World Academy of Science, Engineering and Technology
International Journal of Geological and Environmental Engineering
Vol:10, No:4, 2016

Detection of Leaks in Water Mains Using Ground Penetrating Radar

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Open Science Index, Geological and Environmental Engineering Vol:10, No:4, 2016 waset.org/Publication/10004124

***Abstract*—**Ground Penetrating Radar (GPR) is one of the most effective electromagnetic techniques for non-destructive non-invasive subsurface features investigation. Water leak from pipelines is the most common undesirable reason of potable water losses. Rapid detection of such losses is going to enhance the use of the Water Distribution Networks (WDN) and decrease threatens associated with water mains leaks. In this study, GPR approach was developed to detect leaks by implementing an appropriate imaging analyzing strategy based on image refinement, reflection polarity and reflection amplitude that would ease the process of interpreting the collected raw radargram image.

***Keywords*—**Water Networks, Leakage, Water pipelines, Ground Penetrating Radar.

I. INTRODUCTION

WATER Distribution Networks (WDN) are considered to be one of the most valuable and crucial municipal infrastructure systems. They constitute the core of urban population growth, public health, welfare and safety [1]. Nevertheless, according to a 2006 World Bank report, water losses through WDN were summed up to 45 million cubic meters daily in developing countries and more than 32 billion cubic meters annually on the global level [2]. Water losses in water networks do not only mean the loss of an invaluable resource, but also the loss of money spent on treating and transporting it; moreover, the deterioration of the subterranean infrastructure [3]. With the significant population growth and subsequent increase in population density [4], the amount of stress on the network increased and the risk of decreasing its lifetime and potential leaks have become much higher. Water leakage is a primary sign of pipe deficiency; therefore, monitoring the network and promptly detecting leaks is essential for its longevity and the reduction of water losses.

An electromagnetic technique namely, GPR was used to detect and locate water leak in water networks through emitting and receiving pulses of electromagnetic waves (EM) that create a subsurface features profile. Several techniques and approaches were developed and implemented toward efficient water leak detection; some of which are visual techniques such as the closed-circuit television (CCTV) [5], and the laser scan [6], others are acoustic and vibration techniques such as sonar profiling system [7], LeakfinderRT system [6], Sahara system [5], Impact echo [5], and smartball system [6]. Ultrasound techniques were also used in leak detection, for instance guided wave method [6], discrete ultrasound method [5] and phased array technology [5]. Moreover, radiographic method [5] and infrared thermography techniques [6] were part of the leak detection process. However, these techniques had some limitations that restrained their function, where visual and acoustic techniques are considered as destructive approaches and no longer applicable in case of discontinuity or limited to specific pipe diameter.

II. GROUND PENETRATING RADAR (GPR)

GPR sends EMs through the ground to the subsurface then reflections from the underground objects will be received again by the radar [8]. The waves are emitted and received back through an antenna, creating a profile of the subsurface. In 1929, the first attempt to determine the depth of ice in a glacier was performed in Austria using GPR demonstrating that electromagnetic energy is capable of traveling in media other than air [8]. Forty-three years later, NASA had built a prototype GPR system to be sent on Apollo17 to the moon to study the geological and electrical properties of the moon's crust [8]. The potential of using GPR had become attractive to the archeological community because of its ability to detect buried archeological features and associated sediments. Thus, in 1975 the first application of GPR in archeology was conducted in Chaco Canyon New Mexico [8]. From the late 1970s to the mid-1980s, several surveys had been conducted in Cyprus, El Salvador and Japan to locate burial rises and buried houses [8]. Cultural resource management projects (CRM) gained some attention in the period between the late 1980s and early 1990s that encouraged the use of GPR in some archeological contexts [8]. In the late 1990s to mid-2000s extra efforts were performed in the area of GPR data processing, where various research had been implemented to demonstrate the differences in data collection and analysis [8], [9]. A MALÅ GPR, placed on a Terraplus Rough Terrain Cart (RTC), was used in this study (Fig. 1). The MALÅ GPR was equipped with two shielded antennas, 250 MHz antenna (Dimensions: 0.74 x 0.44 x 0.16 m – Weight: 7.85 kg) and the shielded 500 MHz antenna (Dimensions: 0.50 x 0.30 x 0.16 m – Weight: 5.0 kg).

