LONG RANGE INSPECTION OF RAIL USING GUIDED WAVES - FIELD EXPERIENCE

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Abstract: Ultrasonic techniques have been used for many years for the inspection of rail. These measurements can detect the presence of a wide variety of defects but there are practical difficulties with the technology. While large transverse cracks of the type likely to cause catastrophic failure can be detected, the large, critical defects can be masked by large numbers of small, surface defects along the length of the rail. It would be very useful to be able to determine reliably the largest defect size in a length of rail. Also alumino-thermic welds are difficult to inspect due to the typical defect orientation and the attenuation of the weld material. Guided waves provide a very attractive solution to these problems; they travel along the rail, for tens or hundreds of metres, and are partially reflected by any defects which are present. They are particularly sensitive to vertical defects and they are used at relatively low frequency so they are not significantly attenuated by weld material. With financial support from Network Rail, the authors have developed a practical inspection tool based on guided wave measurements. This paper describes the design of a pre-production prototype guided wave instrument suitable for site trials. Results obtained at a level crossing are presented that demonstrate the use of the system as a practical screening tool.

Introduction: The current authors have previously described the development of a rail inspection system financially supported by Network Rail that uses low frequency guided acoustic waves to inspect long lengths of rail and alumino-thermic welds. A comprehensive description of this work may be found in Wilcox *et al.* [1]. The G-Scan guided wave rail testing system, as it is now called, is at its pre-production prototype stage and has been used in a number of site trials around the UK. In this paper results are presented from one such site trial that demonstrate how the system can be used to screen rail passing through a level crossing without disruption to either road or rail traffic. However, first the key features of the G-Scan system and guided wave inspection are summarised.

Guided Wave Inspection vs. Conventional Ultrasonic Inspection: Conventional ultrasonic inspection systems that operate in the megahertz range have been used for many years for the in-service testing of rail. Two specific areas that can present significant challenges for ultrasonic testing as currently deployed are the detection of smooth transverse/vertical defects and the volumetric examination of alumino-thermic welds. These two areas are of great importance as 39.5 % of rail breaks on the UK rail network operated by Railtrack plc. were attributed to transverse/vertical defects and a further 22.4 % were caused by faults at alumino-thermic welds [2].

The use of guided acoustic waves with frequencies in the tens of kilohertz range offers an efficient and reliable means of screening rail for transverse/vertical defects and enables alumino-thermic welds to be tested. While conventional ultrasonic waves with wavelengths of a few millimetres can propagate in any direction within a rail and travel a few hundred millimetres, low frequency guided waves with wavelengths of hundreds of millimetres always propagate along the length of a rail and can travel for tens or even hundreds of metres.

A key advantage of guided waves is that they are particularly sensitive to transverse vertical defects since the waves travel along the length of a rail. A further advantage is that at the frequencies used, material attenuation due to grain boundary scattering is very low and hence alumino-thermic weld material can be readily penetrated and tested. These benefits make guided wave testing very attractive.

The complications of using guided waves are that, in a system such as a rail, there are many different types (or modes) of guided waves that can exist, and in general these modes have different, and frequency dependent, velocities. Without careful design of the transduction system and a full understanding of guided wave mode behaviour, the superposition of multiple modes all travelling at different velocities will result in data that is impossible to interpret. The key to an effective and practical test is the determination of the particular guided wave modes that are required for the test and the preferential generation and detection of these modes relative to the other unwanted modes [3].

Guided Waves in Rail: A finite element (FE) model has been developed to predict the modal characteristics (velocity, mode shape etc) of the multiple guided wave modes that can propagate in rail [4]. The dispersion curves for BS113A type rail and some example mode shapes are shown in Figure 1. An experimental programme was undertaken in parallel with the FE modelling to investigate which of the predicted guided wave modes and at which frequency could propagate over long distances in real rail. As a result of this work and other investigations into the interaction of various modes with defects in rail, a number of guided wave modes were selected for use by the initial G-Scan prototype guided wave rail inspection system.

