Subsurface Utility Identification at ITERA Campus Using Multi-frequency Ground Penetrating Radar

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Abstract. Infrastructure development at the Sumatra Institute of Technology is growing rapidly, hence, it requires new utilities installation network such as cables and pipes to supply electricity and clean water. Installing new utility line, it is necessary to secure and know the existence and depth of the previously embedded utility network to avoid damage that could hamper the construction process or cause large losses. Accessing the sub-surface information, geophysical method, such as Ground Penetrating Radar (GPR) can be utilized for identifying buried utility networks, ensuring the safe installation of new utilities, and preventing damage to existing embedded utilities. In this study, a GPR device with a frequency range 40 MHz-3.4 GHz comprising 5 lines was employed. The acquired data underwent processing using GPR Insights software, generating a radargram cross-section that provides information about the subsurface. The results from the radargram reveal a hyperbolic reflection anomaly, signifying the presence of a utility network beneath the surface, suspected to be pipe and cable utilities. The utility network is detected at varying depths of 0.5 m, 0.8 m, 1 m, and 1.2 m at different distances. Furthermore, several anomalies in the form of hyperboles are observed, suggesting potential utilities due to their continuity with other paths.

Keywords: Utility, radargram; GPR, Multi-frequency

Abstrak. *Pembangunan infrastruktur di Institut Teknologi Sumatera berkembang pesat sehingga memerlukan jaringan instalasi utilitas baru seperti kabel dan pipa untuk menyuplai listrik dan air bersih. Pada pemasangan jalur utilitas baru, perlu dilakukan pengamanan dan mengetahui keberadaan serta kedalaman jaringan utilitas yang tertanam sebelumnya untuk menghindari kerusakan yang dapat menghambat proses konstruksi yang akan menimbulkan kerugian yang besar. Untuk mengakses informasi bawah permukaan, metode geofisika, seperti Ground Penetrating Radar (GPR) dapat digunakan untuk mengidentifikasi jaringan utilitas yang terkubur, memastikan instalasi utilitas baru yang aman dan mencegah kerusakan pada utilitas tertanam yang sudah ada. Pada penelitian ini digunakan perangkat GPR dengan rentang frekuensi 40 MHz-3,4 GHz yang terdiri dari 5 lintasan. Data yang diperoleh diproses menggunakan perangkat lunak GPR Insights yang menghasilkan penampang radargram yang memberikan informasi tentang bawah permukaan. Hasil radargram menunjukkan adanya anomali refleksi hiperbolik yang menandakan adanya jaringan utilitas di bawah permukaan yang diduga berupa utilitas pipa dan kabel. Jaringan utilitas terdeteksi pada kedalaman yang bervariasi 0,5 m, 0,8 m, 1 m, dan 1,2 m pada jarak yang berbeda. Selain itu, beberapa anomali dalam bentuk hiperbola diamati, menunjukkan potensi utilitas karena kemenerusannya dengan jalur lain.*

Kata kunci: *Utilitas, radargram, GPR, multi-frekuensi*

INTRODUCTION

Sumatra Institute of Technology (ITERA) is a state university that was officially founded in 2014. The increasing number of students each year at ITERA has led to the development of infrastructure, such as lecture buildings, laboratories, roads, and even utilities [1]. In line with the rapid development of new infrastructure, it requires a supply of electricity and clean water channeled through the installation of new utility lines such as electric cables, telecommunication cables, power cables and water pipes or gas pipes [2, 3].

Installing new utility line, it is necessary to secure and know the existence and depth of the previously embedded utility network to avoid damage that could hamper the construction process or cause large losses. Knowing the existence of these embedded utilities can also facilitate efficiency in excavation and can be used as information to avoid problems in the future. Therefore, action is needed to determine the position of the embedded utility network by detecting and mapping subsurface utilities. Efforts to detect and map subsurface utility networks are carried out using geophysical methods, one of which is the Ground Penetrating Radar (GPR) [4, 5, 6].

GPR is a device using electromagnetic waves for subsurface study, which is mostly used for shallow exploration with high resolution [7, 8] The GPR instrument transmits radar waves below the surface and then these waves are reflected because they are influenced by the electrical and magnetic properties of each medium or rock layer which consists of several parameters including conductivity, electrical permittivity, and magnetic permeability [8]. The reflected wave returns to the surface and is received by the receiving antenna [9].

