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Research Article

Detection of Leakages of Underground Pipes By GPR, LRUT, and PAUT Measurements

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Keywords

Ground Penetrating Radar, Non-Destructive Testing, Underground seepages, Long Range Ultrasonic Test, Phased Array Ultrasonic Testing.

Abstract

Generally, subsurface water seepages are caused by underground utilities, and nearby large water bodies are a major problem in the industries. These underground leakages cause severe damage to the foundation/basement of the building and facilities and the underground pipelines. In this study, we have identified the subsurface seepage source locations in one of the oil and gas facilities in India. We have proceeded with an integrated approach by combing Ground Penetrating Radar (GPR) survey and Non-Destructive Testing (NDT) methods. We have used 100 MHz and 400 MHz GPR antennas to scan the underground utilities and find the saturation of the subsurface layers by finding their resistivity. Long Range Ultrasonic Test (LRUT) and Phased Array Ultrasonic Testing (PAUT) are performed on the various diameter underground pipelines. The combined analysis and in-depth investigation of the results/outputs from GPR survey and NDT have successfully identified the reasons for the underground seepage points. These studies will help the industries save time and money to investigate the variability in the subsurface moisture distribution, find out the water channels, prevent damage to structures, and recommend suitable solutions to avert the damage to future installations.

1. Introduction

Underground water seepages are major problems in constructing railways, buildings, industrial plants, and onshore facilities. Generally, Industries couldn't identify the subsurface seepages without testing or encountering water encroachment on surfaces. In most cases, seepages from the wastewater treatment plants, sewage and oil and gas treatment plants cause environmental problems by polluting groundwater tables, leading to loss of lives and vegetation in the contaminated area [1]. The underground seepages also cause technical and maintenance difficulties to the underground utilities such as pipelines and foundations [2]. Ignoring the underground leakages and water seepages also cause sinkholes and shallow layer subsidence in the ground, which have severe implications for the ongoing constructions and existing facilities (infrastructures) [3][4]. Industries spend a huge capital on unground pipeline installations and maintenance, but there are many reasons for pipelines to lose their integrity and cause leakages. Corrosion is the main reason for pipeline disintegrations. A periodic pipeline inspection must be carried out to avoid any such events like leakages and bursts. There are numerous methods available for finding leaks in the buried pipelines.

This study integrated the Ground Penetrating Radar, Long Range Ultrasonic Test, and Phased Array Ultrasonic

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Testing methods to identify the pipeline leakage in the oil and gas facility plant. The acoustic testing is carried out on an 8" pipeline covering an area of about 1400mm and a 6" pipeline with an area coverage of 200 mm.

2. Methodology and Experimental

To inspect the site to find the possible source of water seepage and pipe leakage and recommend further studies.

•Detection of Leakage from pipes by GPR method and LRUT Test

• Identification of saturated layers by GPR method

• Evaluation of subsurface irregularities by GPR method

• Estimation of velocities and moisture distribution at different depths by GPR 3D

• Analysis of API inspector.

2.1. Ground Penetrating Radar (GPR)

Ground Penetrating Radar (GPR) is a non-invasive geophysical tool that uses a high-frequency radar antenna and advanced signal software to probe underground structures, voids, and objects accurately. The prime focus of our investigation is to identify the fractures in the near-surface and identify the anomalies in the soil properties by velocity analysis to clarify the stability of the locations. GPR works on the principle of propagation and reflection of Electro-Magnetic (EM) waves. The reflection of EM waves provides the information of the subsoil/subsurface, especially the dielectric constant and the electric conductivity [5]. GPR with high frequency has low penetration depth, which also depends on the soil properties, which is greater than that obtained by other geophysical methods, makes this technique suitable for high-resolution shallow studies like moisture content and shallow stratigraphy mapping. GPR 2D profiles were taken roughly with wide spacing, and for detailed study, we collected closely spaced profiles in 2D and 3D mode. Transects were spaced at every 1m to 2m interval (antenna size is a factor of spacing between transects), and 3D was collected in a zigzag pattern. GPR data collection works best with a grid format. For this survey, we collected at least one 3D profile from each site. The size of the grid was modified to fit within the area of interest. For this investigation, 400MHz and 100 MHz antennas were used.