Development of G-Scan Guided Wave Rail Testing System: In the initial G-Scan prototype guided wave rail inspection system, an array of transducers was clamped onto the rail using a combined mechanical/pneumatic system as reported in [1]. The system electronics was in separate instruments controlled from a laptop PC. An array of transducers is necessary in order to obtain both modal and directional selectivity to guided waves.

The system has subsequently been optimised and now comprises a single instrument that contains an array of significantly fewer transducers and the necessary electronics. The pre-production G-Scan instrument is shown in Figure 2. The combined mechanical/pneumatic clamping system is essentially the same as in the initial prototype, except that the pneumatic air supply is now provided by an electric pump within the instrument. This allows rapid deployment onto a rail, which typically takes around 30 seconds, including the time taken to operate the transducer clamping mechanism. It should be stressed that the dry contact transducers do not require any preparation of the surface of the rail and also do not in any way damage the rail. The time taken to perform a test requires the instrument to remain on the rail for between 30 and 90 seconds depending on the length of rail to be tested. The subsequent processing of the results to extract signals from different guided wave modes and to identify features currently takes between 90 and 300 seconds (again depending on the range of the test), but this may be performed after the instrument has been removed from the rail. In order to remove the instrument from the rail the clamping mechanism must be released, so the maximum time for removal is about 10 seconds. If necessary, the instrument can be removed from a rail mid-test. The instrument is battery operated and can be used for a complete shift without recharging. There is also the facility to connect a remote compressed air cylinder to actuate the pneumatic clamping to conserve battery life further.

