Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 6 Issue 7, July - 2019

Detection of Buried FRP Composite Pipes Using Ground Penetrating Radar

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***Abstract*— Millions of miles of pipelines are used in the United States to transport natural gas and petroleum products. The traditional metallic pipelines undergo significant amount of corrosion related degradation in the field environment, which have led to numerous explosions and accidents. This research proposes innovative Fibre Reinforced Polymer (FRP) composite pipes for replacing degraded metallic pipes and for new pipeline construction. The FRP composite pipes are lighter, non-corrosive, and have a long service life. However, they pose a challenge for subsurface detection and mapping since the traditional techniques used by construction crews to detect buried metallic pipes do not work for non-metallic composite pipes. This research investigates the use of Ground Penetrating Radar (GPR) based Nondestructive Testing (NDT) technique in conjunction with innovative strategies to make buried FRP composite pipes detectable, which is crucial for the field implementation of new generation of pipelines.**

Keywords*— Corrosion; excavation damage; CFRP; GFRP; PVC; buried pipe detection; Ground Penetrating Radar (GPR)

I. INTRODUCTION

The pipeline industry in the United States (US) is an important component of the nation's economy, and essential for maintaining the standard of living of its citizens. Pipelines are crucial in transporting water, natural gas, and petroleum products from the production/refinery centres to consumers. According to data available from the US Energy Information Administration (EIA), the US consumes about 100 quadrillions Btu of energy annually. Natural gas and petroleum products account for about 63% of the total energy consumption (27.9% and 35.5% for natural gas and petroleum products respectively). Natural gas is almost exclusively transported by pipelines while over 70% of crude oil and petroleum products are transported by pipelines. Thus, 53% of all energy commodities consumed in the United States are transported by pipelines [1,2]. The importance of pipelines (particularly energy pipelines) "to the US economy and our standard of living requires that these assets be safely maintained and appropriately expanded to sustain demand." [3].

The pipeline infrastructure in the US is facing major challenges, especially, corrosion of steel/metallic pipelines and excavation damage of onshore pipelines [4-10]. Problems associated with corrosion of metallic pipelines can be avoided by using non-corrosive materials such as the commonly available and widely used PVC (Polyvinyl Chloride) for water/sewer pipelines and Glass Fibre Reinforced Polymer (GFRP) composite pipelines for transporting high-pressure oil and natural gas. But buried GFRP and PVC material is not easily detectable using the available ground sensory technologies, which can lead to increased excavation damage during construction and rehabilitation works [4,11].

This paper presents methods to develop, investigate, and compare alternative strategies for creating easily locatable Carbon and Glass Fibre Reinforced Polymer (CFRP and GFRP) pipes and PVC pipes that could help address the aforementioned corrosion and excavation damage problems. Results from this research have shown that, using carbon fabric and aluminium foil overlay on non-metallic pipes before burying significantly increases their detectability using GPR.

II. EXPERIMENTAL SET-UP FOR GPR TESTING

To make it easier to detect buried non-metallic pipelines using GPR, 152.4 cm (5 ft.) long GFRP and PVC pipe samples were wrapped with carbon fabric and aluminium foil overlays in the form of rings and strips before burying as shown in Fig. 1. Carbon nanoparticle coating was also applied on the surface of one of the pipe samples to investigate its detectability with GPR. Materials used for the surface overlays or wraps and coatings (that is carbon fabric, aluminium foil, and carbon nanoparticles) are electrical conductors, and are therefore expected to reflect incident radar waves much better than buried non-metallic pipes and the surrounding soil. Better reflection of radar waves from these overlays will make it much easier to locate the buried non-metallic pipes using GPR. Some of the buried pipe samples were not wrapped, and used as control specimens during GPR testing. CFRP and steel pipe samples without any wraps were also buried and tested in addition to the GFRP and PVC pipes for comparison. The pipe segments were all capped at both ends to prevent ground water from filling them when buried, since the goal was to detect the pipe material without relying on any benefit that may be provided by the content of the pipe. A total of 33 pipe segments, each 152.4 cm (5 ft.) long, of different materials and different external surface finishes were buried in 3 trenches (Fig. 2). A combination of 7.6 cm, 15.2 cm, and 30.5 cm (3 in., 6 in., and 12 in.) diameter pipes were buried with 61.0 cm and 91.4 cm (2 ft. and 3 ft.) depth of soil cover. Two 30.5 cm (12 in.) wide steel plates were buried at about 7.6 cm (3 in.) depth to mark the beginning and end of each trench (one steel plate at each end of the trench) for GPR testing. The trenches were backfilled, compacted, and seeded with grass to restore the field to its original condition. GPR testing of buried pipes commenced after the grass had grown over the trenches.