In this study, the GPR tool used is a multi-frequency GPR tool with an antenna frequency of 40 MHz to 3.4 GHz so that it can provide clarity of data or images with high resolution and better depth of penetration [10]. This research consists of 5 lines with different line lengths and is carried out in parallel. By using this multi-frequency GPR tool, identification and validation can be carried out that there is a subsurface utility network based on the results of the radargram obtained. The obtained radargram provides subsurface information, related to depth, trajectory distance, velocity value, and target anomaly in the form of a hyperbole. It is hoped that this research will provide information that can be used to avoid damage and unwanted events in the future as well as to secure the installation of new utilities.

GEOLOGY OF THE RESEARCH AREA

The research area is the Sumatra Institute of Technology located in Way Huwi Village, Jati Agung District, South Lampung Regency, Lampung. Based on **Figure 1** of the geological map of the Tanjungkarang sheet, it shows that the study area is composed of rock units consisting of old to young, namely: tuffaceous claystone, tuffaceous sandstone, pumice tuff, unified tuff, and rhyolitic tuff from the Lampung Formation (QTI) [11]. Apart from the Lampung Formation, around the study area there are Young Volcano Sediment (Qhvp) units in the form of breccias, lava (andesite-basalt), and tuff, there are also Tarahan Formation (Tpot) units, Way Galih Sekis units (Pzgs), Alluvium (Qa) and Inseparable Granite Rock (Tmgr) [12].

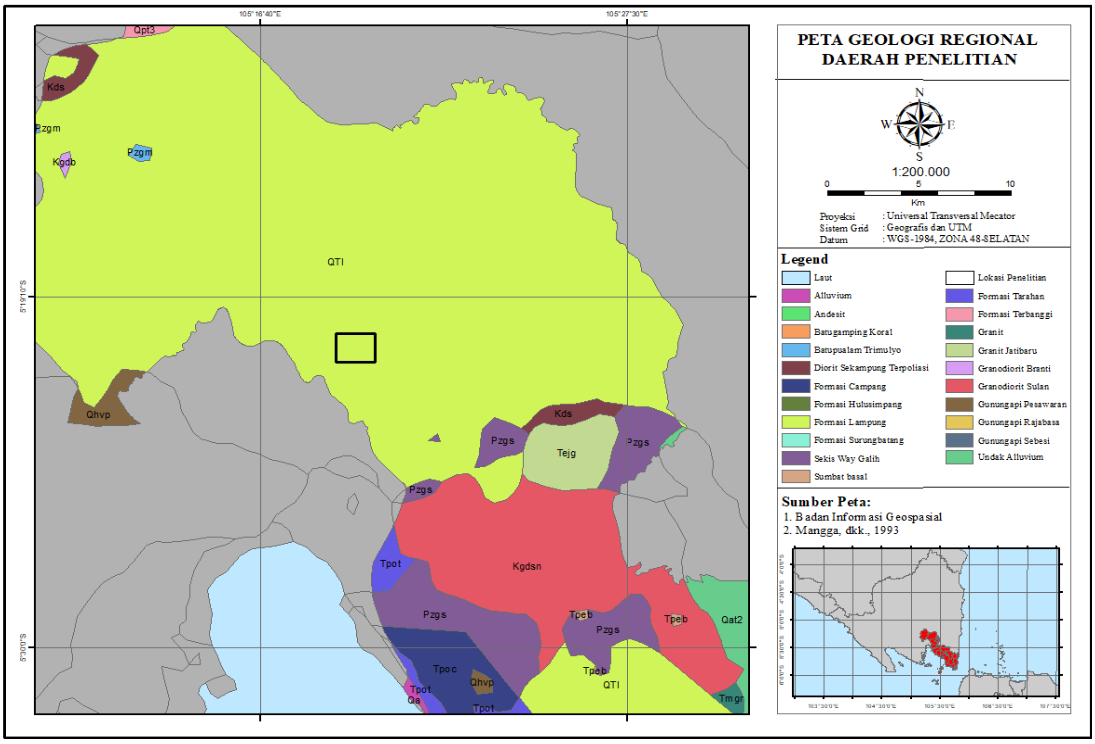

Figure 1 Geological map of the Tanjungkarang sheet in South Lampung, Lampung [11].

