GPR acquisition and modeling of interferences buried in the border of Santarém-PA

Jozinei Ferreira Lopes (IEG, UFOPA)*, Jorge Kysnney Santos Kamassury (IEG, UFOPA), Darliene Araújo Prata (ICTA, UFOPA), Marcos Kazuo Okada Moreira (IEG, UFOPA), Mauriceia Colares Lima (ICTA, UFOPA) and Raimundo Nonato Colares Carneiro (IEG, UFOPA)

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Abstract

The objective of this work was to acquire and present geophysical data using the Ground Penetrating Radar (GPR) method and to compare them with the 2D GPR numerical modeling. The GSS GSSI 3000 was used by UFOPA, manufactured by the American company GSSI (Geophysical Survey Systems Inc) together with a frequency antenna of 270 MHz in two small areas on the border of the municipality of Santarém, state Of Pará, aiming the mapping and characterization of the existing metallic and concrete pipes in subsurface. The processing of the actual records (GPR profiles) as well as the modeling of the synthetic data were processed in the REFLEXW v. 7.2.3. The GPR profiles of real data presented good resolution, good detail, low noise besides the significant depth achieved, effectively detecting the targets (concrete pipes and metal pipes) in subsurface, being characterized by clear hyperbolic reflections. The comparison between the actual results and the results of the 2D numerical simulations had a good agreement.

Introduction

Currently the urban areas face several problems related to the intense use of the physical space in both surface and subsurface. In subsurface, focus of this study, there is intense demand for infrastructure implementation, such as construction of subway lines, construction of underground garages, passage of most utility networks, such as water/sewage/gas pipes, electric cables Medium and high voltage, fiber optic and telephony cables, rainwater galleries, among others.

There is constant damage during the network's implementation/maintenance works by utility concessionaires, such as water supply network, as a result of the disruption of underground networks causing inconvenience and burdening public coffers, which can affect the economy Local, transportation and communication systems, and even endanger the lives of the population.

In the present research, the geophysical data were obtained with the GPR - Ground Penetrating Radar method in 2D mode with shielded antennas of 270 MHz, in order to map and characterize the targets in the subsoil, these being related to metallic pipes, plastic pipes, shackles Concrete, light and water pass-through boxes.

Also in this research were characterizations and modeling of pipes for application in the prediction of analogous occurrence in subsurface, which is an alternative to understand a real data. From the integrated knowledge of its geometry and its electrical properties it is possible to develop predictive models in subsurface, which leads us to a better interpretation of the data acquired in the field.

The GPR method was applied to locate targets or geological interfaces in subsurface (Daniels et al., 1988), after the discovery of its ice penetration capacity, to determine its thickness, initially in Germany in 1929 (Olhoeft, 1996). This method was also used in Greenland in the 1950s after crashes caused by the collapse of ice sheets (Olhoeft, 1996). In fact, one of the greatest successes of this method was obtained in the determination of the thickness of the glaciers in the Arctic and Antarctica (Scaife & Annan, 1991).

Although the GPR method existed since 1929, its global recognition as a method of geophysical exploration by geoscientists was only possible in the 80's, due, in particular, to the technological advance, which enabled not only the development of equipment with digital record acquisition modes Also made them portable, of low cost and practicality of use (Porsani, 1999).

The current rise of GPR is mainly due to the evolution of the software processing resources and methodologies coming from seismic. Add to that the advantage of being a non-destructive and non-invasive technique, providing sections geology-friendly and admitting a wide range of applications that may vary according to the frequency of the antenna to be used.

GPR has been applied mainly to: i) study glaciers, ii) obtain geological information, iii) produce geotechnical data, such as civil buildings, asphalt, pipes, landing strips, floors and sidewalks, iv) generate information on the environment, (V) identify bombs and other objects hidden under the ground in the case of forensic criminals; (vi) locate utensils and buildings of ancient peoples by assisting in research on paleontology And archeology (Souza, 2012).

The context of the transformation of the physical space of the city of Santarém-PA is not so different from big cities like São Paulo, Rio de Janeiro, Belém, Manaus and so on. What is common between these cities is the problems of urban infrastructure mentioned above due mainly to the disorderly growth of large centers. In particular, the Santarém shoreline (Figure 1) was used as an open-air geophysical research laboratory, since there are numerous underground pipelines in it.

