Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Significance of GPR Studies in Urban Planning and Road Works - A Case Study from Gujarat, India

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Abstract. In this study, Ground Penetrating Radar (GPR) survey has been carried out at proposed underpass location of Vaishnodevi Circle, Ahmedabad, Gujarat, India. The aim of the study is to map all the possible underground utilities (up to 8m depth) including cables, water pipelines, gas lines and sewerage to prevent any potential damage to the same during future constructions. The main focus of the study is to exactly map the alignment of two water pipelines found at depth of 5.5m from the natural ground level during piling works. Considering site requirements and expected depth of utilities, the area has been surveyed using 100MHz, 200MHz and 400 MHz central frequency antennas mounted on SIR 3000 and SIR 4000 GPR systems to cover the depth upto 8m with fair resolution. The data has been collected both in longitudinal as well as transverse directions and at night to have least disruption to traffic flow and ensure safety of people at site. The data has been properly processed and efficiently interpreted on the basis of observed features in the data, surface features and inputs from the local public and site engineers. A total of 26 utilities along the road and a number of utilities across the road stretch were found running beneath the ground at different depths and with different alignments. The study helps in minimizing the risks in future construction phases and also plan the excavation and drilling works after GPR survey results to arrive at best possible location and alignment of piles.

Keywords: GPR, Utility mapping, Urban Planning, Road Works, NDT.

1 Introduction

In a developing country like India, roads and highways constitute an important mode of transport. India, with the second largest road network in the world has the roads constituting main infrastructure of the country. They play a pivotal role in defining in the socio-economic and overall development of the country including performance and social functioning of the nation. Road transport, being quicker, more convenient and flexible, determines the overall quality and well-being of common people residing in an urban area. Railways are highly dependent on road networks and connectivity. They serve many important purposes ranging from simple living to military and national defense services including transportation of goods and passengers for short and medium distances and makes door to door services possible.

One of the striking underlaying facts is the bad condition of roads. India, being a developing nation demands a good quality infrastructure, transportation and related services. Major efforts are undertaken and major projects are implemented to modernize the country's road infrastructure connecting many of its manufacturing, commercial, agricultural and cultural centers. Expansion of existing roads, construction of important bridges, flyovers, subways are some of the important steps taken into consideration. Different development works often require to shift utilities like telephone cables, electric cables, water pipelines, etc. which leads to severe loss of economy and disruption of basic facilities to the people dependent on such utilities. Such losses could be avoided with proper planning and if non-destructive techniques (NDTs) are used well before planning of any road excavation and allied works.

Ground Penetrating Radar (GPR) is advanced and real-time NDT that uses electromagnetic waves with high frequency (10 MHz to 2.5 GHz) and responds to changes in the electromagnetic properties of the shallow subsurface. Being non-invasive subsurface imaging technique. It has potential to image through different materials including soil, rock, tarmac, wood, concrete and even water. It could fairly be utilized to determine the shape, size, extent and depth of a different buried objects. Different studies show that it has potential to be deployed to find pipes, foundations, voids, trenches, geological layers, reinforcing bars, etc. It can work in dry as well as wet and saturated soil conditions. It successfully aids in the diverse fields such as archeology, glaciology, landmine detection, road evaluation, landfill mapping, mineral exploration, underground utility mapping and leakage detection. [1-11]

In almost every construction or maintenance works on or adjacent to roads and streets, the exact alignment of underground utilities has become a prerequisite. Different utilities lie under street networks and along main highways, which if disrupted can lead to sever losses and chaos in the people dependent on them. Past studies show that GPR is capable to be used for underground utility mapping which in turn helps in efficient planning and prevention of different hazards. Different laboratory experiments and case studies reported so far indicate the potentiality of GPR in successful underground utility mapping and road evaluation. [9-11]

No detailed information was available about the existing underground utilities in the area under study (Fig 1). The study site is located at Vaishnodevi Circle, Ahmedabad, Gujarat, India and was proposed for underpass construction. During the pile driving process, the two water pipelines were disrupted, causing an immense chaos and confusion for the administration responsible and people dependent on it. Thus, an immense need was felt to make use of NDTs and find the proper location and alignment of utility lines in the area upto a depth of 8 m. To avoid any further losses, GPR survey was carried out in the area hatched in Fig 1 represents the area surveyed and presented here. This study attempts to map the all the existing utilities including cables, water pipelines, gas lines and sewerage in the study area upto the depth of 8 m with special focus on two water pipelines existing at depths 5.5m which were destroyed during the piling works. The data was collected both in longitudinal and transverse directions. The collected data was processed and further interpreted to prepare the plans of existing utilities found during the survey. A total of 26 utilities along the road and a number of utilities across the road stretch were found running beneath the ground at different depth levels which possess different alignments. Thus, the present study proves helpful in minimizing the losses to utilities in the future constructions.

