Application of the GPR (Ground Penetration Radar) method for soil investigation and building structure analysis test

D Parwatingtyas

1Physics Departement, Faculty of Mathematics, and Natural Science, Indonesia Defense University, Indonesian Peace and Security Center (IPSC) Sentul, Bogor

E-mail: diane.tyas@gmail.com

Abstract. The large number of infrastructure improvements in Indonesia, causing the need for an underground investigation first, so that the buildings become sturdy and have a small risk of natural disturbance (landslides, land subsidence, earthquakes), etc. One of method used in underground investigations is the Ground Penetration Radar (GPR) method. The GPR antenna system consists of a sending antenna (transmitter antenna), as an electromagnetic signal transmitter and part of the receiving antenna (receiver antenna), that is as a detector of reflected electromagnetic waves. The scope of this research is to collect data in the field using the GPR method, and perform data processing using the Reflex-W application software to obtain information on the condition of the structure, depth of the building foundation, as well as its subsurface information. After all the information on the above values is obtained, we are able to manage the area of the local building more conducive and stable, especially those related to the dynamics of ground movement. GPR data collection was carried out for 3 days, at PANASONIC COMPANIES Tapos Depok, Jakarta – Bogor street on August 7th and 8th 2019. Then data processing and report writing were carried out at the office of Putra Cipta Jaya Consultant from August 12th to September 8th 2019. Based on the results of the GPR inversion processing using Reflex-W software from 9 measured areas, information was obtained that the condition of the Building and its surroundings as a whole was still in good condition. There are only a few parts of the area that are attention in detail here, which is the office area, 1st factory building, 1st floors, as well as the generator building area, which in general, the three areas of this underground structure there is a land that moves down approximately 1-5 metres from the east and west direction. Therefore the building structure of this area is made a deep pondation, which is approximately 10 to 26 metres.

1. Introduction

Every year, Indonesia always carries out overall infrastructure improvements, both in urban and rural areas. Therefore, with this activity, underground investigations are needed first, so that the resulting building becomes sturdy and has a little risk of natural disturbances (landslides, land subsidence, earthquakes) etc. One of the efforts made for this underground investigation is by using the GPR (Ground Penetration Radar) measurement method [1]. Ground Penetrating Radar (GPR) is part of a geophysical method that uses the electromagnetic microwave band principle. GPR can be used in a variety of media including rock, soil, ice, sidewalks, and other hard structures, which is why this method can detect objects, changes in material, and cavities, subsidence, fractures or cracks in building structures or the subsurface and its uses others on geotechnical purposes. The GPR antenna
system consists of a transmitter antenna, as an electromagnetic signal transmitter and a receiver antenna, which detects reflected electromagnetic waves. The electromagnetic pulses emitted by the transmitting antenna to the earth's surface will be transmitted, reflected and scattered by the rocks beneath the earth's surface and received by the receiving antenna. Electromagnetic waves that are usually used are radio waves with a radio frequency range between 10 MHz - 1000 MHz. Waves sent by the transmitter into the ground will be reflected back by the reflector to the surface due to differences in electromagnetic properties such as dielectric constant and conductivity with the surrounding environment. The dielectric constant contrast at the surface boundary causes radar waves to be reflected and the speed of the radar wave is very dependent on the dielectric constant of the medium through which the wave passes.

The amount of penetration or depth that can be reached by radar waves depends on the size of the frequency used. The smaller the frequency used, the greater the penetration that can be achieved by radar waves and vice versa. When radar waves are emitted from the transmitter it will produce a reflection wave and a different amplitude. The amplitude of the waves recorded in the receiver depends on the electromagnetic properties of the objects below the surface through which the radar waves pass. The electromagnetic properties of various subsurface materials are closely related to the mineral composition and water content of these materials. Both are the main controllers of the speed and attenuation that occurs in the propagation of radar waves through the material. When the radar waves from the GPR transmitted from the transmitter hit an object or material below the surface that has high conductivity, the amplitude of the waves recorded in the receiver will be very small. This is because the transmitted waves are absorbed by materials that have high conductivity.