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Fig. 1 GPR on a Terraplus Rough Terrain Cart

III. METHODOLOGY

A. Radargram Refinement

The process starts with collecting GPR profiles along the pipeline length. After collecting the required profiles, the raw data need to be refined. The refinement process includes removing diffractions and modifying the effects of dipping layers (also known as migration). The refinement process was implemented using Reflex2DQuick software.

Migration is a process that shifts dipping reflectors to their proper position on the subsurface and collapses hyperbolic diffractions. Hyperbolic reflectors may appear as a sign of the existence of objects with finite dimensions. Shallower objects and steeply dipping surfaces are two reasons that may cause misinterpretation of the size and geometry of subsurface objects. Radar energy may be diffracted as a result of steeply dipping surfaces. Also shallower objects may obscure deeper objects that appear as interfering hyperbolic reflectors. In this study fk migration technique that is also known as Stolt migration has been implemented to enhance efficiently and mute the irritating subsurface reflections and pulses, create more interpretable and cohesive radargram images and improve wave traces. fk migration technique is a rapid 2D migration method based on performing a constant velocity and it works in the frequency-wavenumber range [9].

In the case of GPR data analysis, constant propagation velocity of the EMs had been calculated as follows [10]:

$$V=c/\sqrt{\varepsilon} \tag{1}$$

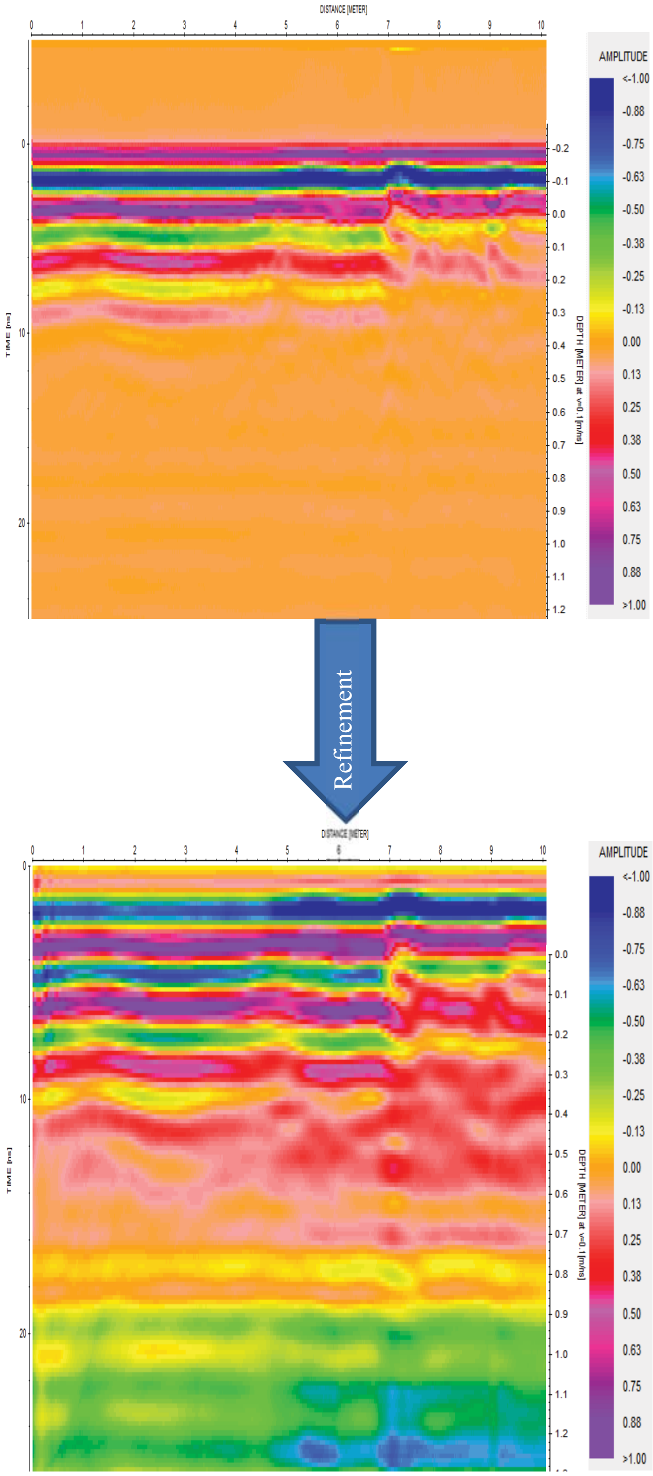

Fig. 2 Difference between the raw radargram data and the refined data after migration

where V is the propagation velocity, c is the speed of light in air (0.3m/ns) and ε is the material dielectric constant. Fig. 2 shows the difference between the raw radargram data and the refined data (after migration). Additional refinement includes eliminating the undesirable features of the radargram profile such as the