Construction and Building Materials 179 (2018) 614–618

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

The inspection of level crossing rails using guided waves

Mark Evans [a,*], Andrew Lucas [b], Ian Ingram [c]

[a] Guided Ultrasonic Ltd, Reynard Business Park, London TW8 9LY, United Kingdom
[b] Network Rail, York, United Kingdom
[c] Network Rail, Doncaster, United Kingdom

HIGHLIGHTS

- Description of the costs and limitations of current inspection methods for level crossing rails.
- Introduction to Guided Wave Testing (GWT) for rails.
- Description of the applicability of this method to the inspection of level crossing rails.
- Practical experiences and results of trials by Network Rail.

ARTICLE INFO

Article history:
Received 2 February 2014
Received in revised form 9 February 2016
Accepted 23 May 2018
Available online 2 June 2018

Keywords:
Guided waves
GWT
Level crossings
Rail inspection
Rail monitoring

ABSTRACT

Level crossing rails are high risk areas due to the combination of the limited effectiveness of current inspection methods and high corrosion rates which often exist. This paper discusses the current UK standard practices for the periodic inspection of level crossing rails using visual (VT) and conventional ultrasonic (UT) methods. The limitations of these methods are discussed and how these limitations affect the overall maintenance program for level crossings.

A new inspection method, guided wave testing (GWT) is then described with particular emphasis on its advantages for inspecting level crossings. GWT was first commercially used for the inspection of pipes from around 1999 (Alleyne et al., 2001) [1] and has now gained very widespread usage.

Finally, a review is given of the current Network Rail trial of GWT on level crossings using the G-Scan system, with representative results which demonstrate the effectiveness of GWT for this application.

1. Introduction

Level crossings allow road traffic to cross railway lines at track-level by means of a set of removable roadway panels (often referred to as the 'deck'), which fit between the rails. The deck panels vary in materials and geometry but fit tightly between the rails with the minimum gap required to allow the passage of trains. This inevitably means that the rail within the crossing is not visible (apart from the top of the head and gauge-face). Additionally, the deck panels tend to trap moisture and road-salt around the rail causing accelerated corrosion of the lower sections of the rail, especially the toe, see Fig. 1. The corrosion rates observed in level crossings vary significantly from one crossing to another, depending on the local conditions. Some crossings exhibit no corrosion even after more than 15 years of service, others may exhibit critical corrosion within 2 years of service. The inspection frequency for each crossing is decided by the local track management team based on their experience of the corrosion rate observed during previous inspection intervals.

Using current testing methods, detection of defects at the toe of the rail is only possible using visual inspection and sizing of these defects can only be carried out using manual measurement of the loss of rail foot width. These inspections require the entire deck to be removed to allow direct access to the rail which is a very invasive and expensive process. There are currently just over 6500 level crossings in the UK which, on average, require visual inspection every 2 years with an estimated annual cost of over £2.5 million. This is the estimated cost for inspection alone and does not include re-railing, emergency road closures or delay costs.

In most cases visual inspection shows the rail to have no defects and the deck is simply replaced, however, in a significant number of cases the rail is found to have severe corrosion which requires rail replacement within 24 h and emergency measures to be put in place. Occasionally the corrosion reaches such an advanced state

* Corresponding author.
E-mail addresses: mark@guided-ultrasonics.com (M. Evans), Andrew.lucas@networkrail.co.uk (A. Lucas), Ian.ingram@networkrail.co.uk (I. Ingram).

https://doi.org/10.1016/j.conbuildmat.2018.05.178
0950-0618/

Fig. 1. Corrosion of the rail foot commonly found within level crossings with little or no loss in rail depth.

