Jurnal Teknik Sipil & Perencanaan 26 (1) (2024) p 11-14

UNNES JOURNALS

JURNAL TEKNIK SIPIL & PERENCANAAN

http://journal.unnes.ac.id/nju/index.php/jtsp/index

Interpretation of Subgrade Conditions Beneath Flexible and Rigid Pavement Layers Using Ground Penetrating Radar (GPR)

Detria Ardhila Kumala Sari[,a)] and Rini Kusumawardani[2]

[1,2]Undergraduate Civil Engineering Study Program, Department of Civil Engineering, Faculty of Engineering, Universitas Negeri Semarang

[a)] Corresponding author:

Abstract. Ground Penetrating Radar (GPR) is a device commonly utilized in non-destructive testing (NDT) applications. Its principal advantage lies in its non-invasive nature, allowing for subsurface exploration without causing damage to existing structures or the surrounding environment. Due to this characteristic, GPR has become a leading technology in subsurface investigation.

GPR is regarded as an optimal solution for rapidly and efficiently assessing subsurface conditions without inflicting damage on the pavement surface. In this research, GPR technology is employed to analyze the subgrade layers beneath flexible (asphalt) and rigid (concrete) pavements, with the objective of enhancing the effectiveness and sustainability of road maintenance strategies.

The data acquisition process is supported by the GAS XPC software for field data recording, while data processing is conducted using GPRSoft and GSSI RADAN 7. A comparison between raw and processed data reveals distinctions that facilitate a more in-depth analysis. Furthermore, discrepancies in data interpretation were observed between the outputs of GPRSoft and GSSI RADAN 7. These differences serve as valuable references for refining data analysis methods and improving the accuracy and reliability of future GPR-based investigations.

Keywords: Ground Penetrating Radar, flexible pavement, rigid pavement

INTRODUCTION

Ground Penetrating Radar (GPR) is one of the most widely adopted near-surface geophysical methods for infrastructure imaging. A GPR system transmits radio wave signals into a structure and detects the echoes generated by changes in the material properties within that structure.

The GPR system consists of a transmitting antenna that emits electromagnetic signals and a receiving antenna that detects the reflected electromagnetic waves. The electromagnetic pulses emitted by the transmitting antenna into the ground are reflected, scattered, and transmitted by subsurface materials and are subsequently captured by the receiving antenna. These waves are reflected back to the surface by subsurface reflectors due to contrasts in electromagnetic properties, such as dielectric permittivity and electrical conductivity, relative to the surrounding environment.

Through this process, GPR records data representing the subsurface conditions. The recorded data can then be interpreted to produce a clearer depiction of soil structure, the presence of underground objects, or other geological characteristics.

GPR and geotechnical methods have been extensively applied in civil engineering, particularly for the inspection of pavement layers. In road assessment, a primary application is evaluating the variability of volumetric water content in the sub-base or subgrade, thereby enabling the monitoring of soil stability in the area.

In this study, the data acquisition process was supported by GAS XPC software for field data recording, while data processing was carried out using GPRSoft and GSSI RADAN 7.

LITERATURE REVIEW

Electromagnetic waves are unique in that they can propagate through a vacuum without requiring a medium such as air or water. These waves consist of electric and magnetic field components that are perpendicular to each other and also perpendicular to the direction of wave propagation.

The behavior of electromagnetic waves is mathematically described by Maxwell's equations. Maxwell's equations consist of four field equations, each representing the relationship between the fields and their sources (i.e., charge or current distributions).

Maxwell's first equation states that a changing magnetic field can induce an electric field:

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

Maxwell's Second Equation states that a magnetic field is generated by the flow of electric current:

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

Maxwell's Third Equation states the existence of a closed-loop property of electric displacement in the presence of electric charge density:

$$\bar{\nabla} \times \bar{D} = q \quad (3)$$

Maxwell's Fourth Equation states that the magnetic flux forms a closed loop in the absence of free magnetic currents:

$$\bar{\nabla} \times \bar{B} = 0 \quad (4)$$

Notation:

E = Electric field vector (V/m)

B = Magnetic field vector (Tesla)

J = Electric current density vector (A/m^2)

D = Electric displacement vector (C/m^2)

H = Magnetic field intensity vector (A/m)

q = Electric charge density (C/m^3)

t = Time (seconds)

Ground Penetrating Radar (GPR) is a highly effective method for detecting subsurface conditions up to a depth of 10 meters with high-resolution results, making it frequently used in fields such as archaeology, civil engineering, and subsurface utility mapping.

Resolution refers to the ability to distinguish between two distinct objects located close to each other. It is crucial in determining spatial attributes such as position, size, shape, and thickness. High resolution can only be achieved using shorter wavelengths, which in turn require higher operating frequencies.

Fundamentally, GPR operates based on the reflection of signals. Electromagnetic waves are emitted from the transmitting antenna (Tx) into the target medium, traveling through the material at a velocity primarily determined by the material's permittivity.

A portion of the wave is reflected or scattered back to the surface when encountering a boundary with differing electrical properties, while the remaining energy continues downward until it encounters another subsurface object. The reflected signal is then captured by the receiving antenna (Rx), and the system produces an output in the form of a radargram.

SYSTEM COMPONENTS

The component system used in the GPR data acquisition process consists of four main parts: the antenna, control unit, display unit, and power supply. The antenna functions as both the transmitter and receiver of the electromagnetic waves that propagate beneath the surface. Several types of antennas have been developed by Geoscanners, one of which is the GCB model antenna.

The control unit serves to convert the analog signals received from the antenna into digital signals, which are then transmitted to the display unit. Generally, there are two types of control units compatible with the GCB antenna model: the Akula 9000B and Akula 9000C.