(a) (b) (c) (d)

Fig. 1. *Pipe samples - (a) 15.2 cm or 6" diameter PVC with carbon fabric rings, (b) 30.5 cm or 12" diameter PVC with carbon fabric strip, (c) 30.5 cm or 12" diameter GFRP with aluminium rings, and (d) 30.5 cm or 12" diameter GFRP with aluminium strip*

Fig. 2. *15.2 cm and 30.5 cm (6" and 12") diameter pipe samples being buried*

III. GPR Test Equipment

The GPR system used in this study was the SIR-20 manufactured by Geophysical Survey Systems, Inc. (GSSI). This is a versatile data acquisition system that works with multiple antenna frequencies. The system can operate with either 120V AC or 12V DC power supply, and can be mounted on a cart, a vehicle, or used without any mount. A cart mounted set-up was used during this study. A 200 MHz antenna with a specified penetration depth of up to 9 m (30 ft. – in dry sandy soil) and a 400 MHz antenna with a specified penetration depth of up to 4 m (12 ft. – in dry sandy soil) were evaluated with this system. These penetration depths depend on the complex dielectric permittivity of the soil medium, and therefore can be significantly less in soils with high moisture and/or clay contents. The GPR system and antennae used in this study are shown in Fig. 3.

The GPR system has survey wheels with optical encoder for tracking horizontal distance along the ground surface. A survey wheel attached to the GPR cart is used to track the horizontal distance when the 400 MHz antenna is used, while the 200 MHz antenna has a separate survey wheel that can be attached to the antenna itself for horizontal distance measurement.