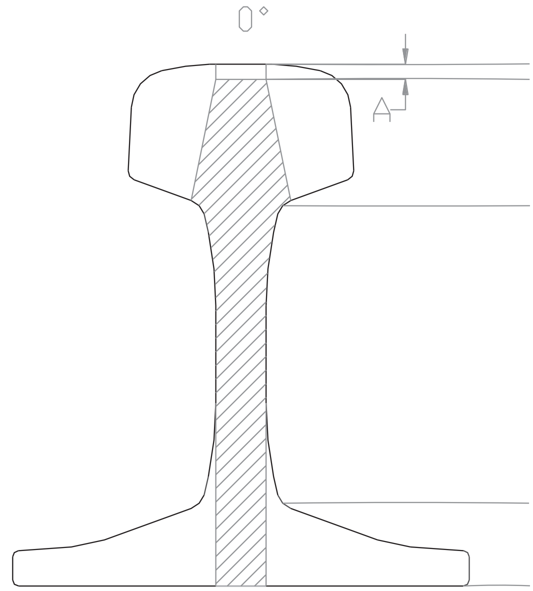

Fig. 2. The tested area of the rail using the zero degree ultrasonic rail depth measurement is limited to the centre-line only. The dead-zone (A) is typically between 3 and 8 mm.

that the rail breaks before the defects are detected as shown in Fig. 1. In the situation where severe corrosion is found during visual inspection there is usually insufficient time or resources available to replace the rail immediately. The deck must therefore be replaced, to allow for the re-opening of the road, and a speed restriction placed on the line until an emergency possession can be obtained to allow re-railing. In practice, the re-railing is usually carried out within 48 h due to the financial penalties which are incurred for applying speed restrictions.

2. Current inspection methods

In general, the majority of the rail in the network is inspected ultrasonically and visually every 8 weeks. The ultrasonic inspection utilizes several transducers coupled to the rail head with different beam angles to look at head and base defects which can be deployed using a manually operated trolley or mounted on an inspection train. The ultrasonic inspection is optimized for the detection and sizing of defects within the head and web sections of the rail where the majority of defects occur, however, UT methods are effectively blind to the corrosion defects commonly found in level crossings.

2.1 Ultrasonic testing (UT)

The main ultrasonic test method which is most applicable to level crossings is known as U15 in which the depth of the rail at the centre-line is measured using a vertically oriented (zero degree) transducer, as shown in Fig. 2 [2]. The corrosion found at level crossings typically does not affect the centreline but is concentrated at the toe sections of the rail as shown in Fig. 1, therefore, the result of the U15 inspection often does not correlate with the rail condition within the crossing and potentially catastrophic defects can go undetected. Additionally, some crossings cannot be ultrasonically inspected with the manual inspection trolley as the flanges on the inspection wheel will not fit between the rail and the deck.

The case-study for Belmont Forest, shown in the results section of this paper, is good example which highlights the limitations of UT inspection at level crossings. In this case a recent UT inspection had not detected any significant problem with the rail shown in Fig. 9 which required emergency replacement.

2.2 Invasive visual testing (VT)

The lifting of level crossings to allow VT is a complex and expensive process and requires planning and booking of road closures a minimum of 1 year in advance (on average 2 years in advance).

Once possession of the track is taken heavy machinery is used to remove each deck panel one by one, see Fig. 3. An average team of six men are required and the process of removing the panels which can take more than 2 h to complete. Replacement of the panels is the reverse process and requires a similar amount of time.

Fig. 3. Lifting the deck to allow visual inspection of the rail.

The average shift only allows between 6 and 8 h to complete all of the work and reinstate the crossing and so, in some cases, it is not possible to completely lift, inspect and replace the crossing in a single shift.

Once the panels have been removed the rails and substructure are cleaned and visually inspected following the Network Rail guidelines [3]. This is an extensive list of observations including:

- Rail head, web and foot
- Fastenings
- Pads
- Sleepers
- Ballast

The inspector subjectively assigns a condition rating (Bad, Medium, Normal) to each feature which is converted into a 'score'. This score is then used as part of the risk assessment in order to schedule the next visual inspection. If corrosion is observed at the base of the rail it is sized manually by measuring the width of the rail at the base using a steel ruler. The loss in width is calculated and the minimum actions are applied as specified in the guidelines.

There are several potential shortcomings of this inspection process:

- In order to get a reasonably accurate measurement of the remaining width the rail should be well cleaned and all loose corrosion products removed which is very time consuming.
- There can be significant loss of cross section of the rail before there is any measureable loss in foot width so the measurement is not a true representation of the rail condition.
- In many cases the worst corrosion occurs at the sleepers and so it is not visible or directly measurable without unclipping and lifting the rail.
- The time available to carry out the inspection is very limited, as previously discussed, which puts pressure on the inspector which can lead to defects going undetected.