area of the ground surface (separation between the antenna and the ground surface). This area is illustrated by the negative values of the depth scale. Those anomalies were processed using the static correction function. As mentioned earlier, electromagnetic properties of the scanned medium or mediums identify the nature of the reflected GPR waves (signatures). Signatures such as reflection strength, polarity, signal attenuation, two-way travel time and hyperbolic reflection are fundamental for the qualification and identification of subsurface features.

IV. RESULTS AND DISCUSSION

A. Pipe Locating

To accurately detect the leak location, precise pipeline profile should be performed. The pipe was located through a set of runs perpendicular to the suspected location of the pipe. Hyperbolic shapes would indicate the location of the pipe at the predefined depth of 0.8 m (Fig. 3). Magnitude and phase analysis were focused at the pipe depth.

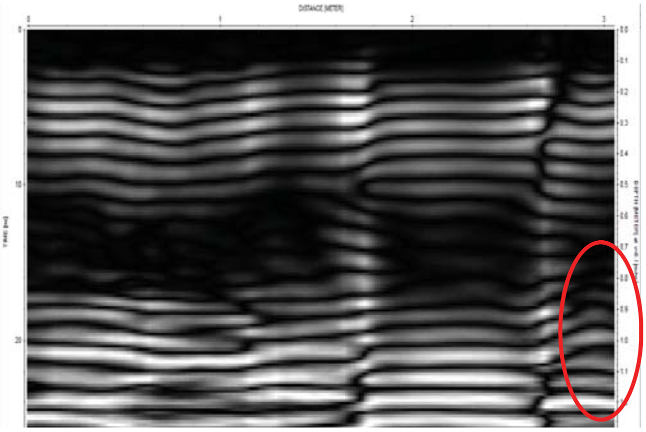

Fig. 3 Radargram of the pipe location

B. Radargram Analysis

A refinement process has been carried out which is based on the fk-migration function in Reflex2DQuick software discussed earlier. Fig. 4 (A) shows the radargram before refinement and Fig. 4 (B) shows the radargram after refinement. Since the important features that need to be tracked from the acquired radargram data were all related to the leak event, fk migration was adjusted based on the propagation velocity of the EMs passing through the wet sand with a dielectric constant of ε = 20-30. Consequently, the velocity of migration was calculated as:

$$V = \frac{c = \frac{0.3m}{ns}}{\sqrt{\varepsilon} = \sqrt{\frac{20+30}{2}}} = 0.06\frac{m}{ns}$$

A radargram image for the dry location (Fig. 5) collected after pipe repairing shows a consistent and smooth profile surrounding the pipe with almost no anomalies detected. Distortions associated with the repairing and rehabilitation of the leaked pipe can be clearly highlighted due to excavation and soil refill processes.