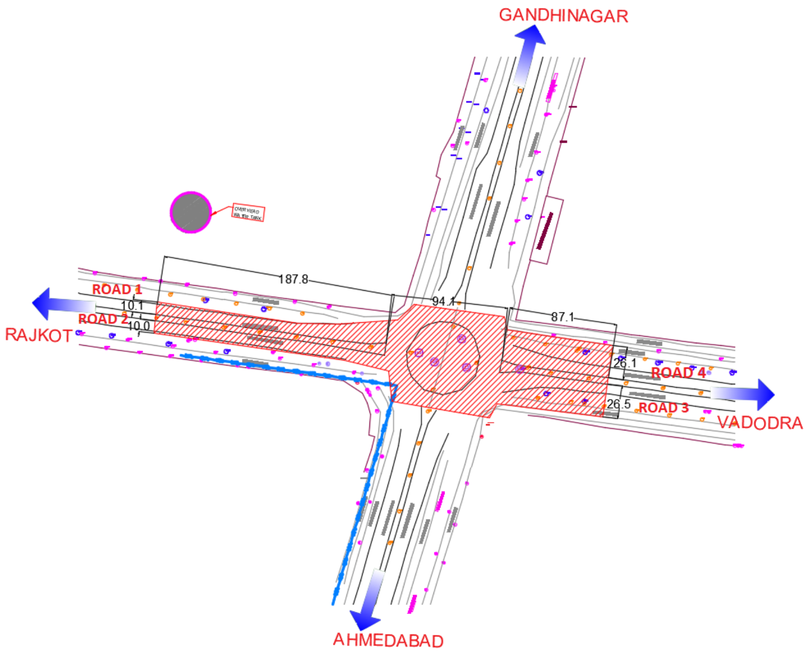

Fig. 1. Lay out of the Study Area

2 Methodology, Data Acquisition and Data Processing

GPR radiates high frequency electromagnetic (EM) waves into the subsurface via its transmitting antenna. These waves travel downwards till they encounter any subsurface interface or any buried object with different electromagnetic properties. The reflected waves are then recorded by the receiving antenna of GPR system. While travelling from one medium to another, some part of EM waves may be reflected, refracted or transmitted depending upon the dielectric contrast of the two media. The receiving antenna collects the reflected waves, records the two-way travel time and amplitude of the reflected signals. Two-way travel time (t) is utilized to obtain the corresponding depth (d) using equation 1 by knowing the velocity (v) of EM waves in the particular medium. Velocity of EM waves in a medium depends on its dielectric constant (ε) and can be calculated using equation 2. The details about working of GPR can be found from reference. [12]

$$d = \frac{vt}{2} \quad (1)$$

$$v = \frac{c}{\sqrt{\varepsilon}} \quad (2)$$

where c is the velocity of light in vacuum.

GPR presents the subsurface features with dielectric contrast in the form of hyperbolic reflections. It has potential to identify utility lines buried in the ground. GPR has also certain limitations like contrast between resolution and depth, attenuation of wave energy in a conductive medium, unwanted noise from the local sources like radios, mobiles etc. Therefore, interpreted results may sometimes vary from actuality.

In the current study, data has been obtained by carrying out a GPR survey over a stretch of around 371 m. The area was scanned with a grid spacing of 10 m across the road and 5 m along the road. Appropriate personal protective equipments (PPE) and barricades were used for the safety of equipments and team working on site. GSSI SIR-3000 and SIR-4000 GPR systems equipped with 100MHz, 200MHz and 400MHz antennas were employed to scan the required depth with a fair resolution. The data was collected upto maximum accessibility. Data was collected in distance mode with the antenna in mono-static mode. For 200 MHz antenna, the 120 ns time window, 80 scans per unit and transmission rate of 100 kHz were used as the parameters while for 100 and 400 MHz antenna, the time window of 220 and 60 ns were used, keeping all other specifications same. Around 140 profiles were collected for the execution of this work.

To improve signal to noise ratio (SNR) and acquire good quality data with higher resolution, a stacking of 64 was applied. To ensure the least possible error in mapping any underground utility, the survey wheel was calibrated on the field. Similar specifications were applied throughout the stretch surveyed.

The existence of undesirable noise in the GPR data acquired from the field makes it difficult to interpret the raw data directly. Therefore, it was mandatory to process the data for proper interpretation and identification of subsurface features. The conventional processing was carried out for the whole acquired data using RADAN 7. The processing steps were applied in order. Time zero correction was applied to correct for reflections from air-ground interface, so that all the traces are brought to common starting point. Background removal was aimed to remove the constant noise in the form of continuous horizontal bands in GPR profiles. Band pass filtering was done to remove unnecessary high and low frequencies, other than the range of dominant frequency. Besides, band pass filters of 60 MHz-450 MHz for 200 MHz antenna, 30 MHz- 230 MHz for 100 MHz and 100MHz- 850 MHz for 400 MHz antenna was decided based on the dominant frequency content obtained from spectrum in RADAN 7. Range gain was applied to regain the lower amplitude signals from greater depths. It was aimed to cover the effects of attenuation of waves with depth. The processed data obtained after these steps in order, had a better interpretability and was therefore further analyzed for obtaining different results. The calibration of EM wave velocity for depth estimation is done by using Kirchhoff's migration in RADAN by fitting Ghost hyperbola. Hence, the dielectric constant of the medium is obtained to be around 14.0.

