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CHARACTERIZATION OF BURIED PIPES USING GROUND PENETRATING RADAR: CASE STUDY AT THE CRAWFORD WTS

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Abstract: When the presence of buried hydraulic pipes should be identified, noninvasive methods are of particular relevance because they allow infrastructure rehabilitation for less expensive investigations than traditional methods (excavations, boreholes, etc.). The objective of this study was to identify, through a case study, existing buried hydraulic pipes at the Crawford Water Treatment Station in the municipality of Curvelo, MG for infrastructure rehabilitation. Ground penetrating radar equipment was used at the station Crawford, covering an area of 20 m² where longitudinal and transverse profiles spaced 1 m apart were studied to collect data. The presence of DEFOFO and Ocher PVC hydraulic pipes with different diameters could be identified based on the relationship between the characteristics of the existing pipe and the propagation speeds of the electromagnetic signal through the hyperbolas identified in radargrams. Additionally, the path of buried hydraulic pipes could be defined, which demonstrated the effectiveness of the Ground penetrating radar method for identifying and characterizing buried hydraulic pipes for infrastructure rehabilitation.

Resumo: Nos casos em que é necessário identificar a presença de tubulações hidráulicas enterradas, os métodos não invasivos são de grande relevância, pois permitem a reabilitação da infraestrutura com investigações menos dispendiosas (com equipamentos e mão de obra para escavações e movimentação de terras) do que os métodos tradicionais. O objetivo deste estudo foi identificar, através de um estudo de caso, as tubulações hidráulicas existentes na Estação de Tratamento de Água (ETA) Crawford no município de Curvelo/MG para a reabilitação da infraestrutura. Para isso, utilizou-se o Ground penetrating radar na estação Crawford, abrangendo uma superfície de 20m² onde foram estudados perfis longitudinais e transversais espaçados de 1m, sendo possível realizar o levantamento dos dados. Através deste estudo foi possível identificar a presença de tubulações hidráulicas de PVC DEFOFO e PVC ocre com diferentes diâmetros, por meio da relação entre as características da tubulação existente com as velocidades de propagação do sinal eletromagnético, através das hipérboles identificadas nos radargramas. Além de definir também a trajetória desta tubulação hidráulica. Isso demonstra a eficácia da utilização do Ground Penetrating Radar para essa finalidade e a reabilitação da infraestrutura.

Palavras-Chave – reabilitação da infraestrutura, ground penetrating radar (GPR), contexto urbano.

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1. INTRODUCTION

In urban context, buried hydraulic pipes are common, with characteristics that may vary in relation to the diameter, type of material used, and depth. Buried pipes provide an efficient means of transporting large volumes of water over long distances, ensuring uninterrupted surface activities while maintaining the safety, reliability, and sustainability of essential urban services. Some places contain no projects or projects that do not match the actual scenario, which can complicate possible interventions for improvements, maintenance, or expansion of the water-supply system network and water pipes. These interventions, when they occur without knowing the actual location of buried pipes, can result in perforations owing to inaccurate identification and even increase maintenance activities. Thus, these buried pipes must be identified using noninvasive methods because it reduces the need for excavation.

These urban contexts are characterized by a high concentration of underground networks, including water, gas, sewage pipes, and power cables. The use of Ground Penetrating Radar (GPR) enables the accurate identification of these infrastructures' locations, thereby preventing damage during construction or maintenance activities. Traditional excavation methods for locating underground pipes are often costly and time-consuming. In contrast, GPR provides a non-invasive and faster solution for pipe detection, reducing project costs and minimizing prolonged disruptions to urban roads or essential services. Additionally, by identifying the precise location and type of pipes, GPR helps prevent accidents, such as gas line ruptures or electrical cable failures, which pose significant risks to public safety. This study also enhances the management of underground networks by facilitating preventive maintenance. Through the characterization of pipes, public authorities and companies can plan interventions more effectively, thereby avoiding infrastructure failures that could cause major disruptions in urban areas. Moreover, the method reduces the need for unnecessary excavation, thus lowering environmental impacts such as erosion and soil disturbance. It also mitigates disruptions to daily urban life, such as road closures and traffic interruptions.

