Benefits of high speed GPR to manage trackbed assets and renewal strategies

Asger Eriksen, Ben Venables, Jon Gascoyne & Shubho Bandyopadhyay

Zetica Rail, Holdan House, 26 Bridge Street, Witney
Oxon OX28 1HY, UK

rail@zetica.com

Abstract— **This paper outlines recent advances in the acquisition, processing and interpretation of GPR data in relation to a high-speed train-mounted multiple-antenna GPR system for non-destructive assessment of the railway trackbed. These developments are discussed in the context of new tools for permanent way engineers to manage assets and renewals strategies. A novel way of collecting high quality data at line speeds of 100 km per hour and above is presented. Automatic processing tools have been developed to extract ballast layer thickness, reduce the effect of non-steel sleepers in the data and identify surface objects along the line. The ability to record high speed GPR data on a repeatable basis offers the permanent way engineer numerous benefits including optimised targetting and scoping of site investigations, better planning of ballast maintenance activities, more accurate scoping of formation renewals works, optimising ballast cleaning activities, renewals quality control and auditing, and monitoring ballast deterioration rates for improved forward planning.**

I. INTRODUCTION

Ground Penetrating Radar (GPR) has evolved as a popular technology for Non-Destructive Testing (NDT) and site investigations since the mid 1980's. The range of applications of GPR has spread over a wide spectrum.

In the rail industry, GPR is being extensively used for monitoring trackbed conditions. The quality of ballast plays a vital role in the stability of the trackbed. Formation conditions can also have a profound influence on track performance. Accurate knowledge of the substructure is therefore increasingly seen as essential for trackbed maintenance and efficient planning of renewals.

Ballast performs several important functions as part of permanent way structure. The main functions of ballast can be summarised as follows:

1. Resist vertical, lateral and longitudinal forces applied to the rail sleepers in order to retain the track in the required position.
2. Provide large voids for the drainage of fouling material away from the structural elements.
3. Permit direct drainage of surface water
4. Increase the sleeper bearing area in order to reduce stress levels to acceptable values.

Recent papers [1, 2, 3, and 4] have demonstrated the utility of GPR in solving a variety of problems related to trackbed characterisation. Nuaimy, Eriksen and Gascoyne [5] have shown that GPR can be used to provide rapid, objective and quantitative information about the depth and degree of deterioration of ballast with minimal disturbance to the actual trackbed. Ballast quality calibration using non-contact methods of calculating the in-situ propagation velocity of electromagnetic (EM) waves through ballast has been explored by Gallagher, Leiper and Forde [6]. The use of a multi-channel road-rail GPR for improved productivity and reliability of ballast inspection has also been presented by Nuaimy, Eriksen and Gascoyne [7]. Significant effort has also been focused towards the extraction of meaningful physical interpretations from the GPR data using novel signal/image processing and pattern recognition techniques. Shihab, Nuaimy and Huang have presented a Neural Network target identifier based on statistical features of GPR signals [8]. Moisture content plays an important role in ballast characterisation and depth assessment since the relative dielectric permittivity is dictated to a large extent by the soil water content. Lunt, Hubbard and Rubin [9] have demonstrated soil moisture content estimation using GPR. A review of GPR for soil moisture content determination has been presented by Huisman, Hubbard, Redman and Annan [10].

The present paper introduces a GPR system for high-speed data acquisition and storage at line speeds of 100 km per hour or more, eliminating the cost of track possessions. This approach is a much faster and economic method of identifying problematic areas of the trackbed and addressing issues of ballast maintenance and renewal in good time.

Zetica's advanced rail radar (ZARR) acquisition system was developed specifically for use on railways and to conform with strict Electromagnetic Compatibility (EMC) Regulations. The system combines GPR antennae mounted beneath inspection trains, train tachometer inputs, global positioning system (GPS) and video technologies to achieve the precise data registration required for accurate calibration of the GPR results. ZARR has been shown to consistently collect high quality data of rail ballast with a sampling interval of less than 5cm at line speeds of 100 km per hour.