As for the relationship between the GPR method and the soil investigation, the analysis of the building structure, the author tries to conduct a research, namely is measured some subsurface location using the GPR method at the predetermined area, which aims to obtain information on the condition of the foundation, building structure, and also condition information on the subsurface layers. The GPR method used is the GPR Radar Reflection Profiling (RRP) method and its processing uses the Reflex-w software. After all the information on the analysis of the subsurface ground is obtained, we are able to manage the local building area in a more conducive and stable manner, especially which is correlated with the dynamics of ground movement [2].

2. Method

Investigation was carried out for 3 days. The first stage we carried out a survey and introduction of safety to the research area, namely at PANASONIC COMPANIES, Jakarta-Bogor streets, Tapos Depok, on July 29th 2019. So that, we will know which areas will be measured, as well as the stages of implementation and work safety at the time of measurement. And at the second and third days, is on August 7th and 8th 2019, we recognized, measured and collect the data at the investigation location using the GPR method. Meanwhile, data processing and report preparation were carried out at the Putra Cipta Jaya Consultant office from August 12th until September 8th 2019. The stages of measurement and processing of GPR data are briefly shown by flow chart in Figure 1.

The investigation was carried out with Georadar exploration using the GPR Radar Reflection Profiling system, and the software used to process this data was using the Reflex-w software. The raw data processing used would be filtered data. The instrument used is the instrument 1.4 GROUND PENETRATING RADAR (GPR) MALA - Easy Locator Pro WideRange, which is able to detect underground conditions up to a depth of 25 meters (Figure 2a). This tool has a frequency variation of 160 MHz and 670 MHz with the type of device the antenna which mounted is shielded (transmitter and receiver antennas in one device and has a predetermined distance). Measurement of the GPR method is accompanied by 1 set trimble static GPS (Global Positioning System) (Figure 2c) and 1 set trimble RTK GPS (Figure 2d) for positioning coordinates. The GPR tool features include:

1. Antenna Horn.
2. Wifi antennas.
3. Velocity.
4. Band Frequency.
5. Automatic medium procedure for the layers.
6. Modular and 4 pieces of battery.

![Flowchart of the research methodology](image)

**Figure 1.** Flowchart of the research methodology

![Image of Georadar](image)

**Figure 2.** (a) 1 Unit Georadar merk MALA with display monitor to see the condition of subsurface structures, according frequency variation, (b) Measurement preparation, (c) 1 Set Trimble Static GPS and (d) 1 Set RTK GPS
While the GPR/Georadar measurement procedure includes:

- First of all, we conduct a survey to determine the trajectory of the building and road locations to be measured.
- Determine the location of the coordinates. Once determined, then we install a set of static GPS devices at that location.
- Setting up static GPS and trimble GPS for measurement.
- Preparing the GPR tool, then installing the battery in the tool, calibrating the coordinates on the GPR tool that appear on the monitor screen which is according to the GPS.
- Start measuring (Figure 4). The system that works from GPR consists of a transmitting antenna (transmitter), as a transmitter of an electromagnetic signal, and a part of a receiving antenna (receiver), which is a detector of reflected electromagnetic waves. The transmitter antenna generates pulses of electromagnetic waves at certain frequencies according to the characteristics of the antenna. The receiver antenna is set to perform a scan that normally achieves 32-512 scans / second at each predetermined path (Figure 3). Each scan result is displayed on the monitor screen (real time) as a function of time (Figure 5).
The data obtained from measurements are then processed using the Reflex-w software. Where the Reflex-W software will be processed using the GPR filter data. The output is an imaging map that will detect subsurface cracks or buildings (Figure 6).