Several nondestructive methods for identifying subsurfaces are available, including GPR, whose operating principle is based on the emission of electromagnetic waves (Jol, 2009). Davis and Annan (1989) indicated the diverse applications of GPR, such as groundwater monitoring and geotechnical and archaeological investigations. According to Martini (2019), for a correct interpretation of GPR data, the objectives of the survey and knowledge of the electrical properties of the object and the environment in which it will be used must be known. Thus, other tools that complement the results obtained can be used, consequently providing greater reliability.

Furthermore, according to Stryk *et al.* (2013), the accuracy of the results obtained with the GPR method depends on factors such as the central frequency of the antenna, the correct determination of the propagation speed of the electromagnetic signal, and the accuracy in determining the beginning of the measurement.

Coster *et al*. (2019), Liu and Shi (2022) and Gamal *et al*. (2023) have successfully employed Ground Penetrating Radar in the investigation of buried hydraulic pipes, demonstrating its effectiveness in detecting and mapping subsurface structures. Kavi and Halabe (2023) has explored alternative strategies for investigating buried non-metallic pipes using GPR. Their findings confirm the reliability of GPR as a non-invasive method for assessing urban infrastructure, providing accurate detection and characterization of underground features. The success of these studies further underscores the value of GPR as a key tool in such applications.

This paper addresses the application of the GPR method to identify buried hydraulic pipes located in a water treatment station (WTS) in the municipality of Curvelo, MG, which is monitored by the Minas Gerais Sanitation Company (COPASA), the company responsible for water supply in the municipality. This method can aid in mapping these buried pipes, as the company does not have all the networks cataloged, thus making network maintenance and expansion difficult.

Pinto (2010) used 200 MHz antennas to locate buried pipes that supply water to the urban area of the municipality of Belém, Pará, and was able to detect pipes located at depths of less than two meters. However, the author highlighted the need for higher frequency antennas, such as 400 MHz, as the signal was unclear owing to the presence of a strong noise caused by the reverberation of the signal in the antennas. The noise may have been caused by the type of soil or wavelength used.

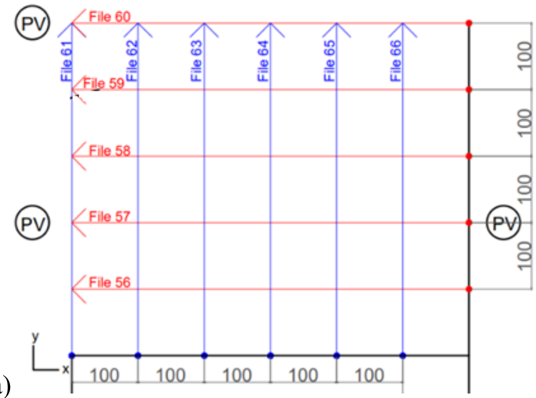
The Crawford water treatment station, located in the municipality of Curvelo, MG, contains several buried hydraulic pipes that transport water for treatment. This is a Cerrado region, where the predominant soil type is Latossolo (Oxisol, clayey). A survey using the GPR method at station Crawford (Figure 1a) was conducted in March 2021 during the COVID-19 pandemic.

This study aimed to establish a relationship between the characteristics of an existing buried pipe (diameter and type of material) and the propagation speed of the electromagnetic signal through the hyperbolas identified in the radargrams, in addition to defining the path of the buried hydraulic pipe. The approach is based on the recognition of hyperbolas, following the methodologies of Coster *et al*. (2019), Karle *et al*. (2022) and Chun *et al*. (2023). This comparison was based on the floor plan of the area provided by COPASA. The main objective of this study was to locate and characterize these buried hydraulic pipes.