The processing and interpretation of large volumes of radar data generated during train surveys requires a post-processing system that is robust, reliable, fast, accurate and consistent in its interpretations. The following sections outline some of the procedures and techniques utilised by ZARR to deliver results to permanent way engineers.

II. GPR BASICS

It is known that GPR is capable of mapping, delineating and locating subsurface features and anomalies, and is being used extensively in the examination and assessment of the structural integrity of railways. GPR is often used in conjunction with destructive assessment methods such as coring, trial pits and excavation, but the major benefit is the ability of acquiring continuous data at line speed, without the need for track possessions.

Ground coupling affects the shape and duration of the wavelet that is propagating downwards with the pulse broadened due to attenuation of the higher frequency components of the signal. The reflection event consists of several wavelets, and this fact has important implications during interpretation of the radar data. The measurement system should have sufficient dynamic range and sensitivity to be able to detect the low signal strengths associated with the returning radar pulses. A list of the most important parameters to be taken into consideration while designing a GPR antenna configuration for a specific application may be summarised as follows:

1. Operating frequency
2. Sampling interval
3. Station spacing
4. Antenna separation
5. Antenna orientation
6. Electrical properties of the host environment
7. Resolution frequency
8. Clutter frequency
9. External interferences

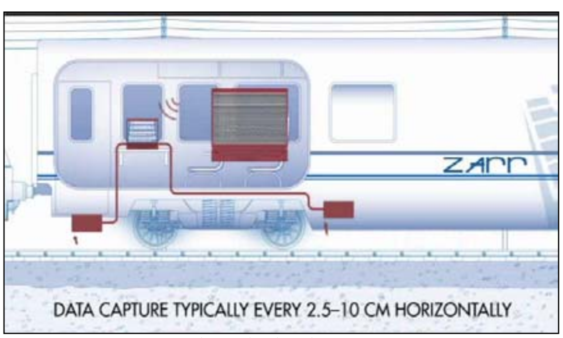


Figure 1 Schematic showing antennae moun ted beneath inspection train and main system components

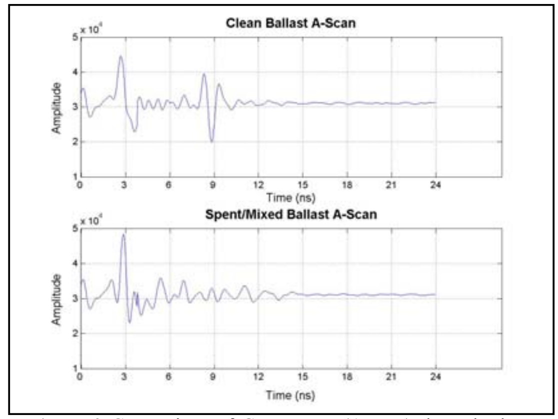


Figure 2 Comparison of GPR traces (A-scan) through clean and spent ballast materials

Information from ballast beneath sleepers is probably more important than ballast characterization in the cribs. By automatically identifying the location of non-steel sleepers within the data a continuous GPR dataset can be separately analysed over sleepers and within the cribs. Figure 4 shows an example of continuous GPR data collected in Durham, UK and demonstrates voiding and wet beds below sleepers only.

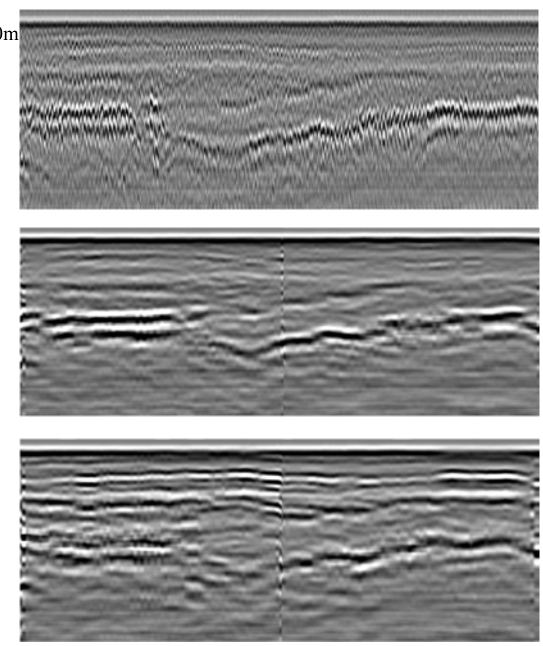
0m  50m

Figure 3 B-scans showing results of separating the data acquired within the cribs (centre) and over the sleepers (bottom) from the complete dataset (top).

