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Ground Penetrating Radar Survey for Diagnosing Ballast and Sub-Ballast Pathologies in a Railway Segment

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Abstract

This study presents the results of a Ground Penetrating Radar (GPR) survey conducted on a 200-meter railway section in northern Brazil to investigate subsurface anomalies affecting track stability. Data were acquired using 400 MHz GGSI antennas and a 250 MHz IDS system. Radargrams revealed some pathologies in the ballast and sub-ballast, including metallic targets, subsurface depressions and potential structural discontinuities. A significant subsidence feature was identified near a central drainage, where both ballast and sub-ballast layers showed a downward shift of up to 1.5 meters.

Introduction

The investigated railway segment is currently under operational restriction due to suspected structural anomalies, including voids, water pockets, and material loss beneath the track. These issues pose risks to the performance and safety of the permanent way. As a result, trains traveling through this section are required to reduce speed, affecting overall network efficiency. To support the maintenance planning, a high-resolution geophysical survey using GPR was carried out to map and characterize subsurface conditions. The objective was to identify and localize anomalies that may compromise the structural integrity of the railway line. Similar GPR-based investigations have proven successful in diagnosing and resolving comparable issues in other critical sections of the railway (Kovacevic et al, 2019; Wang et al, 2022; Liu et al, 2022; Arcieri et al, 2024).

Method

Ground Penetrating Radar (GPR) is a non-destructive geophysical technique that detects subsurface changes based on contrasts in dielectric permittivity. Since air and water represent the two extremes of this property (air having the lowest and water the highest, 1 and 80 respectively) GPR is particularly effective at identifying features such as voids (air-filled) and moisture accumulation (water-filled). This makes it a valuable tool for railway investigations, especially when aiming to detect structural voids, water pockets, and stratigraphic variations within the ballast and sub-ballast (Kovacevic et al, 2019; Arcieri et al, 2024).

In this work, GPR was employed to investigate subsurface anomalies beneath the railway track using two distinct antenna systems. Data acquisition was performed with a GSSI SIR-3000 system equipped with 400 MHz antennas, and an IDS system operating at 250 MHz.

Four GPR profiles were acquired using the 400 MHz antennas: two positioned internally between the rails and two externally still over the sleepers. These lines covered a total distance of 200 meters along the railway track. Additionally, two supplementary profiles were acquired with the IDS 250 MHz antenna, placed over the ballast, outside the sleeper area. Due to discontinuities in the track, these external lines were shorter in length.

Results

The GPR survey revealed distinct structural anomalies in both ballast and sub-ballast layers along the investigated railway section. Figure 1 illustrates the data acquisition setup, showing the dual 400 MHz GSSI antennas positioned over the track during fieldwork.

Figures 2 and 3 present the radargrams acquired along the left and right rails, respectively, using the 400 MHz antennas. A prominent central subsidence zone is visible between 80m and 120m, where both the ballast and sub-ballast layers dip toward a drainage structure. Additionally, a secondary anomaly is observed between 20m and 40m at approximately 1m depth in the sub-ballast. These features indicate localized structural degradation and material displacement beneath the track.

Figure 4 shows the radargram acquired with the IDS 250 MHz antenna, positioned outside the sleepers. This dataset provided greater signal penetration and depth resolution, clearly confirming the same central subsidence zone identified in Figures 2 and 3, as well as an isolated metallic target on the right side.

