U.S. Department of Transportation
Federal Railroad Administration

RESEARCH RESULTS
FRA OFFICE OF RAILROAD POLICY & DEVELOPMENT

RR 14-24 | **July** 2014

GROUND PENETRATING RADAR EVALUATION AND IMPLEMENTATION

SUMMARY

Six commercial ground penetrating radar (GPR) systems were evaluated to determine the state-of-the-art of GPR technologies for railroad track substructure inspection.

Phase 1 evaluated GPR ballast inspection techniques by performing testing at the Transportation Technology Center (TTC) in Pueblo, CO. The evaluation was conducted at the Facility for Accelerated Service Testing (FAST) on the High Tonnage Loop (HTL). Investigators from TTC compared the ballast fouling and layer depth outputs of different GPR systems. The outputs of the different systems were compared with one another and with other known conditions. Also, a moisture sensitivity test was performed to confirm the ability of GPR to sense relative changes in moisture.

Three different proprietary methods were used to determine ballast fouling. Scattering (System 1) and dielectric dispersion methods (Systems 2–5) produced generally similar results, whereas the propagation analysis method (System 6) produced significantly different results.

A number of ballast samples were also taken from trenches at various locations on the HTL at FAST, and sieve analysis was performed to define the particle size distribution of the sample. Less emphasis was eventually placed on this approach, because there were limitations to comparing discrete ballast samples with the GPR data (in terms of where the samples were taken) and relating them to the limited amount of ground truth data available.

Figure 1 shows a typical hi-rail-based GPR system, and Figure 2 shows a radar image of the subsurface profile produced by recorded GPR data.

Figure 1. GPR antennas mounted to a hi-rail vehicle

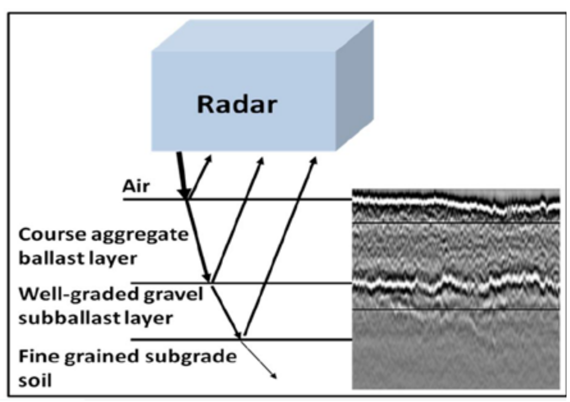

Figure 2. Example of Processed GPR Image Showing the interface of Layer Boundaries in the Track Substructure

BACKGROUND

GPR is a nondestructive geophysical technique that is widely used to identify and visualize subsurface structural and material conditions. The basic technique is well documented and involves GPR antenna transmission of a radio frequency (electromagnetic energy) into the ground or other physical medium by means of a short electromagnetic pulse.

Some portion of the transmitted energy is reflected by contrasts in material dielectric permittivity and electrical conductivity at material interfaces. Such contrasts appear in the form of changes in soil layers, ground water surfaces, or buried objects.

The amplitude and return time of signal reflections are captured by a receiving antenna as the transmitted wave penetrates the medium and the antennas move along the surface of the medium. The recorded data is then processed by a proprietary software package to produce an image (radargram) of the subsurface profile (see Figure 2) where the wave reflections are shown as functions of the wave travel time. The wave travel time is converted to penetration depth on the basis of wave velocity.

Assessment of the track subsurface condition requires interpretation of the processed image. Commercial track inspection systems have developed specialized software to interpret the GPR signals for specific outputs that include:

- Degree of ballast fouling, moisture presence, ballast layer thicknesses, and subgrade surface contour.

Track geometry and gage restraint measurement data can be used to supplement the GPR information.

OBJECTIVES

This project is designed to enhance the use of GPR technologies as a track substructure inspection tool by evaluating commercial GPR systems to establish the state-of-the-art for track inspection techniques and to develop guidelines for GPR implementation in North America.

METHODS

The evaluation included a comparison of the ballast fouling conditions and layer depth interpretation outputs of the different systems at various FAST HTL sections.

Table 1 describes the six GPR systems that were included in the evaluation and produced final results. The testing incorporated a mix of antenna types, antenna manufacturers, engineering teams, and geophysics providers.

