Benefits of routine ballast inspection using ZARR – Zetica’s Advanced Rail Radar

Background

The ballast layer is designed to distribute the loading force of a passing train evenly over the formation layer to preserve a smooth ride. The ballast also acts as a drainage layer to prevent significant accumulations of moisture. The optimum ballast thickness is the thickness where ballast exerts constant pressure on the subgrade. The design thickness is a function of the load and speed of traffic.

A homogenous ballast layer results in a stable and safe track. Any departure from the construction design such as changes in the thickness of the ballast layer and the degree of contamination within the ballast matrix will affect the dynamic behaviour of the trackbed. Contaminated ballast causes an unstable pressure distribution on the subgrade.

ZARR utilises ground penetrating radar (GPR) and is a uniquely powerful desk study tool to continuously map changes in the thickness and quality of the ballast layer across a network.

Figure 1: 400m of GPR data (a) collected on Network Rail’s UTU3 inspection train. Changes in the thickness of the primary ballast layer (b) are very clearly indicated in a ‘Manhattan Skyline’ plot (c) as deviations from the design depth.

The following sections describe how ZARR can be used for planning maintenance, site investigations and ballast cleaning / renewals.
Measures of ballast layer geometry and identification of discrete faults

The quantity of raw GPR data collected in a typical ZARR survey is around 50Mb per km. ZARR summarises this information in a number of indices to provide a statistical representation of the data which serves to guide track engineers to problem trackbed areas.

The ballast depth exceedance (BDE) index, which is defined by the difference in modelled ballast thickness versus a desired depth, provides a visual indication of the spatial variation in ballast thickness, helping the engineer to quickly identify layer thickness irregularities. The BDE is typically displayed as a colour-coded ‘bar-code’ style strip chart. Colour-coding thresholds are customisable based on traffic characteristics.

Figure 2: Example of combining track geometry (a) showing top left and right standard deviations with trackbed geometry indices derived from GPR. (b) BDE = Ballast depth exceedance, PWB = Probable wet bed, (c) LRI = Layer roughness index for 2 wavelengths, (d) TQI = Trackbed quality index. The area outlined in red is discussed in the text.

In Figure 2 the red-coloured BDE represents a severe exceedance, corresponding to an area where the ballast layer thickness is less than 50% of the design depth. The red rectangle identifies a significant BDE recorded in two GPR runs, which is not associated with any track geometry anomaly. Elsewhere the cause of track geometry anomalies can be clearly related to ballast layer irregularities and wet beds.

Small wavelength variations in the ballast-subgrade interface can be significant as an indicator of subgrade erosion. A layer roughness variation index (LRI) for characterising subgrade erosion as well as larger scale ballast pocket indications is provided. LRI thresholds can be used to prioritise maintenance and to measure changes in time. The trackbed quality index (TQI) is derived from a weighted ranking of a series of trackbed GPR metrics including layer thickness and layer roughness variation.

The following case studies demonstrate the value of ZARR for a range of engineering applications including trackbed maintenance, site investigations and quality control of works carried out.

An underbridge was relayed in 2004 and the track engineer assumed ballast depth was compliant. In 2008 recanting works halted when a tamper struck the bridge deck. ZARR data was accessed off a national database in a local office after receiving an urgent phone call from site. Review of the GPR data (red rectangle in Figure 3) shows less than 250mm from top of sleeper. Advice was given to abort works in this area resulting in minimal downtime for the tamper. A redesign with 130mm track lift was proposed and delivered 2 weeks later once consent agreed to increase loading on bridge deck.
The information provided by ZARR can also be used to plan follow-up site investigations (Figure 4).

Compared with ballast monitoring through systematic manual sampling methods, up to 50% of the budget required to investigate sites by hand can be saved by focusing on areas showing significant change only. ZARR allows robust planning of site investigation works and reduces the possession duration to complete.

ZARR further provides an independent measure of the quality of works carried out and a register of located assets.

**Figure 3:** Example of the use of a standard ZARR report to provide detail to manage tamping site works. Location of underbridge is highlighted within the red rectangle.

**Figure 4:** Traditionally a site investigation based on a fixed 50m interval would have resulted in 8 holes (circle symbols) in potentially unrepresentative locations. GPR can be used to target ½ the number of holes (triangle symbols) to sample the trackbed in more representative areas.
Figure 5(a) shows a section of track before relaying works took place. Figure 5(b) shows the trackbed following extensive upgrade works. The works allowed line speeds to be increased from 70mph to 125mph on a main line in the UK.

