



U.S. Department  
Of Transportation

**Federal Railroad  
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# Research Results

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## Non-Destructive Evaluation of Railway Track Using Ground Penetrating Radar

### SUMMARY

The Federal Railroad Administration (FRA) Office of Research and Development sponsored a study under the Track and Structures Program for evaluating railway track conditions using ground-penetrating radar (GPR). The track conditions targeted by the GPR research contribute to its overall performance and the safety of railway operations including the rate of track geometry deterioration, track buckling potential, and overall track support conditions as covered by the FRA Railway Accident Incident Reporting Systems (RAIRS) train accident cause codes T101-T108, T109, and T001, respectively (FRA, 1997). GPR can provide a rapid, non-destructive inspection for evaluating railway track substructure integrity. As shown in Figure 1, the equipment is non-contact and allows data collection at normal vehicle track speed. GPR provides continuous top-of-rail measurements of substructure layer conditions, with the potential to measure the layer thickness, water content, and density of the substructure components (ballast, sub ballast, subgrade). GPR is also capable of observing trapped water from poor drainage, soft subgrade due to high water content and related deformation, and is potentially capable of distinguishing fouled ballast from clean ballast. The study shows that GPR can quantify the thickness, lateral, and longitudinal extent of substructure layers. GPR can provide useful profiles of the track substructure showing variation in condition and depth along and across the track, indicative of differences in track performance.



*Figure 1. GPR Test Equipment Deployed for Track Inspection*



## BACKGROUND

The goal of the study has been to develop GPR systems and procedures for determining track substructure conditions such as layer thicknesses and zones of trapped water. The work was completed in 3 phases. Phase 1 of the study consisted of an initial series of laboratory and field measurements. Phase 2 focused on improving the radar equipment and techniques and demonstrating the benefit of obtaining measurements at multiple positions across the track. Phase 3 consisted of automating data collection procedures and additional field-testing to verify processing techniques and algorithms. This document describes the cumulative accomplishments of this program.

## GROUND PENETRATING RADAR (GPR)

GPR transmits pulses of radio energy into the subsurface and receives the returning pulses that have reflected off interfaces between materials with different electromagnetic properties. GPR antennas are moved across a test area (Figure 2a) recording a continuous series of radio pulses (Figure 2b), producing a profile of the subsurface (Figure 2c). The raw profile is distorted due to antenna position geometry, orientation, and material properties, but data processing techniques are used to limit the distortion.

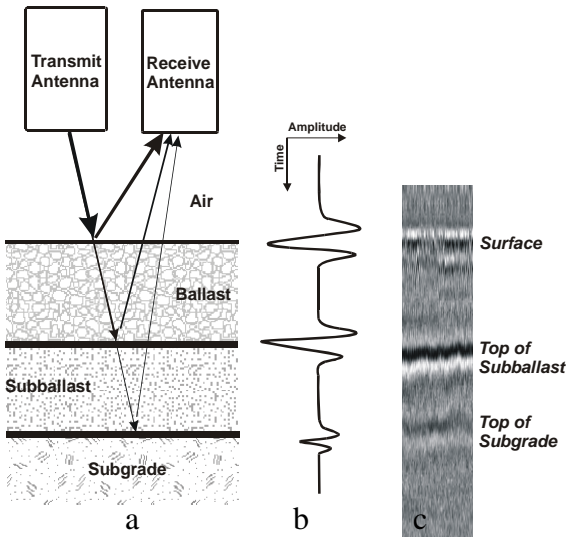


Figure 2. GPR Profile Generation

The key material properties are the dielectric permittivity, the magnetic permeability, and the electrical conductivity. The *dielectric permittivity* dominantly controls the velocity of

electromagnetic wave propagation and is a function of the density, water content, and type of material. The *magnetic permeability* also controls velocity, and is commonly neglected (assumed to be the value of air), though it may be important when iron-bearing materials are present such as some slag and iron ore fouling. The *electrical conductivity* is the main electrical parameter controlling the depth of investigation, and is the ability of the material to conduct electrical current, which is affected by the amount of water in the track.

## DATA COLLECTION AND ANALYSIS

GPR provides a continuous characterization of the track substructure, quickly locating areas of potential trouble for further investigation or maintenance. GPR has the ability to provide a rapid, non-destructive evaluation of substructure condition indicators and can be used to provide numerical data for development of substructure condition indices (Hyslip, et al, 2003).

Material and moisture variation within the track substructure are easily detected using GPR. Water possesses a high dielectric permittivity compared to the other materials in the substructure and produces a strong effect on the GPR profiles. The open voids in clean ballast also produce a strong effect on GPR data. The voids in clean ballast may cause diffraction of the GPR pulse at the particle interfaces allowing the relatively coarse-grained ballast layer to be recognizable from the comparatively finer-grained subballast layers. The variations in the GPR profile may allow fouled ballast to be identified, since the voids in fouled ballast are filled with finer particles, limiting diffraction.

To verify and calibrate the GPR data, cross trenches were excavated and the substructure variations correlated with GPR data. Figure 3 shows a typical GPR image along a 500 ft (150 m) section of track. Figure 3 also shows photos of the cross trenches that were excavated and logged for calibration of the GPR data. Depths to key substructure layers were measured in the cross trenches and used with travel times from the radar data to determine average velocities. The velocities were used to calculate the material properties values such as dielectric permittivity.



Track substructure conditions can vary over short distances and across the track. To account for variations from center of track to either shoulder, GPR antennas collected data from all 3 locations. In Figure 4, trapped water near a grade crossing resulted in poor track performance and coincided with lack of lateral drainage. Using GPR, the zone of trapped water was targeted and drainage enhancements targeting only the problem area could be identified, as shown on the westside image.