2.1. Theoretical basis

2.1.1. Ground Penetrating Radar (GPR). GPR, which was first introduced by Cook in 1960, has undergone a fairly rapid development and its use is quite extensive. The widespread use of georadar is because the detection results provide very accurate information at shallow depths. In addition, GPR can be operated easily and quickly. Basically, the GPR method has the same principles as seismic reflection, it's just that in reflection seismic acoustic waves are used and their penetration is deep enough, in the georadar method, electromagnetic waves are used with relatively shallow penetration. The electromagnetic waves used in the georadar method are obtained from the Frequency Modulation (FM) radio waves transmitted through the transmitter antenna (transmitter). The pulse wave will propagate into the ground and because of the conductivity of the subsurface material which is the reflector, part of the pulse wave will be reflected. The reflection of this wave pulse will be detected by the receiving antenna (receiver) and then printed on the recording paper [3]. Figure (7) below is the method of propagating incoming waves at anomaly which functions as a reflector and a sketch of the GPR record from the measurement.

Figure 6. Schematic of GPR data processing in the field

Figure 7. Wave propagation and recording sketch
2.2. Electromagnetic Wave Equations for GPR Analysis

The behavior of electromagnetic waves has been studied and formulated mathematically by Maxwell. This formulation forms the basis of all electromagnetic phenomena. Maxwell’s equations where it is possible to have a charge and a conductive current in an area are generally written in the form [4]:

\[ \nabla \cdot E = \frac{\rho}{\varepsilon} \]  \hspace{1cm} (1)

\[ \nabla \cdot B = 0 \]  \hspace{1cm} (2)

\[ \nabla \times E = -\frac{\partial E}{\partial t} \]  \hspace{1cm} (3)

\[ \nabla \times B = \mu_0 E + \mu_0 \frac{\partial E}{\partial t} \]  \hspace{1cm} (4)

With:  
- \( E \) = Electric Field (Volt/m).  
- \( B \) = Magnetic Field (Weber/m\(^2\)).  
- \( \rho \) = Resistivity (Ohm.meter).  
- \( \varepsilon \) = Permittivity (Farad/m).  
- \( \mu \) = Permeability (Hendri/m).

For free current, the continuity equation is:

\[ \nabla \cdot J = -\frac{\partial \rho}{\partial t} \]  \hspace{1cm} (5)

\[ J = \sigma E \]  \hspace{1cm} (6)

With \( J \) = Free current (Ampere).  
\( \sigma \) = Conductivity (Siemen/m).

In accordance with Ohm’s law and Gauss’s law, the equation is:

\[ \frac{\partial \rho}{\partial t} = -\frac{\sigma}{\varepsilon} \rho \]  \hspace{1cm} (7)

With vector intensity, if equations (3) and (4) perform a differential vector operation then substitute equations (3) and (4) into their respective equations, then the wave equations for E and B are obtained as follows:

\[ \nabla^2 E = \frac{\mu}{\varepsilon} \frac{\partial^2 E}{\partial t^2} + \frac{\mu_0}{\varepsilon} \frac{\partial E}{\partial t} \]  \hspace{1cm} (8)

\[ \nabla^2 B = \frac{\mu_0}{\varepsilon} \frac{\partial^2 B}{\partial t^2} + \frac{\mu_0 \mu}{\varepsilon} \frac{\partial B}{\partial t} \]  \hspace{1cm} (9)

The first and second terms on the right side of the equation above are the distribution and diffusion equations, respectively. The solutions of the two equations are:

\[ E^*(x, t) = E_0^* e^{i(kx - \omega t)} \]  \hspace{1cm} (10)

\[ B^*(x, t) = B_0^* e^{i(kx - \omega t)} \]  \hspace{1cm} (11)

With \( k = k_- + ik_+ \) (complex)  \hspace{1cm} (12)
\[ k_\pm = \omega \sqrt{\frac{\varepsilon \mu}{2}} \left[ \sqrt{1 + \left( \frac{\sigma}{\varepsilon \omega} \right)^2} \pm 1 \right]^{1/2} \]  

(13)

For a good conductor \((\sigma \gg \varepsilon \omega)\), \(k_-\) and \(k_+\) the value is almost the same:

\[ k_+ \approx k_- \approx \sqrt{\frac{\omega \sigma \mu}{2}} \]  

(14)

**Annotation:**
- \(K\) = Propagation constant \((\text{m}^{-1})\).
- \(k_-\) = Phase shift constant \((\text{m}^{-1})\).
- \(k_+\) = Attenuation factor \((\text{m}^{-1})\).
- \(\omega = 2\pi f = f = \text{Frequency} \ (\text{Hz})/\text{Hz})\).