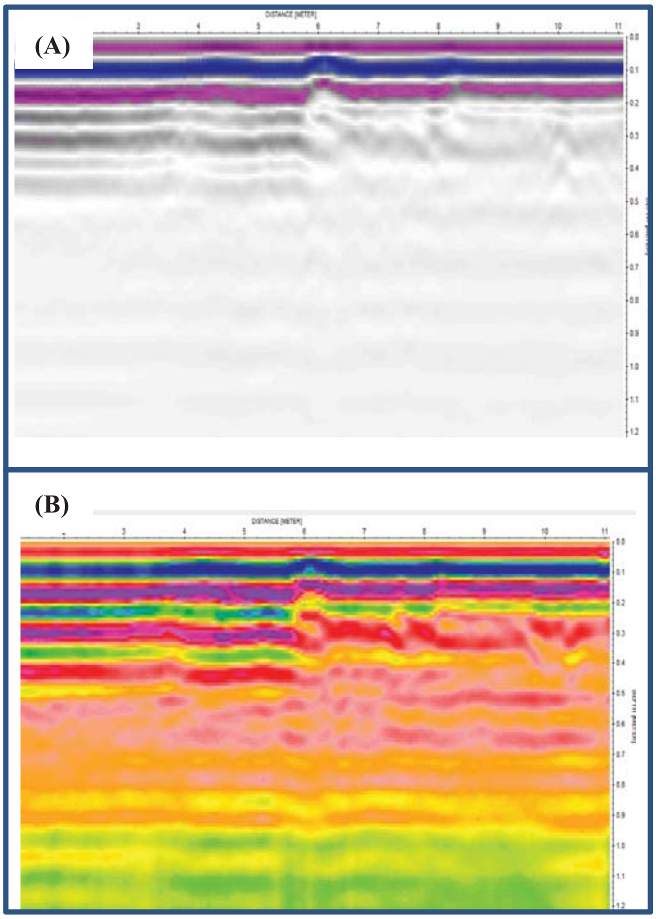

Fig. 4 (A) Raw radargram, (B) Refined radargram

In the leak case (before rehabilitation), it can be noticed that the radargram included two distinct zones (Fig. 6); Zone 1 from 0-5.8 m and Zone 2 from 5.8 m – 10 m along the pipe length. Zone 1 characterizes the dry situation, where the reflected EM waves drew gentle subsurface layout (free of discontinuities or disturbances). At the length of 5.8 m until the end of the pipe an abnormal anomaly appeared 10 cm below the ground surface. The layers disorder continues to a depth of 35 cm. Another disturbance was noted at the pipe expected location, where a trend discontinuity has been monitored along the pipe length between 5.8 m - 6.4 m and 7.8 m – 10 m represented by the color degradation change from yellow (indicates negative reflection) to light brown (indicates positive reflection). All of the observed anomalies in Zone 2 conclude that the subsurface condition had been changed from that in the dry radargram, which can be attributed to a leak event.

