Rail Accident Investigation Branch

Rail Accident Report

Class investigation into rail breaks on the East Coast Main Line

Report 24/2014
November 2014

This investigation was carried out in accordance with:

- the Railway Safety Directive 2004/49/EC;
- the Railways and Transport Safety Act 2003; and
- the Railways (Accident Investigation and Reporting) Regulations 2005.

Any enquiries about this publication should be sent to:

RAIB
The Wharf
Stores Road
Derby UK
DE21 4BA

Email: enquiries@raib.gov.uk
Telephone: 01332 253300
Fax: 01332 253301
Website: www.raib.gov.uk

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Class investigation into rail breaks on the East Coast Main Line

Contents

Appendices 64

Summary

This class investigation considers the occurrence and management of rail breaks on Network Rail's East Coast Main Line (ECML). It includes consideration of rail breaks which occurred at three locations during 2012 and 2013 and which, together with reports that the occurrence of rail breaks on the ECML was relatively high, triggered the investigation. None of these three rail breaks resulted in injuries or damage to trains.

A rail break at Corby Glen, near Grantham was triggered by wear of the pad intended to separate the rail from the underlying concrete sleeper. Breaks at Copmanthorpe, near York, and at Hambleton, about 15 miles (24 km) south of York, were due to movement at rail joints caused by inadequate support from the underlying ground.

Rail break statistics show that, after allowing for differences in route length and the amount of traffic, the ECML has more rail breaks than comparable main lines. After considering both the types of rail break occurring on the ECML and the measures being taken by Network Rail to manage these, the investigation concluded that the most significant factor in the relatively high number of rail breaks on the ECML between 2009 and 2013 was the relatively high proportion of older track.

Network Rail has recognised the relatively high level of rail breaks on the ECML and is replacing older track components on this line. It has also altered the maintenance criteria on the ECML to increase the likelihood of replacing moving (dipped) joints before they cause rail breaks. These measures appear to be reflected in a recent reduction in the occurrence of rail breaks.

The RAIB has made four recommendations relating to rail breaks and addressed to Network Rail. The first seeks research to improve detection of the very small precursor cracks which usually occur in rails a significant period before the rail breaks. The second relates to the wider adoption of lessons learnt from managing rail breaks on the ECML while the third seeks a routine process for identifying and replacing defective rail pads. The fourth recommendation seeks implementation of improved techniques for detecting precursor cracks if trials using equipment recently fitted to Network Rail's test trains (ultrasonic testing units) prove successful.

A fifth recommendation, also addressed to Network Rail, arises from an observation not directly related to rail breaks and deals with improved highlighting of updated information in safety critical documents.

Introduction

Preface

1 The purpose of a Rail Accident Investigation Branch (RAIB) investigation is to improve railway safety by preventing future railway accidents or by mitigating their consequences. It is not the purpose of such an investigation to establish blame or liability.

2 Accordingly, it is inappropriate that RAIB reports should be used to assign fault or blame, or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

3 The RAIB's investigation (including its scope, methods, conclusions and recommendations) is independent of all other investigations, including those carried out by the safety authority, police or railway industry.

Key definitions

4 All dimensions in this report are given in metric units, except locations which are given in imperial units, in accordance with normal railway practice. The locations are given as a distance from London (Kings Cross) station. Where appropriate the equivalent metric value is also given.

5 The report contains abbreviations and technical terms (shown in *italics* the first time they appear in the report). These are explained in appendices A and B.

Background

6 This investigation into the occurrence and management of *rail breaks* on the East Coast Main Line (ECML) was initiated by a reported rail break at Corby Glen, near Grantham, on 14 September 2012 and reports of other incidents indicating that the occurrence of rail breaks was higher on the ECML than on some other lines carrying similar traffic. The investigation also considers an incident at Copmanthorpe, about 4 miles (6 km) south of York, on 28 November 2012 and an incident at Hambleton, about 15 miles (24 km) south of York, on 1 February 2013 (figure 1).

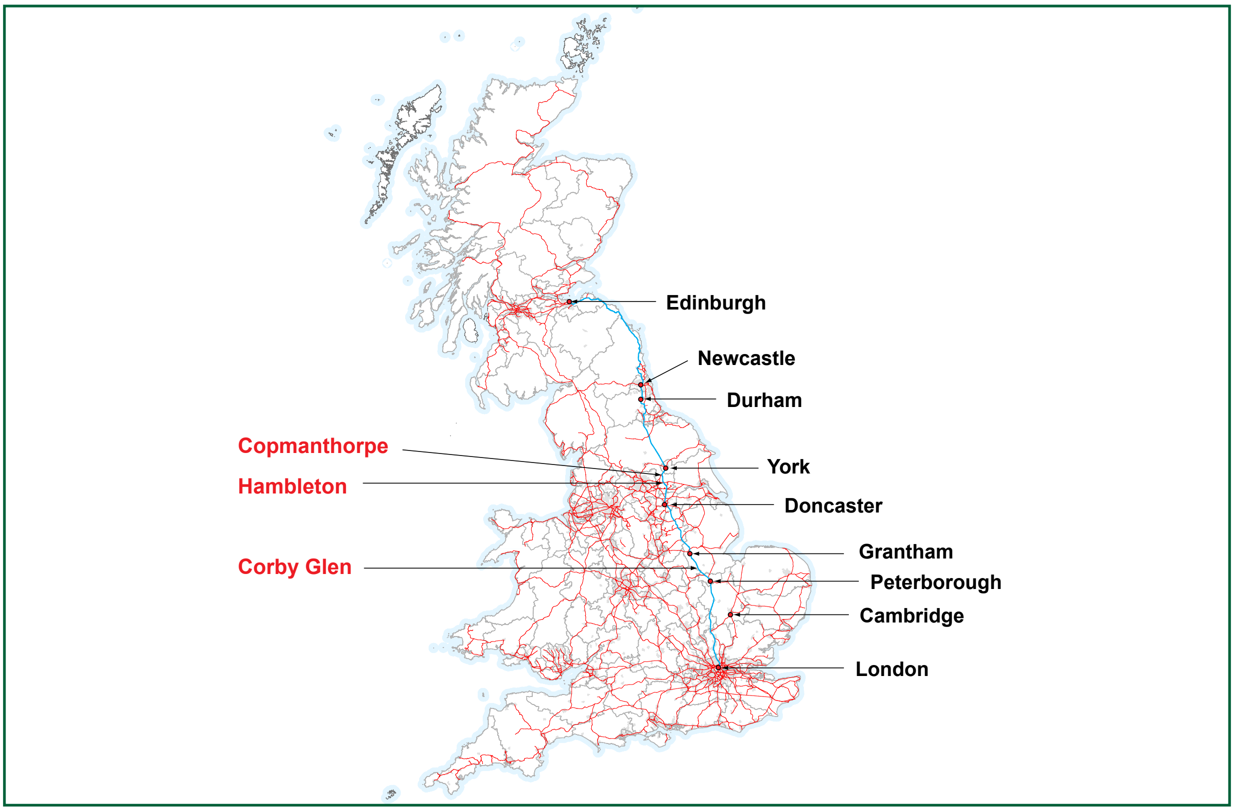

Figure 1: East Coast Main Line (ECML)

7 The objectives of the investigation were to:

- establish the particular circumstances of the incidents at Corby Glen, Copmanthorpe and Hambleton;
- determine whether rail breaks occurred more frequently on the ECML than on other comparable parts of Network Rail infrastructure;
- identify the factors which lead to differences between the occurrence of rail breaks on the ECML and occurrences on other comparable lines; and
- make recommendations targeted at reducing the frequency of rail breaks on the ECML and other parts of Network Rail infrastructure.

8 As this class investigation focuses on themes, rather than the specific details at each rail break site, the RAIB has obtained most details of specific events from industry reports. The RAIB has however commissioned additional testing where necessary.

Specific incidents

Corby Glen

9 At 13:20 hrs on 14 September 2012 a member of the public contacted Network Rail to report excessive noise when trains were were passing over a section of track near Corby Glen, about 8 miles (13 km) south of Grantham. The driver of train 1B84, the 12:08 hrs Kings Cross to Newark service, examined the line while travelling at slow speed and reported a 'slight dip' in the track. The line was closed to traffic at 14:00 hrs after maintenance workers had arrived and found that a rail had broken leaving a 15 mm gap between adjacent sections of rail (figure 2). The line reopened at 16:17 hrs on the same day after a temporary repair had been implemented.

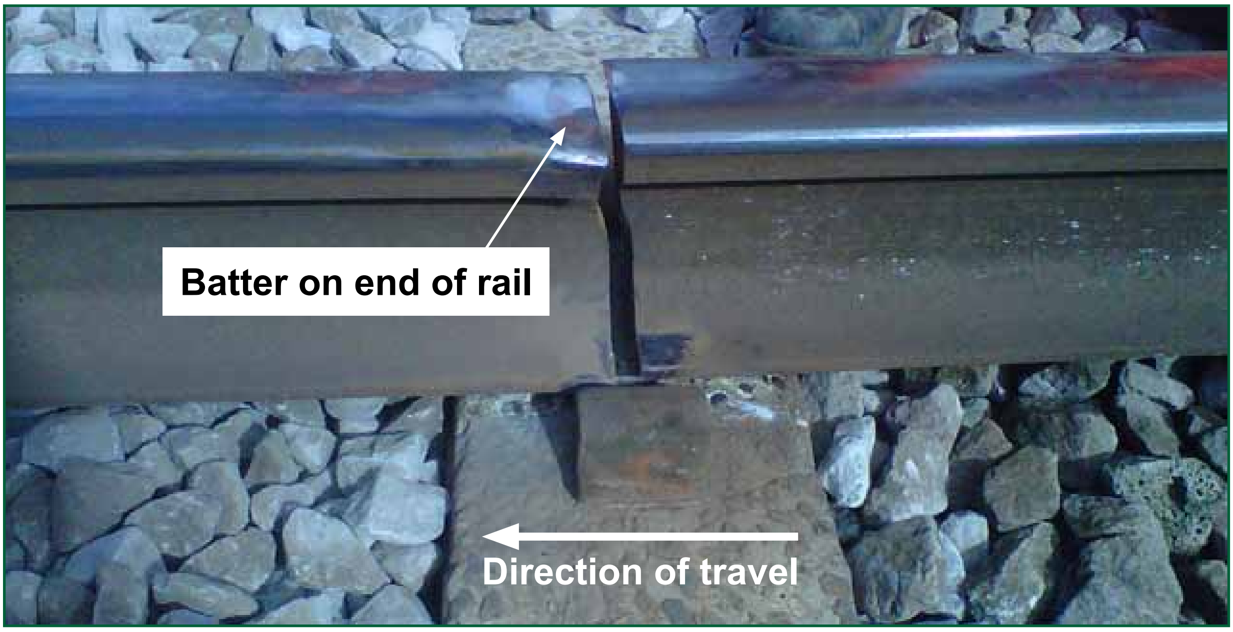

Figure 2: Corby Glen - Broken rail (image courtesy of Network Rail)

10 The break occurred at 97 miles 62 yards on the *down* main line of the ECML in an area of straight *continuous welded rail* with a maximum permitted train speed of 125 mph (200 km/h). The rail was of the *flat bottom* type designated BS113A and had been manufactured in 1985. It was clipped to concrete *sleepers* with a *pad* between the rail and each sleeper. Trains travelling in the normal direction of traffic passed over a weld joining two pieces of rail about 1.5 metres before the location of the break.

11 Tata Steel Rail Technologies examined the broken rail at Network Rail's request and concluded that the break developed because:

- pad wear immediately beneath the rail resulted in moisture collecting between the rail and the sleeper (figure 3);
- the moisture caused corrosion which led to two small *corrosion pits* developing on the underside of the rail;

- stresses in the rail caused by train loads were concentrated into areas of rail very close to the corrosion pits and these initiated cracks, known as *fatigue cracks*, for reasons explained in paragraph 59;
- the fatigue cracks grew as a result of forces imposed by passing trains, merged together, and then continued to grow;
- as crack size increased, the stresses at the crack tip probably increased for reasons explained in paragraph 60;
- a sudden break (*brittle fracture)* occurred when the fatigue crack size meant that the remaining intact rail was unable to carry the stresses imposed by a train;
- the break allowed a gap of about 15 mm to open between the rail ends as they moved apart due to the tension in the continuous welded rails (paragraph 41); and
- train wheels striking the exposed rail end after passing over the gap caused batter damage to the rail (figure 2).