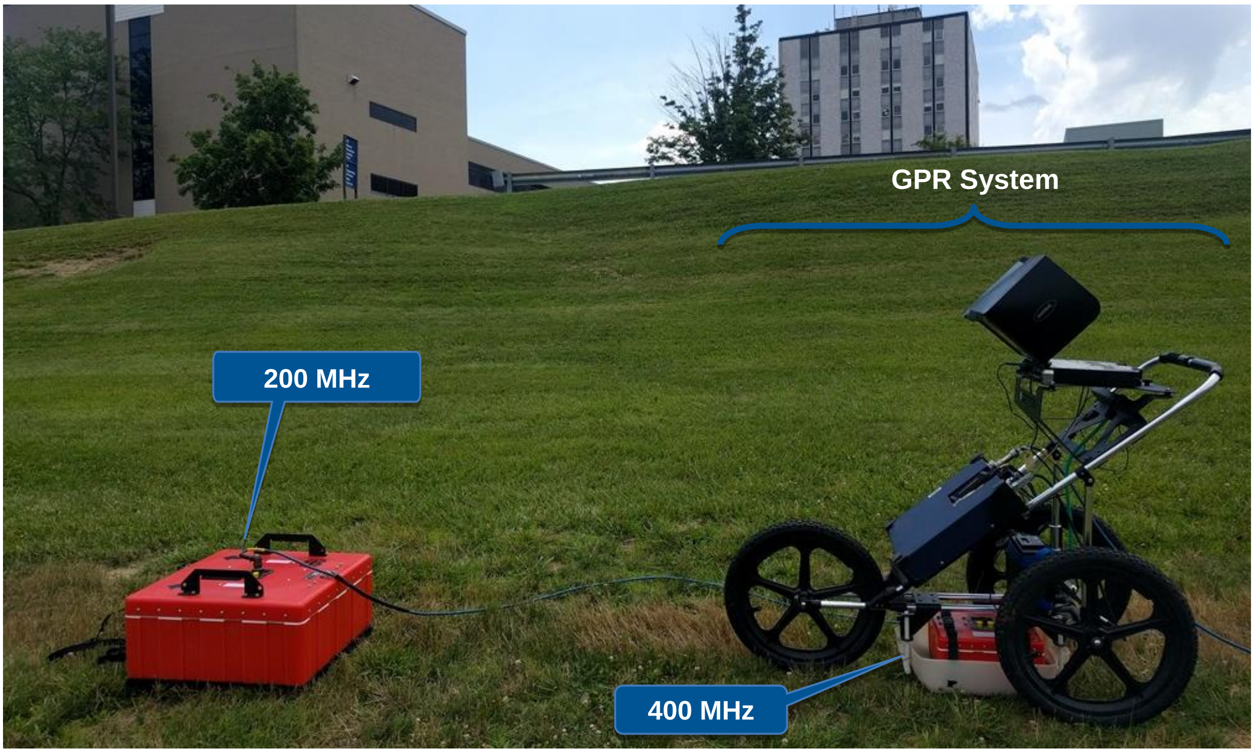


Fig. 3. *SIR-20 GPR system and radar antennae used for testing*

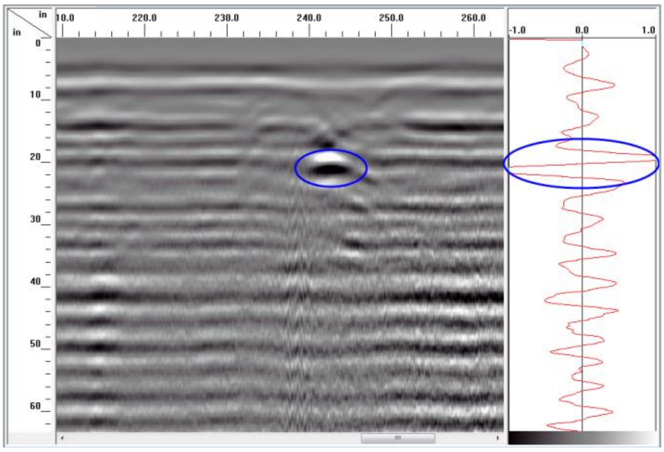
IV. GPR Test Results

GPR scans were carried out in both the longitudinal direction along the trenches, and transverse direction across the pipes/trenches. Scans from the 400 MHz antenna are shown in Fig. 4. The 400 MHz antenna was able to locate some of the pipes buried at 61.0 cm (2 ft.) depth. Signals from this antenna were particularly good over pipes with CFRP (carbon) fabric overlays as shown in Fig. 4a and 4b – transverse scan (perpendicular to the pipe/trench) and longitudinal scan (along the pipe/trench) over a 7.6 cm (3 in.) diameter pipe wrapped with carbon fabric. Fig. 4c and 4d show additional longitudinal scans. As shown in Figure 4c, a CFRP pipe produced high GPR signal reflection at 61.0 cm (2 ft.) depth. However, the 400 MHz antenna was not able to detect any of the pipes buried deeper with more than 61.0 cm (2 ft.) of soil cover, since the soil medium was very wet with average dielectric constant of 21.65 and high signal attenuation. Thus, further tests focused on the use of 200 MHz antenna for detecting pipes buried at deeper depths up to 91.4 cm (3 ft.).