2. MATERIAL AND METHODS

This section presents the data acquisition methodology, location of the data collection area, antenna, GPR equipment, usage parameters, and data processing proposal. The equipment used in this study belongs to the Civil Engineering Postgraduate Program at the CEFET-MG-Nova Gameleira Campus (PPGEC). Note that this survey followed all safety protocols to combat the COVID-19 pandemic.

For the radargram acquisition methodology at the Crawford water treatment station, a region with an area of 5 m length and 4 m width was determined with longitudinal and transverse profiles spaced every 1 m (Figure 1b). The spacing must be determined based on the orientation of the pipes, the target dimensions, target depth, antenna frequency, and the specific objectives of the investigation. The spacing considered was the same as in the studies by Sperandio (2018) with 100 and 200 MHz antennas and Porsani *et al.* (2006) with 250 MHz antennas. Eleven profiles were obtained, with profiles 56–60 (red arrows) acquired horizontally and 61–66 (blue arrows) acquired vertically.

 (a) 

(b)

Figure 1: (a) Aerial view of the site analyzed at the Crawford WTS and (b) mesh used in the survey. Source: Authors, 2021.

During the survey, a GSSI SIR 3000 GPR was used, consisting of a portable control unit, cables, a survey wheel, and a shielded antenna with a frequency of 200 MHz, as shown in Figure 2.

Figure 2: Photo of GPR data collection on surface feat 200 MHz antenna. Source: Authors, 2021.

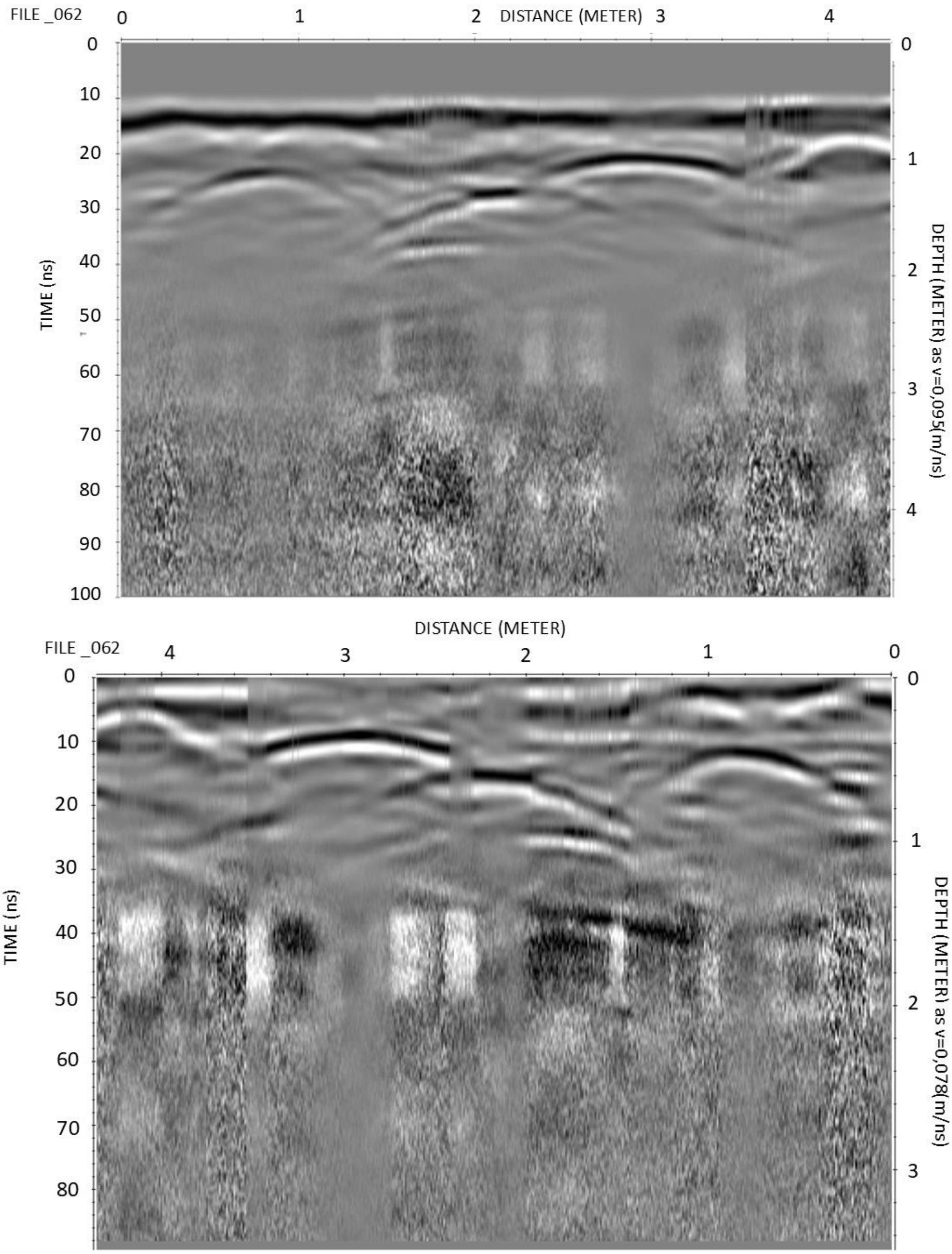
For data acquisition, the parameters provided by the manual (GEOPHYSICAL SURVEY SYSTEMS, 2017a) were considered, such as sample=512, bits=16 and gain=5. The other parameters were established according to the local conditions. Scenario 1 refers to the parameters used from profiles 56 to 58 and Scenario 2 refers to the parameters used from profiles 59 to 66 (Table 1). The dielectric constant (Diel) was adjusted from 12 (Scenario 1) to 20 (Scenario 2) to match the type and conditions of the local soil.