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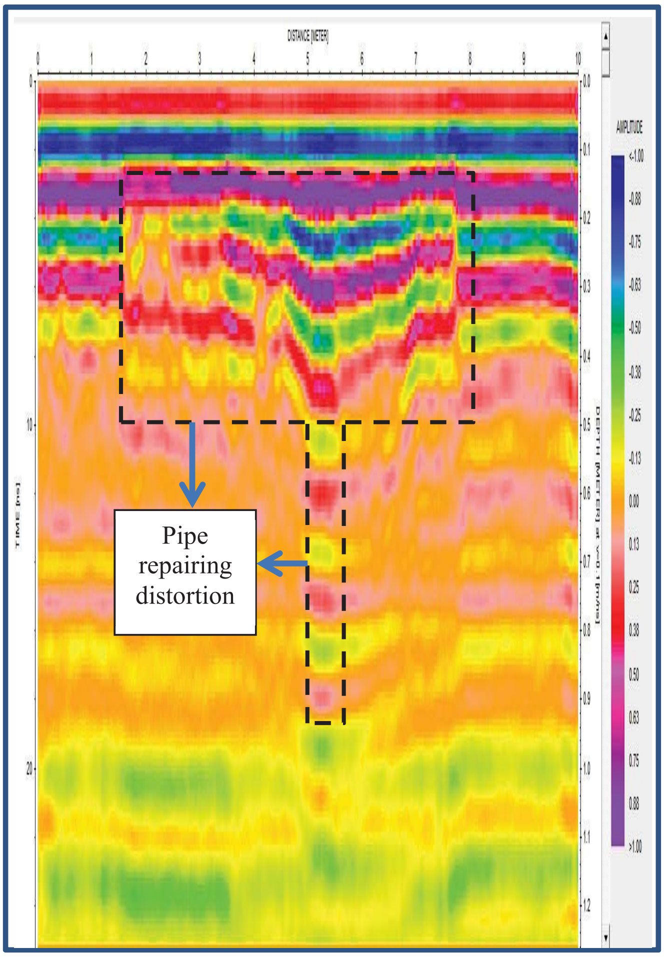

Fig. 5 (Refined radargram of the dry case)

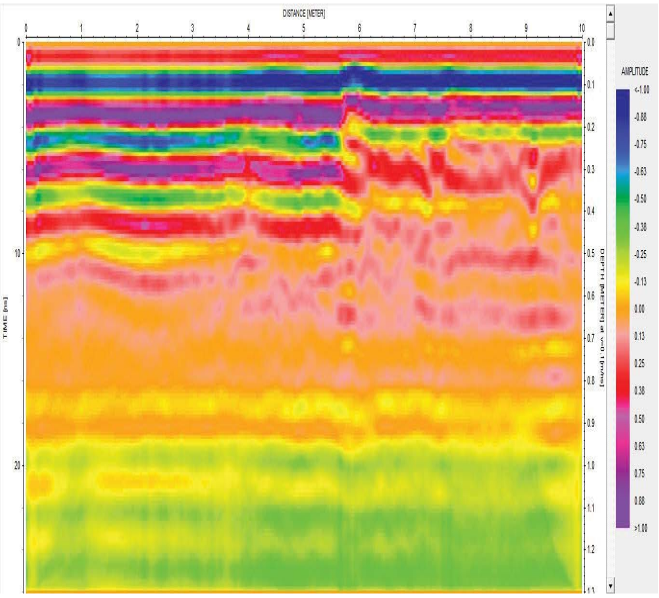

Fig. 6 Refined radargram of the wet case

V. CONCLUSION

This paper presented a study on the use of an electromagnetic technique (GPR) to examine subsurface features surrounding WDNs in order to detect water leaks. The proposed process is considered to be a non-destructive, non-invasive, rapid and simple technique for water leak detection. GPR was able to successfully detected a water leak in a ductile iron pipe found at a depth of 0.9 meters. The radargram data was captured by a 500 MHz GPR antenna. Radargram refinement, reflection polarity check and reflection amplitude check were the core of the radargram data analysis. The refinements were implemented in order to convert the raw images collected by the GPR into an interpretable data that could detect the water leak. The developed approach successfully detected and localized the water leak within an accuracy of 95%.

ACKNOWLEDGMENT

This publication was made possible by NPRP grant # (NPRP-5-165-2-055) from the Qatar National Research Fund (a member of The Qatar Foundation). The statements made herein are solely the responsibility of the authors. The authors would also like to acknowledge Qatar general electricity and water (KAHRAMAA) for their cooperation and help in collecting the required data.

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