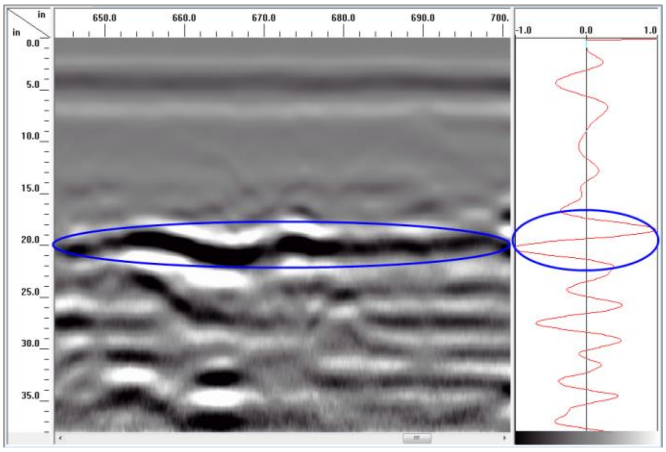
GPR survey data on the buried pipes using a 200 MHz antenna are shown in Fig. 5 and Fig. 6 for depths of 91.4 cm (3 ft.) and 61.0 cm (2 ft.) respectively. In Fig. 5 and Fig. 6, "CFRP Ring GFRP" means GFRP pipe wrapped with CFRP/carbon fabric rings, "Unwrapped PVC" means PVC pipe without any surface wrap (control sample); similar naming schemes are used for all the other pipes in Fig. 5 and Fig. 6. It can be observed in both Fig. 5 and Fig. 6 that non-metallic pipe samples (GFRP and PVC pipes) wrapped with carbon fabric or aluminium foil before burying generally show up much better in the GPR scans compared to the control samples (GFRP and PVC pipes without any surface wrap). These results prove the potential for carbon fabric and aluminium foil to be used in making buried non-metallic pipelines easily detectable during GPR surveys.

Fig. 6 also shows that the application of carbon nanoparticle coating on GFRP pipe before burying did not improve the detectability of such pipe when GPR survey was conducted. As shown in Fig. 6, the GFRP pipe with carbon nanoparticle coating produced GPR reflection with very low amplitude, compared to the GFRP pipe with carbon fabric strip and the GFRP pipe with no wraps. The possible explanation for the poor performance of carbon nanoparticle coating is that there was no interconnection between the individual carbon nanoparticles in the coating to form a continuous conductor, hence the coating did not act as an electrical conductor.

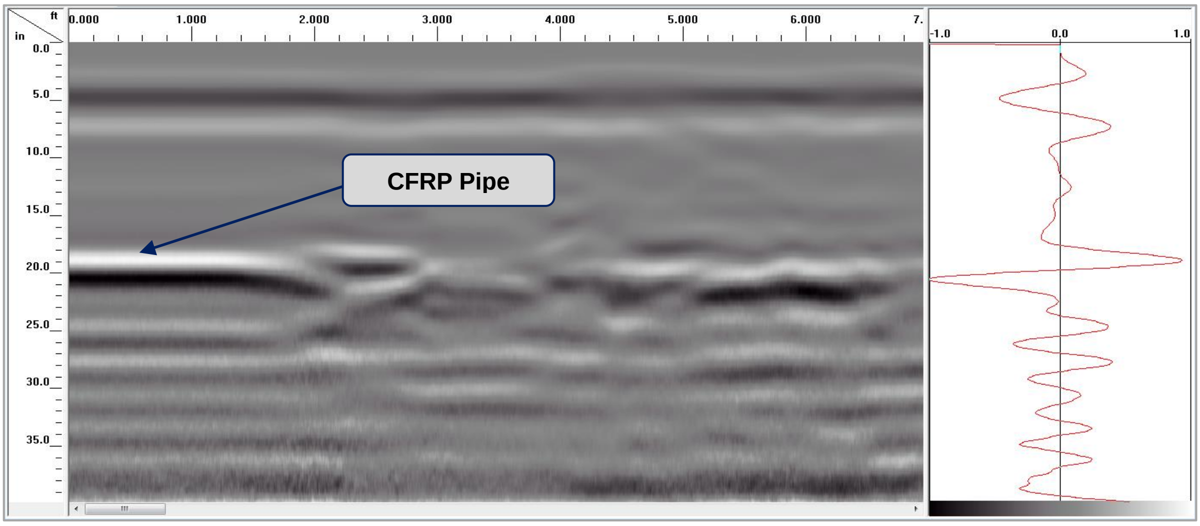
Fig. 5 and Fig. 6 show that overlaying with CFRP rings and strips have both been very effective in enhancing the detectability of non-metallic buried pipes. In case of non-metallic pipes overlaid with aluminium (Al) foil, the Al strips resulted in significantly higher radar reflection signal compared to the pipes with Al rings as shown in Fig. 5.