III. PRESENTATION OF GPR DATA

A vital aspect for successfully deploying GPR for trackbed investigations is presenting the information in an intuitive and useful way for permanent way engineers.

Track engineers typically require anything from 200m sections to continuous 5km sections to be provided as interpreted depth / quality sections and/or as raw data / TQ combinations. Figure 4 and 5 are examples of customized outputs for engineers in the UK for 200m sections.

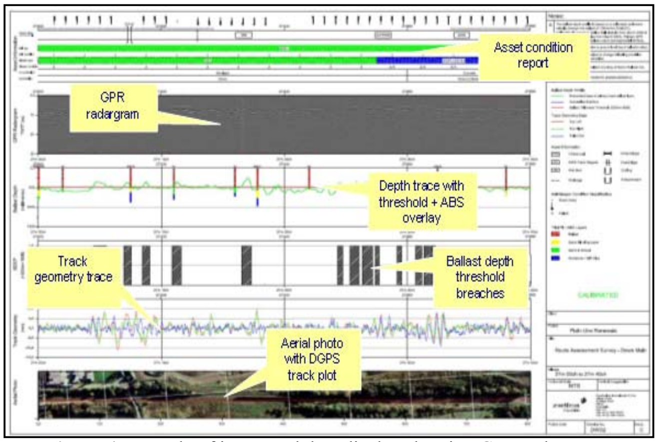


Figure 4 Example of integrated data display showing GPR radargram with asset condition report, ABS calibration, depth exceedances from an assessment threshold, track quality data (35mm top) and aerial photograph

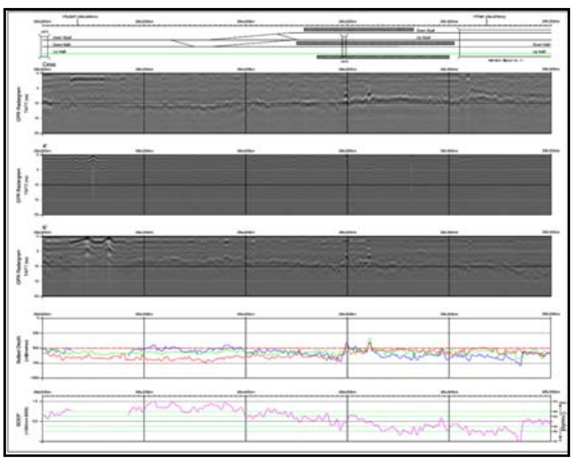


Figure 5 Example of multichannel GPR survey showing assets (1st panel), GPR data from cess, 4ft and 6ft (2nd – 4th panel), interpreted depths (5th panel) and trackbed crossfall gradient (6th panel). Used to QC renewals, site in the UK.

A further requirement is the presentation of ballast condition according to set rules depending on the track being surveyed. ZARR provides an overall ballast condition ranking system using both depth exceedance and ballast quality as inputs (see examples in Figure 6 and Figure 7).

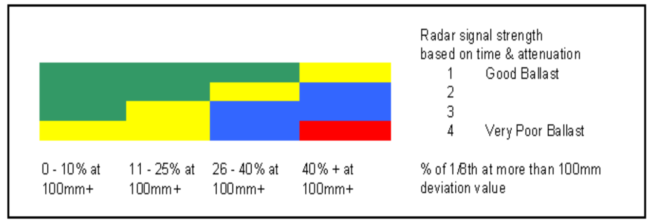


Figure 6 User defined colour-coding to indicate overall ballast condition ranking based on depth threshold exceedances and ballast quality (as implemented in ZARR).

