U.S. Department
Of Transportation

**Federal Railroad
Administration**

Research
Results

**RR02-03
September 2002**

Ground Penetrating Radar for Railway Track Substructure Investigation

SUMMARY

The Federal Railroad Administration (FRA) Office of Research and Development's Track and Structures Program sponsored a study for evaluating railway track conditions. Ground Penetrating Radar (GPR) can provide a rapid, non-destructive measurement technique for evaluating railway track substructure integrity. This is being proven in an ongoing study to develop GPR for defining the condition of the railway substructure. Examples of the results of the GPR project to date are shown in Figures 1 & 2. The scan in Figure 1 shows the varying thicknesses of ballast and subballast which, in this example, is an indication of a problem associated with lateral subballast spreading on top of a clay subgrade. The scan in Figure 2 shows ballast pockets that have developed under the track. 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, subballast, subgrade). GPR is also capable of observing trapped water from poor drainage, soft subgrade from high water content, and is potentially capable of distinguishing fouled ballast from clean ballast. The study concluded that GPR images can give a good indication of the subsurface layer configuration and patterns within the data can give a good indication of subsurface condition.

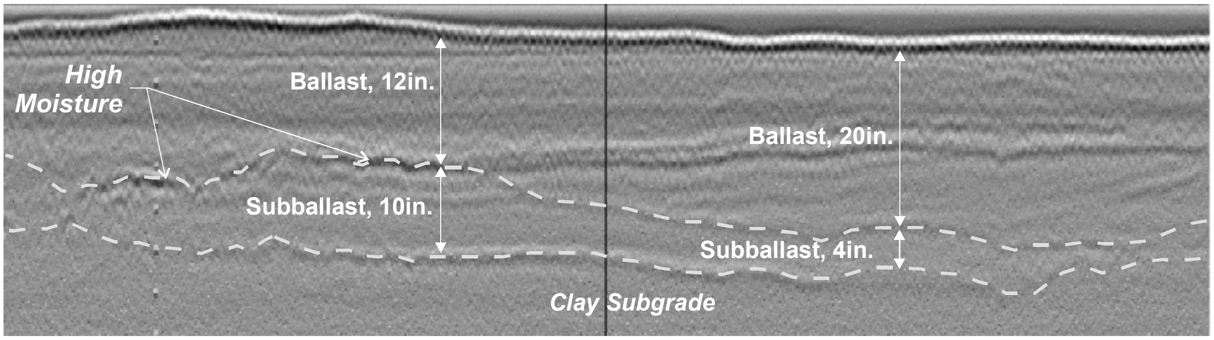

Figure 1. Example GPR Results of Spreading Subballast

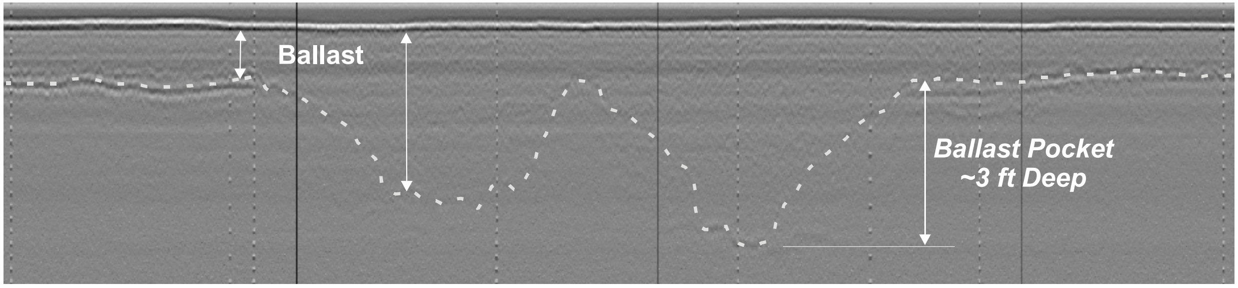

Figure 2. Example GPR Results of Ballast Pocket

BACKGROUND

The goal of the study has been to develop GPR procedures for determining track substructure conditions such as layer thicknesses and wet spots. So far, two phases of the project have been completed. Phase 1 of the GPR study consisted of an initial series of laboratory and field measurements, and Phase 2 focused on improving the radar equipment and techniques and demonstrating the benefit of obtaining measurements at multiple positions across the track.