The initial data processing in 3D involves the generation of amplitude slice maps [6]. Amplitude slice maps are a 3D tool for viewing differences in reflected amplitudes across a given surface at various depths. Reflected radar amplitude signals are necessary since high or strong amplitude reflections indicate denser materials and vice versa. Comparison of reflected amplitudes at all vertical profiles is carried out for the generation of amplitude slices. Amplitude slice maps have a series of x, y, and z values, with x and y being the location on the ground surface at each grid and z. Time slice maps are built averaging the amplitude (or the square amplitude) of the radar signal within consecutive time windows of width Δt. GPR data is processed using GSSI's RADAN 7 software. The advantage of using RADAN is that it can process GPR data in 3D, remove background noise, apply different filters, and calculate radar velocity through the ground. Once a 3D image was generated in RADAN for each grid, it could create time slices at regular depth.

In the velocity analysis, it is crucial to calculate the velocity at each interval layer which is given by the Eq. (1)

$$v_{int,n} = \sqrt{\frac{t_n\, v_n^2 - t_n\, v_{n-1}^2}{t_n - t_{n-1}}} \tag{1}$$

V_{n-1} and V_n are the velocities from the datum to the reflectors above and below the layer, and t_{n-1} and t_n are the respective time.

The soil moisture content of the soil is estimated from the relation between petrophysical methods and soil, and the following expression is used for calculating the moisture of the soil, apparent Permittivity (ε), and volumetric soil water content (θ) (m3/m3) .

$$\theta = -5.3\times10^{-2} \div 2.92\times10^{-2}\varepsilon - 5.5\times10^{-4}\varepsilon^2 + 4.3\times10^{-6}\varepsilon^3 \tag{2}$$

2.2. Long Range Ultrasonic Test (LRUT)

NDT method was developed to find the pipeline in integrity by measuring the pipe metal loss both inside and outside the pipe diameter, as shown in Figure 1. It works on the principle of piezoelectric transducers. Guided wave energy is generated in the material, based on the piezoelectric effect, by positioning the transducer in contact with the material and pulsing it with an electrical charge to generate mechanical vibration [7]. Returned energy encountered by the piezoelectric transducer is converted from mechanical energy to an electric voltage. The electrical voltage produced proportional to the magnitude of the mechanical force [8].

$$\Delta A\% = \frac{A_1 + A_2 + A_3}{\pi D t} \times 100$$

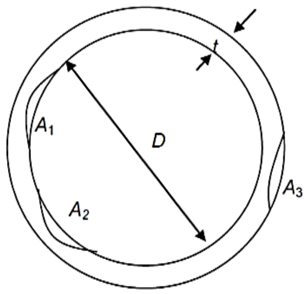

Figure 1. Percentage Loss of cross-section area

3. Results and Interpretation

GPR measurements are recorded at four different locations, both in 2D and 3D. At location -1, the structures make the anomalies in the radargram at 2m, 6.5m, and 11m ground distance. The leakage spot is at ~8.25m away from the pit, and the saturated zone extends >8m depth with a horizontal distance of 8.25 - 10.2m, which is shown in Figure 2. 3D data is collected from the location-1 which is 1m away from the excavated pit, the depth profile of the 3D data shows the significant variation in the signals captured, which is illustrated in Figure 3(a), the saturation profiles of the subsurface soils have a significant variation on the moisture content which is shown in Figure 3(b), the depth details and the moisture content are shown in Table .1

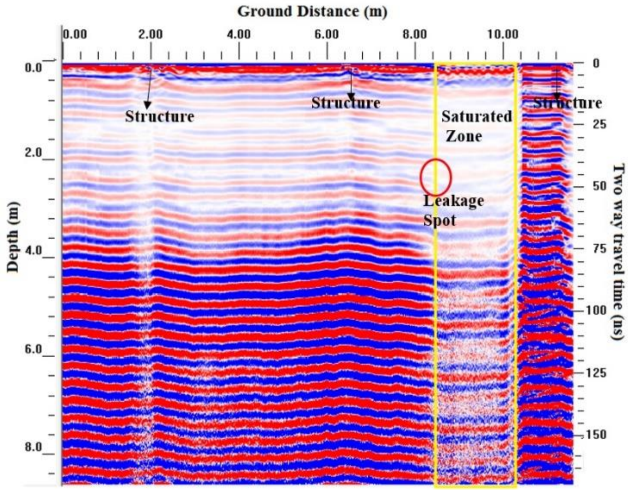

Figure 2. The profile is along the pipe, starting from the excavated pit.