The red rectangle confirms a change in formation treatment with new ballast and sub ballast layers. The green rectangle shows a new junction with 5 drive units and an automatic warning system (AWS) magnet. The blue rectangle confirms that the newly laid ballast layer conforms to the minimum design depth specified for the required load and line speed.

**Figure 5:** Results of repeat surveys over a relaid section of track in the UK. The most significant changes are outlined by coloured rectangles and are discussed in the text.
Prioritisation of ballast cleaning

GPR can be used to provide an indication of priority areas on the network that require ballast cleaning and trackbed maintenance or renewals. Figures 6 and 7 show how ZARR summarises this information in statistical charts and maps.

Figure 6: In this example Index1-4 represents relatively highly fouled to clean ballast for GPR scans of both shoulders and the centre. One division comprising 60km of track (a) clearly has a greater proportion of relatively highly fouled ballast (Index 1) compared with the other (b).

Figure 7: Geographic display of results of GPR survey using Google Earth

Significant changes can occur at different stages in the lifetime of a ballast layer under repeated loading. Regular monitoring with GPR allows decisions to be made on timely and cost effective interventions to extend the ballast life.

This allows the development of a robust ballast management strategy and prioritisation between sites which can result in significant cost savings.
Defining the extent of works

For many railroad companies the cost of rehabilitating ballast before the expected end of life of the asset is high. One company reported that the implementation of the incorrect work scope and limits had caused an 11% revisit rate within an 8 year timescale. Their aim is to have a ballast life of at least 15-20 years so any revisits within 8 years is a significant under performance. By introducing GPR into the assessment of work sites their aim is to reduce this waste to less than 1% within the next 3 years.

Revisits are often caused by insufficient information on the nature and extent of trackbed problems, which are therefore not effectively addressed during routine maintenance. ZARR can be used to delineate the extent of maintenance work required.

One major railroad company found that 7% of sites have been withdrawn from the renewals programme on the basis that the GPR data, supported by targeted trial hole data, did not justify ballast renewal, thus providing significant financial saving. In addition to this, one in eight sites had the original limits and scope of work changed to ensure that the appropriate mileage and depth of renewal is undertaken. An example of such a revision is shown in Figure 8.

![Figure 8: ZARR was used to accurately define the extent of works required to clean/renew ballast.](image)

The benefit of the use of ZARR is to provide specification accuracy leading to more cost forecasting certainty and the correct allocation of resources. The number of revisits to correct problems can also be significantly reduced.
Detailed follow-up surveys

Regular monitoring with GPR also allows decisions to be made on timely and cost effective interventions to remediate structures. For example, early indications of ballast thickening derived from inspection train based GPR systems can be flagged for detailed follow-up with ground GPR surveys (Figure 9).

![Figure 9: Example of contouring the thickness of ballast derived using GPR collected in the centre and over the shoulders of two lines (Up and Down) over an embankment. The red arrow marks the extent of the thickest ballast (>1m) correlating with a zone of embankment instability.](image)

Train-based and ground GPR systems can also highlight the possible presence of buried hazards such as cross-cutting services and buried rails which could affect the safety and progress of intrusive works such as ballast cleaning or renewals.

![Figure 10: Schematic cross section showing a possible failure surface in the embankment that could be inferred from a measured ballast pocket.](image)
Summary

This paper has outlined various practical applications of ZARR to assist track engineers and planners to more efficiently manage ballasted trackbed.

Impressive cost savings can be achieved through:

• Reduction in the number of trial holes required to investigate sites,
• Improved targeting of intrusive investigations to maximise the value of time on site,
• More accurate prioritisation of problem trackbed,
• More accurate delineation of the extent of remedial works required,
• Improved quality control measures, and
• A reduction in the number of interventions during the planned life of the ballast.

In addition a number of safety benefits can also be achieved such as reduced exposure of staff to the hazards of working trackside, less risk of striking buried services or other hazards during intrusive site works and reduced risk of rough ride or derailment by focused repairs to discrete faults early in their evolution.

In the words of the Head of Development at Network Rail, GPR has made “…a significant impact on maintenance and renewals decisions by providing accurate and regular information on trackbed condition.”

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