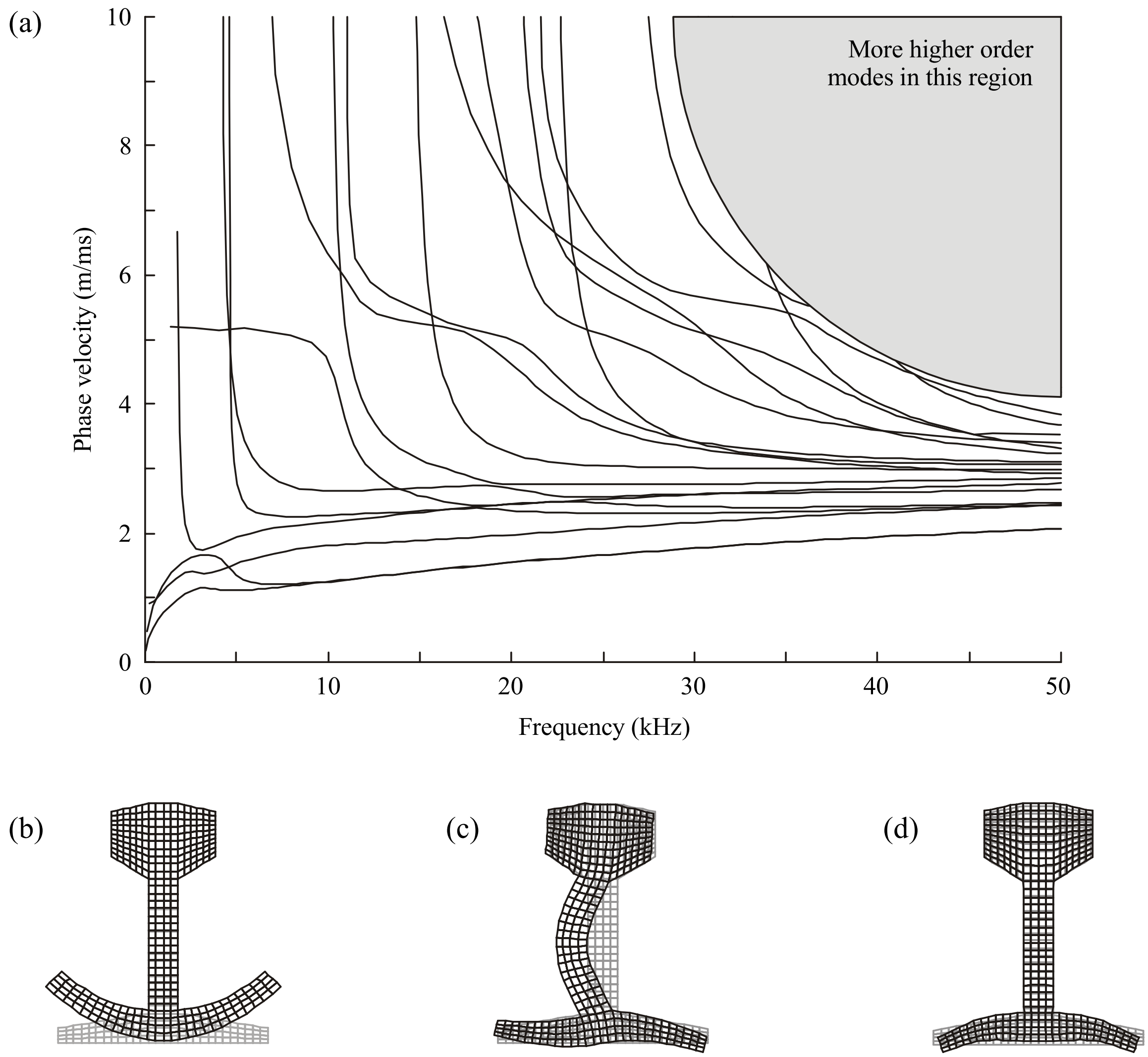

Figure 1. (a) Phase velocity dispersion curves for guided wave modes in BS113A type rail and some examples of guided wave mode shapes for (b) a mode with energy concentrated in the foot, (c) a mode with energy concentrated in the web and (d) a mode with energy in all portions of the rail cross section.

Results of Level Crossing Inspection: Level crossings present a challenge for rail inspection as access is only available to the running surface of the rail. Furthermore, the enclosed environment within the level crossing may lead to more rapid corrosion of the rail foot than that which normally occurs in free rail.

The pre-production G-Scan system has been used to inspect rail on the 'up' and 'down' lines at a Network Rail level crossing. This is part of an ongoing programme of testing to collect a large body of data on different rail conditions and to optimise the interpretation of features and presentation of results. The layout of the level crossing and the test locations are shown in Figure 3(a). Figures 3(b) and (c) show pictures of the G-Scan equipment in use at the level crossing. The tests were performed with both road and rail traffic in close proximity.

Each of the four rails was tested from both sides of the level crossing, hence requiring eight tests to be performed in total. The results (in the form of combined A-scans of the key guided wave mode data) for the rails on the 'up' and 'down' lines are plotted in Figures 4 and 5 respectively. The results are presented in pairs, with each pair corresponding to the tests performed on the same rail from opposite sides of the level crossing.