MATERIAL AND METHOD

Ground Penetrating Radar (GPR) is a geophysical method that uses electromagnetic waves (in the radio spectrum) to investigate subsurface conditions with high resolution [8]. GPR utilizes the nature of the propagation of electromagnetic waves in the form of radar (radio detection and ranging) with a frequency between 10 MHz - 1 GHz and is influenced by the electrical and magnetic properties of the target material which consists of several parameters, namely conductivity (σ), electrical permittivity (ε), and magnetic permeability (μ) [8, 9]. The principle of GPR in utilizing electromagnetic waves is based on Maxwell's equations. Maxwell's equations are the development of experimental (empirical) results that underlie electromagnetic phenomena. Differentially, Maxwell's equations which depend on frequency can be formulated in the following equation [8]:

$$\nabla \times \vec{E} = -\frac{\partial B}{\partial t} \quad (1)$$

$$\nabla \times H = J + \frac{\partial D}{\partial t} \quad (2)$$

$$\nabla . D = q \quad (3)$$

$$\nabla . B = 0 \quad (4)$$

where E is the electric field strength (V/m), B is the magnetic flux or induction (T), H is the magnetic field intensity (A/m), J is the electric current density (A/m^2), D is the electric displacement (C /m^2), and q as the electric charge density (C/m^3) [8]. From Maxwell's equations, it can be obtained that the speed of propagation of electromagnetic waves in the medium depends on the speed of light (c = 3.00×10^8 m/s) and the dielectric constant, to determine the depth of the object. The equation is written in the following formula [8]:

$$v = \frac{c}{\sqrt{K}} \quad (5)$$

The GPR method relies on the parameters of the relative permittivity, conductivity, and magnetic permeability of the subsurface medium which causes the waves to be transmitted [7]. The reflection coefficient (R) is the ratio of the reflected energy to the incident energy. The difference in the value of the dielectric constant (K) in layer 1 and layer 2 and the difference in the speed of propagation of electromagnetic waves (V) will affect the value of the reflection coefficient. The reflection coefficient (R) can be formulated in the following equation [8]:

$$R = \frac{V_1 - V_2}{V_1 + V_2} = \frac{\sqrt{K_2} - \sqrt{K_1}}{\sqrt{K_2} + \sqrt{K_1}} \quad (6)$$

Radar signal is always transmitted through the boundary layer or medium causing energy loss. As a result of this lost energy, the propagation of the radar signal is attenuated. The cause of the loss of energy occurs due to absorption (change of electromagnetic energy into heat energy). Radar signals through the boundary layer will encounter the electrical and magnetic properties of the medium. This causes wave attenuation which is the main factor for energy loss. The rate at which the loss of energy or amplitude decreases is called the attenuation constant (α). In general, the attenuation constant depends on the physical and magnetic properties of the medium which can be written in the following equation [8, 13]:

$$\alpha = \omega\sqrt{\frac{\mu\varepsilon}{2}}\left[\left(1 + \left(\frac{\sigma}{\omega\varepsilon}\right)^2\right)^{\frac{1}{2}} - 1\right]^{\frac{1}{2}}$$

$$\approx \begin{cases} \sqrt{\frac{\omega\mu\sigma}{2}} & \text{untuk } \omega\varepsilon \ll \sigma \\ \frac{\sigma}{2}\sqrt{\frac{\mu}{\varepsilon}} & \text{untuk } \sigma \ll \omega\varepsilon \end{cases} \quad (7)$$

where α is the wave attenuation coefficient (dB/m), σ is the conductivity (mS/m), μ is the magnetic permeability (H/m), ε is the dielectric permittivity (F/m), and ω is the frequency (Hz). The wave equation ($\sigma \ll \omega\varepsilon$) for GPR provides a much simpler equation [13].

Skin depth is the propagation distance or depth that a radar wave can penetrate with a certain frequency, where the amplitude of the EM wave decreases to 1/e, which is 37% of the original amplitude. Skin depth is limited by high resistivity or low soil conductivity. In subsurface investigations, the depth of penetration is greatly influenced by the frequency used, especially in the conducting medium. The higher the frequency used, the shallower the depth of penetration. And if the lower the frequency used, the deeper the penetration depth. However, by using this low frequency, the resolution obtained is low, in contrast to using high frequencies, it will produce high resolution. Skin depth can be written in the following equation [8]:

$$\delta = \frac{1}{\sqrt{\pi\mu_0}}\sqrt{\frac{1}{\sigma f}} \approx 503\sqrt{\frac{1}{\sigma f}} \quad (8)$$

where σ is the conductivity (mS/m), f is the wave frequency (Hz) and μ_0 is the magnetic permeability of the vacuum (1.257×10-6 H/m).