Method

The GPR method

This Ground Penetrating Radar (GPR) method is an electromagnetic geophysical method that employs radio waves at very high frequencies (typically between 10-2500 MHz) to locate shallow geological structures and features of the subsurface or locate objects buried by man.

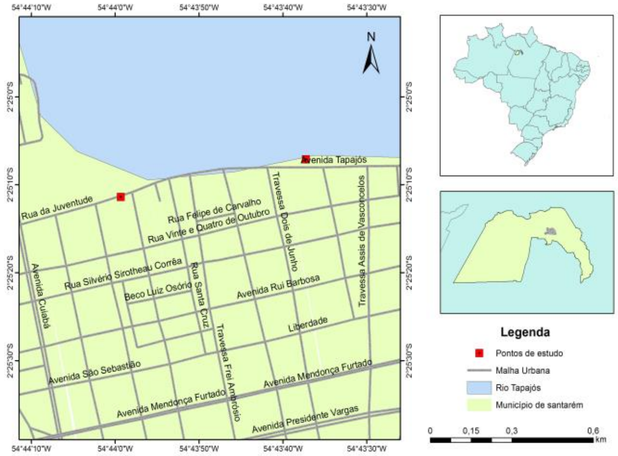

Figure 1 - *Areas of study*

The GPR data acquisition technique is similar to the seismic reflection technique and the sonar technique in the physical principle and field survey methodology, with the exception that GPR is based mainly on the transmission and reflection of electromagnetic waves.

In focus, this method consists of obtaining a very high-resolution image of the subsurface through the transmission of high frequency of electromagnetic waves, which in turn is repeatedly radiated into the Earth by a transmitting antenna placed on the surface. Changes in electrical properties (electrical conductivity or dielectric permissiveness) in subsurface cause part of the signal to be reflected. Radar waves reflected and diffracted in subsurface are received through another antenna, called receiver antenna also placed on the surface of the Earth. In the present work, shielded antennas were used to avoid the reflection of unwanted signals from targets on the surface. The reflected energy is recorded as double time (round-trip), which is amplified, digitized and recorded on a computer's hard disk, leaving the data ready for further processing as needed (Davis & Annan, 1989; Porsani, 1999).

Data acquisition

For the data collection using the GPR to be successful, it is essential that there be knowledge of the study site, regarding the structure of the medium and the depth of the targets for the choice of antennas. It is imperative that there is contrast in the electrical properties of the materials so that the signal response is satisfactory.

There are four modes of data acquisition using GPR. They are: "*common offset*", "*wide aperture reflection or refraction*" and "*common midpoint*". Among these data acquisition methods, the most common mode was used, the "*common offset"*, where the transmitting and receiving antennas are kept at a fixed and constant distance. Thus, these are transported along lines on targets resulting in a profile, where on the vertical axis is recorded the measurement of the double travel time of the reflected waves and the horizontal axis is the position of the antennas. The profiles were oriented perpendicularly to the targets under study.

Procurement procedures

The acquisition of the data of this work was obtained by the equipment SIR SYSTEM 3000, belonging to Federal University of Western Pará - UFOPA, manufactured by the American company GSSI (*Geophysical Survey Systems Inc*), together with a 270 MHz frequency antenna. Two profiles were made (Profile 1 and Profile 2) With GPR, as shown in Figure 2.

Figure 2 - *Profiles 1 and 2, respectively, on concrete pipes and metal pipes*

In numerous geophysical surveys, data processing is the most important step and for the GPR method this is no different. Since the objective is to emphasize features of interest, it is necessary to follow some steps to achieve it.

For the processing of the profiles as previously mentioned, Software Reflexw v. 7.2.3, since this software has a significant variety of processing tools, such as filters, gains, time conversion in depth among others. Figure 3 shows a flowchart with the basic processing steps of GPR data.