Parameters	Scenario 1	Scenario 2
Sample	512	512
Format (bits)	16	16
Range (nS)	100	100
Diel	12	20
Rate	64	64
Scan/Unit	100	100

Table 1: Parameters used in the survey.

The 2D data-analysis software ReflexW and Radan software were used for the radargram processing. The processing in Radan included time zero, background removal, range gain (5, 8, 20, 0, and 0), and the acquisition of the propagation speeds of the electromagnetic signal of the hyperbolas. ReflexW was used for velocity analysis, time/depth conversion, profile inversion, and printing/exporting of radargrams. The propagation speed of the electromagnetic signal used for printing was 0.078 m/ns, which corresponded to the average speed obtained. The obtained value was close to that reported in the literature.

The importance of the processing stage is evident in highlighting hyperbolas, inverting profiles, removing noise, and facilitating data interpretation. Figure 3 presents radargrams before (a) and after (b) processing.



(a)

(b)

Figure 3: Radargram before (a) and after (b) the processing stage. Source: Authors, 2022.

With a time-zero adjustment, the vertical position of the profile changes, with the upper part of the sweep defined closer to the ground surface. Background removal is a filter that aims to remove horizontal bands of noise. The range gain enables changes in the gain curve at different points to obtain a better view of the information collected in the profile (GEOPHYSICAL SURVEY SYSTEMS, 2017b).

Figure 4 shows an overlay of the mesh used on the day of the survey and part of the plan provided by COPASA. The red arrow indicates the direction of acquisition. The buried hydraulic pipes used in the study area were Ocher and DEFOFO PVC pipes, with diameters of 150, 200, 250, and 300 mm.