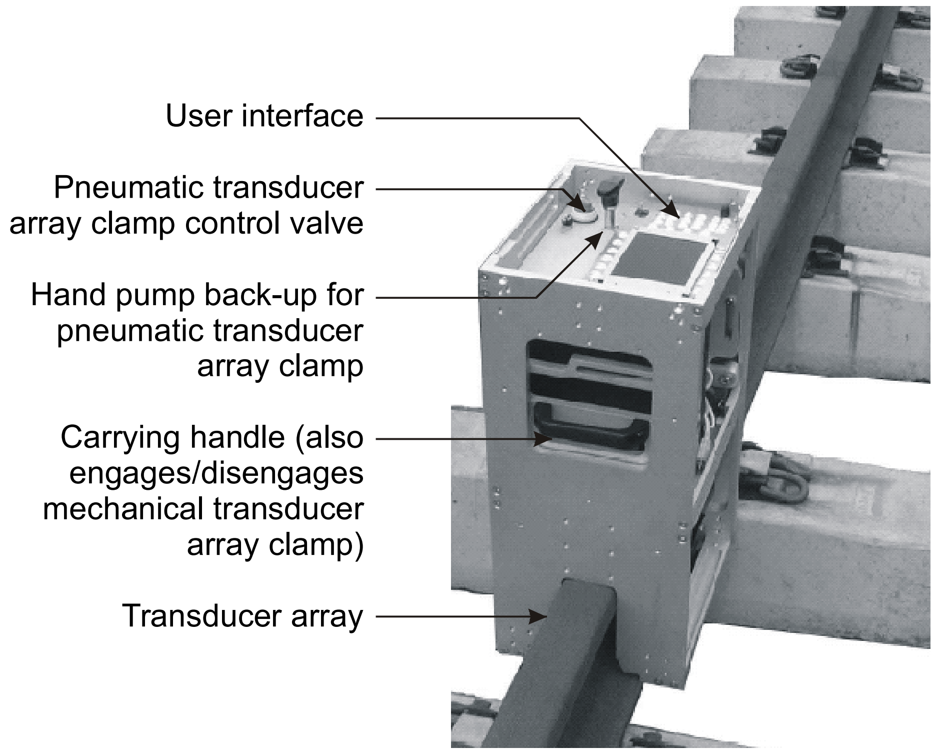

Figure 2. Photograph of pre-production G-Scan guided wave rail testing system.

In the 'up' line results shown in Figure 4, signals corresponding to documented alumino-thermic welds and insulated block joints are clearly identifiable in all the results. The results from the rails on the 'up' line are reasonably clean and indicate the level of background coherent noise that may be expected on rail in good condition.

The decaying signals that are visible in the two results when the test location was on the south side of the level crossing are due to reverberations. The mechanism that causes these reverberations is not yet fully understood, but it is thought to be due to the relevant test locations being in-between two large reflectors (an alumino-thermic weld and an insulated block joint) that are in close proximity. These reverberation signals do not correspond to physical features in the rail.

The results from the 'down' line shown in Figure 5 are markedly different from those obtained on the 'up' line. Again, signals from alumino-thermic welds are clearly visible but there are also numerous other distinct signals present that do not correspond to any documented features. When the right hand rail was tested from the south side of the level crossing, a signal was observed just before the rail entered the level crossing area (marked B in Figure 5). Visual inspection revealed that there was a wheel-burn at this location. There were several other wheel-burns in the vicinity on this line, but none of the others gave a significant G-Scan signal, hence indicating that this particular wheel-burn may have had greater transverse penetration of the rail than the others.

There are also a large number of signals present within the crossing on the 'down' line (marked '?' in Figure 5) that do not correspond to known features. The ragged nature of these signals is indicative of corrosion rather than man made features, and the reflection coefficient maps [1] suggest that many of these signals correspond to a loss of material in the foot of the rail. It is therefore reasonable to conclude that the rail on this line has experienced a moderate degree of foot corrosion. The rail on this line was visually observed to be somewhat older than that on the 'up' line.