It is clear from the discussion above that the visual inspection of level crossings is an expensive and impractical process which yields subjective and often misleading results. Where defects are detected they are usually too serious to be managed in an effective manner as immediate emergency procedures must be applied.

3. Guided wave inspection

3.1. Introduction

Guided wave testing (GWT) offers a solution to this problem as it is capable of testing the rail section through the level crossing in a cost effective way without lifting the roadway or disturbing the road or rail traffic movements. GWT is a low frequency pulse-echo inspection method [1] which utilizes waves which travel along the length of the rail and are sensitive to a wide variety of transverse rail defects [4]. The development of the GWT method for the inspection of rails was carried out for Network Rail between 2002 and 2005 [5] by Guided Ultrasonics Ltd.

3.2. GWT method

The basic principle of operation utilizes a static array of piezoelectric transducers which is temporarily dry coupled to the rail surface. Guided waves, which travel up to 30 m along the rail in both directions from the transducer array, are transmitted and received in a pulse-echo configuration. This allows defects within the diagnostic range of the test to be detected, located and prioritised [6,7].

Guided wave testing (GWT) differs from conventional ultrasonic inspection (UT) primarily in terms of the area of the rail section which is inspected, as follows (see Fig. 4);

- The guided wave modes which are used are sensitive to defects at any position within the rail cross section. This includes the areas of the foot and toe of the rail which are normally un-inspected using UT methods but where corrosion defects are most common.
- The guided wave modes travel along the length of the rail and so the method is able to remotely test sections of rail. This is particularly advantageous in areas which are untestable by conventional UT due to minor rail head irregularities (such as corrugation) or where the rail is partially inaccessible for visual inspection such as level crossings (Fig. 5).

3.3. Display of results

GWT results are displayed using an A-Scan representation, see for example Fig. 6, where the distance along the rail is shown on the X-axis and the amplitude of the reflected signal is shown on the Y-axis. The position of the test is the origin of the distance scale with results from both sides of the test location shown on the same A-Scan result. The dead-zone around the test location is indicated by a shaded area.

The signal amplitude is correlated to the cross sectional area loss of the rail using calibration curves, often referred to as DAC curves, which are represented using dashed lines. For the results shown in this paper the DAC curves representing 5% and 10% loss of cross section are displayed. The severity of individual indications is assessed by comparing the amplitude of the reflected signal to the DAC curves and converting that to a corresponding cross sectional change. It is not possible from the A-Scan trace to predict what part of the rail section in lost (head, web or foot), however, if no defects have been detected using ultrasonic testing it is a reasonable assumption that the defect is in the toe section of the rail.

3.4. How this applies to level crossings and the benefits

A particularly suitable application for GWT is for the detection of corrosion at the foot and toe sections of the rail within level crossings where the rail is inaccessible for visual inspection.

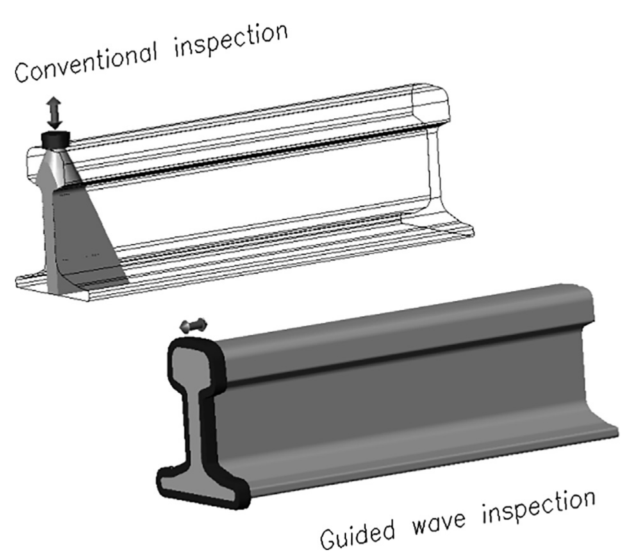

Fig. 4. The tested volume using conventional UT and Guided Wave testing.

