a range of 16 MHz to 3200 MHz frequencies enabling them to investigate objects with at wide range of depths and resolutions. GPR now are being used to investigate even deep geological features to very high-resolution concrete structure integrity. However, major advancement of GPR features are as follows:

1. Simultaneous multi frequency data acquisition
2. Built-in DGPS with high precession of location
3. High sampling rates and huge data storage capacity (up to 1 TB)
4. Simplified graphical user interface
5. In-the-field processing and interpretation facility
6. 3D processing and modeling software

3. GPR Surveys in India:

GPR survey in India started in 1990s. Wadia Institute of Himalayan Geology was one of the initiators who carried out GPR surveys mainly to study the glaciers of Himalaya and Antarctica during this period. In November 1995, they carried out GPR profiling to measure ice thickness of Dokriani Bamak (glacier) using pulseEKKO IV radar (Gergan et al., 1999). GPR sounding was carried out from the snout, the accumulation zone of the glacier. GPR was also used in XX Indian Antarctic Expedition, 2001 for sub-glacial tectonic features (Gergan et al., 2006). In the year 2002, Central Water and Power Research Station (CWPRS, Pune) acquired RAMAC GPR system and started testing it for various engineering geophysical problems. CWPRS used GPR to study Antarctic polar ice cap (Figure 1) thoroughly to map sub-glacial bed rock topography, sub-glacial lakes (Figure 2), crevasses, yearly snow depositional patterns, predicting health of retreating glaciers etc. during XXII Indian Scientific Expedition to Antarctica (ISEA), 2003 (Sinharay, 2008). Another significant achievement of GPR studies of XXII ISEA was the detection of buried Dakshin Gangotri hangar and retrieving lost ice cores stored inside it. Later, CWPRS carried out several GPR surveys to study different dams and canals structures (Wadhwa et al., 2008), buried landmines, buried archaeological structures, studying tunnels (Chaudhari et al., 2014), soil contamination (Subbarao et al., 2014) etc. During 2003, GPR was used as advanced technology to study controversial Babri Majid-Ram Mandira structure. Archaeological Survey of India (ASI) further used GPR to delineate Nalanda ruins in 2007. During same period Pujari et al. (2007) used GPR to assess the pollution in landfill areas near Nagpur, Maharashtra. National Geophysical Research Institute (NGRI) used GPR for ground water exploration in Granitic terrain (Maheshwari et al., 2013). GPR is also being used to map shallow tectonic features, active faults and seismic hazard assessment (Maurya et al., 2005; Saikia, 2015). Geological Survey of India (GSI), Polar Studies Division also have procured GPR system for glaciological studies and regularly carrying out GPR surveys for polar research (Shrivastava et al., 2017)

Figure 2 GPR survey near Indian station "Maitri" during XXII ISEA, 2003.

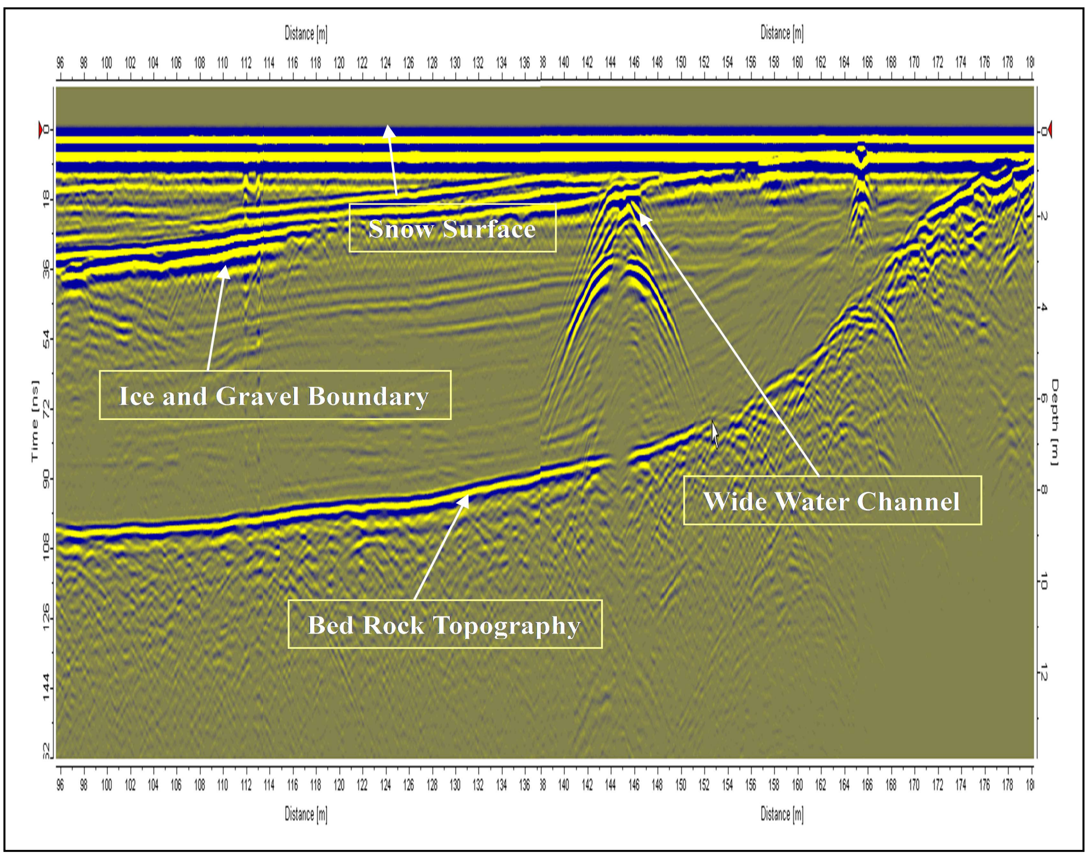

Figure 3 GPR section over a sub-glacial lake at Schiermacher Oasis, Antarctica acquired during XXII ISEA using RAM AC GPR, 250 MHz shielded antenna

4. Efficiency and Future of GPR:

GPR has been successfully used almost in every possible near surface investigation including polar studies, lunar exploration, geotechnical investigation, agricultural purposes, land mine detection, tunnel surveys, monitoring active fault etc. Present review work finds that high resolution GPR with both shielded and un-shielded antennas can be efficiently used in several river valley and hydroelectric projects to detect cavities below the concrete dam, seepage path of the canals, assessment the health of old concrete structures etc. GPR also can detect the near surface fractures, lineaments, lithological boundaries and active faults and very useful for near surface geological characterization of the civil project site. GPR also has proven its tremendous potential to study the glaciers, sub-glacial lakes, permafrost, crevasses, yearly snow depositional pattern etc. Presently the use of GPR for utility surveys has been increase many fold and tens of Indian companies are providing GPR services. Ease, speed, resolution, availability and scope have made GPR the most celebrated near-surface geophysical technique of the present decade.

In future, we may expect few advanced features as following:

i. Artificial intelligence (AI) for automatic 3D object mapping facilities
ii. Remote controlled surveys with robotics
iii. Significantly increased survey depth
iv. Anisotropic 3D modeling software
v. 4D GPR surveys for hazard monitoring and real time alarming system etc.

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