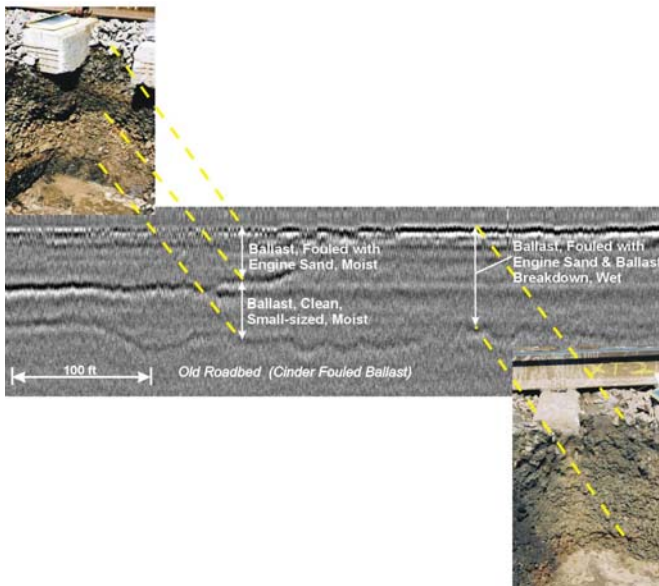


Figure 3. GPR Data with Cross-Trench

applications due to the many miles of survey with condition assessment required in near real-time. Follow-on phases of this work are to utilize the identified strategies to develop robust automated data interpretation.

GPR provides insight to many of the significant railway track deterioration modes and symptoms including:

- Trapped water and/or weak substructure conditions resulting in unstable track or poor track geometry,
- Inadequate substructure layer thickness resulting in weak track or in track not meeting design criteria,
- Variable track conditions resulting in variations in longitudinal track support with the potential for repeated track geometry defects,

The range of track condition indicators results in a variety of potentially substandard track condition diagnoses from GPR. Due to the range of potential defects, a variety of GPR based track condition indices have been developed including:

- A layer thickness variation index,
- A ballast pocket index,
- A layer roughness index, and
- A subballast-thinning index.

The various indices have been correlated with field conditions and poor track geometry. Figure 5 presents a set of GPR data along with the layer roughness index to capture layer variation. Changes in track support and layer thickness can result in track geometry defects, which tend to occur repeatedly; a phenomenon often termed track memory (Selig and Waters, 1994).

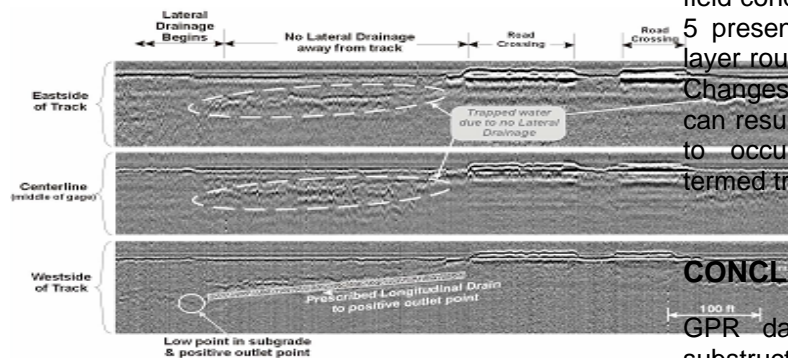


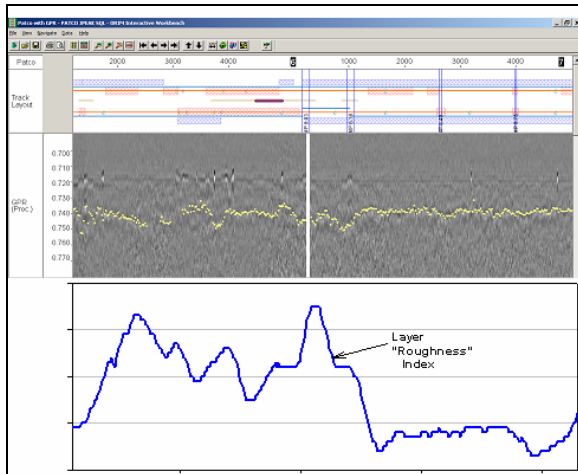
Figure 4. GPR Profiles Along Shoulders and Track Center

### IMPLEMENTATION

To ensure that GPR technology provides operationally significant insight to track safety conditions in a timely manner, automated data processing is required. Furthermore, a level of automatic interpretation is required for railway

### CONCLUSIONS

GPR data provides unique insight to track substructure conditions affecting track support, track stability and overall track safety. Analysis of the data in near real-time is required to make decisions affecting safety and operations of the track. Current research has demonstrated the potential of the technology; however implementation and automation of the identified track conditions diagnosis algorithms require additional research.



**Figure 5. GPR Data and the Layer roughness Index**

### ACKNOWLEDGMENTS

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### REFERENCES

- FRA (1997). FRA Guide for Preparing Accidents/Incidents Reports. Report No. DOT/FRA/RRS-22.
- Hyslip, J., Smith, S., Olhoeft, G., and Selig, E.. (2003). "Assessment of Railway Track Substructure Condition Using Ground Penetrating Radar." *Proc. of the 2003 Annual Conference of AREMA*, Chicago, October.
- Selig, E. and Waters, J. (1994). Track Geotechnology and Substructure Management. Thomas Telford Ltd., London.

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