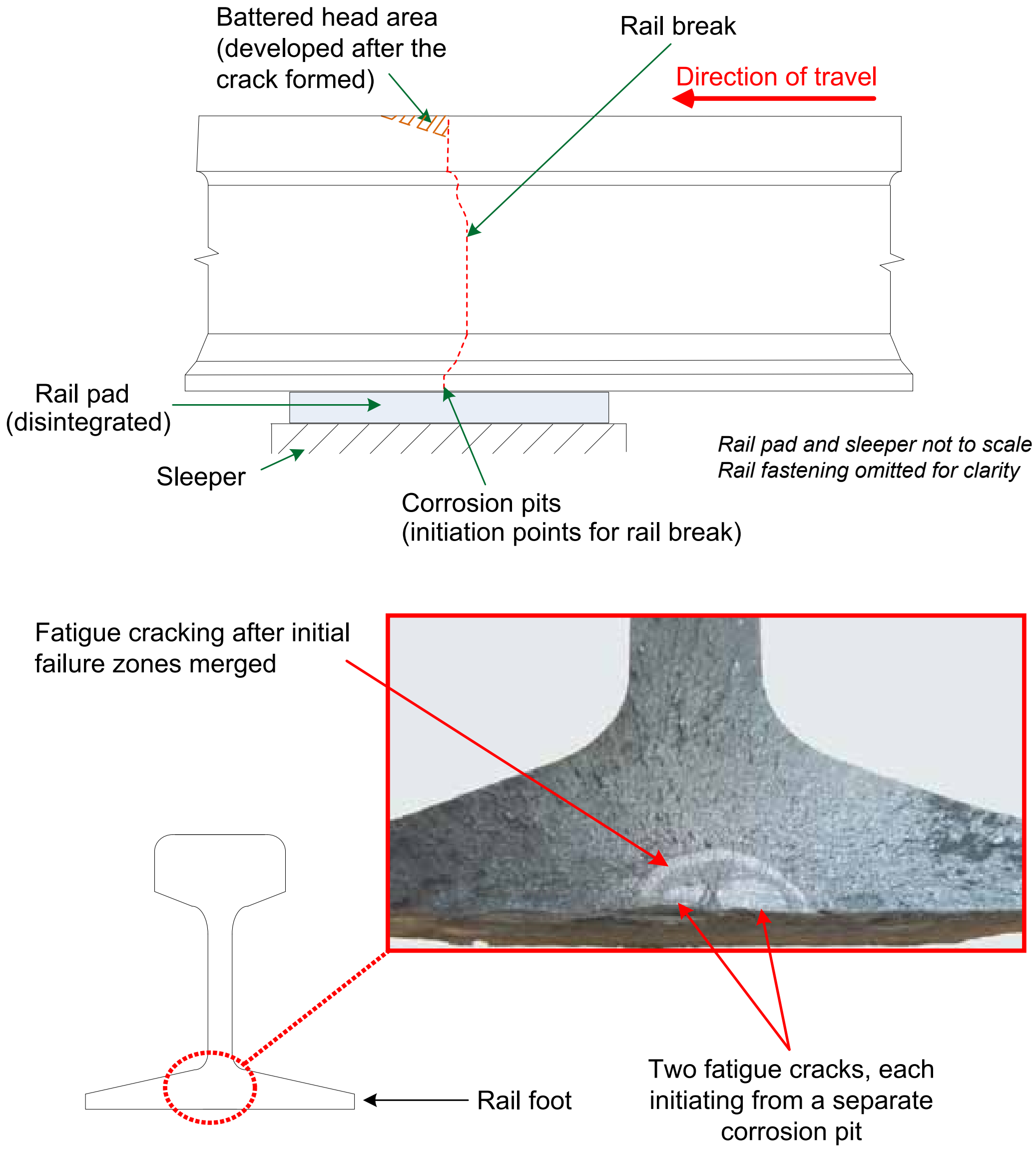

Figure 3: Corby Glen - Failure mode

12 Network Rail has expressed the view that one factor in this break was the small dip in the rail head caused by an old weld about 1.5 metres before the section of rail which broke.

13 It is uncertain exactly when the rail broke. No defects requiring actions were identified by any of the following routine activities:

- *Track geometry* measurements collected by a Network Rail track geometry recording train four days before the break was discovered.
- A visual inspection carried out by a permanent way supervisor three days before the break was discovered.
- Train mounted *ultrasonic testing*, intended to detect cracks within the rail and undertaken by the *Ultrasonic Test Unit* (UTU) train two days before the break was discovered (the crack was probably present but was too far from the rail head to be detected for reasons explained in paragraph 96).

14 Until the rail broke, crack development would not have resulted in a significant change in the way rails deflected under train loading and so there would have been no significant effect recorded by the track geometry recording train. Neither the fatigue cracking, nor the area of pad missing beneath the rail, would have been visible to track maintenance staff until after the rail broke. Improved management of pad degradation is discussed at paragraphs 65, 128 and 129.

15 It is likely that the location and the small size of the fatigue cracking meant that this could not be detected by the UTU as operated at the time of the incident. The RAIB has concluded that the UTU test equipment was operating correctly on this occasion because test records show that defects were found at other locations during the same test run. The reasons for not detecting smaller cracks and possible improvements to the crack detection system are discussed at paragraphs 94 to 97.

Copmanthorpe

16 At 11:50 hrs on 28 November 2012 a broken rail was seen near Copmanthorpe on the *up* main line by the driver of train 1S11, the 10:00 hrs London King's Cross to Aberdeen service, travelling on an adjacent line. He reported what he had seen to the signaller who instructed the driver of train 1E07, the 08:30 hrs Edinburgh to London King's Cross service, to examine the line while travelling at slow speed. This driver reported that there was a gap in the rail, subsequently found to be 110 mm long (figure 4). This train reversed direction to avoid travelling over the gap and the line remained closed until repairs were completed at 19:37 hrs on 28 November 2012.

17 The break occurred at 184 miles 1474 yards on the up main line of the ECML in an area of straight track with a maximum permitted train speed of 125 mph (200 km/h). The break occurred in the end of a rail at a location where an *insulated block joint* connected two lengths of rail. The broken rail was of the flat bottom type, designated BS113A, manufactured in 1976 and laid on concrete sleepers.

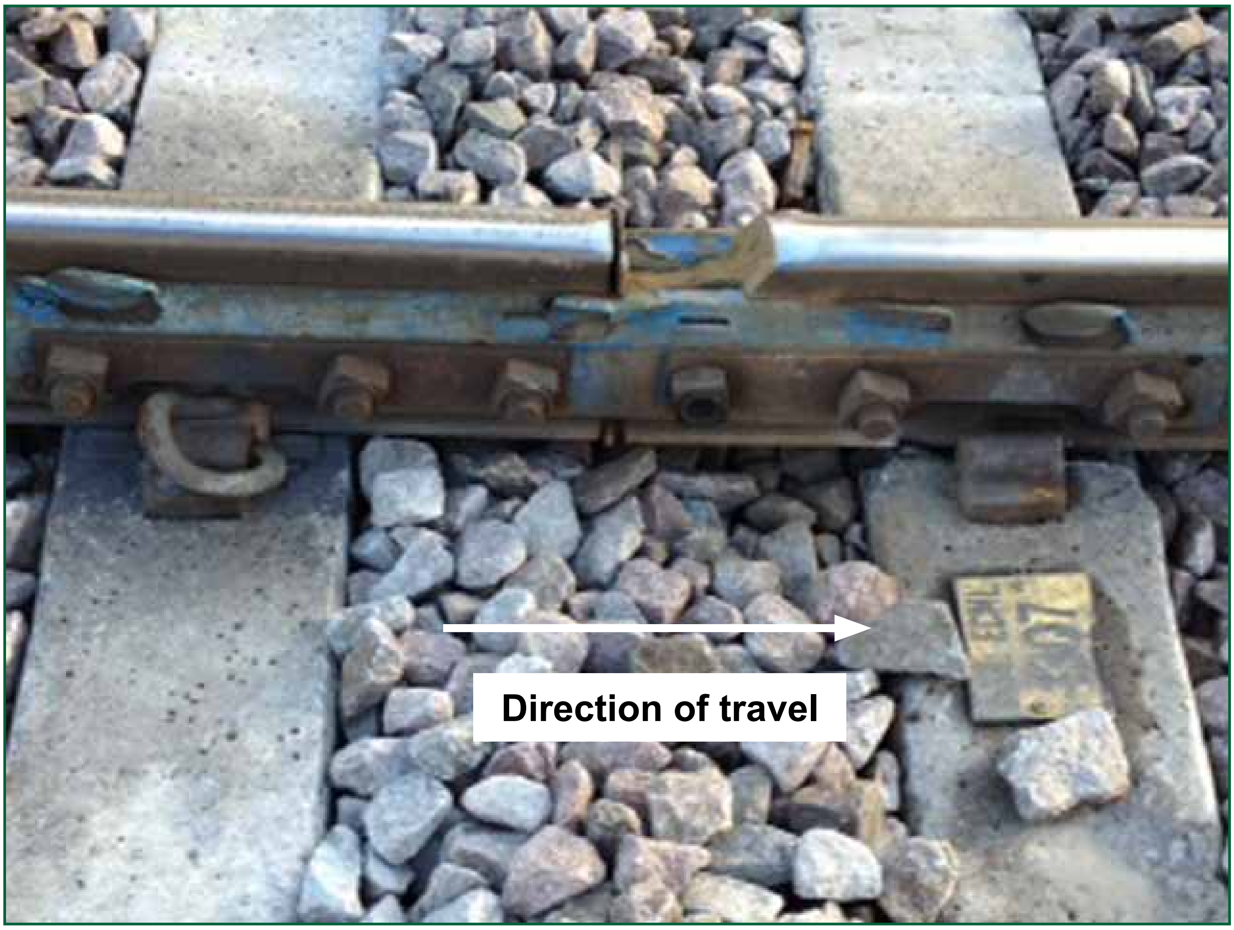

Figure 4: Copmanthorpe - Broken rail (image courtesy of Network Rail)

18 Insulated block joints act as a barrier to electrical currents and allow the rails on each side of the joint to form separate electrical circuits *(track circuits)*. These circuits are used by the signalling system to determine the location of trains. The incident joint was of the *Coronet* type and comprised a layer of plastic insulating material between the rail ends together with a covering of insulating material over the steel plates, known as a *fishplates*, which connect the rails. The fishplates were secured to the rails by three bolts on each side of the joint. The bolts passed through holes formed in the plates and the rail, and were intended to secure the fishplates to both rails in a rigid connection (figures 4 and 5).

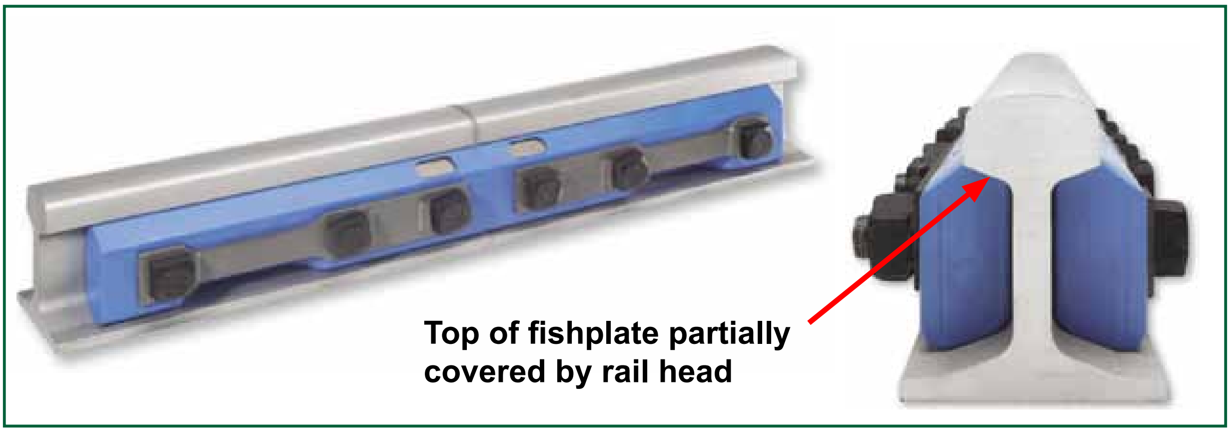

Figure 5: Coronet joint (images courtesy of L B Foster)

19 Serco Rail Technical Services (SERCO) examined the broken rail at the RAIB's request and, taking account of information provided by Network Rail about the condition of the ballast intended to support the sleepers, SERCO concluded that the break occurred because:

- inadequate support to sleepers from the underlying *ballast* meant that part of the train loads intended to be carried by these sleepers were actually carried through the rail to adjacent, better supported, sleepers in a manner which caused additional bending at the joint (figure 6);
- these relatively high loads caused wear (and/or overloading) of the plastic insulating material permitting movement of the fishplates relative to the rail, and thus misalignment of the rail ends on each side of the joint;
- rail misalignment caused wheel impact loads which were greater than the loadings on correctly aligned track and which caused increasing movements, and thus an increasing dip (figure 7);
- these movements resulted in the upper part of the fishplate pressing against the underside of the rail head which, in conjunction with the effects of wheel impacts due to the dipped joint, increased stresses in the rail head;
- the increased stresses caused fatigue cracks to propagate from corrosion pits on the underside of the rail head (the corrosion was not particularly severe but the pits provided a *stress concentration* feature (paragraph 60) which governed the precise location at which cracks initiated);
- the fatigue cracks gradually enlarged until they had penetrated approximately 2 mm into the rail;
- the amount of rust found on the surface of these cracks after the rail broke indicated that the gradual growth probably occurred over a period of several months; and
- a 110 mm length of rail head broke off when the remaining intact rail was unable to carry the loads caused by trains (particularly the high stresses at the tips of the fatigue cracks).

20 It is uncertain exactly when the rail broke but, because there was only superficial corrosion on the final fracture surface, SERCO state that 'the time elapsed between the break and discovery was probably relatively short (possibly up to a day or a small number of days at most)'.

21 The fatigue cracking on the underside of the rail head could not have been seen during routine visual inspections of the track because it was obscured by the fishplate (the last track patrol before discovery of the break took place on 19 November 2012, nine days before discovery). The last routine UTU train test before the incident also took place on 19 November and no cracks were reported, probably because the fatigue cracks were only about 2 mm in size[1] and were too small to detect for reasons explained in paragraph 96. Larger defects were found at other locations during the same test run indicating that the UTU equipment was working correctly.

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[1] In this context, size indicates penetration into the rail.