3 Results and Discussions

The processed data obtained from RADAN 7 has been thoroughly analyzed to observe different feature reflections from underground objects. Based on processed data and visual information from site, best possible efforts have been applied to map the existing pipelines and other utilities with satisfactory accuracy. All the observed features from the analysis have been marked on the plan view at their corresponding positions. The repetitive feature reflections at almost same depths were joined to obtain the utility alignment. The reflections in irregular fashion were discarded as they may arise due to the presence of any localized objects like boulders, voids or any scrap material instead of the target utilities. The detailed findings from this study are shown in Fig 2.

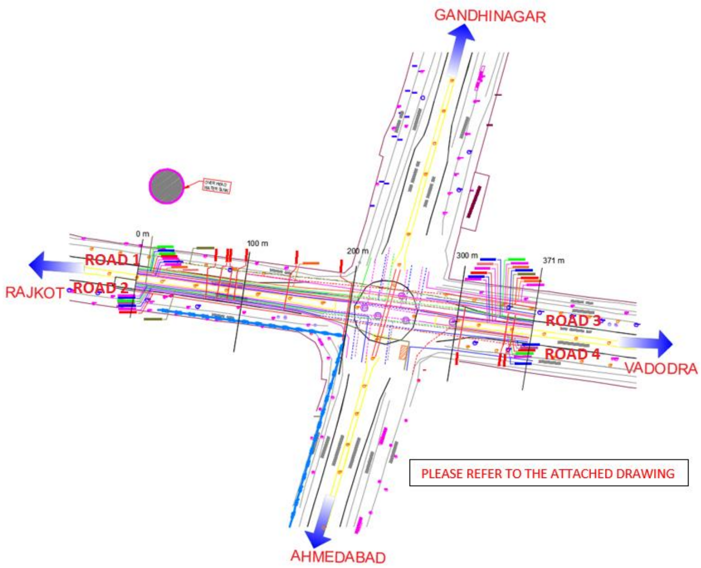

Fig. 2. Plan view with marked utilities.

Following interpretations are noteworthy from the processed data based on constant reflections and some of the radargram samples are shown in Fig 3.

- A total of 26 utilities, named as U1 to U24, EU1 and EU2, are observed to be running at different depths for different stretches of the surveyed road.
- Reflections of utility EU1, are found on Road 1 and Road 4 with their top levels varying between 4.4 m - 5.5 m from ground surface. There is a possibility of this line to be expected water line.

- Utility EU2, is observed to be coming towards the junction from Water tank and found existing below Road 2. At Vaishnodevi circle, similar reflections of the utility are observed on the road running towards Ahmedabad.
- There is varying depth and exact alignment of these utilities (EU1 and EU2).
- Utilities U1, U2, U4, U5, U6, U7, U8, U10, U12, U13, U14 and U16 are found to be present throughout the surveyed road stretch of 371 m.
- Out of these, U1, U2, U4, U5, U6, U7, U8 and U9 are found to exist beneath Road 1 and Road 4 at the average depth of 0.5 m, 0.7 m, 2.1 m, 0.6 m, 0.8 m, 0.5 m, 4.0 m and 3.7 m, respectively.
- Reflections of U10, U12, U13, U14 and U16 are found on Road 2 and Road 3. These utilities are noticed to lie at average depth of 0.7 m, 0.4 m, 0.7 m, 0.7 m and 1.6 m respectively.
- U3 is initially observed at 0 m chainage distance and continues till a Chainage distance of 206 m. There is a possibility that this utility might be turning left towards Gandhinagar side. This utility is observed at an average depth of 0.4 m from ground surface.
- U11 and U15 are found to be running below Road 2 and turning right towards Ahmedabad side. These utilities are found at average depth of 0.9 m and 0.6 m, respectively.
- Utilities, U17, U18, U19, U20 and U21 are mapped below Road 4 and possibly turning right towards Gandhinagar side. The top of these utilities is found at average depth of 0.5 m, 3.3 m, 1.9 m, 0.6 m and 0.6 m, respectively.
- In addition to U10, U12, U13 and U16, 3 more utilities (U22, U23 and U24) are found below the Road 3. There is a possibility that these 3 utilities are turning left towards Ahmedabad side. The average depth of the utilities are 2.8 m, 0.7 m and 0.7 m, respectively.
- However, number of across the road utilities have also been found at various depth levels.
- At some places, utilities are marked with dashed lines, this represent their possibility of extension or network with other lines in non-surveyed area.