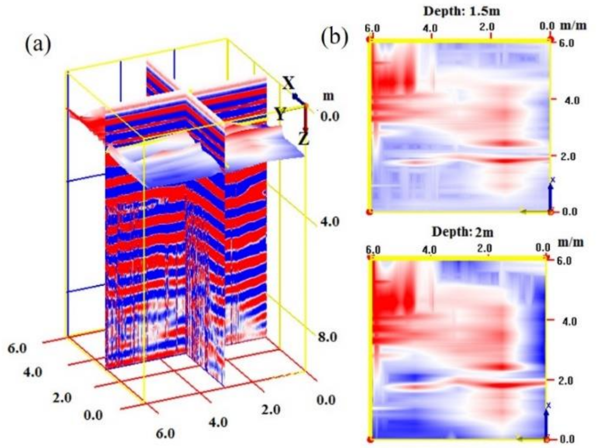

Figure 3. (a) 3D view of 6X6m grid collected from Northside of the excavated pit, ~1m away from the pit, **3 (b)** 3D depth slices from different depths to illustrate the change in the amplitude with varying moisture content.

The results from Location 1 point out the possible leakage spot is at ~8.25m away from the pit with a saturated zone of horizontal distance of 8.25 - 10.2m extends >8m depth. Since the location consists of the structures like drainages, manholes generate the identifying features in radargram at 2m, 6.5m, and 11m ground distance in the GPR profile (Figure 2). Depth slices from 1.5, 2, 2.5, and 3 m show the amplitude variation due to the changes in the moisture content. It varies from 1.7-20.5% at different depths, with maximum, noticed near the leakage spot.

The results from Location 2 point out the possible leakage spot is at ~2.5m away from the excavated pit. The disturbed zone is where the pipe running through is a possible zone of leakage. The dimension of the disturbed zone is of horizontal distance of 1.3-2.3m; and 2.5m from the pit at a depth of 1-3.2m. Depth slices from 1.5, 2, 2.5, and 3 m show the amplitude variation due to the changes in the moisture content. It varies from 3.2-18% at different depths, with maximum noticed near the leakage spot. At Location 3, the excavated pit was not available for the correlation in this location; GPR profiles (number of 10) were acquired. The profile collected on the spot of liquid discharge to the ground is processed and from the interpretation of the radargram. The suspected leakage at a depth of 1.5m from the ground distance of 0-1.8m; 4.5-5.4m and 7.7-8.9m along with the profile (Figure 23). The maximum moisture was noticed at 31% at a depth of 1.5m.

Table 1. Moisture estimated from velocity variations at different depths

Time (ns)	Velocity (m/ns)	Amplitude	Dielectric Permittivity (ε)	Moisture (%)
16.14	0.14	1.01	4.59184	7
42.16	0.13	0.96	5.32544	8.7
62.6	0.09	0.86	11.1111	20.5
86.76	0.04	0.75	56.25	14.4
109.06	0.05	0.72	36	29
135.08	0	0.64	0	5.3
168.53	0.19	0.57	2.49307	1.7

LRUT & PAUT are conducted at different locations when the pits are excavated to expose the pipelines and the surface pipelines, as shown in Figure 4(a). The measurements are taken on different diameter pipelines (8" and 6") covering 1600 mm. Using LRUT, the diagnostic of the length of the pipeline is more than 20m (-10m to 10m) from the focal point of the test, which is illustrated in Figure 4(b).

Results from the LRUT show severe corrosion occurred at a distance of 8.5 -10m from the focal point, which is identified from the amplitude analysis, which is illustrated in Figure 5(a). PAUT scanned the pipeline up to a minimum length, and general corrosion criteria are observed at the measured sites as shown in Figure 5(b), which has a minor effect on the leakage problem. After a detailed integrated analysis from GPR, LRUT, and PAUT we can mark few susceptible leakage locations and excavated those locations where we found the seepages and water influx from neighboring water channels and pipelines shown in Figure 5(b).