The research was conducted in April 2022 located at the Sumatra Institute of Technology, Way Huwi, Jati Agung District, South Lampung Regency, Lampung. The data used is secondary data resulting from the acquisition carried out by PT Bina Berkat Sentosa using a Multi-frequency GPR tool with an antenna frequency of 40 MHz to 3.4 GHz with a side rate of 8 GHz. The GPR acquisition carried out in the ITERA area consists of 5 lines which are carried out in parallel with line lengths varying from 56 meters to 75 meters. The GPR survey in this study was carried out using the radar reflection profiling method, namely by bringing the transmitter and receiver together on the ground [14]. GPR data processing is carried out using GPR Insights software to obtain a good radargram image. The data processing uses several filters, including static correction, dewow, background removal, bandpass filter, gain, and migration which are detailed as follows:

1. Static correction

The static correction filter process is used for each trace and is independent of one another. This filter is used to correct data for elevation and wave travel time due to reduced speed which results in an interface between the transmitter and receiver antennas for the first layer [14, 15].

2. Dewow

Dewow is a process performed to detect data that has low frequency noise recorded by the system. This is due to electronic instruments being saturated by the large amplitude values of direct waves and air waves [15].

3. Gains

This process is carried out to amplify the amplitude of the lost radar wave signal. This filter is used because the signal measured in the previous time is much stronger than the signal measured in the next measurement. This may be due to scattering, attenuation, geometric scattering, or reflection events [13, 15].

4. Background Removal

To eliminate the effects of additional noise on the signal caused by background interference, direct waves, and antenna link effects [14, 15].

5. Bandpass Filter

Aims to eliminate unwanted frequencies or noise frequencies. At this stage, filtering is carried out by limiting the value of the signal frequency range on the radargram [14].

6. Migration

Migration is used to return the trace back to its original position on the radargram. If the trace is not in position it will result in difficulties in analyzing and interpreting the data that has been processed [13, 15].

RESULT AND DISCUSSION

The results of GPR data processing using the GPR Insights software show a radargram cross section with a depth of ± 5 m from the surface. The data used consists of 5 lines with different distances and the lines that are traversed are part of the concrete road and asphalt road with a thickness of the top layer of the concrete road ± 0.1 m and the top layer of asphalt ± 0.05 m. The results of the radargram show an anomalous response under the surface which is visualized in the form of a hyperbole which is suspected to be the presence of utility pipelines and power cables. The radargram also shows an anomaly with a long reflection pattern and this pattern is accompanied by repeated reflections to the subsurface which indicates differences in the constituent materials of the upper and lower layers.

Figure 2 is the processed radargram from line 1 to line 5. Measurements were carried out on two different road material: concrete road and asphalt road. The response anomaly on the radargram shows in the form of a hyperbole which indicates the existence of an embedded utility network beneath the surface located at a depth of between 1.5 and 2 meters.

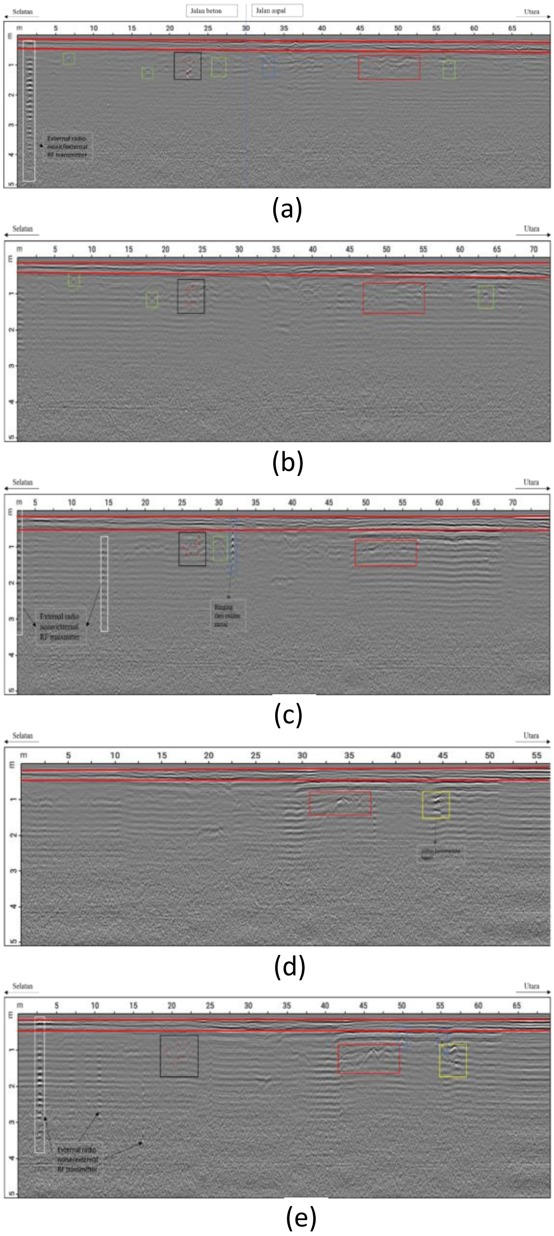

Figure 2. The processed data of line 1 (a) to 5 (e) displayed with hyperbolic response indicating the presence of buried utilities.