Field Measurements

More than ten (10) miles of track were surveyed at Burlington Northern and Santa Fe Railway's Butte Subdivision, using GSSI 4208 1-GHz air-launched horn antennas. The data were acquired and processed from a hi-rail vehicle moving continuously at 10 miles per hour with radar resolution of a few inches horizontally and a fraction of an inch vertically to depths of more than six feet. The antennas were mounted on a standard hi-rail vehicle 19 to 22 inches above the ties in several configurations as shown on Figure 3.

Figure 3. Various GPR configurations on hi-rail vehicles

Typically measurements were made along the track at the ends of the ties and at the track centerline, one location per pass. In this study, radar data were acquired between concrete and wood ties as well as from the ballast shoulders beyond the ends of the ties, and with multiple antenna orientations and polarizations. Data acquisition was controlled by the GRORADAR™ software (Olhoeft, 1998).

Data Processing

Procedures were developed to expedite and simplify radar data processing. Data were calibrated to the recorded time and amplitude (range gain information) and GPR scan images were expanded and contracted (rubber-sheeted) as necessary to match marked locations along the track. The GPR wave velocity was initially calibrated from subsurface reflectors, and later tied to known depths from inspection cross-trenches dug under the tracks in order to get accurate subsurface layer thicknesses and depths. Automatic processing of the data was developed to quickly generate electronic bitmap images and hard copy sections of radar images. The electronic images were put into railroad track performance monitoring software called Optram Right-of-way Infrastructure Management (ORIM) system. Figure 4 shows a screen-grab of the ORIM viewer with the GPR scan aligned with the layout of the track, vertical profile geometry and remedial work locations.

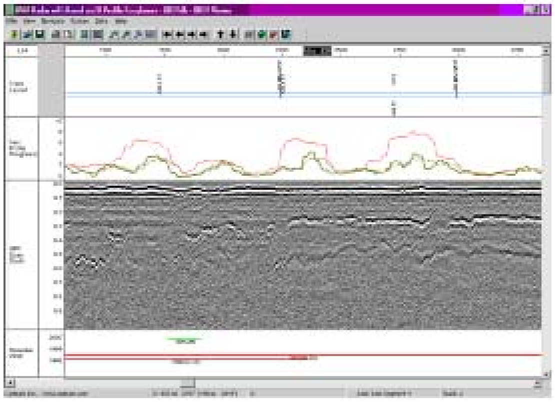

Figure 4. ORIM screen-grab example.

ORIM permitted viewing and correlating the GPR data with railroad information such as track geometry measurements, maintenance input and known subsurface conditions. This allowed for seeing relationship of GPR to track condition and features, as well as visualizing substructure effect on geometry trends and maintenance effort.

To improve the images of the cross sections for observing features of interest, data scans were extracted for modeling. An average background scan was subtracted (to remove constant range scattering mostly from the rails) and image enhancement was applied to the data.

Hardcopy sections of the radar data were produced at 300 feet traverse per 8.5x11 inch sheet for viewing, and files were output in one-mile sections for entry into the ORIM system.

Modeling Method

The GPR data have been modeled using simulated radar pulses that are matched to measured radar pulse to extract material dielectric constants. Water content and unit weight were calculated using relationships with the dielectric constant. This modeling was done on unprocessed data so as not to include the distortion inherent in the data from the processing technique. To verify and calibrate the railway GPR data, it was necessary to dig periodic trenches in locations with key substructure conditions that could be correlated with the radar data. This required real-time data processing into images to locate suitable places to trench. Depths to key substructure layers were then measured in the trenches and used with travel times from the radar data to determine average velocities and convert to dielectric permittivity assuming the magnetic properties of free space. The first air-ballast interface was then calibrated for absolute amplitude from this data and successively deeper reflectors were solved.

RESULTS

The two scans in Figure 5 are from the same track location, the top scan being the north side of the track and the bottom scan the south side. The sand zone (shown in the top scan) acts as a water pocket. The trapped water in this pocket softens the surrounding clay subgrade, causing track geometry deterioration. The “shear key” in the bottom scan was a previous attempt to drain the sand zone by digging a trench and filling it with ballast. The extent of the shear key is well defined in Figure 5.