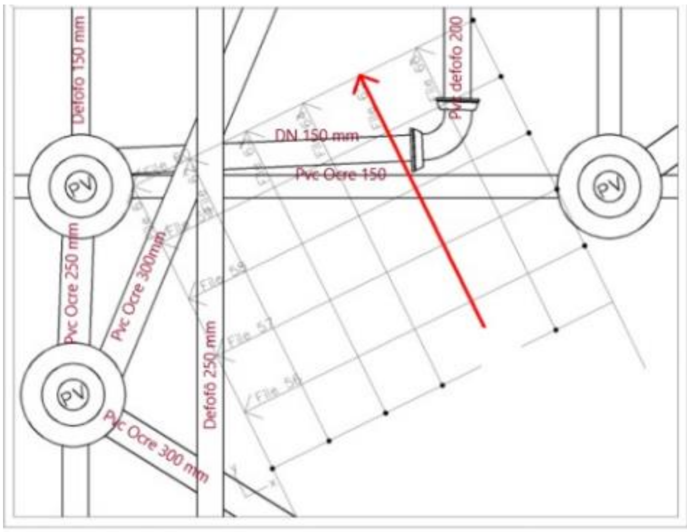


Figure 4: Overlay of mesh and plan. Source: Authors, 2021.

3. RESULTS AND DISCUSSIONS

In the radargrams obtained, when compared to the existing site plan, DEFOFO PVC pipes with diameters of 150, 200, and 250 mm, as well as Ocher PVC pipes with diameters of 150 and 300 mm, were identified at depths ranging from 20 to 100 cm. Figure 5 displays profile 62, which reveals buried pipes of various diameters.

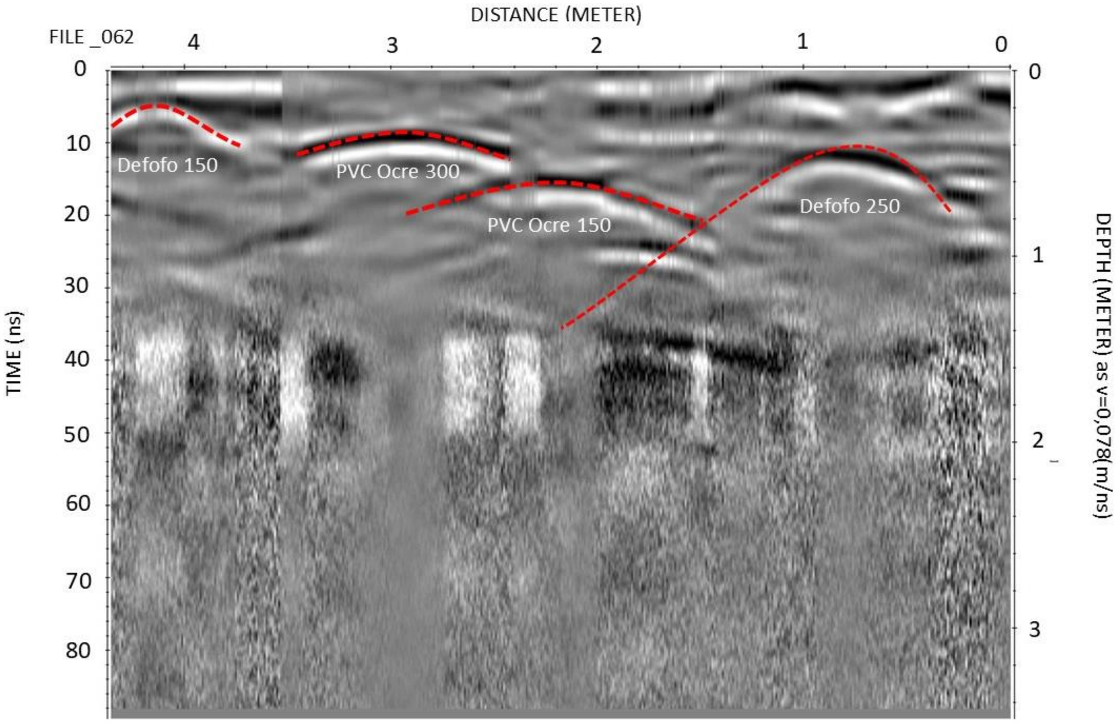


Figure 5: Profile 62. Source: Authors, 2021.

Some profiles, such as profile 58 shown in Figure 6, presented a horizontal line highlighted in blue, which may have indicated a change in the medium. This change can be influenced by different soil types or by a possible layer of compaction. Furthermore, the presence of a pipeline parallel to the acquisition site could generate this configuration.