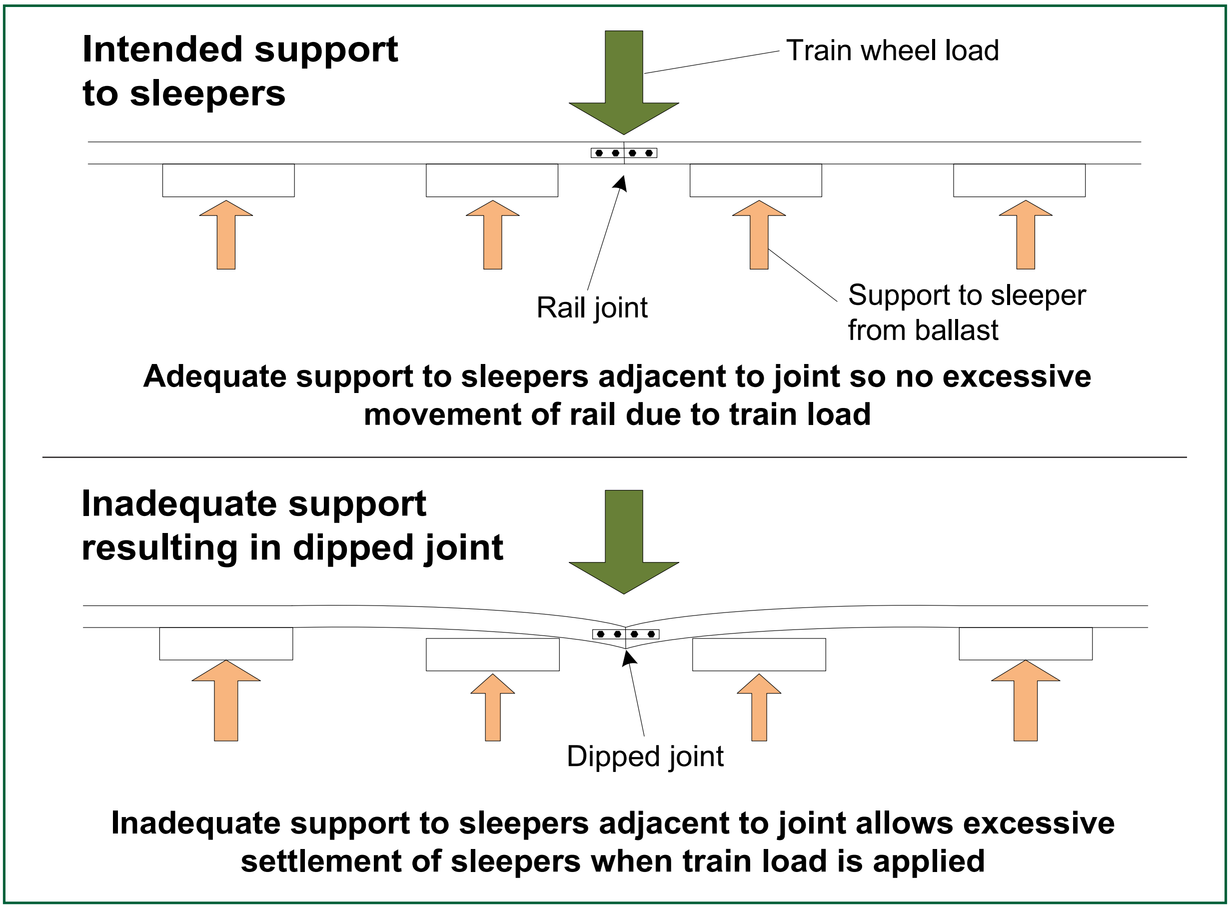


Figure 6: Effect of inadequate support from ballast

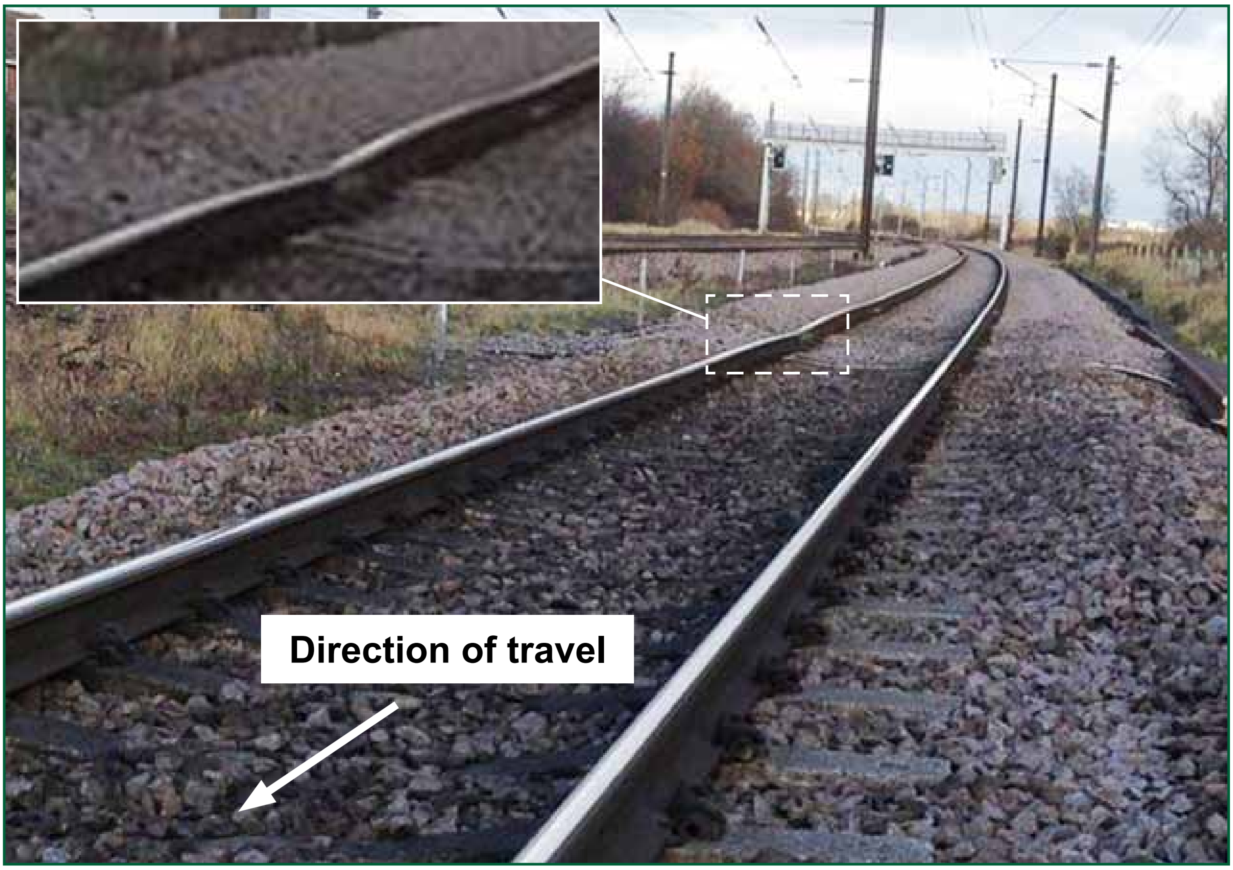
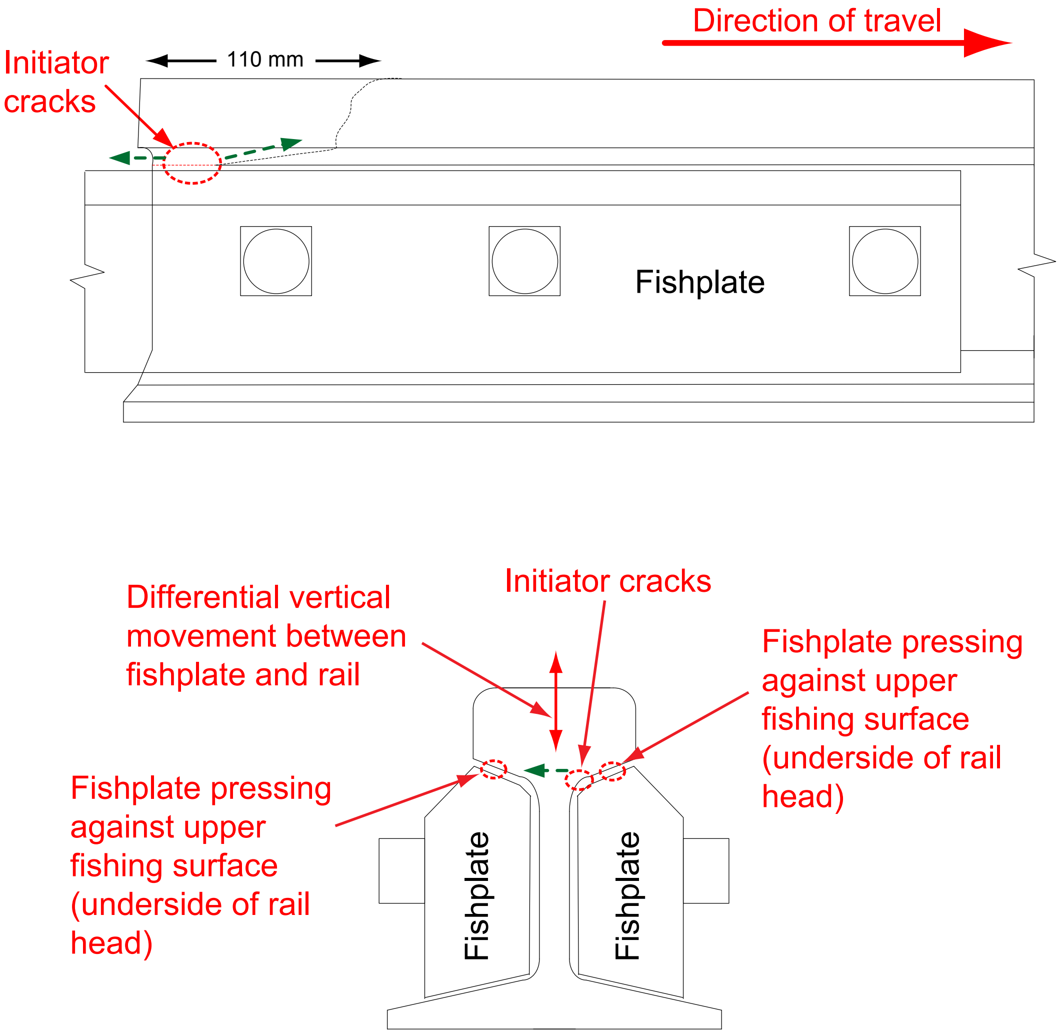


Figure 7: Copmanthorpe - Dipped joint (image courtesy of Network Rail)

Rail with broken portion missing and fishplate removed



Green arrows show direction of crack propagation from initiation points

Figure 8: Copmanthorpe - Failure mode

22 Although the cracks were not detected, the dipped joint had been reported since May 2012 and *wet beds*, a common cause of loss of support from ballast, had been reported since September 2012. These reports triggered maintenance work on five occasions in the ten weeks before the incident (Table 1). The reasons why this maintenance did not prevent the rail break are discussed in paragraph 72 onwards.

23 Contrary to reports in the media shortly after the break occurred, the crack had not been identified and marked with blue paint (as an indication that it needed repair or replacement) four days before the incident. The reports were based on a photograph taken on site which appeared to show areas of blue on the top of the rail and on parts of the fishplates (figure 9).

Figure 9: Copmanthorpe - Photographs showing 'blue' areas

Figure 10: Copmanthorpe - Rail as received by the RAIB (no blue areas)

24 When inspected by the RAIB (figure 10), there were no blue paint markings, and no evidence of blue markings having been removed, on the upper surface of the portion of rail which broke away and none on the rail from which it broke.

25 The blue areas on the fishplates shown in all photographs taken on site correspond to locations where the blue insulating material that covers the fishplate is not obscured by dirt. The rail head covered some of these blue areas before the rail broke and this would have prevented these areas being painted (figure 5).

26 The images on figure 9 show that the extent of the blue area on the upper part of the rail depends on the angle from which the photograph is taken, an indication that this blueness is a consequence of light reflecting from the shiny upper surface of the rail.

Date (2012)	***Event***
14 May to 16 July	Monthly track geometry recording train run records *dip angle* (figure 31) varying between 24 and 29 *mrads*.
10 September	Track geometry train reports joint dip angle of 35 mrads
11 September	Visual inspection reports wet beds
13 September	Sleeper(s) *lifted & packed* using shovel packing
10 October	Visual inspection reports dip and wet beds
15 October	Track geometry train reports joint dip angle of 42 mrads
15 October	Sleeper(s) lifted & packed using shovel packing
7 November	Visual inspection reports dip and wet beds
8 November	Visual inspection reports severe voiding (poor sleeper support)
8 November	Sleeper(s) lifted & packed using shovel packing
12 November	Track geometry train reports joint dip angle of 44 mrads
15 November	Sleeper(s) lifted & packed using hand held powered equipment (more powerful than shovel packing)
22 November	Train driver reports rough ride
22 November	Sleeper(s) lifted & packed using shovel packing
28 November	Broken rail discovered

Notes

Network Rail standard NR/L2/TRK /001 mod 11 requires maintenance action within specified timescales if the dip angle is ≥ 30 mrads (paragraph 73).

Shovel packing is a relatively quick method of lifting and packing to improve track top. It entails packing the track by first lifting it with jacks and then using shovels to move pieces of stone forming the ballast under the sleepers. However, the rail alignment can then deteriorate rapidly as the pieces of stone moved under the sleepers get pushed down under the weight of passing rail traffic. The principle of packing with hand held powered equipment is the same but uses vibrating hammers to pack ballast more effectively under the sleepers.