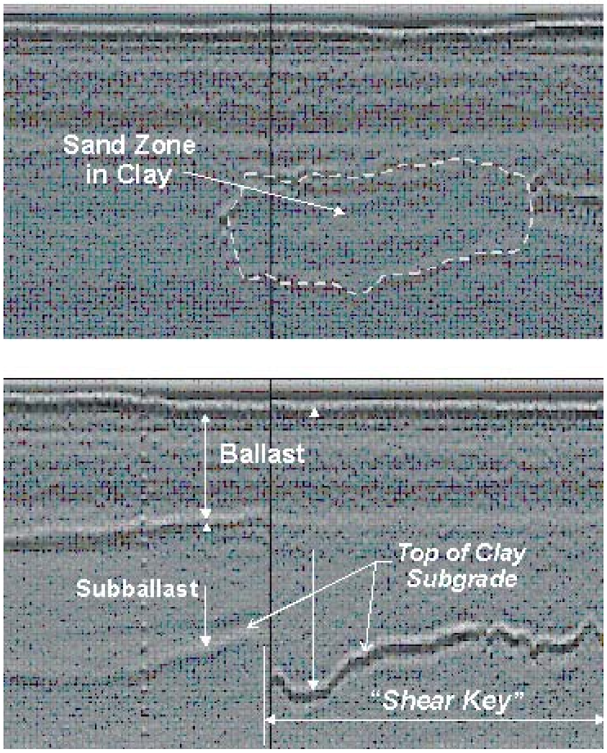

Figure 5. Example GPR scan results showing sand pocket and shear key.

Figure 6 shows a typical example of the subsurface conditions at highway-grade crossings, as detected by GPR. Trapped water immediately adjacent to the crossing is apparent. The decrease in GPR reflection amplitude progressing away from the crossing indicates decreasing moisture content of the subballast and subgrade.

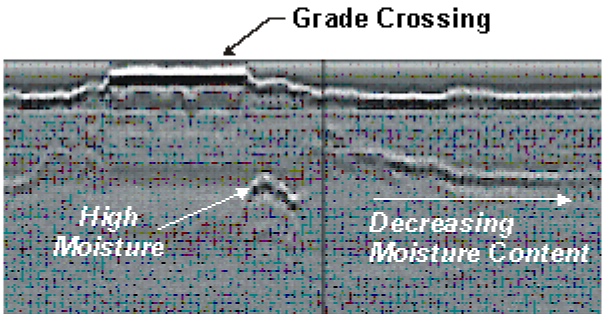

Figure 6: Example GPR scan at highway-grade crossing.

CONCLUSIONS

GPR images can give a good indication of the subsurface layer configuration. Patterns within the data can give a good indication of subsurface condition. GPR is also potentially capable of distinguishing fouled ballast from clean ballast.

GPR provides continuous top-of-rail measurements of substructure layer conditions, with the potential to measure:

- Substructure layer thicknesses,
- Water content and density of the ballast, subballast, subgrade,
- Trapped water from poor drainage,
- Soft subgrade from high water content, and
- Non-uniform and deformed substructure layers and variations in substructure conditions across the track (through multiple passes of a single antenna-pair or with multiple antenna-pairs).

FURTHER WORK

The objective of continued research is to initiate the development GPR measurement and analysis techniques, and to obtain substructure condition indices using GPR. The automated measurement and analysis techniques will be used to produce quantitative indices of track substructure condition that will enable improved cost effectiveness of maintenance planning, increased safety, and reduced train service interruptions. Follow-on work will focus on developing a robust GPR system for use on a hi-rail vehicle or a track geometry car. Further work will continue to develop modeling methods, and automate both the calibration and modeling processes. Additional GPR field measurements, combined with substructure investigations, will also be conducted to improve procedures for interpreting radar data under track, and extend the variety of subsurface conditions tested to improve the generality of the techniques.

ACKNOWLEDGMENTS

This study was performed by Ernest T. Selig, Inc. in collaboration with Dr. Gary R. Olhoeft, Consultant, Golden CO. The Burlington Northern and Santa Fe Railway, through Robert J. Boileau, AVP, supported most of the GPR data collection and much of the interpretation. Mahmood Fateh, from the FRA, provided support for data analysis. The GPR equipment used for the measurements was from Geo-Recovery Systems, Inc. Optram, Inc. provided the ORIM system for displaying the GPR results.

REFERENCES

Olhoeft, G. R., 1998, GRORADAR™: Acquisition, processing, modeling, and display of ground penetrating radar data: ver. 4.0, *7th International Conference On Ground Penetrating Radar*, May 27-30, 1998.

CONTACT

Mahmood Fateh
Federal Railroad Administration
Office of Research and Development
1120 Vermont Avenue NW - Mail Stop 20
Washington, DC 20590
TEL: (202) 493-6361
FAX: (202) 493-6333
Email: mahmood.fateh@fra.dot.gov

KEYWORDS: ground penetrating radar, GPR, track substructure, railroad investigation