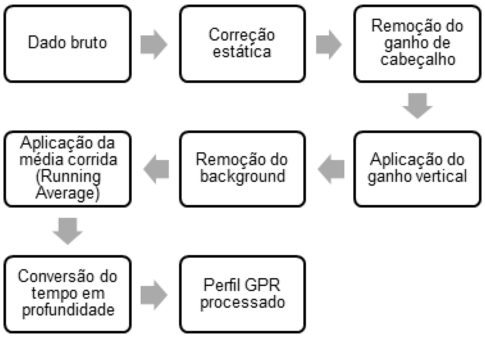

Figure 3 - *Basic GPR data processing flowchart*

The steps shown in the flowchart most of the time are sufficient for a good interpretation of the results. The following details the characteristics of each step.

i) The static correction adjusts the arrival of the airwave to time equal to zero. Step is important and necessary to remove the empty window at the beginning of the radargram generated by the signal that goes directly from the transmitting antenna to the receiving antenna, so the signal register will coincide with the topography of the acquisition site.

ii) Removing the header gain removes the gain inserted into the GPR device during acquisition.

iii) Vertical gain compensates for the attenuation effects of the GPR signal, thus improving the visualization of weak signal structures as deeper targets.

iv) Removal of the background is capable of removing low frequency signals and highlighting the point and inclined reflectors.

v) Running Average is used to accentuate the reflectors and lateral continuity of horizontal reflectors.

vi) Knowing the speed of the MS of the geological environment and knowing that the GPR informs the travel time of the EM wave, then it is possible to convert the time scale into a depth scale.

Performed all the steps described above, we have a processed GPR profile.

GPR numerical modeling

Numerical modeling of the EM wave is a practical and efficient way to simulate the computationally propagation of subsurface EM waves. For this, the described medium characterizing, numerically, its physical properties. This allows analyzing profiles and their behavior for different antenna frequencies. Besides allowing to compare the result of the simulation with a real radargram, a better interpretation of this data.

The propagation of EM waves in dispersive and attenuating media is controlled by three properties: dielectric constant (ε), magnetic permeability (μ) and electric conductivity (σ). Such properties are fundamental for modeling.

As in the processing, the numerical modeling of GPR data was done in Reflexw v. 7.2.3, software that has proven very efficient in previous works of this type. The modeling consists in the application of mathematical and computational procedures to obtain the solution of a problem of scientific character by means of successive numerical approximations. For this, the finite difference method in the time domain - FDTD replaces the differential equations by finite differences obtained through Taylor Series expansion and truncates to the level of the desired error order. Maxwell's equations are solved by algebraic equations, considering the concept of discretization developed by Euler, in which the rates related to the derivatives are replaced by spatial (Δx) and temporal (Δt) increments (Costa, 2002).

Modeling profile 1

For the modeling of profile 1, a GPR profile with 270 MHz antenna was simulated, in which the medium is composed of concrete and the targets, three equal pipes, are also made of concrete and filled with air. The values for the electrical properties of the materials used in this work are present in Polua (2015). Table 1 contains the values used to model this profile:

Table 1 - *Electrical properties of the model materials for profile 1*

Material	*k*	σ (mS/m)	μ’
Concrete	5	0	1
Air	1	0	1

The concrete pipes are 76 centimeters in diameter and 4 centimeters thick. As observed in the field, the tubing 1 is 40 centimeters away from the tubing 2, and this, in turn, is 30 centimeters from the tubing 3 (Figure 4).

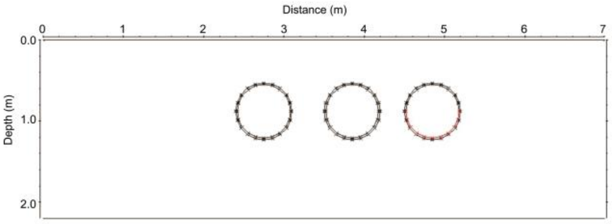

Figure 4 - *Model of three concrete pipes with the same properties*

Modeling profile 2

For the modeling of profile 2, with the same antenna, where the medium is also composed of concrete, the targets are three identical metal pipes and filled with air.

The pipes of this second profile are 50 centimeters in diameter and 4 centimeters thick, but since the material of the target (pipe) is made of metal, the EM wave does not penetrate and is 100% reflected, so it makes no sense to worry about the thickness of the pipe and nor with what it is filled. Therefore, this target was considered to be a massive object. As observed in the field, the pipe 1 is 1 meter from the pipe 2, and this, 1.6 meters from the pipe 3 (Figure 5). Table 2 shows the values used for the second profile:

***Table 2** - Electrical properties of the model materials for profile 2*

Material	*k*	σ (mS/m)	μ’
Concrete	5	0	1
Metal	300	10^9	1

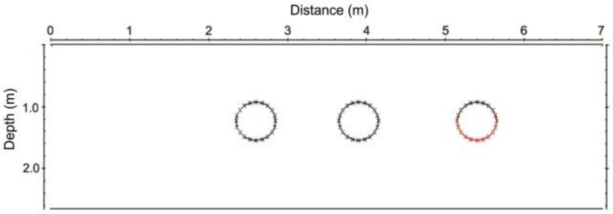

***Figure 5** - Model of three metal pipes with the same properties*

Results

Processing real profiles

The interpretation of GPR profiles is subjective and requires the interpreter to be aware of the purpose of the survey.