Table 1: Copmanthorpe - Track deformation & maintenance (key events)

Hambleton

27 At 11:38 hrs on 1 February 2013 a Network Rail track maintenance team inspecting trackside equipment discovered a broken rail on the down main line near Hambleton. The line was closed immediately and remained closed until 16:30 hrs while repairs were completed. There were no injuries or damage to trains as a result of this incident.

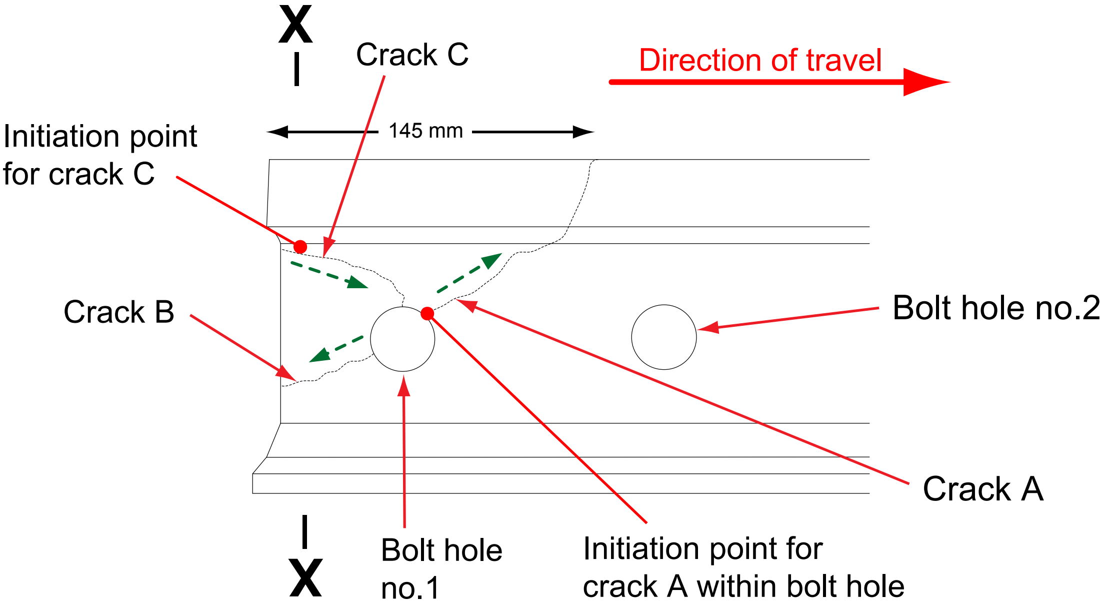
28 The break occurred at 173 miles 902 yards on the down main line of the ECML in an area of straight track with a maximum permitted train speed of 125 mph (200 km/h). The break occurred in the end of a rail at a location where an insulated block joint connected two lengths of rail. The broken rail was of the flat bottom type, designated BS113A, manufactured in 1983 and laid on concrete sleepers (figure 11). An insulated joint was no longer required at this location and wires had been attached to both rails to give an electrical connection across the joint.

Figure 11: Hambleton - broken rail

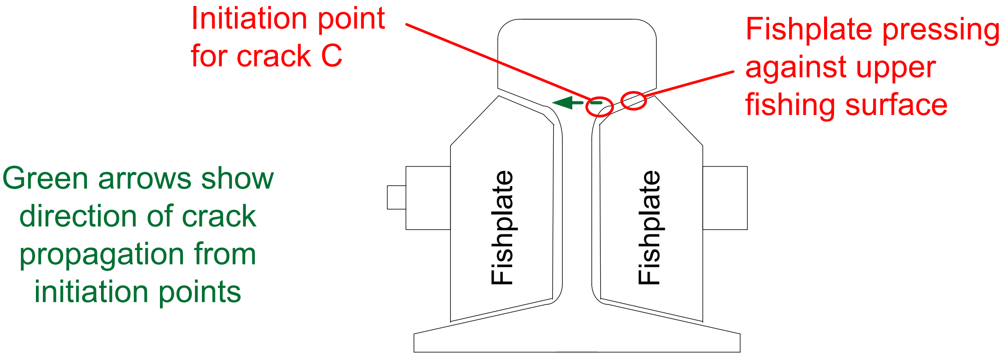
29 The likely sequence of events leading to the broken rail given below is based on an examination of the broken rail undertaken by SERCO at the RAIB's request, and on information provided by Network Rail:

- inadequate support to sleepers meant that part of the train loads intended to be carried by these sleepers was actually carried through the rail to adjacent, better supported, sleepers in a manner which caused additional bending at the joint (this behaviour is commonly associated with increasing track dip and has been inferred because of the increasing track dip described in paragraph 81);
- these relatively high loads overcame the securing effect of the bolts and caused movement of the fishplates and thus misalignment of the rails on each side of the joint;
- rail misalignment caused wheel impact loads which were greater than the loadings on correctly aligned track and which caused increasing movements, and thus an increasing dip;
- these movements resulted in both the upper part of the fishplate pressing against the underside of the rail head and in the bolts rubbing against the sides of the bolt holes through the rail;
- stresses in the rail caused by these movements, coupled with the effects of wheel impacts due to the dipped joint, resulted in fatigue cracks initiating in the web of the rail, close to the underside of the rail head, at the outer end of the rail (crack C in figure 12);
- stresses due to these movements also caused a fatigue crack to initiate in the web of the rail at the 1 o'clock position of the bolt hole nearest the joint (crack A in figure 12);
- the fatigue cracks increased in size until, just before the rail broke, crack C reached a maximum size of 3 mm to 4 mm and crack A reached about 5 mm;
- rust found on the crack surfaces indicates that these cracks had probably developed slowly until this stage;
- a 145 mm length of rail head broke off when stress concentration at the crack tips meant that the remaining intact rail was unable to carry the loads imposed by trains. It is likely that this occurred as a result of the rail end crack (crack C) extending to the nearest bolt hole followed by the 1 o'clock crack (crack A) extending to the rail head, and then a new crack developing at the 8 o'clock position on the bolt hole and extending to the rail end (crack B on figure 12);

Rail reassembled without fishplate



Crack propagation (fishplate not shown)



Section X - X (crack B not shown)

Figure 12: Hambleton - Failure mode

30 It is uncertain exactly when the rail broke and it is possible that trains ran over the joint while the broken portion remained in approximately the ‘correct’ position.

31 The fatigue cracking could not have been seen during visual inspections of the track because it was obscured by the fishplate. If the rail break had occurred with the broken portion remaining in the ‘correct’ position when a visual inspection took place, this should have triggered an immediate response. The last visual inspection before discovery of the break was undertaken on 23 January, nine days before discovery, and no defect was reported. The last routine UTU train test before the incident took place on 17 December 2012 and no cracks were reported, probably because the fatigue cracks were up to 5 mm in size and thus too small to identify (paragraph 94). The RAIB believes the UTU test equipment was operating correctly on this occasion because test records show that defects were found at other locations during the same test run.

32 The lack of support to sleepers had caused a dip at the joint which had been recorded during monthly track geometry train runs since September 2012, with the exception of an apparently anomalous report of no dip in November 2012. The measured dip angles had risen only slightly from 26.09 mrads on 15 September 2012 to 29.58 mrads on 17 January 2013, two weeks before the broken joint was found. The final reading was just below the 30 mrads at which Network Rail standards require that action be taken.

33 Track patrols during the three months before the broken rail was found did not identify any defects in the vicinity of the joint except for a dip found and reported on 9 January 2013 by the last patrol before the rail broke. No remedial work had been taken in response to this report before the rail broke. This is consistent with Network Rail standard NR/L2/TRK/001 which requires that such defects are corrected within one month of discovery.

The investigation

Sources of evidence

34 The following sources of evidence were used:

- witness statements;
- track geometry data obtained by Network Rail’s track geometry recording train;
- ultrasonic test results obtained by Network Rail’s ultrasonic test unit;
- technical reports prepared by Tata Steel Rail Technologies and SERCO detailing their examination of broken rails;
- meetings with Network Rail and SERCO;
- correspondence with Sperry, the organisation which provides Network Rail with ultrasonic testing equipment and analyses of some ultrasonic test results;
- statistical data relating to rail breaks provided by Network Rail; and
- weather data provided by the Met Office.

Analysis

35 The RAIB has investigated:

- overall trends and risks associated with rail breaks throughout Network Rail infrastructure (paragraph 37 onwards);
- rail break distribution across Network Rail infrastructure (paragraph 43 onwards);
- the effect of track age and rail age on the occurrence of rail breaks (paragraph 50 onwards);
- principles relevant to understanding rail breaks (paragraph 59 onwards);
- types of rail break and their distribution on Network Rail infrastructure (paragraph 62 onwards);
- causes and mitigation for breaks originating at the rail foot (paragraph 64 onwards);
- causes and mitigation for breaks developing at joints including breaks due to cracking in the rail ends (paragraph 68 onwards);
- management of track dip at rail joints in order to reduce the likelihood of rail breaks (paragraph 72 onwards);
- causes and mitigation for breaks in rail welds (paragraph 83 onwards);
- causes and mitigation for breaks originating in the head (top) of the rail (paragraph 86 onwards);
- limitations of crack detection by ultrasonic testing and possible improvements to testing techniques (paragraph 89 onwards); and
- track maintenance activities relevant to rail breaks (paragraph 99 onwards).

36 The RAIB's investigation also identified three issues which are not directly related to rail breaks. These are presented as observations (paragraph 105 onwards) and relate to the use of ultrasonic testing for detecting possible track geometry defects, the process for identifying recurring track defects and the process for disseminating changes to Network Rail standards.

Overall trends and risks

37 The number of rail breaks on Network Rail infrastructure has reduced from more than 900 each year in the late 1990s to an average of about 160 each year in the period 2009 to 2013 (figure 13). The improvement has taken place while the amount of rail traffic[2] increased by about a third.

38 The reduction coincides with significant amounts of new rail being installed in the late 1990s and early 2000s, the introduction of improved ultrasonic testing techniques between 2000 and 2003, and the introduction of enhanced requirements for dealing with dipped joints in 2005. Subsequent enhancements to Network Rail's rail break management strategy are discussed later in this report.

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[2] The combined effect of passenger and freight trains, measured as described in paragraph 45, increased from about 6.3 million tonnes per year in the late 1990s to typically 8.5 million tonnes per year in 2009/2013.

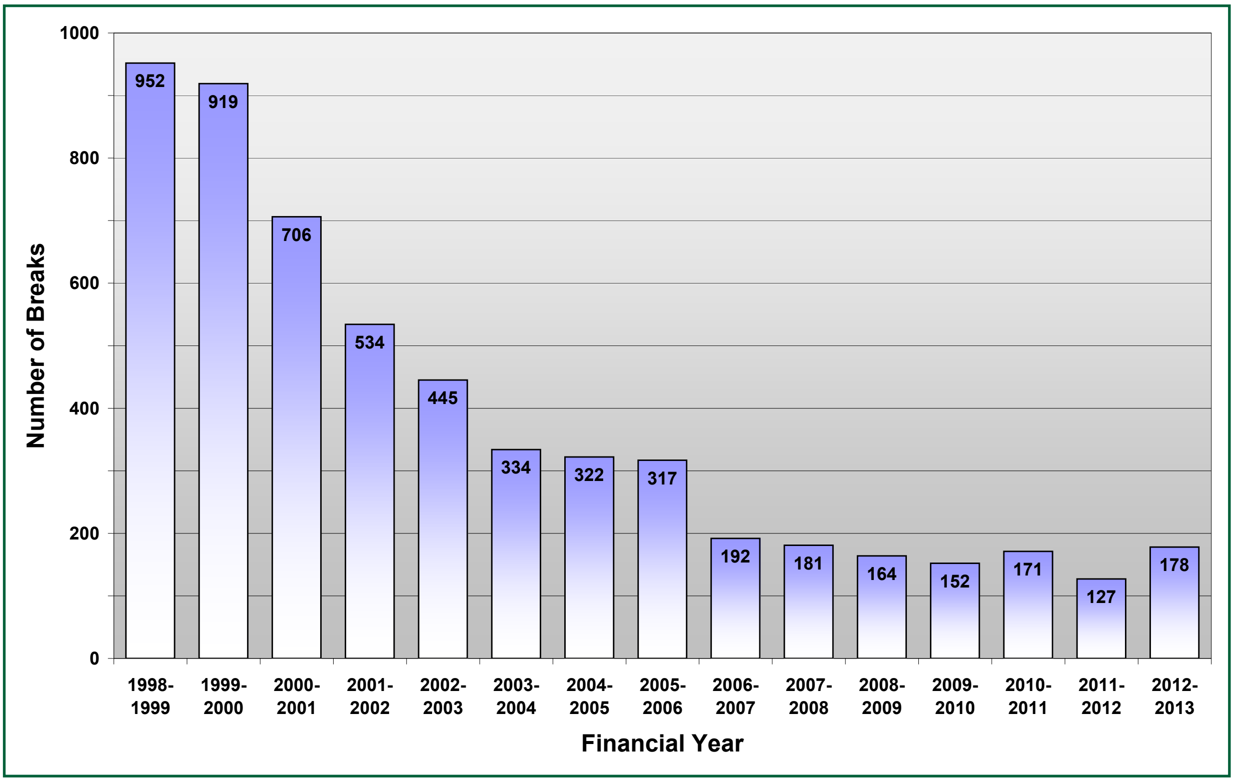

Figure 13: Rail breaks on Network Rail infrastructure 1998 to 2013

39 RSSB maintains a Safety Risk Model which is intended to identify the risk associated with various parts of railway operations. The risk is expressed using an index of fatalities and weighted injuries (FWI), in which ten major injuries are considered equivalent to one fatality. The total railway safety risk given in the 2012/13 RSSB Annual Safety Performance Report is 139.2 FWI excluding suicides. Train accidents, including accidents at level crossings, represent only 8.2 FWI. The remainder of the safety risk consists of trespass, workforce injuries, passenger accidents on stations, etc.