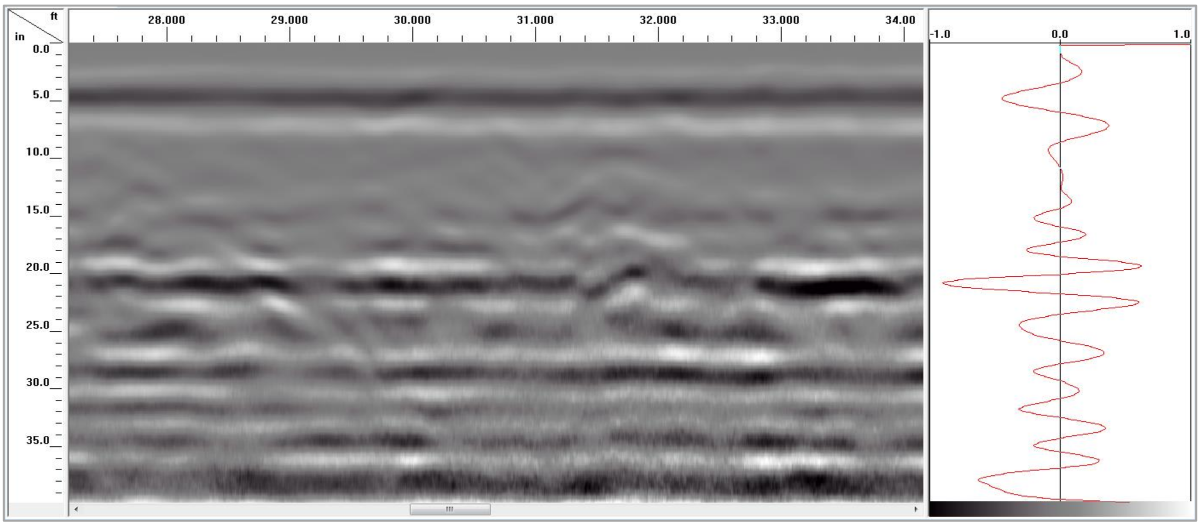
(a) Transverse scan over pipe wrapped with CFRP



(b) Longitudinal scan over the pipe in (a)



(c) Longitudinal scan over section of 7.6 cm or 3" diameter CFRP pipe with 61.0 cm or 2' of soil cover (left quarter of image)



(d) Longitudinal scan over some of the other 7.6 cm or 3" diameter pipes with 61.0 cm or 2' of soil cover

Fig. 4. *Close up views of scans over 7.6 cm or 3" diameter pipes with 61.0 cm or 2' of soil cover using 400 MHz GPR antenna*

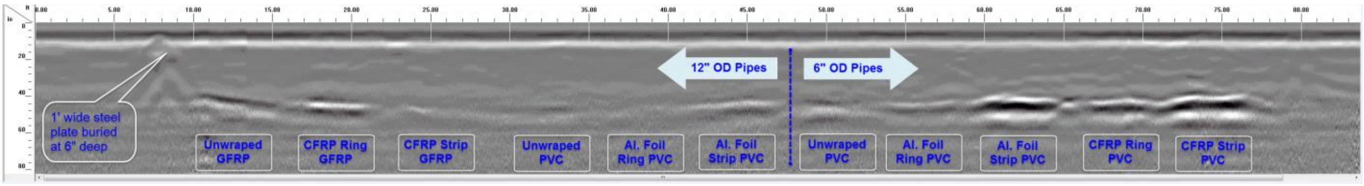


Fig. 5. *Longitudinal scan along the full length of 12" and 6" diameter pipes with 91.4 cm or 3' of soil cover using 200 MHz antenna*