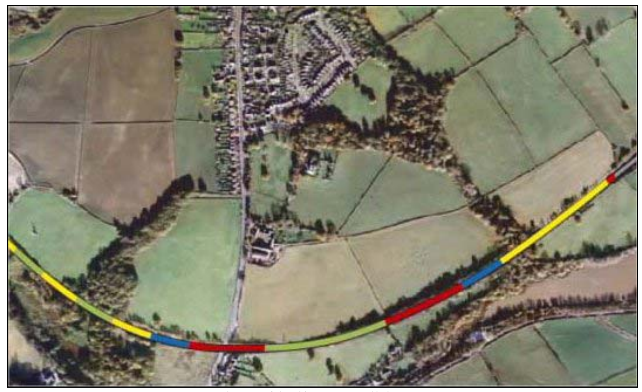


Figure 7 GIS mapping of ballast condition to survey route

IV. FEATURES OF ZARR HIGH SPEED SYSTEM

To date data has been collected using two 400 MHz IDS Bow-Tie antennae and a 1 GHz GSSI Horn antenna. The control systems used were a RIS-K2 unit for the IDS antennae and a SIR-20 unit for the 1 GHz Horn antenna. UK regulations prohibit any part of the data acquisition system from protruding beyond the body of the train so the antennae are mounted under the train in specially designed housings. Rigorous EMC and hardware compatibility tests were required to determine optimum antennae positioning, triggering and shielding.

Spatial resolution ranges from 2.5cm at 100km per hour to a maximum of 10cm for 200km per hour depending on the systems and number of channels used. A typical 250km run produces 5 Gb of GPR data per channel.

Accurate location of GPR data is achieved using a combination of tachometer distance information; differential GPS and the automatic recognition within the GPR data of objects such as AWS magnets (see Figure 8).

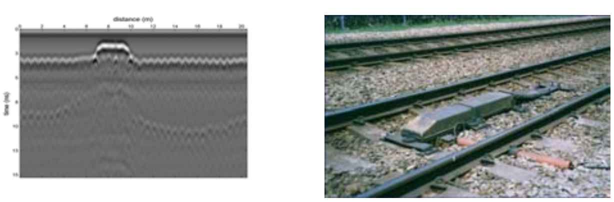


Figure 8 GPR B-scan (left) over AWS magnet (right)

These inputs provide sufficient information (assuming magnets have been mapped) to enable ZARR to accurately map a path through the rail network. Run-on-run spatial repeatability is typically as high as +/- 5cm. This capability is important especially where GPS signal is lost in tunnels or through cuttings.
The train-mounted high speed data collected using ZARR has been validated against slow-speed trolley-based GPR surveys as shown in Figure 9.

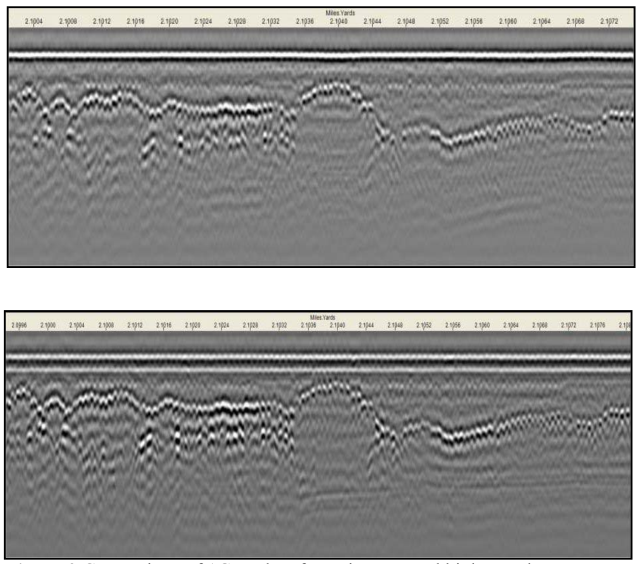


Figure 9 Comparison of 1GHz data for train-mounted high speed survey (at 100km per hour) and 2.5cm resolution (top) and walking speed trolley tests at 2.5cm resolution (bottom).