40 Risk due to derailment caused by a broken rail is calculated by RSSB to be about 0.07 FWI, about 0.05% of total railway safety risk and about 1% of the risk associated with train accidents. Although the calculated risk is low, the derailment of a fast moving train due to a rail break can result in serious consequences, as at Hither Green where 49 people died in 1967[3].

41 Data covering all Network Rail infrastructure (figure 14) shows that rail breaks are more common in colder weather. This is a predictable effect because tension develops in rails during cold periods when fixings restrict rail contraction. This is particularly relevant to continuous welded rail, the type now generally used on all main lines, because this is designed, installed and fixed in a way which results in most of the rail being subject to tension at temperatures below 27°C, with the amount of tension increasing as temperature falls. If not in tension at these temperatures, there is a greater amount of rail compression on hot days and thus a greater risk of rails buckling.

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[3] http://www.railwaysarchive.co.uk/docsummary.php?docID=99.

42 Although figure 14 shows that rail breaks increase with lower temperatures on a nationwide basis, this is not consistently true for the ECML, or for the Network Rail London North & Eastern (LNE) route which includes the ECML. This is demonstrated when LNE rail break data is plotted against average temperature data for central England (the values used with the nationwide rail break data) and when both LNE and ECML data is plotted against temperature data relating to eastern England (figures 14 and 15).

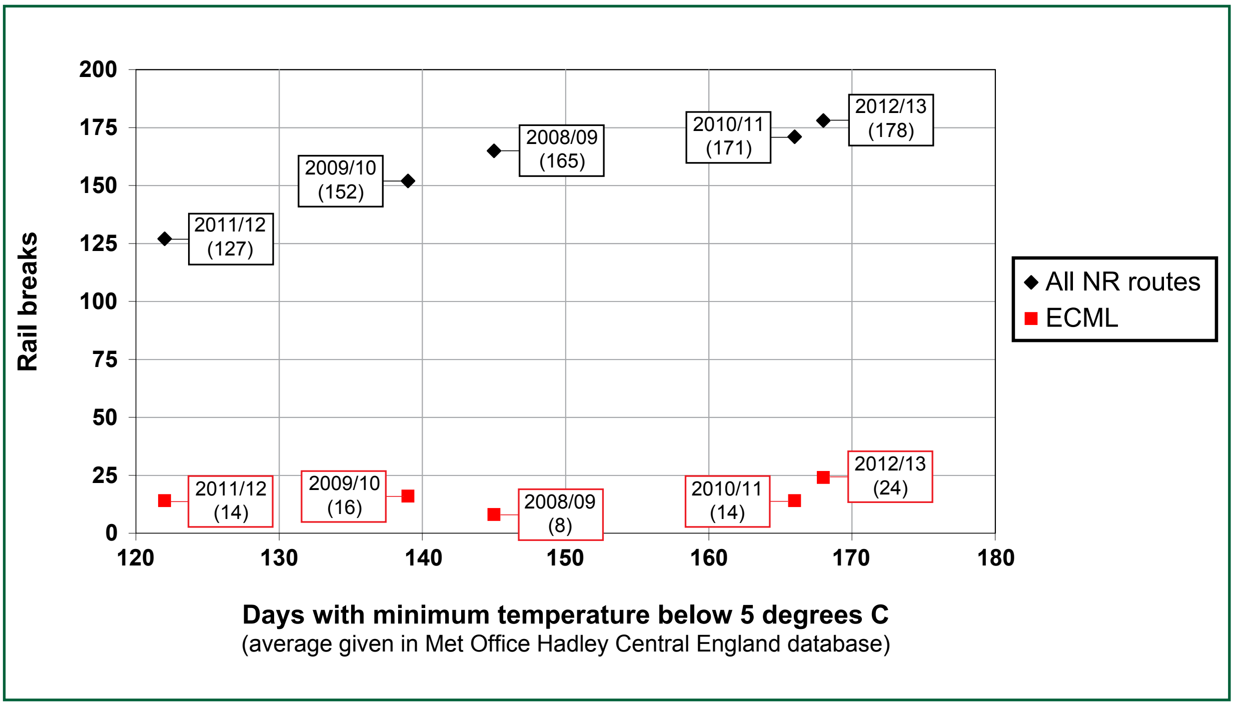
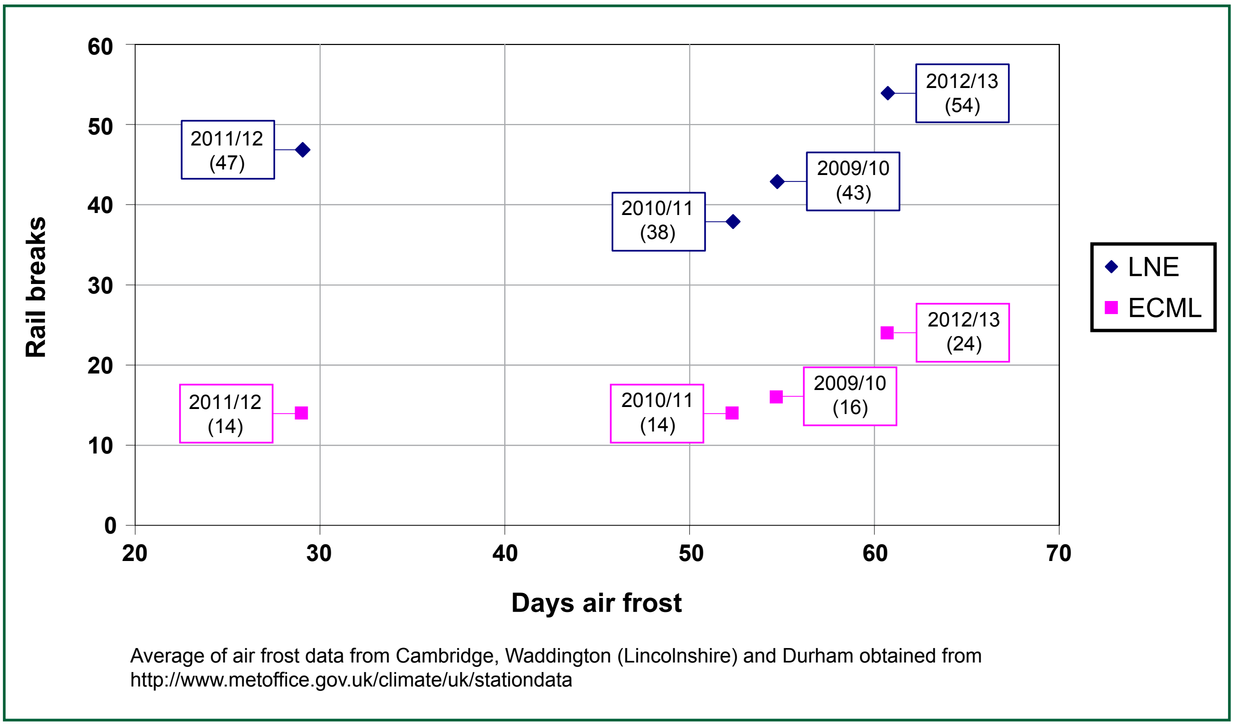


Figure 14: Temperature effects on rail breaks



Average of air frost data from Cambridge, Waddington (Lincolnshire) and Durham obtained from http://www.metoffice.gov.uk/climate/uk/stationdata

Figure 15: ECML rail break relationship with eastern England temperature

Rail break distribution across Network Rail infrastructure

43 The RAIB has considered whether the occurrence of rail breaks on the LNE route, and particularly on the ECML, is consistent with occurrences elsewhere on Network Rail infrastructure. The RAIB has compared occurrences on different routes but has concentrated on comparing the ECML with the West Coast Main Line (WCML, part of London North Western route (LNW)) and the Great Western Main Line (GWML, part of the Western route) because all these main lines carry large amounts of traffic comprising a mix of fast passenger, slow passenger and freight trains. Although both the East Coast and West Coast Main Lines include portions in Scotland, these portions are not included within the ECML and WCML rail break data presented in this report. This is because these portions are maintained by Network Rail's Scotland Route and are included in the rail break statistics for this route.

44 There were 629 rail breaks on Network Rail infrastructure in the four year period from April 2009 to March 2013. Of these, 186 breaks occurred on the LNE route, more than on any other route. The number of rail breaks on the LNE route exceeded those on all other routes in all of these years except in 2010/2011 when London North Western had more (figure 16). The number of rail breaks on LNE increased from 38 in 2010/2011 to 47 in 2011/12 and to 54 in 2012/13. When considering this increase, it should be noted that the number of breaks on other routes also show significant fluctuations and that the amount of rail traffic was increasing throughout this period (paragraph 49).

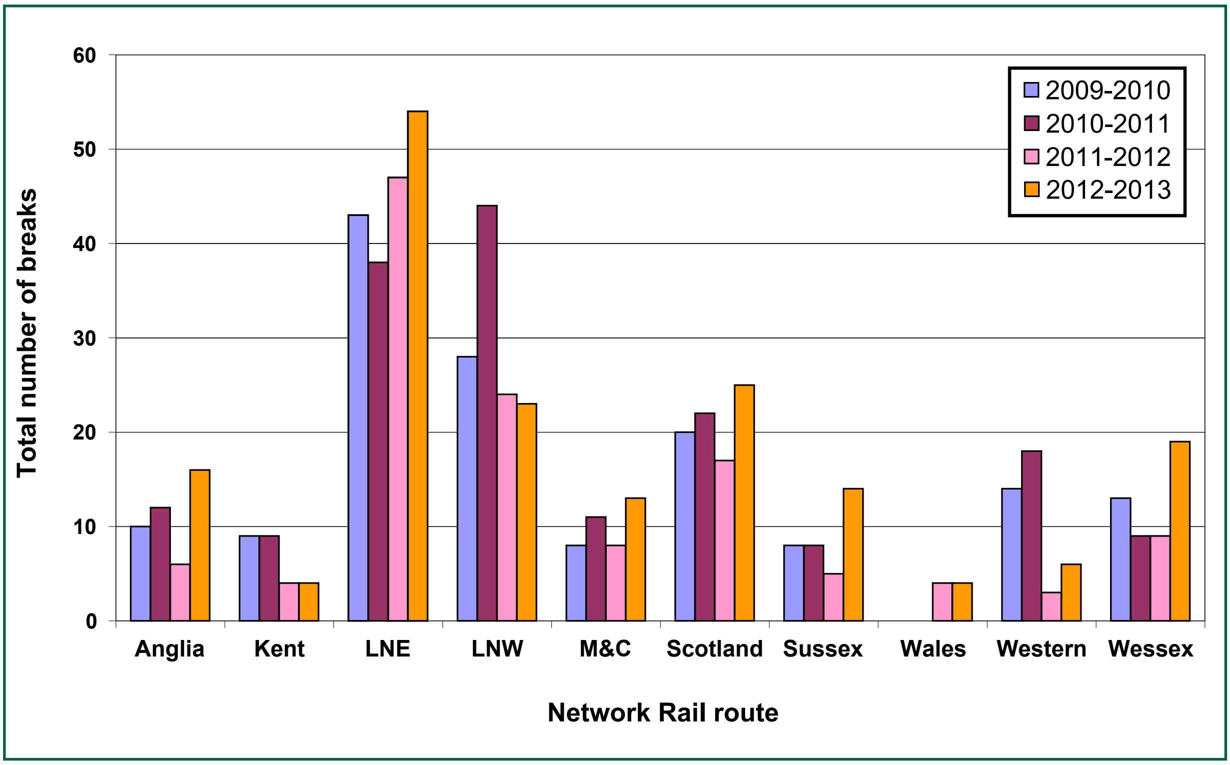


Figure 16: Rail breaks 2008 to 2013, all Network Rail routes

45 The rail break data has been normalised to allow for differing lengths of track and differing current track usage to allow a better comparison of data for different routes. Differing current usage is represented by *equivalent million gross tons per annum* (EMGTPA). This unit of measurement reflects the number of axles passing over a section of track, the increased wear associated with increased speed, and the effect of axle weight (an axle carrying 20 tonnes causes more track wear than two similar axles each carrying 10 tonnes). However, the methodology for calculating EMGTPA, described in appendix D, does not precisely model all train characteristics.

46 Since track usage varies across each route, this report uses representative EMGTPA values calculated by Network Rail for each route or main line. The EMGTPA values used in this report relate to traffic patterns in 2011, the mid-point for the 2009/13 period for which rail break statistics have been analysed. This value does not necessarily reflect the historical traffic patterns (often more freight and less passenger traffic) which will have been experienced by older rails.

47 The normalised data for all Network Rail routes is presented in figure 17 in terms of breaks per billion tonne kilometres[4]. Averaged over the four year period from 2009 to 2013, the LNE route (including the ECML) has the highest number of breaks (1.45 per billion tonne kilometres) with Scotland (1.40 breaks per billion tonne kilometres) being the next highest and most routes lying in the range 0.53 to 0.83 breaks per billion tonne kilometres.