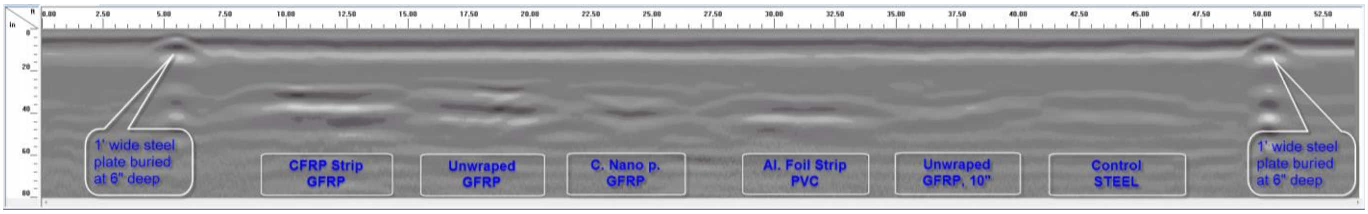


Fig. 6. *Longitudinal scan along the full length of 12" and 10" diameter pipes with 61 cm or 2' of soil cover using 200 MHz antenna*

V. Comparison with Other Techniques

Other nondestructive testing techniques such as Infrared Thermography (IRT) and the tracer wire method can also be used in locating buried non-metallic pipes in certain situations. IRT is applicable in locating buried pipelines transporting fluids that have adequate temperature difference with the surrounding soil medium (fluid with higher or lower temperatures compared to the surrounding soil). The IRT technique for locating buried pipes transporting hot fluids has been investigated in a previous study and found to be very effective [4,12]. This techniques is however not applicable in locating buried pipelines whose content is in thermal equilibrium with the surrounding medium. Tracer wires can be installed along the buried pipe during the construction stage to aid in pipe detection. However, the tracer wires may break over time due to corrosion or other mechanical damage in the field and render the technique ineffective [4].

The GPR approach presented in this study works effectively irrespective of the content being transported by the buried pipeline. Since this approach does not depend on the content of the buried pipe, it is equally applicable to pipes transporting hot/cold fluids as well as pipes whose content temperature is in equilibrium with the surrounding soil. The GPR approach also works equally well in locating empty buried pipelines (pipelines which are not in operation or not transporting any content at the time of GPR survey). Additionally, material used in this study to aid in GPR detection of buried non-metallic pipes (especially carbon fabric) is not prone to corrosion related degradation and therefore can last very long when buried in the field. Finally, the GPR approach presented here is not hampered by any cracks/fractures that may develop in the wraps/overlay materials; thus, it is much more effective compared to the tracer wire technique.

VI. Conclusions

The GPR test results from the study has shown that, carbon fabric and aluminium foil overlays on non-metallic pipes improve the detectability of such pipes when buried. This is because carbon fabric and aluminium foil are electrical conductors, hence they reflect incident radar signal better than non-metallic pipes and the surrounding soil. The pipe sample with carbon nanoparticle coating however did not show any noticeable improvement over the other non-metallic pipes without any surface wraps when surveyed using GPR. The low radar reflection signal from the pipe sample with carbon nanoparticle coating can be attributed to the fact that there was no interconnection between the individual nanoparticles in the coating, hence the coating did not act as a continuous conductor.

This study has also shown that the 400 MHz antenna could not detect pipes buried with more than 61.0 cm or 2 ft. of soil cover in the wet soil medium being investigated. The GPR survey results further showed that the 200 MHz antenna could produce better results (clearer signals) than the 400 MHz antenna for pipes buried at 61 cm or 2 ft. depth. Moreover, the 200 MHz antenna showed capability of detecting pipes buried at higher depths (even at 91.4 cm or 3 ft. of soil cover). The only drawback of the 200 MHz antenna is its larger size and weight (20.5 kg as opposed to 5 kg for the 400 MHz antenna).

Acknowledgments

The authors gratefully acknowledge the financial support provided by the United States Department of Transportation - Pipeline and Hazardous Materials Safety Administration (USDOT-PHMSA) through the Competitive Academic Agreement Program (Projects DTPH5615HCAP09 and DTPH5616HCAP02).

The authors would also like to thank Mr. Jerry Nestor, Lab Instrumentation Specialist at West Virginia University, Constructed Facilities Center (WVU-CFC) for his help in the pipe setup for GPR testing.

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