From the result (**Figure 2**), the target response in the form of hyperbolic curve, which is marked in black, depicting adjacent and irregularly distributed utilities that have continuity in other paths. The strong anomalies indicate the utility made of metal assumed that the target anomaly is a power cable/power cable connected to a lamp in the middle of the road. The radargram response is indicated by a green box, indicating the presence of weak target utility indicating that the target is made of a non-metallic composition. A difference in velocity and the magnitude of the hyperbole which indicates that the target has a different diameter. Based on field surveys, these utilities are PVC pipes below the road surface with large and small diameters. The box marked in red shows a pattern in the form of a hyperbole that is spread regularly and close together at the same depth. This indicates that the target is made of non-metallic composition. From the field survey, the red box on the radargram represents the utility of a PVC (non-metal) pipe which consists of several PVC pipes connected to the laboratory.

At a depth of 1 meter of line 1 (**Figure 2.a**) and line 3 (**Figure 2.c**), the utility marked with a blue box, indicates the presence of target material embedded beneath the surface which is made of metal composition. However, this target cannot be identified clearly because the utility does not have continuity with other trajectories. There are also several other weak hyperbole-shaped shown in the result that may arise from the ground response because it does not show any continuity on other paths.

The different reflection response, marked with a red line, can be also interpreted as the border between the layers. This difference occurs because of the different constituent materials. A strong reflection layer showing the difference with the layer above and below it. This happens because the constituent materials are not the same as the dielectric constant values. The difference in the constituent materials affects the value of the reflection coefficient, thus showing differences in reflection response [3, 19].

The radargram results from these five trajectories are strongly influenced by the geology of the study area composed by tuffaceous claystone, tuffaceous sandstone, pumice tuff, tuff-solid tuff, and rhyolitic tuff from the Lampung Formation (QTI) [11]. The different rocks in the geology of the study area have different permittivity values. This permittivity value will later affect the amplitude of the reflection signal, so that it can affect the appearance or response of the radargram [15]. The GPR lines are carried out in parallel and several meters apart, where some of the lines are at high attenuation locations. This is influenced by subsurface geological conditions which are dominated by tuff, and it can be assumed that the trajectory is partly wet and dry tuff. Where the wet tuff has a high conductivity so that it experiences rapid attenuation and some of the lines are dry tuff with low conductivity. This subsurface conductivity greatly affects the depth of penetration. When the subsurface conductivity is lower ($\sigma \ll \omega\varepsilon$), the depth of penetration is deeper, and it also depend on the frequency [13].

In this study it is assumed that the study area is dominated by wet tuff and the presence of iron material with high conductivity values. This can affect the response of the radargram, where the signal or radar energy transmitted from the GPR device takes longer to reach a certain layer or depth boundary [15]. So that it experiences faster attenuation and a more concentrated signal which causes a shallower depth of penetration [15, 16]. It should be noted that in this study a multi-frequency GPR device was used which should provide good/deep penetration depth with high resolution. However, because the subsurface conditions are locations of high attenuation, the depth of penetration is shallower. The following is an image of the five GPR lines and you can see the continuity of the subsurface utility network and the coating.

Figure 3 it shows the continuity of the utility network from PVC pipes, power cables, and metal utilities. There are 3 utilities from the PVC pipe that have continuity to line 2 and there is 1 utility from the PVC pipe that has continuity to line 3. The utility network in the previous results (**Figure 2**) is marked with a green box. The continuity of the utility cable / power cable in the picture above is marked in red. In the results of the previous radargram, the target response is marked with a black box so that it can be drawn as a continuation of the utility cable and is a utility cable that leads to the lights in the middle of the road. The utility network which is marked with a red box on the radargram of the five lines is the utility of the PVC pipe. The utility network of the PVC pipe has continuity from line 1 to line 5 and is arranged in an orderly manner. The PVC pipe leads towards the laboratory building, possibly some pipes filled with water and some pipes filled with cables. On line 4 and 5, the hyperbole anomaly marked in yellow is assumed to be the utility of metal-composed objects. The metal utilities in the image above are marked in gray.