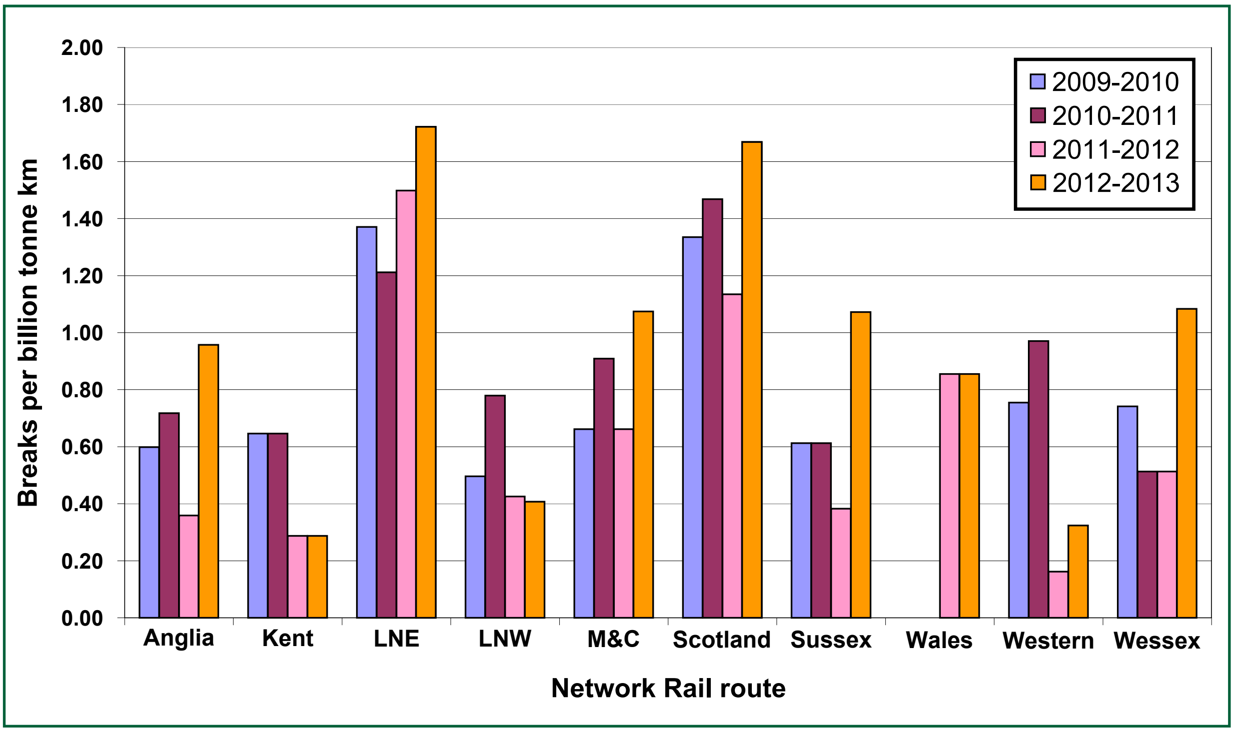


Figure 17: Normalised rail breaks 2009 to 2013, all Network Rail routes

48 Similar data covering only the three main lines is shown in figure 18. This shows that, averaged over the four year period, rail breaks on the ECML were significantly more common than on WCML and GWML (0.58, 0.34 and 0.20 breaks per billion tonne kilometres respectively). All these values are significantly lower than the average values for other lines in the same routes (paragraph 47).

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[4] (number of rail breaks) / (track length x EMGTPA).

49 It is probable that some of the variation between successive years is a consequence of changes in the amount of rail traffic which are shown on figure 19. Traffic levels were generally increasing from 2009 to 2012, a feature which would tend to increase the likelihood of rail breaks.

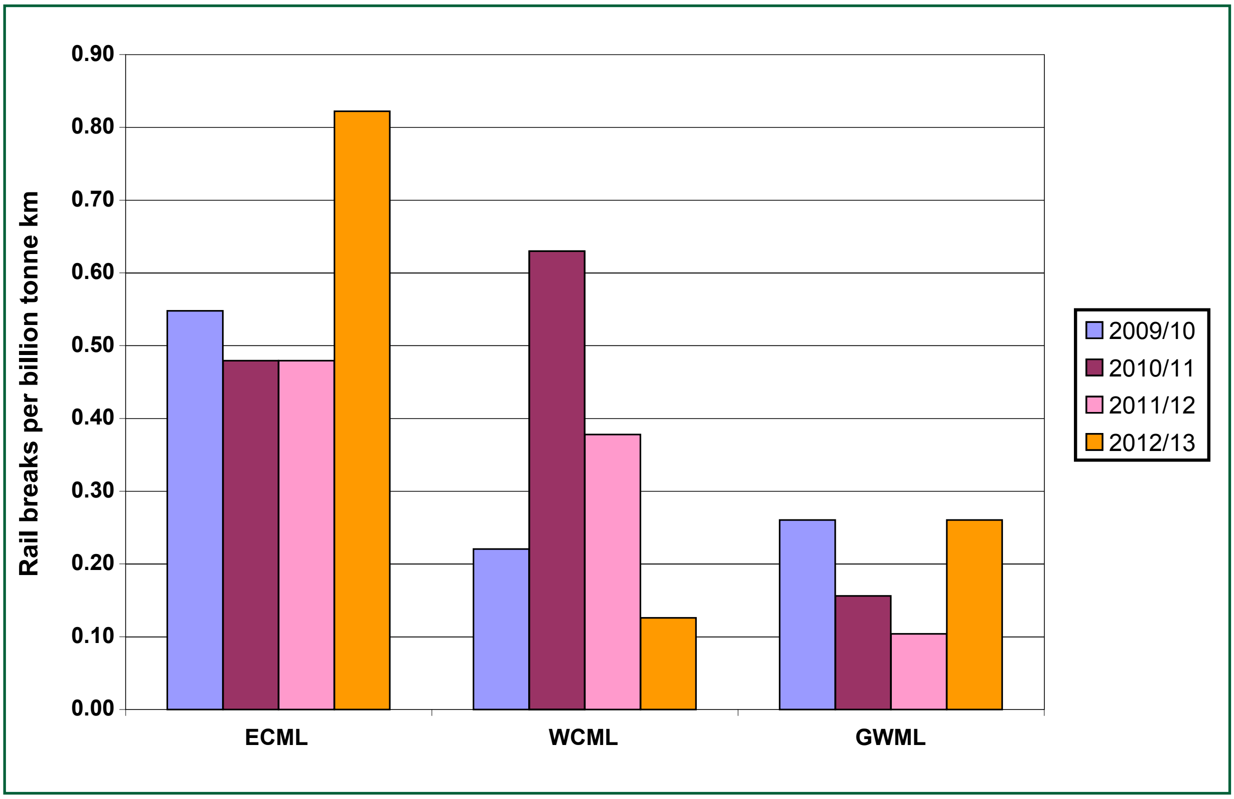

Figure 18: Mainline rail breaks (normalised)

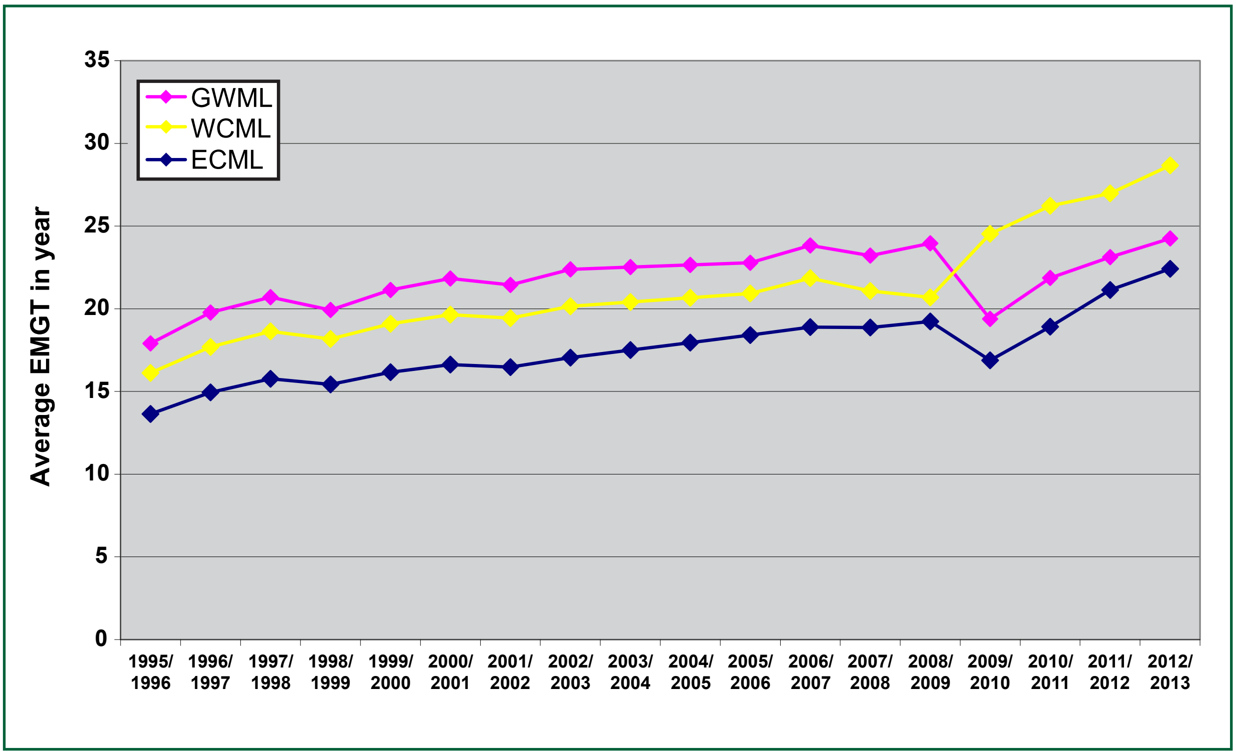

Figure 19: Mainline traffic

Track age

50 Rail breaks are more likely to occur in areas of older track for the following reasons:

- Metal rails and welds can be gradually weakened by the fatigue effect caused by repeated application and removal of train loads. This is a normal characteristic of steel and the risk can be mitigated by appropriate allowances in design and rail/weld replacement strategies.
- Rail pads, located between rails and sleepers, become worn and this reduces their ability to cushion the rail when train loads are applied.
- Support from the trackbed deteriorates when the individual stones within the ballast break into smaller particles.
- The absence of an effective drainage system, or the lack of adequate drain maintenance, leads to excessive amounts of water in, or on, the ground and thus poor track support due to:
  - contamination of the ballast by soil particles washed into the gaps between the stones which form the ballast; and/or
  - loss of strength, thus increased settlement, of the soil beneath the ballast.
- Increased corrosion causes larger numbers of corrosion pits, and thus a greater likelihood of a rail break being initiated.
- Older track includes components which have not benefited from recent improvements in manufacturing techniques and/or recent improvements in understanding system requirements (eg thicker rail pads and modified rail production techniques which result in fewer defects and less *residual stress*, thus a lesser likelihood of cracks developing, in the rail foot).
- The cumulative amount of traffic carried increases as track becomes older.

51 Network Rail has compared the age of existing rails, sleepers, ballast and other trackwork components with the design life given in standard NR/L2/TRK/2102 to estimate the proportion of the track life which has been expended within each route. Data for each Network Rail route, plotted in figure 20, shows a tendency for a greater frequency of rail breaks per billion tonne kilometres on routes with older track, an indicator that track age is a major influence on rail break occurrence. However, the wide scatter on the graph also suggests that track age is not a complete explanation of rail break occurrence.

52 The graph shows that LNE route has the greatest occurrence of rail breaks and is amongst the routes with the oldest track. Rail break occurrence on the LNE route is notably higher than on the London North Western and Western routes. As all routes contain a significant length of secondary lines, the RAIB has made a more detailed study of data relating only to the main lines (ECML, WCML and GWML).