Distance is used to reduce the amplitude of the wave, and then only \(1/e\) from input amplitude called skin depth.

\[ \delta = \left[ \frac{1}{k_-} \right] = \frac{2}{\sqrt{\omega \sigma \mu}} \]  

(15)

With: \(\delta = \text{Skin depth} \ (\text{m})\).

Skin depth is a measure of the depth of penetration of electromagnetic waves into the conductor. If the medium is homogeneous and linear, from Maxwell's equations and by using the classical wave equation:

\[ \nabla^2 f = \frac{1}{V^2} \frac{\partial^2 f}{\partial t^2} \]  

(16)

Then we get the speed of propagation of electromagnetic waves in a vacuum [5]:

\[ C = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} \]  

(17)

And the velocity of propagation in the medium:

\[ V = \frac{1}{\sqrt{\mu \varepsilon}} \]  

(18)

The size of the amplitude of the waves reflected by the reflector can be seen in the georadar recordings. This recording is displayed in contrasting colors. The black color indicates the amplitude of the reflected wave from the large reflector and the white color if the amplitude of the reflected wave is small or equal to zero. Meanwhile, the color between black and white indicates medium amplitude. The color contrast of the georadar record also shows the size of the conductivity value of the detected subsurface material. If the conductivity of the material is small, the amplitude of the reflected wave is large and the recording on the georadar will appear in black and vice versa in white for the high conductivity of the material. By substituting equation (15) into equation (18), we obtained:

\[ V = \frac{1}{\sqrt{K \sigma}} \]  

(18.1)

**Annotation:**
- \(C\) = The velocity at which electromagnetic waves propagate in a vacuum \((\text{m/s})\).
- \(V\) = Velocity of propagation in medium \((\text{m/s})\).

To interpret the georadar record, it is necessary to require data on the speed of wave propagation in the earth's layers or geological data in the study area. To obtain velocity data, it can be done using measurement data in the field or by analyzing the layer of material / earth in the laboratory. The field
data used to obtain the speed is obtained from the measurement results using two transducers, each of which functions as a wave transmitter and receiver. From this recording, data on the distance between the two transducers and the time of propagation of the waves from transmitter to reflector to receiver are obtained. The depth of radar penetration is also very dependent on the value of the dielectric constant and the conductivity of the subsurface material. If the conductivity of the material is large, the radar penetration will be shallow and vice versa. The depth of radar penetration can be determined using the following relationship [6]:

\[ D = \frac{V_{rms} \cdot t}{2} \]  

Where D is a depth (m).

3. Result and Discussion

Figure 8 shows the locations that will be measured by the GPR method:

![Map of the location of PT Panasonic to be measured by GPR](image)

Based on Figure 8 above, there are 9 paths measured by GPR and data taken, including: 1). 1st Factory, 1st floors 2). 1st Factory 2nd floors 3). 2nd Factory 4). 3rd Factory 1st floors. 5). 3rd Factory 2nd floors. 6). 3rd Factory 3rd floors. 7). Generator area. 8). Gas generator area 9). Office building area. The output and interpretation that are processed with reflex-W software are shown in the attachment below:
Figure 9. The results of the cross section of the subsurface / ground image for the 1st factory 1st floors

In Figure 9, namely the 1st factory on 1st floors, the underground structure has a subsidence that moves downward approximately 1 meter to west side. There is no continuous layer. The building blocks are neatly arranged, and the overall building condition is still good. This is more clearly seen in the east to west direction. The detected depth of the foundation is approximately 10 metres.