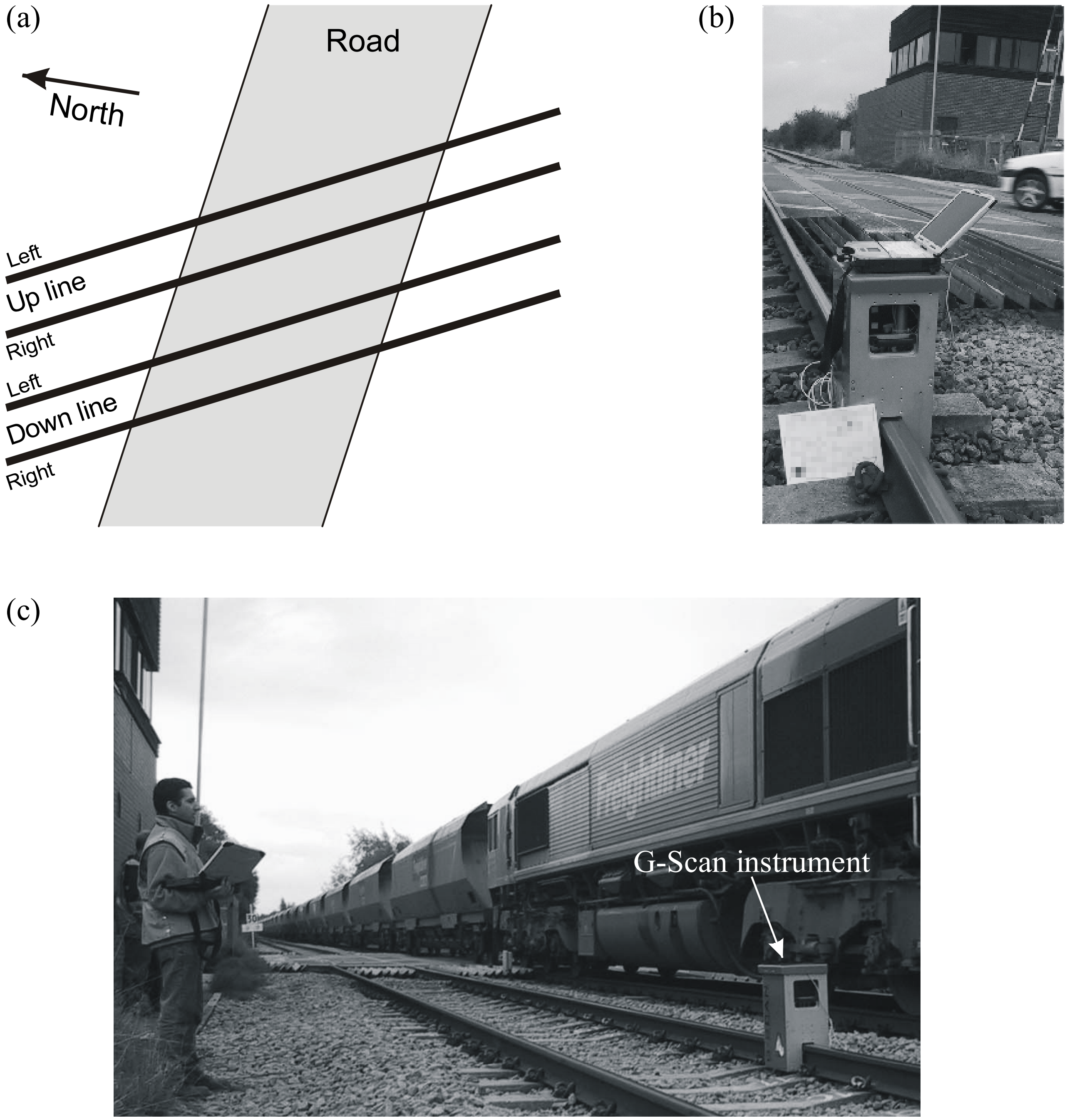

Figure 3. (a) Schematic diagram of the layout of the level crossing inspected, (b) and (c) G-Scan system in use at the level crossing.

Conclusions: Guided waves offer an exciting means of rapidly screening long lengths of rail for transverse defects. It has been shown that the problems associated with guided wave testing in a multi-modal environment can be overcome through careful design of the transduction system. The practical use of the G-Scan guided wave inspection system at a level crossing has been demonstrated. The testing described in this paper is part of an ongoing programme obtain data on many different rail conditions and to optimise the interpretation of features and presentation of results from the G-Scan system.