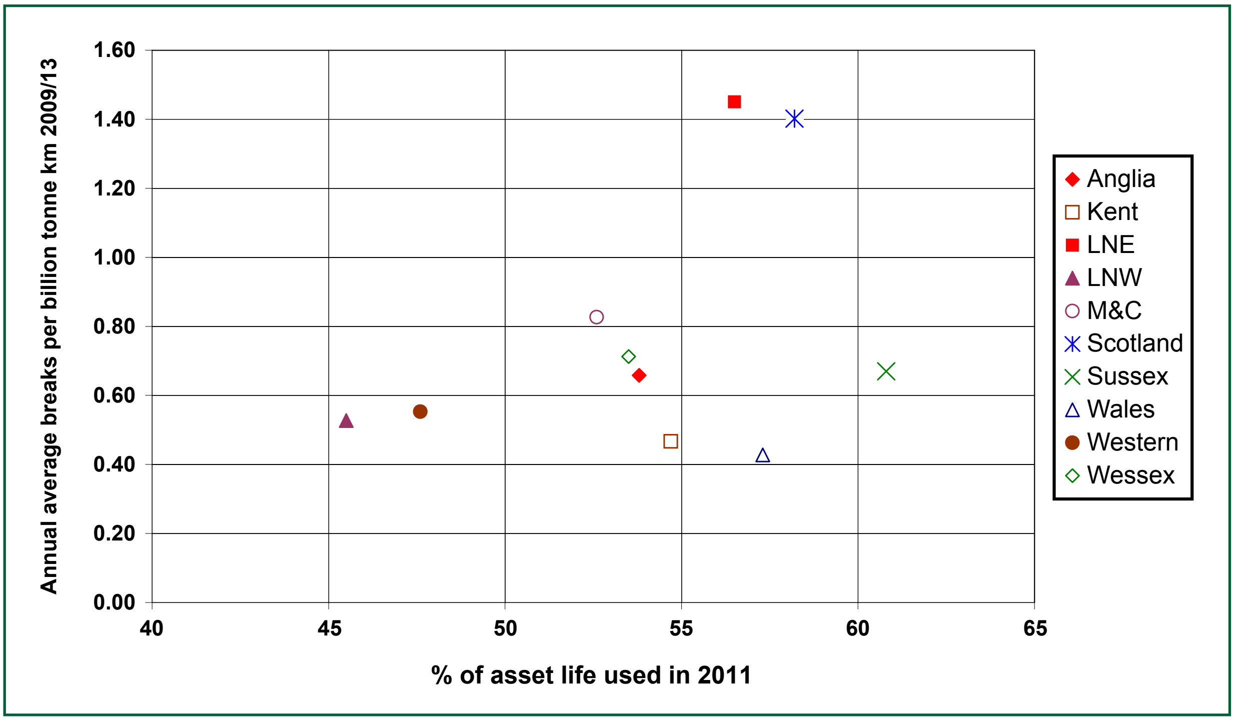

Figure 20: Route track asset used compared to rail breaks

53 Considering track used life in 2011, the mid-point of the 2009 to 2013 period covered by the rail break statistics, approximately 53% of the track life had been used on ECML compared to 42% on WCML and 38% on GWML. The data plotted in figure 21 suggests an increased likelihood of rail break occurrence as the proportion of track used life increases. The asset used data reflect the substantial amount of track renewal work carried out on WCML and GWML between 1999 and 2007 together with subsequent renewal work which maintained an approximately steady state age profile on these lines until (and beyond) 2011. Renewal work on ECML between 1999 and 2011 was insufficient to maintain steady state conditions and the proportion of track asset used rose from 43% to 53% (figure 22).

54 A similar pattern is apparent when rail age is considered. The increasing average age of rail on ECML, and the decreasing age on WCML and GWML, from 1999 to (and beyond) 2011 is presented in figure 23. This shows that, in 2011, the ECML average rail age was 22 years with corresponding values of 16 years on the WCML and 14 years on the GWML. The correlation between increasing rail age and increasing rail break occurrence is shown on figure 24.

55 Further evidence of the effect of rail age is provided by considering the relationship of rail breaks to rail age on the LNE route (figure 25). This shows a tendency for a lesser occurrence of breaks in newer rail using data unaffected by any differences between operation and maintenance practices on different routes. The value plotted for pre-1952 rail is unlikely to reflect performance of rail carrying significant amounts of traffic. It relates to only 2% of the route length and probably relates to rail in lightly used areas.