Figure 10. Cross-sectional image results for the 1st factory, 2st floors

In Figure 10 1st Factory, 2nd floors, the underground structure is not continuous from south to north. There is a subsidence approximately 10 centimetres. Likewise, the subsurface structure area from north to south. The building blocks are neatly arranged, and the overall building condition is still good.
Figure 11. Cross-sectional results of subsurface / ground images for 2nd factory

In Figure 11, the 2nd factory building, the overall section for the south-north direction is shown. The underground structure shows homogeneous and orderly conditions. The structure of the building beams is neatly arranged, and the overall condition of the building is good. The target depth for the underground foundation is 10 metres.

Figure 12. Cross-sectional results of subsurface/ground images for the 3rd factory building, 1st floors

In Figure 12 of the 3rd factory building, 1st floor, the overall section for the west - east direction is shown. The underground structure shows homogeneous and orderly conditions. The structure of the building beams is neatly arranged, and the overall condition of the building is good. The target depth for the underground foundation is 10 metres.
Figure 13. Cross-sectional image results for the 3rd factory building, 2nd and 3rd floors

For figure 13, 3rd factory building, 2nd and 3rd floors, the overall section for the west - east direction is shown. The underground structure shows homogeneous and orderly conditions. The structure of the building beams is neatly arranged, and the overall condition of the building is good.

Figure 14. Cross-sectional results of the subsurface/ground image for the generator area

In this area, Figure 14 is shown the overall section for the south-north direction. In the generator area, the underground structure shows quite a lot of buried objects, especially in the northern part (right side of the section) which is located at a shallow depth (0.5 metres) to a depth of 10 metres. In addition, it is also seen that the soil layer is not continuous at a depth of 2 meters to 10 metres. The discontinuity is a broken layer of soil, which is caused by the inability of the layer to withstand vertical loads from above the surface or due to disturbances in the form of vibrations either due to human activity on the surface or vibrations from within the earth. The inconsistency is consistent from the center of the line to the north. The indicated foundation depth reaches 19 metres.
In the gas generator area, Figure 15, is shown the overall section for the south - north and east - west directions. The underground structure shows a good / continuous soil layer, there are embedded gas pipes. only in the location area towards the east - west there is an empty area. The target depth for the underground foundation is 10 metres.

Whereas in the office building area, figure 16 is shown the overall cross section for the west-east direction. Its underground structure shows instability. It can be seen that there is a diffraction effect caused by the presence of objects below the surface that are not visible as in other soil layers. The soil layer in the western part (left of section) appears to be arranged in parallel, but in the eastern part, there is a decrease in the layer (subsidence) as deep as 5 metres. The decrease in the layer tends to follow the contour / morphology of the measurement area. In addition, in this
layer there is no visible effect of non-continuity of the layer. The foundations of the detected Office building area are more than 26 metres.

4. Conclusion
Based on the results of GPR inversion using Reflex-W software from 9 areas in PANASONIC COMPANIES, Tapos Depok, West Java, the condition of the building and its surroundings as a whole is still in good condition. There are only a few areas that are considered in detail here, which is: Office area. In this area, on the 1st floor of the office building, the underground structure looks unstable, where there is land that is moving downward approximately 5 meters to the east. There is also an unsustainable layer. Therefore, in the building structure of this area a deep foundation is made, where the GPR analysis data shows a foundation depth of more than 26 metres. For the condition of the building, the structure of the building beams is neatly arranged, and the overall condition of the building is still good. This is more clearly seen in the west to east direction. In the 1st factory building on the 1st floors, the underground structure has ground that moves downward approximately 1 meter from the west. There is no continuous layers. The building blocks are neatly arranged, and the overall building condition is still good. This is more clearly seen in the east to west direction. The condition of the building structure remains strong and consistently strong if it is supported by a deep foundation depth. In this area, the depth of the foundations that were detected was good, reaching 10 metres. Generator area, the underground structure shows quite a lot of buried objects, especially in the north (right side of the section) which is located at a shallow depth (0.5 metres) to a depth of 10 metres. In addition, it is also seen that the soil layer is not continuous at a depth of 2 metres to 10 metres. The discontinuity is a broken layer of soil, which is caused by the inability of the layer to withstand vertical loads from above the surface or due to disturbances in the form of vibrations either due to human activity on the surface or vibrations from within the earth. The inconsistency is consistent from the center of the track to the north. The foundation support for this unstable soil structure is good enough, that is, it is indicated up to 19 metres.