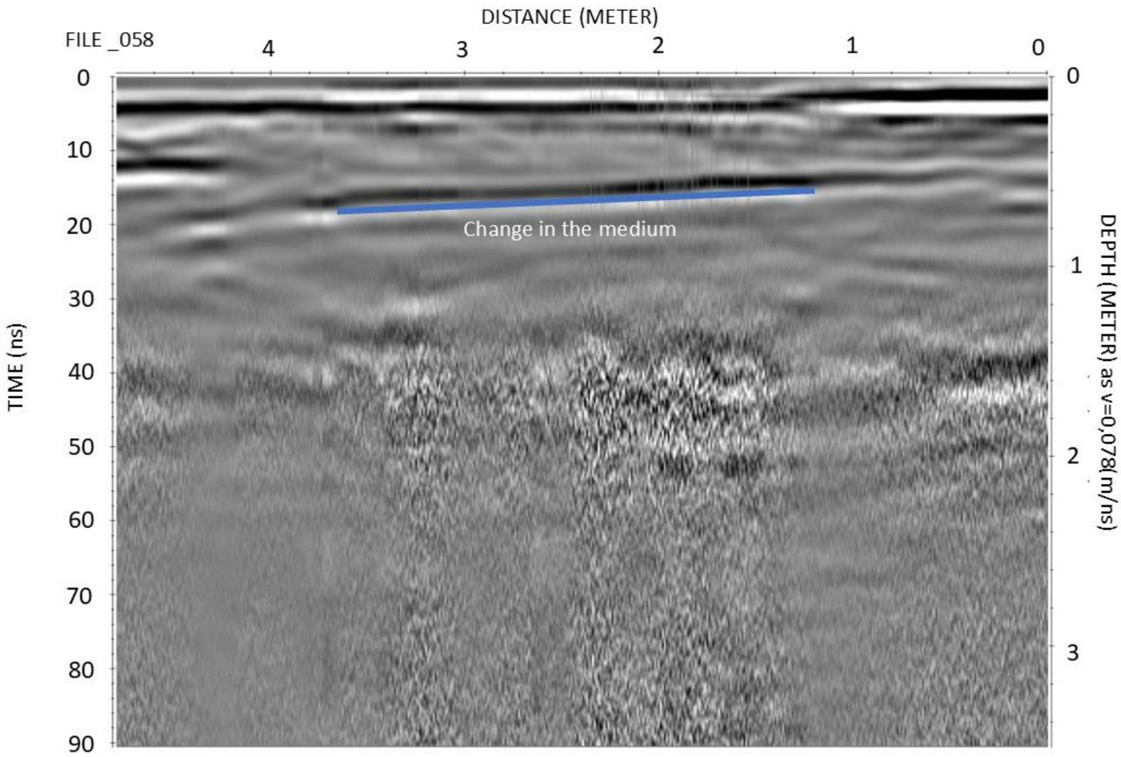


Figure 6: Profile 58. Source: Authors, 2021.

Profiles with difficulties in visualizing the hyperbolas of the buried pipes, such as profile 66 presented in Figure 7, may reflect the presence of gravel in some parts of the terrain, which may have generated interference during the acquisition.