Table 1. GPR System Descriptions

System	Antenna Description	Fouling Analysis
1	Time domain pulsed radar, 400 MHz used for layer depth mapping and 2 GHz used for ballast fouling	Scattering
2	Time domain pulsed radar, 1 GHz	Dielectric Dispersion
3	Time domain pulsed radar, 400-MHz antenna manufacturer 1	Dielectric Dispersion
4	Time domain pulsed radar, 400-MHz antenna manufacturer 2	Dielectric Dispersion
5	SFCW* radar manufacturer 3, 150 MHz to 2.5 GHz frequency range, air coupled	Dielectric Dispersion
6	Time domain pulsed radar, 400-MHz and 900-MHz antenna manufacturer 2, ground coupled	Propagation Analysis

*SFCW = stepped-frequency continuous-wave

A moisture sensitivity test was also performed to confirm the ability of GPR to sense relative changes in moisture. The test was conducted before and after water was artificially introduced into a short segment of the HTL loop for moisture detection.

RESULTS

Figure 3 is a comparison showing a statistical distribution of the normalized fouling categories for each GPR system.

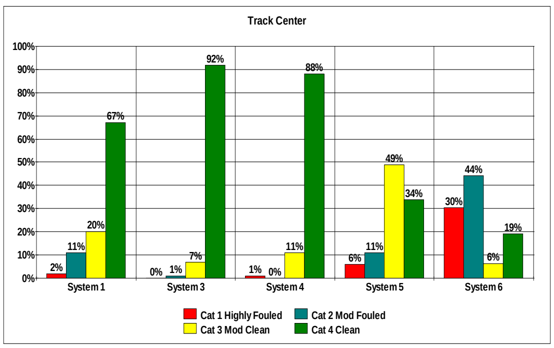

Figure 3. Distribution of Track Center Ballast Fouling Categories for All GPR Systems on FAST HTL

Fouling values were normalized to a generic categorization with 4 being clean and 1 being highly fouled. No attempt was made to relate these categories to any type of fouling index or percentage of fouled material.

CONCLUSIONS

Results of the analysis in Figure 3 are summarized as follows:

- System 2 track center fouling data was not submitted because of noise issues.
- Systems 1, 3, 4, and 5 all showed 6 percent or less of the track center being highly fouled. However, these systems differed in the interpretation of clean, moderately clean, and moderately fouled conditions.
- System 6 results were substantially different from the other systems' results. System 6 interpreted the FAST HTL ballast condition as being primarily fouled, whereas the other systems interpreted it as being primarily clean.

Gradation analysis of ballast samples taken in FAST HTL Section 25 were in general agreement with the fouling data from all systems except System 6.

All systems, with two notable exceptions, produced similar ballast layer interpretations, although variances of 6 to 9 inches in the reported primary layer thickness values were fairly common.

All systems were able to distinguish changes in moisture and were also able to determine that the water was draining, as denoted by a change in the moisture profile of the data output.

FUTURE ACTION

Further research and performance monitoring is currently under way. The objective of this second phase is to advance the use of GPR by:

- Further evaluating existing GPR systems;
- Developing recommendations and guidelines for GPR implementation; and
- Developing performance requirements for incorporating GPR technology into FRA track inspection vehicles.

GPR testing and monitoring is currently under evaluation at two revenue service sites. Periodic inspections are being performed using both hi-rail and fixed rail vehicle-based systems.

- The first site is located on a western high tonnage and heavy axle load coal route and will be used to determine if ballast degradation can be monitored using GPR technology.
- The second test site, an east coast line that carries both passenger and freight traffic, is currently being upgraded for high-speed passenger operations. This test site will be used to determine if changes in ballast moisture content can be monitored using GPR technology.

At both of these test sites, ballast samples are collected when the GPR surveys are conducted. The samples are then analyzed and compared with the GPR inspection outcomes to measure the GPR performance.

Lastly, in addition to typical GPR testing at hi-rail speeds of 35 mph, additional testing was conducted at speeds between 50 and 80 mph with GPR equipment mounted on the FRA's DOTX218 research vehicle, a first for North American railroads.

ACKNOWLEDGEMENTS

TTCI conducted this research under joint funding from FRA and AAR. David Read and Dingqing Li, TTCI, were the principal investigators.

The following organizations and individuals, listed in alphabetical order, participated in this project: 3D Radar: Andy Stevens; Balfour Beatty Rail, Inc.: Steve Atherton, R.T. Swindall; HyGround Engineering: Jim Hyslip, Mike LaValley; IDS Ingegneria dei Sistemi SpA: Guido Manacorda; Roadscanners Oy: Mika Silvast, Bruce Wiljanen; Zeticarail: Asger Eriksen, Jon Gascoyne

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KEYWORDS

GPR, ground penetrating radar, ballast, subballast, substructure, fouled ballast, ballast moisture