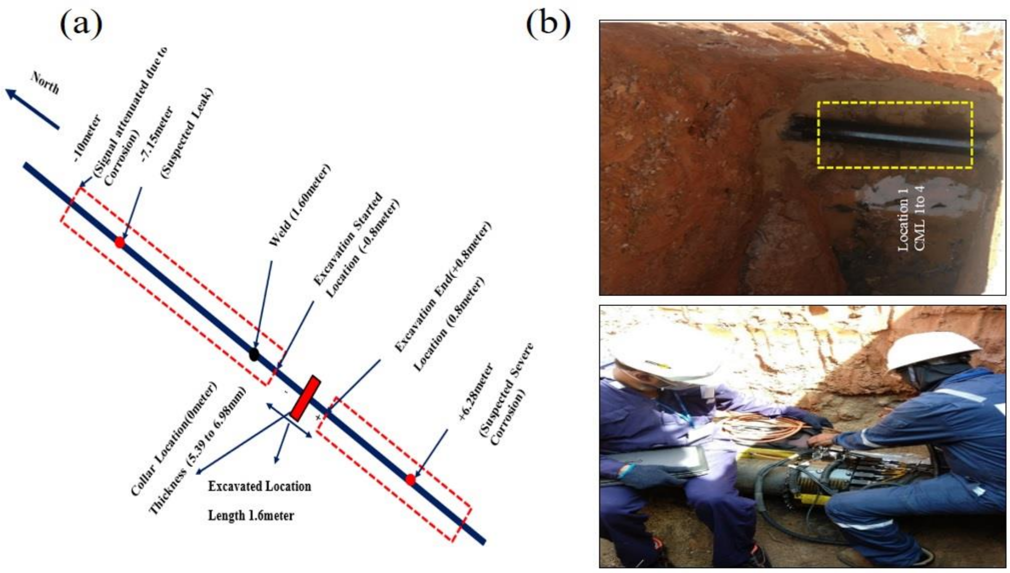

Figure 4. (a) illustrates the schematic diagram of the LRUT test and its range of investigation; 4 **(b)** Excavated pit location to expose buried pipeline and team working with LRUT installation on the pipeline.

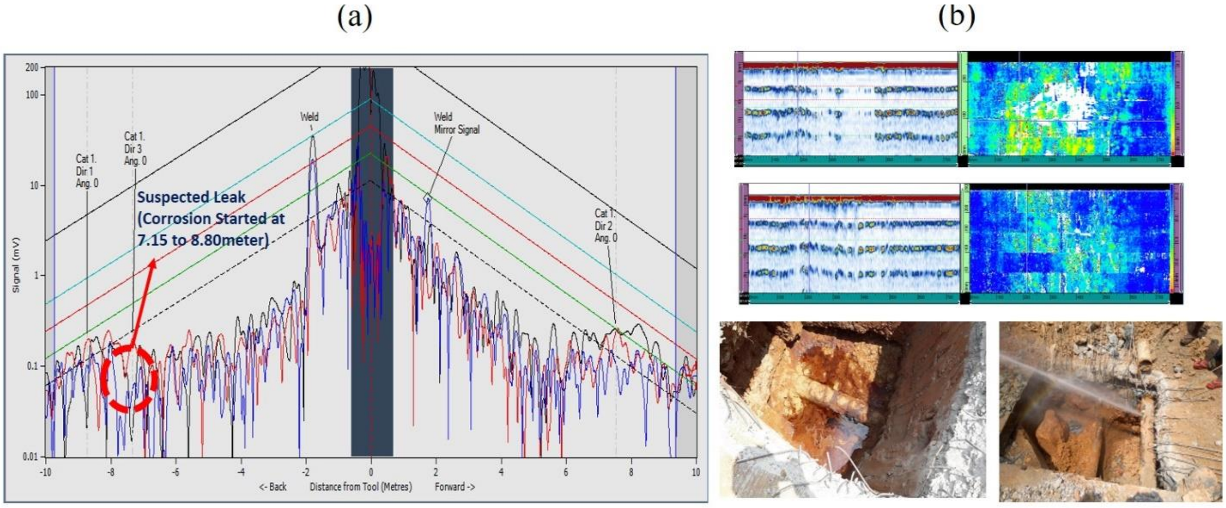

Figure 5. (a) LRUT results showing the wave amplitudes varying with length and in the marked red area, high corrosion is observed **5(b)** shows the results from PAUT testing indicating a general corrosion criterion at the focal point and actual leakage points after excavation.

4. Conclusions

This study aims to find the underground water seepages from various sources (buried pipelines, near water bodies). We had an integrated approach to find the possible leaks by combing the GPR survey and LRUT and PAUT tests. 100 MHz and 400 MHz GPR antennas were used for developing 2D and 3D GPR surveys. Combined low and high-frequency GPR surveys gave high-resolution subsoil data collection. The velocity analysis of each layer was performed to generate depth profiles, and the water saturation in the subsurface soil was found out by determining the soil's moisture content. LRUT and PAUT tests work on the principle of sending the acoustic waves for long rage using piezoelectric transducers were used to find the pipeline integrity; results found the disintegrated pipeline diameter due to external and internal corrosion. We have performed the tests from 4 different locations and identified the possible leakage points. We have excavated those locations and noticed the water influx into the pits and leakage in the buried pipeline. Based on the current study leakage points, recommendations are detected in all three locations; it is advised to continue with periodic GPR, LRUT (low frequency), and PUAT (high frequency) methods around the total plant areas and new construction sites. Periodic pipeline integrity tests at every facility using flow pressures and other advanced NDT methods to avoid causing any catastrophic events and affecting the environment.

Conflict of Interest Statement

The authors declare no conflict of interest.

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