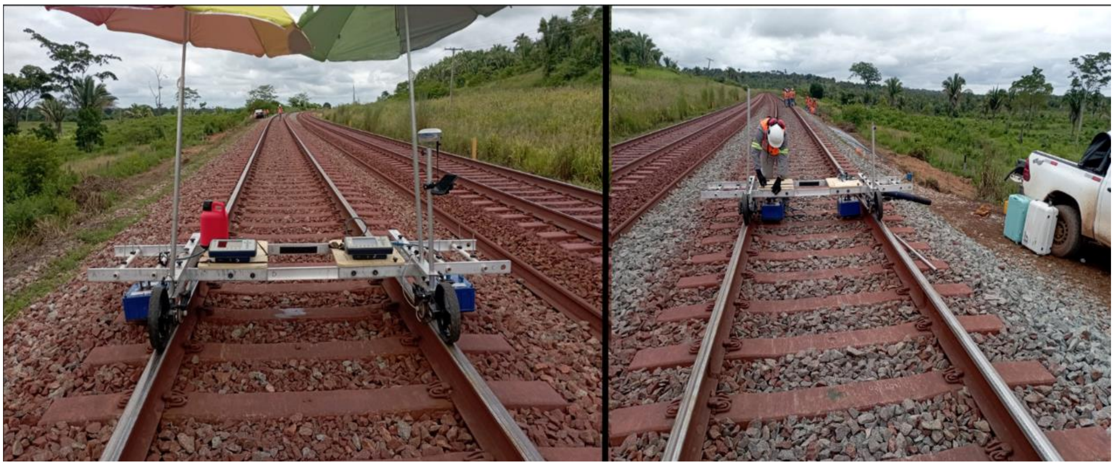

Figure 1: GPR survey setup with dual 400 MHz GSSI antennas positioned over the railway track. This configuration was used to acquire the data presented in Figures 2 and 3.

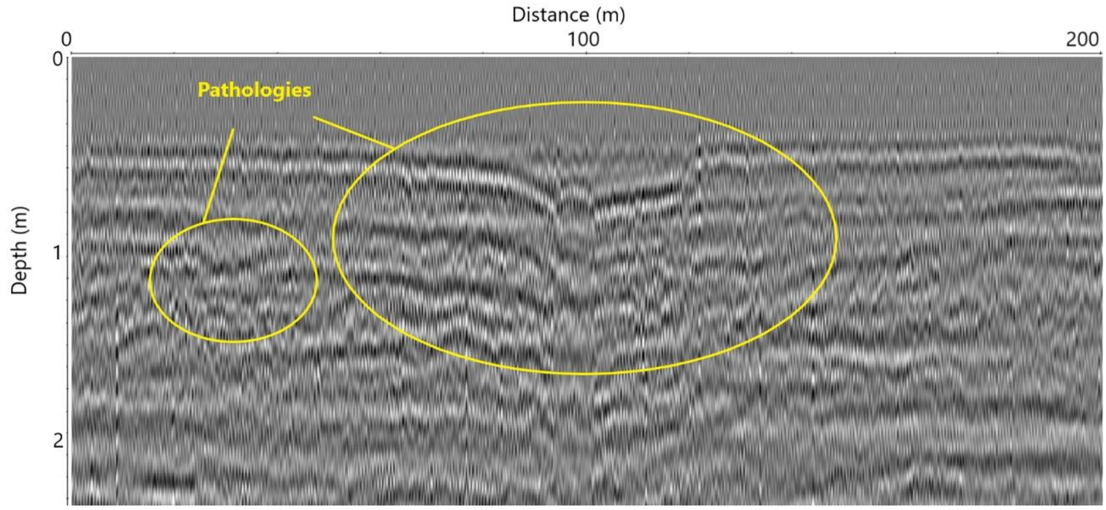

Figure 2: Radargram acquired with a 400 MHz antenna along the left rail, showing a prominent central subsidence between 80m and 120m, where the ballast and sub-ballast layers dip downward. A secondary anomaly is visible between 20m and 40m at approximately 1m depth in the sub-ballast.