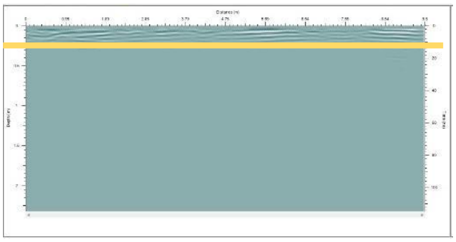
Each GPR manufacturer provides specialized applications or software integrated with their GPR systems for both data acquisition and processing. Geoscanners has developed two main software tools for GPR users: GAS XPC and GPRSoft. In comparison, GSSI RADAN 7, developed by GSSI, is also used as a benchmark software for data processing.

RESULTS

This section presents the results and analysis based on the processed data. The data analysis aims to identify the subsurface layer features beneath the road pavement, as interpreted from the radargram outputs. Additionally, a comparison is made between the results obtained from two different data processing software tools: GPRSoft and GSSI RADAN 7.

Point A (Candi Raya Street) (Flexible Pavement)

(a) Point A1 (Good Surface Road) (GPRSoft)



(b) (GSSI RADAN7)

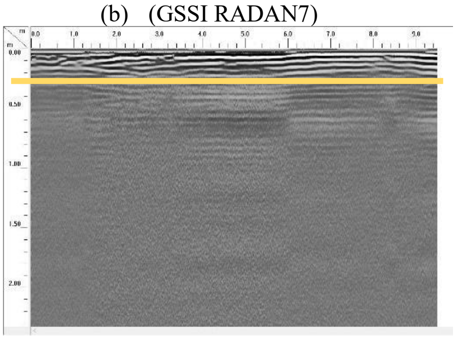
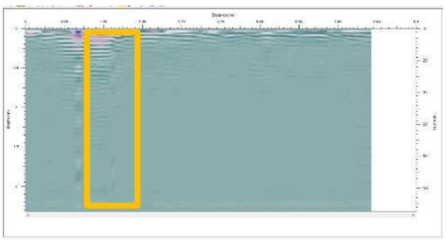


FIGURE 1. (a) & (b) Processed Result of Point A1

(a) Point A2 (Cracked Surface Road) (GPRSoft)



(b) (GSSI RADAN 7)

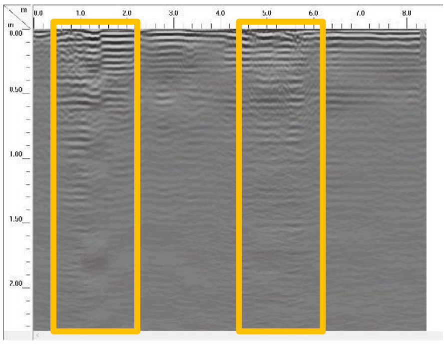


FIGURE 2. (a) & (b) Processed Result of Point A2

Based on the results of data processing using both GPRSoft and GSSI RADAN 7, a noticeable difference can be observed in the visibility of subsurface layers—GSSI RADAN 7 provides clearer stratigraphic details compared to GPRSoft. In sections with damaged road surfaces, the data can be interpreted as indicating weak zones or layer failures. Furthermore, GSSI RADAN 7 reveals additional anomalies not visible in GPRSoft.

For road segments with good surface conditions, the processed data also shows differences. GSSI RADAN 7 detects an anomaly that may indicate a weak subsurface layer, which is not as clearly represented in GPRSoft. However, in segments with damaged road surfaces, both software tools identify anomalies at approximately the same locations, showing no significant difference in the interpretation of the damaged layer positions.

CONCLUSIONS

It can be observed from the GPR data results for two types of road pavements—flexible and rigid—and two surface conditions—good and damaged—that the following conclusions can be drawn: for both pavement types (flexible and rigid), weak zones were identified in the sub-grade layer at multiple points along roads with damaged surfaces. In contrast, on roads with good surface conditions, differences in interpretation emerged; anomalies were detected in the sub-grade layer of the rigid pavement section, while no such anomalies were observed in the flexible pavement section.

Based on the GPR data interpretation, several differences were identified between the two software tools, GPRSoft and GSSI RADAN 7. Anomalies that were visible in GSSI RADAN 7 were not detected in GPRSoft. These differences also extended to the interpretation accuracy of pavement layer boundaries. Therefore, the use of more than one software tool can serve as validation and comparison, highlighting the necessity of using multiple applications to improve the accuracy of GPR data interpretation.

REFERENCES

[1] Elfarabi, Widodo, A., & Syaifudin, F. (2017). Pengolahan Data Ground Penetrating Radar (GPR) dengan menggunakan software MATGPR R-3.5. 6(1).

[2] Feranie, S., Tohari, A., Karmila, I., & Puspitasari, A. D. (2023). Penerapan Metode GPR dan Geoteknik pada Kajian Jalan, Jembatan, dan Lereng. *Jurnal Sains dan Edukasi Sains*, *6*(2), 51-64.

[3] Lai, W. W. L., Derobert, X., & Annan, P. (2018). A review of Ground Penetrating Radar application in civil engineering: A 30-year journey from Locating and Testing to Imaging and Diagnosis. *Ndt & E International*, *96*, 58-78.

[4] Nugroho, U., & Susanto, N. C. J. (2023, June). Comparison of GPR (Ground Penetrating Radar) Penetration Results Using the GCB-400 Antenna on Flexible and Rigid Pavement. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1203, No. 1, p. 012022). IOP Publishing.

[5] Solla, M., Pérez-Gracia, V., & Fontul, S. (2021). A review of GPR application on transport infrastructures: Troubleshooting and best practices. *Remote Sensing*, *13*(4), 672.