Fig. 5. G-Scan equipment being used to inspect a level crossing, the work is carried out in 'Red Zone' conditions with both road and rail open to traffic.

Using GWT it is possible, in most cases, to inspect the rail through the entire level crossing without suspending the road or rail traffic and without removing the deck. This provides an obvious time and cost saving compared to visual inspection.

Additionally, by inspecting the crossings regularly, for example annually, it would be possible to monitor the condition of the rails and to prioritise visual inspection and maintenance. This would allow for advanced planning of rail replacement work which is significantly more cost effective than emergency works.

4. Network rail guided wave level crossing trials

Guided wave equipment (G-Scan) has been used for the past 18 months for level crossing inspections in the York and Doncaster regions as part of the existing crossing inspection program. The plan was designed in conjunction with the level crossing lifting plans so that visual verification could be completed as quickly as possible, without unnecessary disruption to normal operations.

The trials have been led by the LNE Route asset management team, in conjunction with Sheffield, Doncaster and York rail engineers using G-Scan equipment which was purchased by Network rail in 2005 and is already approved for use on the infrastructure. The project plan consisted of the requirement to inspect level crossings with G-Scan, followed by visual examination with the crossing removed.

In all, around 30 level crossings have been inspected to date; two example case studies are given below. The G-Scan results for most of these crossings have been largely similar showing little or no cross-sectional loss indications. The visual inspections have subsequently shown that these crossings have no significant corrosion. The first case study shows the result for Mansfield Road crossing which is a typical example.

The G-Scan results for several crossings, however, showed large cross sectional loss indications which were then confirmed during the visual inspection and the rails required immediate replacement. A typical example for this scenario is shown in the case study for Belmont Forest crossing.

5. Case studies

5.1. Mansfield road

This was one of the first level crossings to be tested for the trials. The A-Scan result for one of the rails is shown in Fig. 6 where the limits of the crossing are indicated by the grey shaded area. The 5% DAC curve is the lowest intervention level and the results clearly indicate that no indications of concern were detected anywhere within the crossing. This was later verified visually; see Fig. 7, which shows only light surface scaling and no measureable loss of cross section.

5.2. Belmont Forest

The Belmont Forest level crossing was inspected and the A-Scan result for one of the rails is shown in Fig. 8. Severe indications of

Fig. 7. No significant corrosion of the rail at Mansfield Road level crossing.

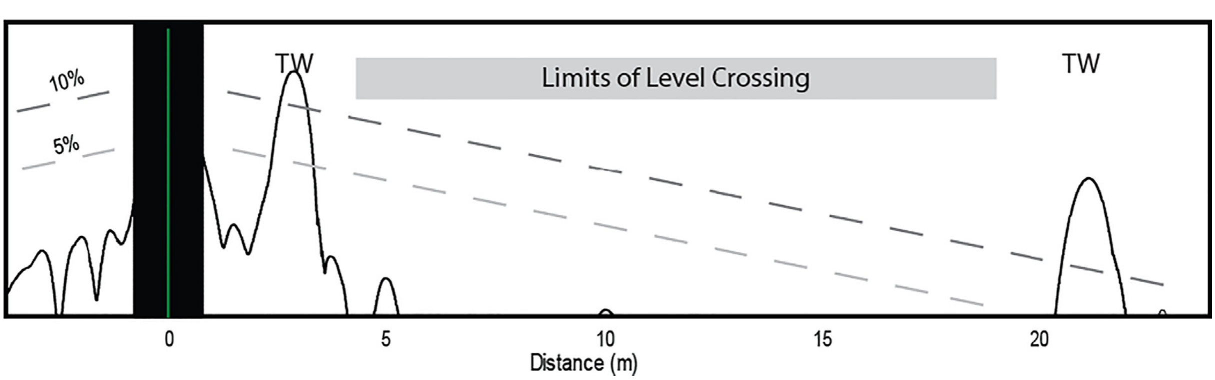

Fig. 6. GWT result from Mansfield Road level crossing showing no significant indications.