4 Conclusions

In the current study, underground utilities mainly two disrupted water pipelines up to a depth of 8 m were mapped using GPR. A total of 26 utilities along the stretch were observed along with numerous pipelines across the stretch in the surveyed area. Different utilities, their alignment and possible form (cable, PVC pipe, metal pipeline, etc.), A detailed plan was prepared for the whole area which will serve as guide for future construction and maintenance works. Although the interpretations are made on the basis of the available information and the observed features in GPR data, they do not imply the existence of those utilities with surety.

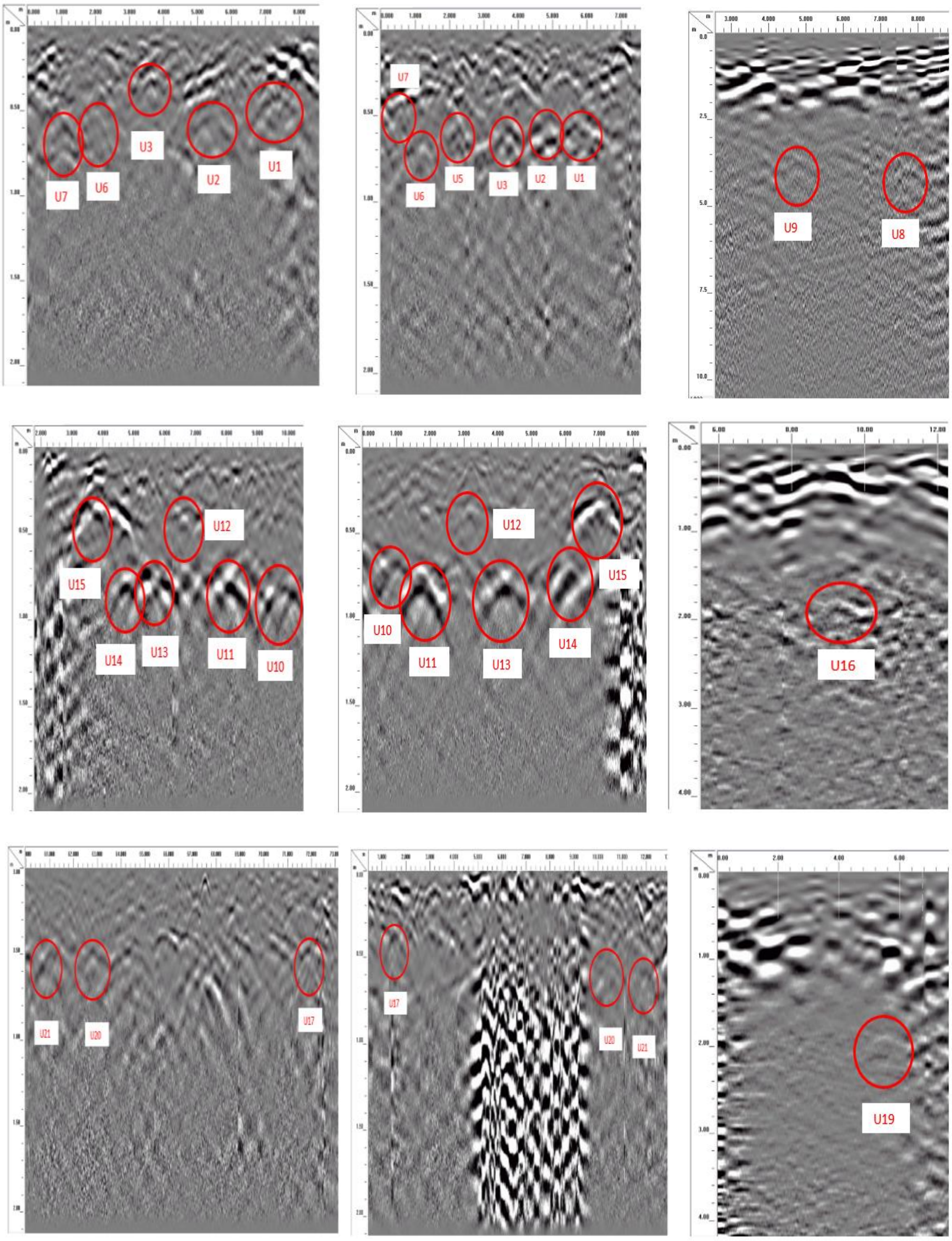

Fig. 3. Radargram Samples corresponding to different utilities.

Acknowledgement

The authors sincerely thank the project staff at Geocarte Radar Technology, Pvt. Ltd for their tireless efforts in completing the project work well before stipulated time.

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