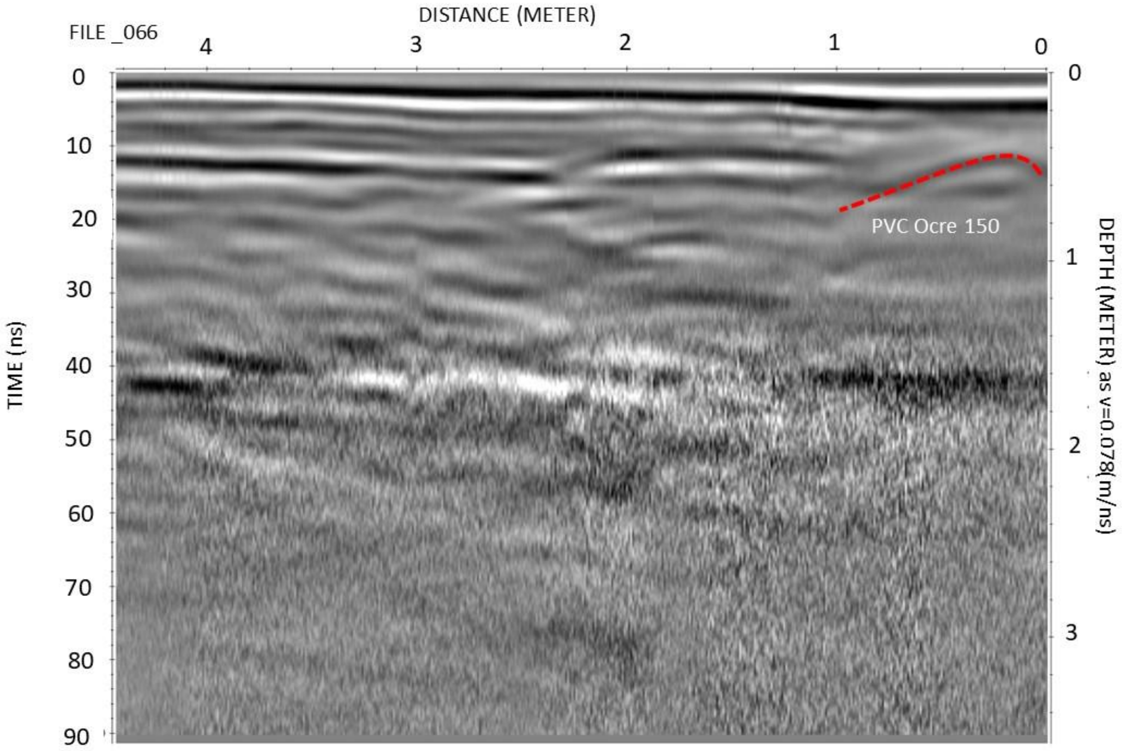


Figure 7: Profile 66. Source: Authors, 2021.

The average speeds for each pipe were identified based on the propagation speeds of the electromagnetic signals of the hyperbolas found using AutoTarget during processing and crossing with the information from the floor plan, as shown in Table 2.

PVC piping	Speed (m/ns)
DEFOFO 150 mm	0.083
DEFOFO 200 mm	0.097
DEFOFO 250 mm	0.059
Ocher 150 mm	0.060
Ocher 300 mm	0.082

Table 2: Electromagnetic signal propagation speeds for each pipe

The speed adjustment used by Cavalcanti (2013) in a contamination plume delineation was 0.07 m/ns. In his work on locating buried pipelines using the GPR method, Wahab *et al* (2018) used an average speed of 0.18 m/ns among velocities determined to convert the section into depth.

Note that the 200 MHz antennas were sufficient to identify the surface to a depth of approximately 1.50 m. Subsequently, data based on the established parameters could not be acquired.

4. CONCLUSIONS

In this study, the relationship between the location and characterization of existing buried hydraulic pipes, diameter, and type of material (DEFOFO and Ocher PVC pipes), and the propagation speeds of the electromagnetic signal through the hyperbolas identified in the radargrams was investigated.

We concluded that with the distribution of the mesh used on the ground, the variation in the position of the hyperbolas in the profile could be observed; thus, the path in which the hydraulic pipe was located could be defined.

The study generated a database regarding the characteristics of the buried pipes, which can be a source of consultation in future research, particularly in areas with no projects, for infrastructure rehabilitation.

The presence of DEFOFO and Ocher PVC hydraulic pipes with different diameters could be identified based on the relationship between the characteristics of the existing pipe and the propagation speeds of the electromagnetic signal through the hyperbolas identified in radargrams. Additionally, the path of buried hydraulic pipes could be defined, which demonstrated the effectiveness of the Ground penetrating radar method for identifying and characterizing buried hydraulic pipes for infrastructure rehabilitation. This is of growing importance given that much of the world's infrastructure is aging and requires maintenance and repair.

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