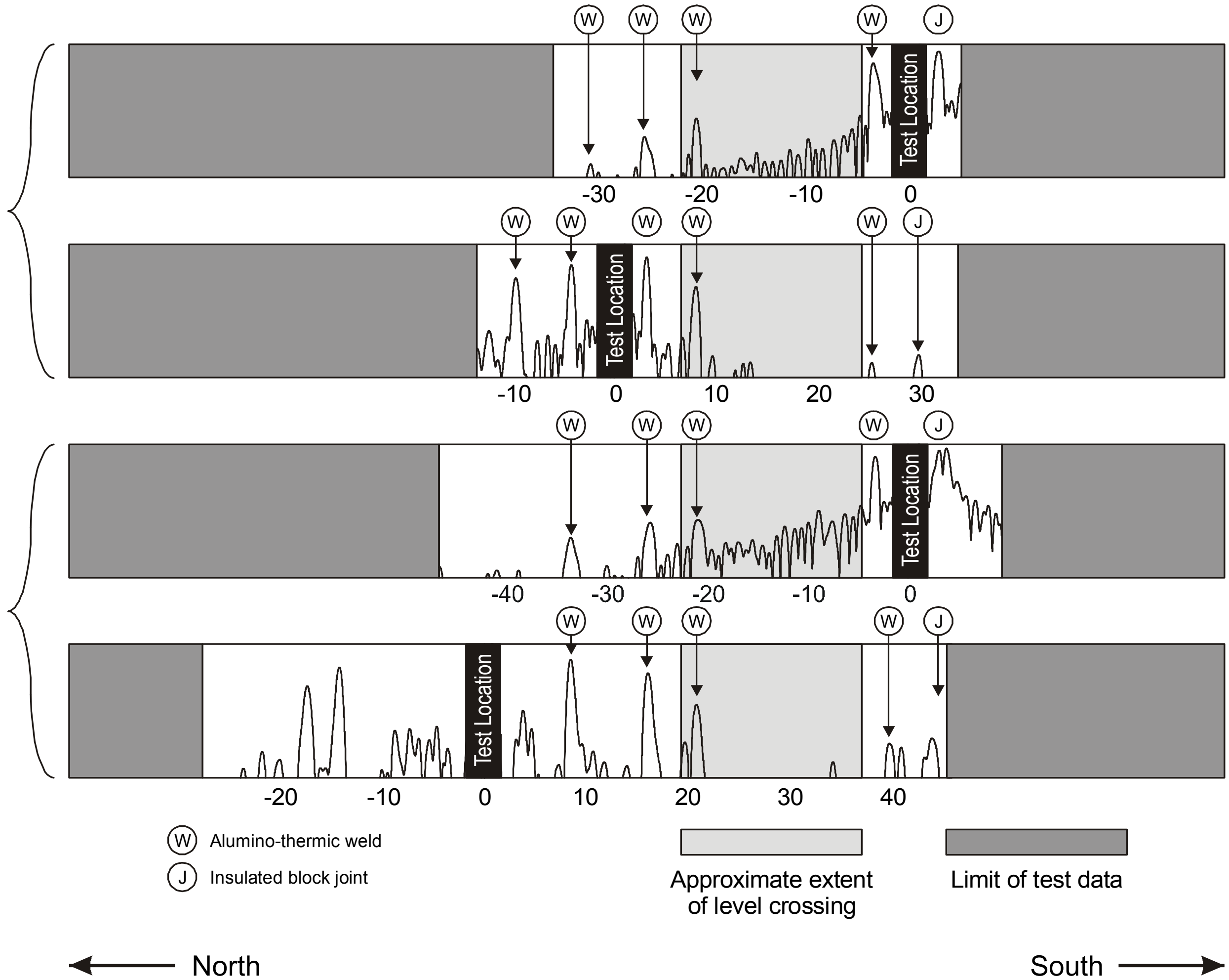

Figure 4. Results obtained from the 'up' line at the level crossing. Distances from the test location are marked in metres.

The results from that test indicate that the geometry and construction of the level crossing have not hindered the deployment of the G-Scan system. Guided wave inspection has been demonstrated to be an effective method for rapidly screening the condition of rails traversing a level crossing. In the future, it is hoped that the G-Scan system will be used as a tool for prioritising level crossing rails that are in need of more thorough, and possibly invasive, testing by other means.