Thus, in Figures 6 and 7 it is possible to verify that the three targets, both concrete and metal targets were well detected, indicated by the yellow arrows, and are characterized by clear hyperbolic reflections, which are at a depth of 0, 80 m.

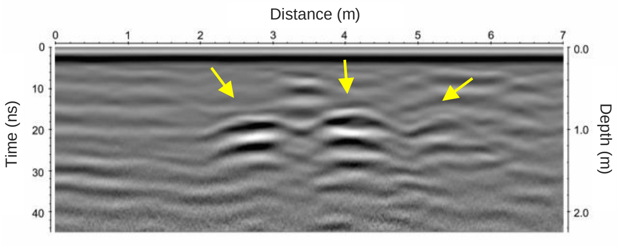

***Figure 6** - Radargram of profile 1 processed*

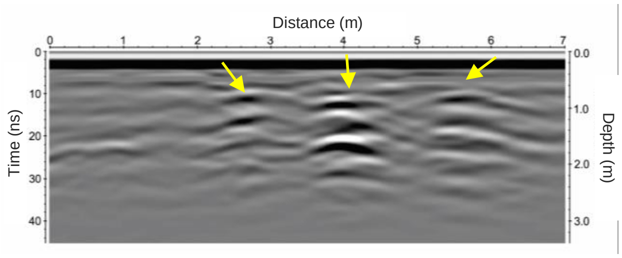

***Figure 7** - Radargram of profile 2 processed*

Modeling

As for modeling, we can see the result of the modest simulation for profile 1 in Figure 8, a model created simulating the study site for the 270 MHz antenna and flat wave type source. Those simulated here are well detected and characterized by strong hyperbolic reflections.

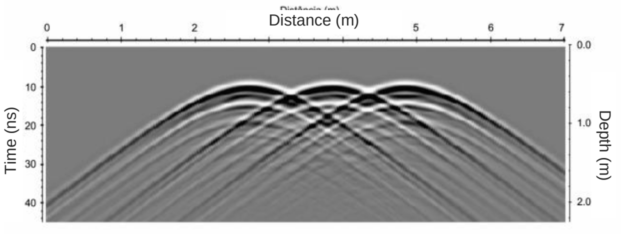

***Figure 8** - GPR response to the model of figure 4*

For the profile 2, whose model that simulates the study site for the 270 MHz antenna and flat wave type source, the response to Figure 5 is shown in Figure 9, it is verified that the targets were also detected, characterized by sharp Hyperbolic reflections. In addition, it is noticed that all the electromagnetic energy of the GPR when entering contact of the surface of the targets is totally reflected.

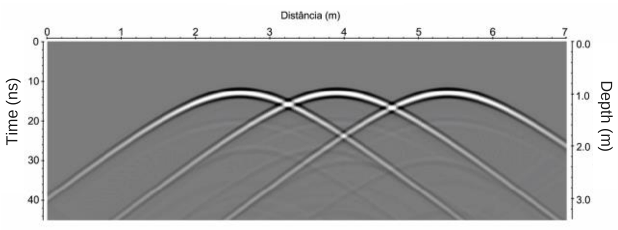

***Figure 9** - GPR response to the model of figure 4*

Conclusions

The research on the mapping and GPR modeling of buried interferences in the Santarém-PA border, using antennas of 270 MHz, made it possible to identify subsurface pipes, these being metal or concrete, under a concrete medium. The numerical modeling GPR was successful in simulating the propagation of the electromagnetic waves in a synthetic 2D model, constructed according to the characteristics of the medium and the chosen targets. The comparison between the actual results and the results of the numerical simulations shows a good agreement. Although the real radargrams present several interferences (noises, loss of signal and attenuation) the modeling corresponded to the expectations, being an important tool to help in the interpretation and/or validation of the data obtained in this research.

Finally, the GPR method is endorsed as an important tool for urban planning, such as road constructions, repairs to sewage networks, identifying and locating subsurface pipes, among other applications.

Acknowledgments

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