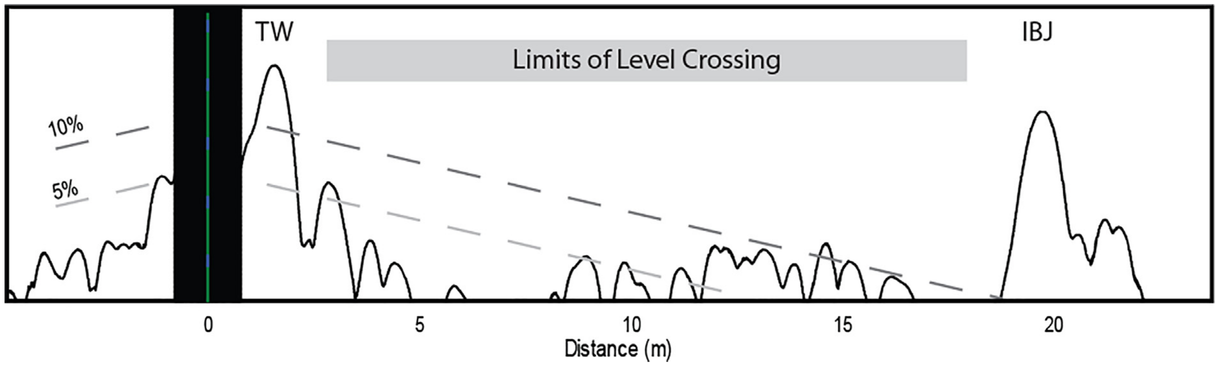

Fig. 8. A-Scan result for Belmont Forest showing severe indications of between 10% and 15% cross sectional loss.

Fig. 9. The corroded section, at between 8.9 m and 16.5 m on the A-Scan result shown in Fig. 8, was then verified using VT showing severe corrosion of the toe section of the rail.

between 10% and 15% cross sectional loss were detected between 8.9 m and 16.5 m section. Subsequent lifting of the crossing revealed extensive corrosion of the rail foot causing large reductions in the cross section of the rail which required immediate emergency action.

It is important to emphasise at this point that the regular UT inspections of the rails at this crossing, one of which was carried out a less than 4 weeks prior, did not indicate any significant corrosion of this rail.

6. Conclusions

The results from the GWT testing for all of the crossing tested in the trial have been compared with the measurements using conventional visual testing demonstrating the accuracy and reliability of the GWT method. Based on these results a set of minimum actions have been developed to allow monitoring of level crossing rail condition and prioritising of crossings for visual inspection in the future.

Using GWT it is possible, in most cases, to inspect the rail through the entire level crossing without suspending the road or rail traffic and without removing the road-way panels which provides huge time and cost saving compared to visual inspection.

By inspecting the crossings regularly, for example annually, it is possible to monitor the condition of the rails and to prioritise visual inspection and maintenance. This would allow for advanced planning of rail replacement work which is significantly more cost effective than emergency works.

Network rail plans to use GWT for the routine inspection of level crossing rails in the future.

Conflict of interest

None.

References

[1] D.N. Alleyne et al., Rapid, long range inspection of chemical plant pipework using guided waves, Insight 43 (2001) 93–101.
[2] RT-CE-S-055 Rail-Testing-Ultrasonic-Procedure, 1998.
[3] NR/L2/TRK/001/MOD09, Issue 5 'Inspection and maintenance of permanent way – Rail management', Network Rail company standard, 2nd June 2012.
[4] BS 9690-1:2011, Non-destructive testing. Guided wave testing, General guidance and principles.
[5] P. Wilcox, M. Evans, O. Diligent, M. Lowe, P. Cawley, Dispersion and excitability of guided acoustic waves in isotropic beams with arbitrary cross section, in: D. O. Thompson, D.E. Chimenti (Eds.), Review of Progress in Quantitative NDE, vol 21, American Institute of Physics, 2002, pp. 203–210.
[6] P. Wilcox, M. Evans, B. Pavlakovic, D. Alleyne, K. Vine, P. Cawley, M. Lowe, Guided wave testing of rail, Insight 45 (2003) 413–420.
[7] P. Wilcox, M.J. Evans, B. Pavlakovic, D.N. Alleyne, K. Vine, P. Cawley, M.J.S. Lowe, Long range inspection of rail using guided waves – Field experience, Proc Railway Engineering – 2003, London, 3–4 July, 2003.