Acknowledgement
On this occasion, the authors would like to thankfull the geophysics team from Putra Cipta Jaya Consultant, and Pertamina University, who assisted the author in conducting research, as well as PANASONIC COMPANIES and the City Government of Depok as the donor of this research project grant. Hopefully in the next opportunity, the cooperation and solidarity that is achieved can always be improved even better. We also thank profusely to the ICTAP 2020 comittee, who is willing to publish the result of this research into the IOP journals.

References
[1] Muttaqin 2015 Ground Penetration Radar Study on Several Medium ETD: Journal of Electronic These and Dessertations 3(2) 10-25
[2] Aji P S, Arya P and Iryanti M 2016 Application of the Ground Penetrating Radar (GPR) Method to the Crack Patterns in the Batu Tegi Lampung Dam Journal of the Indonesian University of Education (UPI) Physics Forum 1(1) 32-41
[3] Difia N 2017 Identification of Subsurface Structures Using the Ground Penetrating Radar (GPR) Method in the Coastal Area of Samatiga District, Aceh Barat ETD: Journal of Electronic These and Dessertations 2(1) 20-35
[4] Murjono 1993 Electromagnetics Sari Book Schaum, Publisher Erlangga p 158
[5] Safrida A, Ismail N and Marwan 2019 Investigation of Shallow Fault Structures Using the Ground Penetration Radar (GPR) Method in Pangwa Village, Trienggadeng District, Pidie Jaya Regency Aceh Physich Society Journal, Earth Engineering Department, Faculty of Engineering, Syiah Kuala University 8(2) 35-40
[6] Elfarabi, Widodo A and Syaifudin F 2017 Ground Penetration Radar (GPR) Data Processing Using MATGPR R-3.5 Software ITS Journal of Engineering 6(1) A47-A50
[7] Luga A, Ivansyah O and Muliadia 2019 Identification of Subsurface Metal Pipes Using the Ground Penetrating Radar (GPR) Method *PRISMA FISIKA Journal* 7(1) 20-29

[8] Kusumaningsih A R P, Nugroho D and Ivansyah O 2019 Determination of the Depth of the Peat Layer Using Ultra Ground Penetrating Radar to Estimate Carbon Stocks in Pedamaran District *PRISMA FISIKA Journal* 7(3) 304-311

[9] Azizah 2016 Radar Image Focusing for Surface Penetration Radar Modeling Using Distance Migration Algorithm *ELKOMIKA Journal* 4(1) 110-122

[10] Pakiding A 2014 Analysis and Interpretation of Subsurface Structures Using the Georadar Method *Journal of KIP Mathematics Education Study Program, Teaching and Education Faculty, Toraja Christian University* 2(3) 255-266

[11] Deniyatno 2011 Identification of landslide slip zones using the Georadar method *Journal of Physics Applications* 7(2) 69-76

[12] Fadlan M and Intan S 2016 Georadar in Archeology Research in Indonesia *Journal of the National Archaeological Research Center* 10(1) 25-40

[13] Jatmiko F A W, Mandang I and Budiono K 2016 Interpretation of Subsurface Sediments Using the GPR (Ground Penetrating Radar) Method in the Kulon Progo Beach Area, Yogyakarta Special Region *Proceedings of the Science and Technology Seminar, FTMIPA Unmul* 1(1) 13-17

[14] Kuseno T 2014 Application of EM-Conductivity Loop Vertical Coplanar System to Identify the Distribution of Fertilizer on Agricultural Land in Sungai Raya, Kubu Raya, West Kalimantan *Journal of the Physics Study Program of the Faculty of Mathematics and Natural Sciences, Tanjungpura University. Pontianak. POSITRON* 4(1) 01-06

[15] Pranowo 2016 Preliminary Modeling of Ground Penetration Radar with Galerkin and PML Barenger Discontinuous Methods *JNTETI Journal* 5(2) 115-121