In the radargram response, the target marked with a red box and assumed to be a PVC pipe, shows a hyperbole with a strong/clear reflector compared to other hyperboles. This is caused by the reflection of the air interface or the possibility of a PVC pipe containing several power cables. When the pipe is filled with air or an object with a metal composition, it will have a high reflection coefficient, so that the target response on the radargram looks clearer [15].

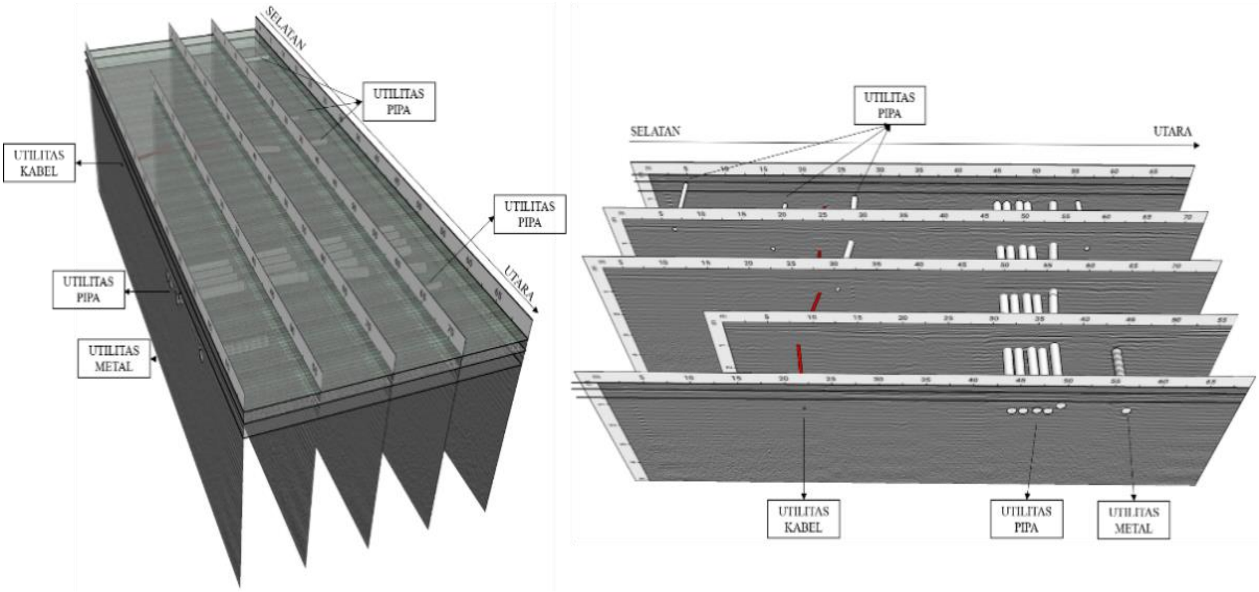

Figure 3. Visualization of GPR data on 5 lines with a depth of ± 5 m

The difference between utility power cables/electrical cables and pipes can be seen in the appearance of the hyperbolic shape. The appearance of the reflector in the form of a hyperbole with rather sharp edges, arranged close together and irregular, is suspected as an anomaly from the utility power cable/power cable. Meanwhile, the pipe is marked with a hyperbole-shaped reflector that is slightly larger than the power cable/electrical cable [15]. The difference between strong and weak target responses indicates that the target is made of metal and non-metal composition [7]. Materials made of metal have a high dielectric constant so that if the measurement is carried out in dry sand it will have a large reflection coefficient. A large reflection coefficient gives a large amplitude value so that it provides a clear or strong contrast on the radargram [5, 16].

CONCLUSION

GPR method can provide an overview of the subsurface utility network which is characterized by hyperbolic target responses and indicates differences in subsurface layers. Using a multi-frequency GPR tool can validate the existence of embedded utilities in the subsurface which is characterized by a hyperbolic reflection anomaly response on the radargram. Reflection anomaly in the form of a hyperbole which is assumed to be several PVC pipes and power cables/electrical cables and metal utilities found at a depth of 0.5 m; 0.8 m; 1 m; and 1.2 m at different distances. Radargrams from all lines indicate that there are utilities that are interconnected or have continuity with other lines, so that when carrying out construction it is necessary to avoid the location of the utility network. The limitations of GPR in subsurface detection can be influenced by the nature of the medium which can affect the ability of the tool's performance.

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