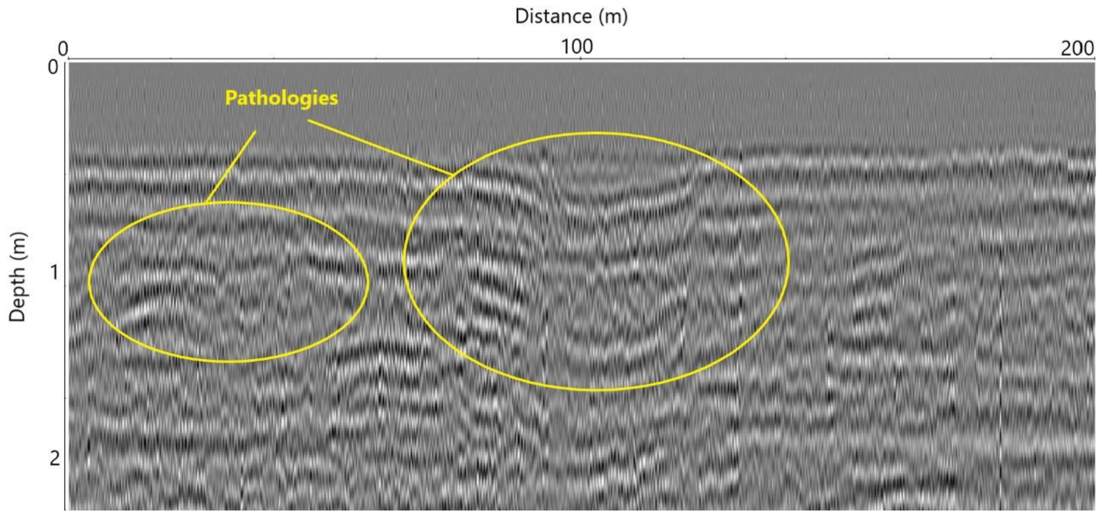

Figure 3: Radargram acquired with a GSSI 400 MHz antenna along the right rail. It presents the same main and secondary anomalies as in Figure 2, confirming the subsurface dip between 80m and 120m and the smaller sub-ballast anomaly between 20m and 40m.

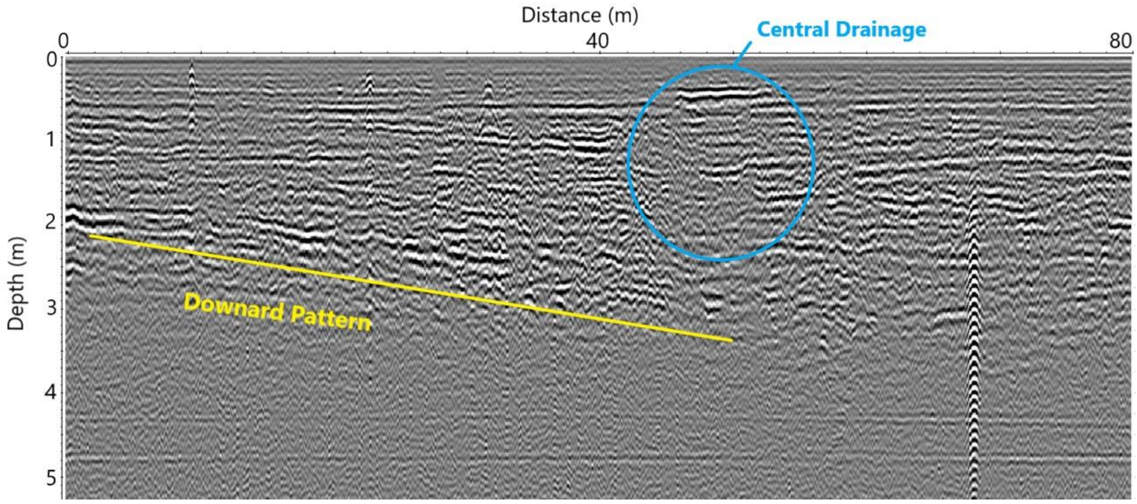

Figure 4: Radargram acquired with the IDS 250 MHz outside the sleepers, covering 0–80 m. The image reveals a subsurface dip toward to the central drainage structure. A metallic object can be seen at the right side.

Conclusions

The application of GPR techniques with both 400 MHz and 250 MHz antennas enabled the identification of structural anomalies beneath the railway track. A central subsidence zone was consistently detected across both rails and confirmed with the data acquired outside the sleepers. This deformation is associated with a drainage structure and likely results from water infiltration and progressive sub-ballast instability. The presence of additional localized anomalies suggests complex degradation patterns that require further geotechnical investigation. These findings highlight the value of multi-frequency GPR for detecting critical subsurface conditions and guiding maintenance planning in the railway infrastructure.

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