The processing and interpretation of the gigabytes of radar data generated during high speed surveys requires post-processing system that is robust, reliable, fast, accurate and consistent in its interpretations. The software at the heart of ZARR has been developed to facilitate full processing of 150km of data in a few days. For example, the layer picking routine executes with excellent precision at high speed with minimum user-interaction. This essentially results in reduced computation time and increased productivity for rail ballast analysis.

V. BENEFITS OF ZARR TO P-WAY ENGINEERS

Based on the proven accuracy and efficiency of the ZARR system, permanent way engineers can achieve the following range of benefits:

- Improved targeting of intrusive site investigation works, such as ABS tests and trial pits. ZARR provides an overview of the exact areas that require specialist investigation with the accurate planning of track access and resource required for site investigations.
- The link between GPR data and track quality information enables engineers to focus planning of ballast maintenance activities such as in-situ reballasting and remediation of ballast-related track quality issues.
- Whole routes can be assessed for trackbed asset condition by linking renewal proposals, track quality data and GPR ballast condition via deterioration rates. This enables a more focused renewal plan, optimisation of ballast cleaning operations and the accurate scoping of ballast renewal works.
- ZARR can also be used to provide evidence of the quality of work done by renewals contractors as part of an audit function.

REFERENCES

[1] Hyslip, J.P., Smith, S.S., Olhoeft, G.R., and Selig, E.T., 2003, 'Assessment of Railway Track Substructure Condition using Ground Penetrating Radar', AREMA, 5-7 Oct. 2003, Chicago, 20p.

[2] Olhoeft, G.R. and Selig, E.T., 2002, 'Ground Penetrating Radar Evaluation of Railroad Track Substructure Conditions', GPR 2002, 9th Int'l. Conf. On Ground Penetrating Radar, Santa Barbara, CA, April 2002, S.K. Koppenjan and H.Lee, eds., Proc. SPIE vol. 4758, pp. 48-53.

[3] Olhoeft, G.R., 2003, 'Electromagnetic Field and Material properties in Ground Penetrating Radar', Proc. 2nd Int'l. Workshop on Advanced GPR, 14-16 May 2003, Delft, The Netherlands, A.Yarovoy, ed., p.144 –147 +2pl.

[4] Selig, E.T., Hyslip, J.P., Olhoeft, G.R. and Smith, S., 'Ground Penetrating Radar for Track Substructure Condition Assessment', Proc. of Implementation of Heavy Haul Technology for Network Efficiency, IHHA/REMSA, World Rail Expo. May 2003, Dallas, TX, p. 6.27 – 6.33.

[5] Al-Nuaimy, W., Eriksen, A. and Gascoyne, J., 'Train-Mounted GPR for High-Speed Rail Trackbed Inspection', 10th Int'l. Conf. On Ground Penetrating Radar, 21-24 June 2004, Delft, The Netherlands.

[6] Gallagher, G.P., Leiper, Q.J. and Forde, M.C., 2000, 'How to Calibrate Radar Testing of Trackbed without Trial pits', Int'l. Railway Engineering Conf., 2000, London, UK.

[7] Al-Nuaimy, W., Eriksen, A. and Gascoyne, J., 'Improved Productivity and Reliability of Ballast Inspection using Road-Rail Multichannel GPR', Int'l. Railway Engineering Conf., 2004, London, UK.

[8] Shihab, S., Al-Nuaimy, W., Huang, Y. and Eriksen, A., 'A comparison of segmentation techniques for targets extraction in ground penetrating radar data', European Association of Geoscientists & Engineers, Near Surface Geophysics, no. 2, pp. 45-53, Feb 2004.

[9] Lunt, I.A., Hubbard, S.S. and Rubin, Y., 'Soil Moisture Content Estimation using Ground Penetrating Radar Reflection Data', Journal of Hydrology 307, 2005, pp. 254-269.

[10] Huisman, J.A., Hubbard, S.S., Redman, J.D. and Annan, A.P., 'Measuring Soil Water Content with Ground Penetrating Radar: A Review', Vadose Zone Journal 2.