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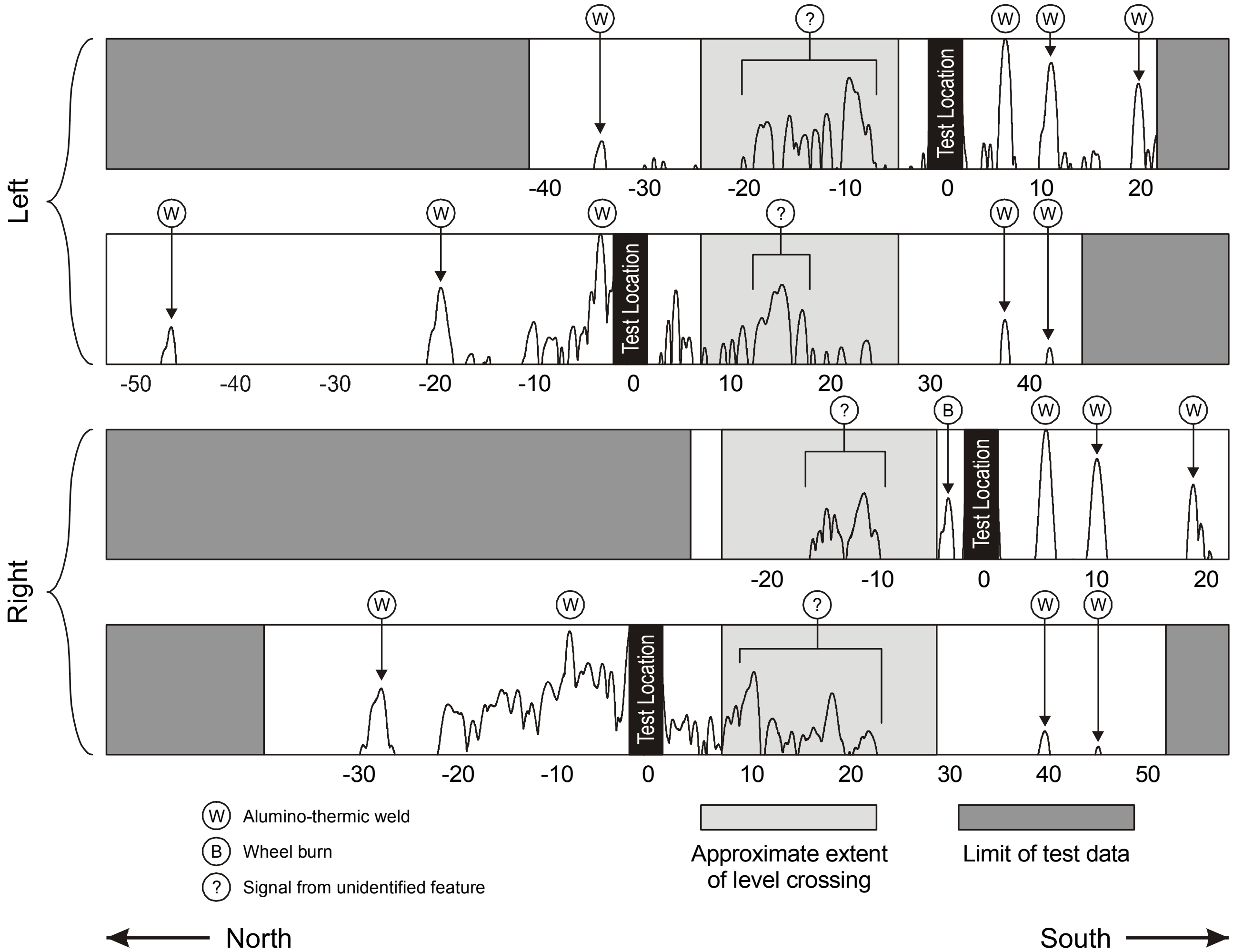

Figure 5. Results obtained from the 'down' line at the level crossing. Distances from the test location are marked in metres.

References

1. Wilcox, P. D., Pavlakovic, B. N., Evans, M. J., Vine, K. A., Cawley, P., Lowe, M. J. S. and Alleyne, D. N. (2003), "Long Range Inspection of Rail Using Guided Waves" in *Review of Progress in Quantitative NDE*, vol. 22, pp236-243 edited by Thompson, D. O. and Chimenti, D. E., Plenum Press, New York.
2. Sawley, K. and Reiff, R.(2000), "Rail Failure Assessment for the Office of the Rail Regulator", report no. P-00-070 produced by Transportation Technology Center, Inc., Pueblo, Colorado, USA.
3. Alleyne, D. N. and Cawley, P. (1992), "Optimisation of Lamb wave inspection techniques", *NDT and E International*, vol. 25, pp. 11-22.
4. Wilcox, P. D., Evans, M. J., Diligent, O., Lowe, M. J. S. and Cawley, P. (2002), "Dispersion and Excitability of Guided Acoustic Waves in Isotropic Beams with Arbitrary Cross Section" in *Review of Progress in Quantitative NDE*, vol. 21, pp. 203-210, edited by Thompson, D. O. and Chimenti, D. E., Plenum Press, New York.