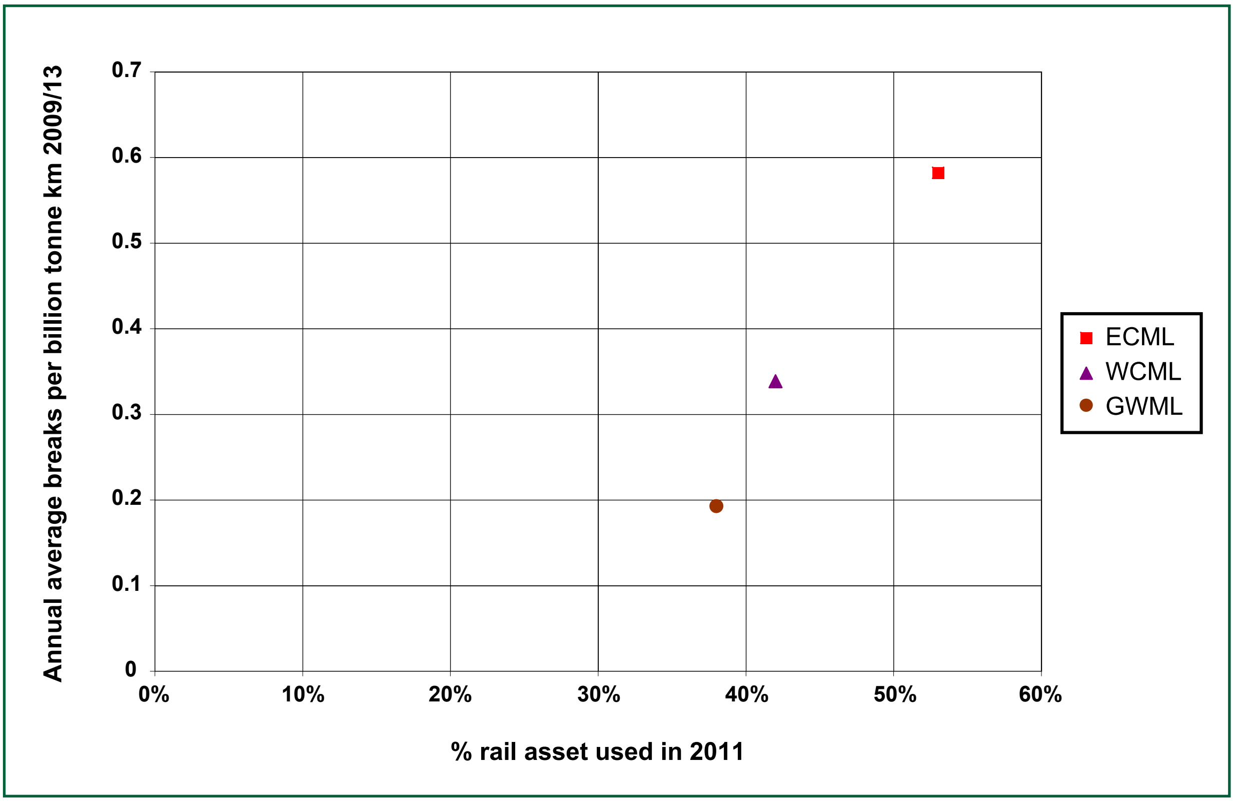

Figure 21: Mainline track asset used compared to rail breaks

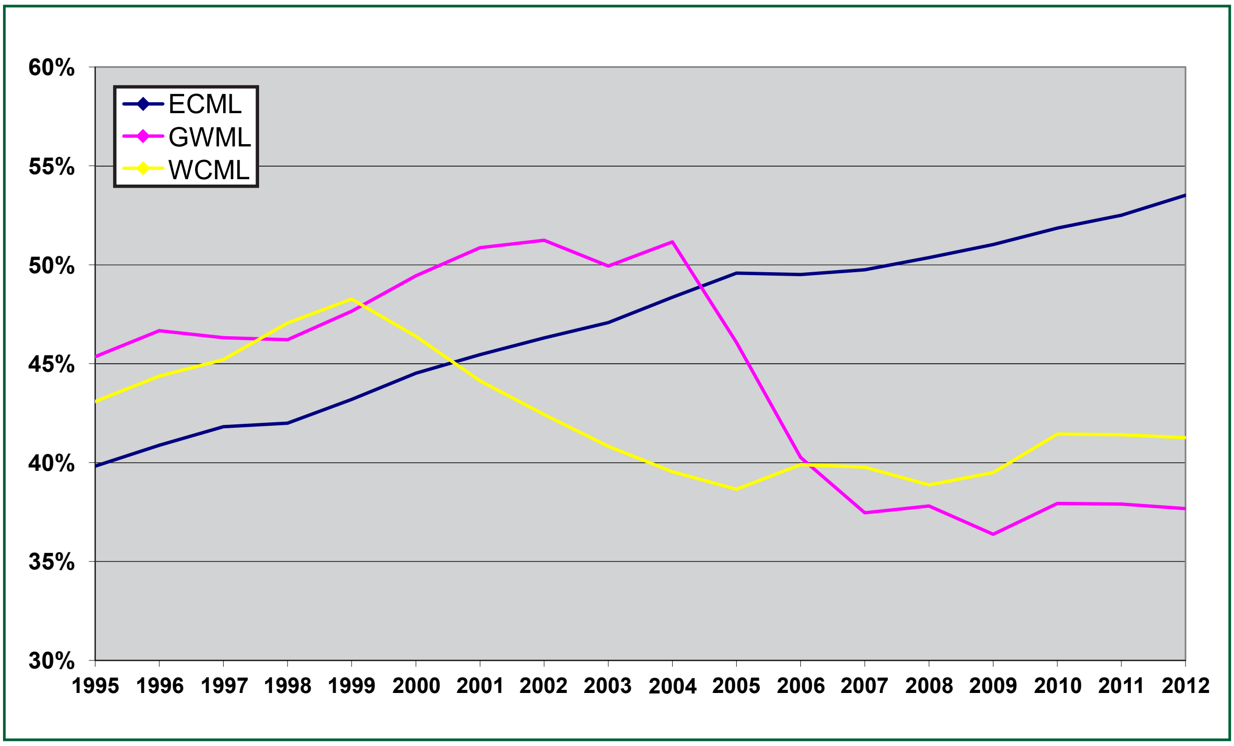

Figure 22: Mainline track life used 1995 to 2012

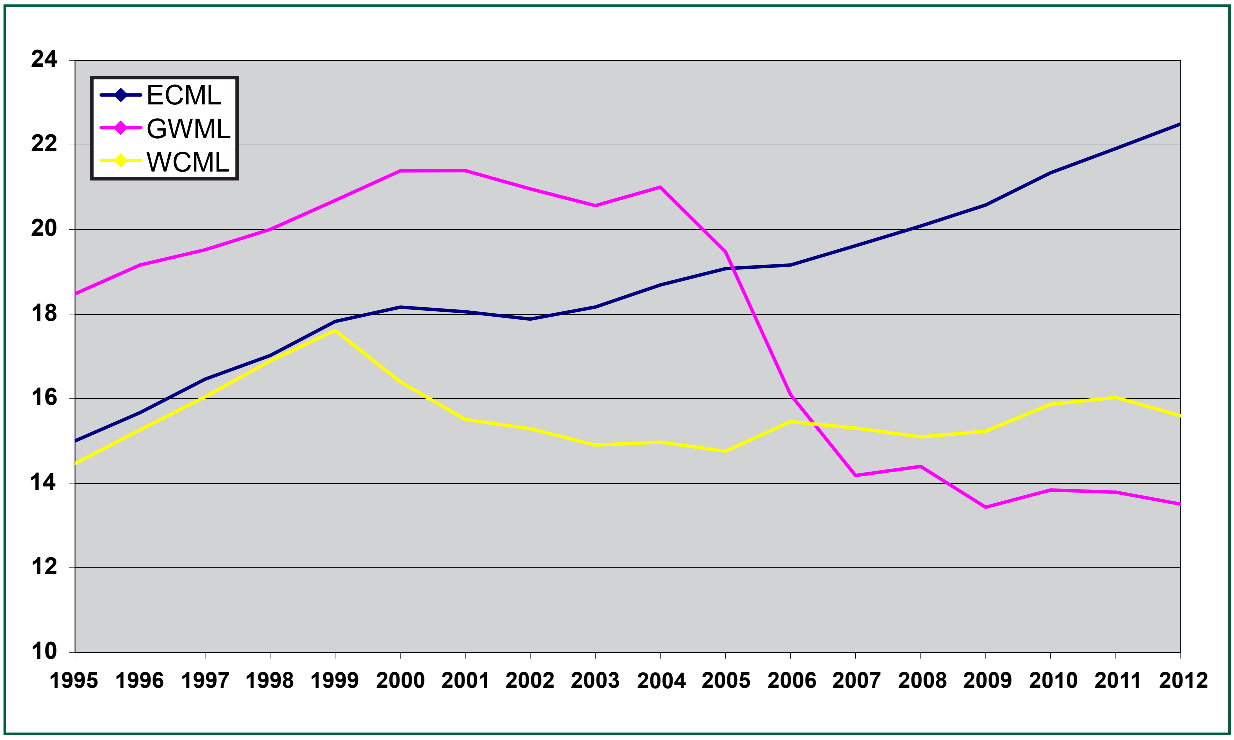

Figure 23: Mainline average rail age 1995 to 2012

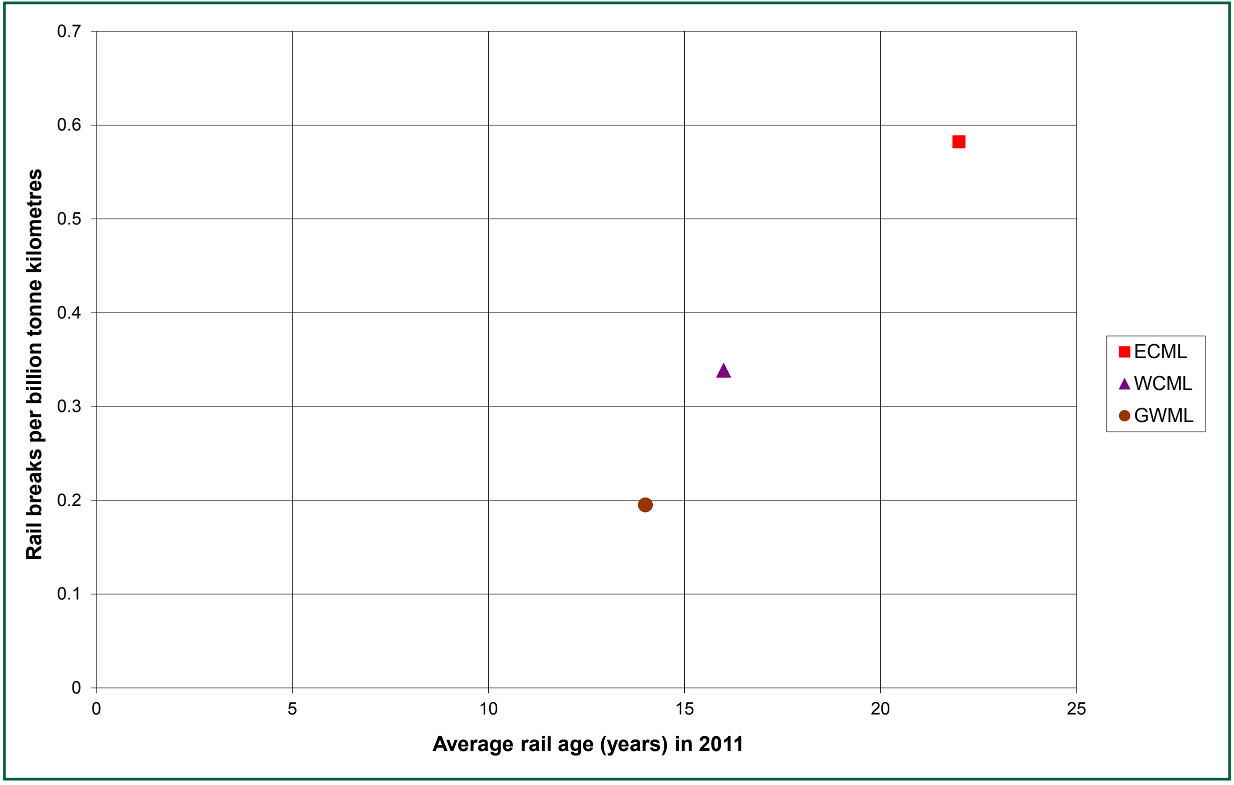

Figure 24: Mainline rail age compared to rail breaks

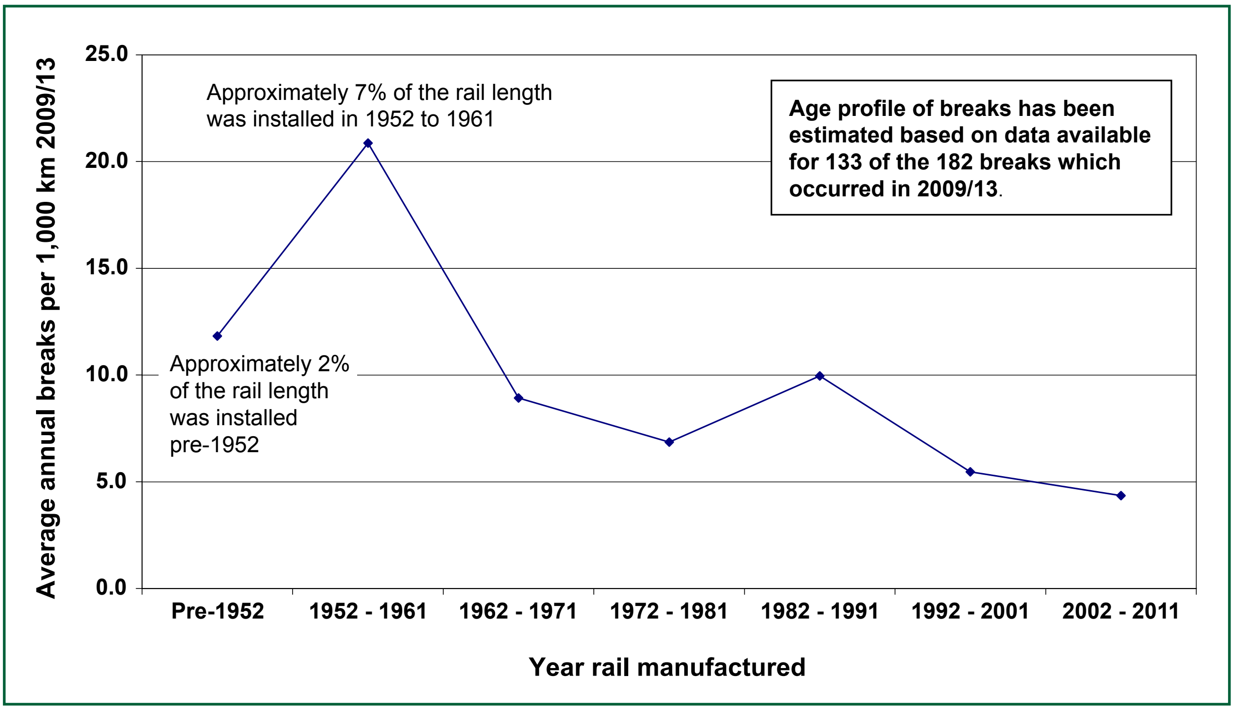

Figure 25: LNE rail breaks related to year of manufacture

56 It is certain that track age (including both rail age and the age of other track components) is a significant factor in the higher occurrence of rail breaks on ECML compared to WCML and GWML. Although there is insufficient statistical data to determine the precise extent to which other factors affect occurrence, the RAIB considers track age to be the most significant factor.

57 Although replacement of rails and other trackwork components forms part of Network Rail's plan to deal with the relatively high level of rail breaks on the ECML (paragraph 128), substantial lengths of older track will remain in use for a significant period of time during which it will require appropriate mitigation against rail break risk. This is illustrated in figure 23 which shows that the average age of main line rails remained at approximately 17 years between 2002 and 2012.

58 Given the on-going need to manage rail break risk, the RAIB has reviewed key aspects of Network Rail's rail break management strategy on the ECML to identify possible safety learning applicable to both this line and the wider rail network.

Management of rail breaks

Rail break principles

59 Most rail breaks are caused when relatively high loads are concentrated into small areas of the rail leading to very high stresses which cause cracking of the rail. In most instances a single loading is insufficient to cause an immediate failure of the rail. It is more usual for a single loading to either initiate a very small crack or cause a small increase in the size of an existing crack (fatigue cracking). The rail only breaks when the concentration of stress at the tip of the crack exceeds the steel strength and a brittle fracture occurs.

60 Cracks are normally initiated at a location where a defect or localised weakness acts as a stress concentration feature. This can be a surface irregularity, such as an irregularity on the edge of a bolt hole, a pit caused by surface corrosion, or a defect within a rail or weld. The mechanism is illustrated in figure 26.

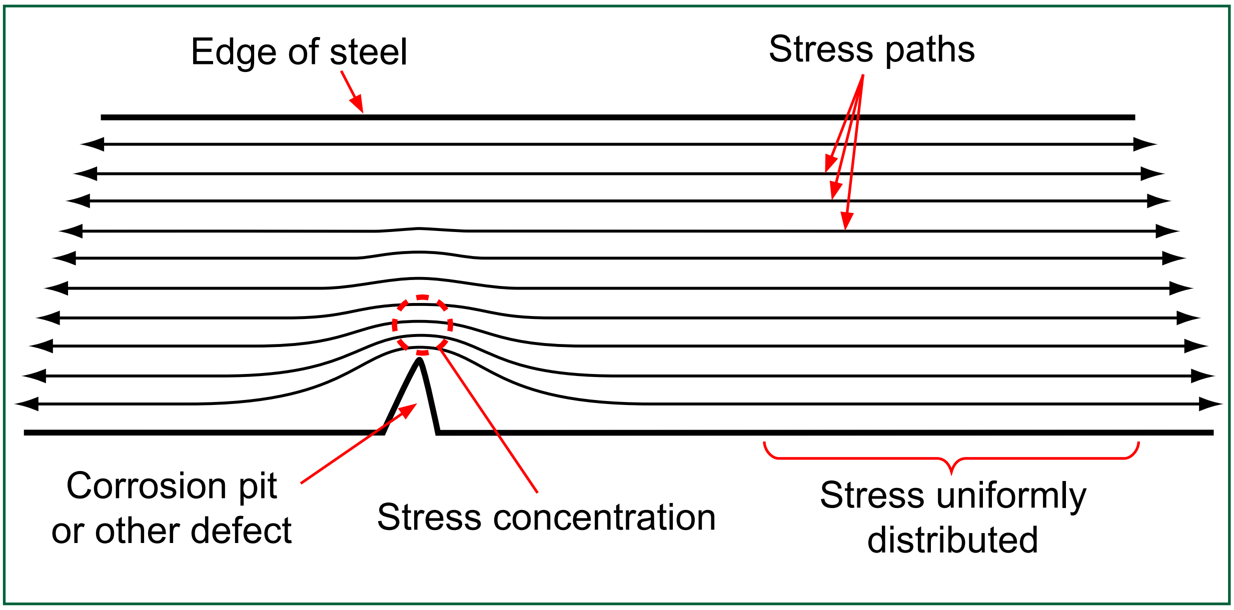

Figure 26: Stress concentration feature

61 Corrosion is an important factor because it can lead to corrosion pits which are usually small but act as stress concentration features. A concentration feature is normally required before a break occurs because the amount of uncorroded rail is normally sufficient to carry the applied loads if these are distributed uniformly through the uncorroded rail. Increasing corrosion causes increasing numbers of corrosion pits and thus a greater likelihood that the shape and location of a corrosion pit will lead to initiation of a fatigue crack. The significance of corrosion in the context of particular rail break mechanisms is described in paragraphs 64 onwards.

Types of rail break

62 Rail breaks are classified by Network Rail based on the location of the break. Most are classified as occurring in the rail head, the rail foot, at a weld joining two pieces of rail, or at the end of a rail where fishplates join two rails (figure 27).

63 The distribution of breaks by type is shown in figure 28. The distribution is generally similar for the ECML and the WCML. The GWML has a greater proportion of breaks at welds and considerably lower proportion of breaks in the rail foot compared to the ECML. The RAIB has not established the reasons for this and further investigation of this issue is unlikely to affect the recommendations made in this report.

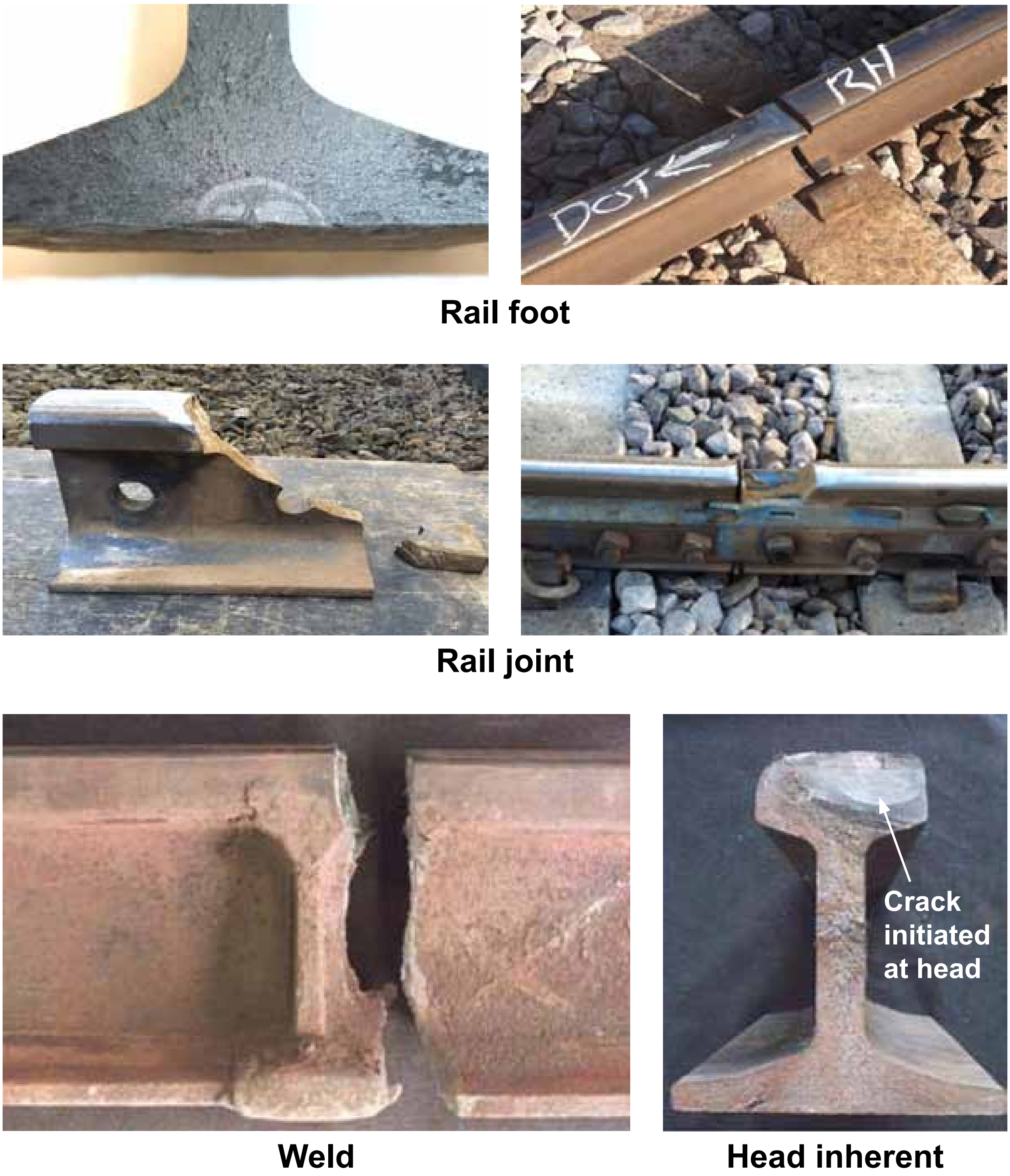

Figure 27: Examples of rail breaks

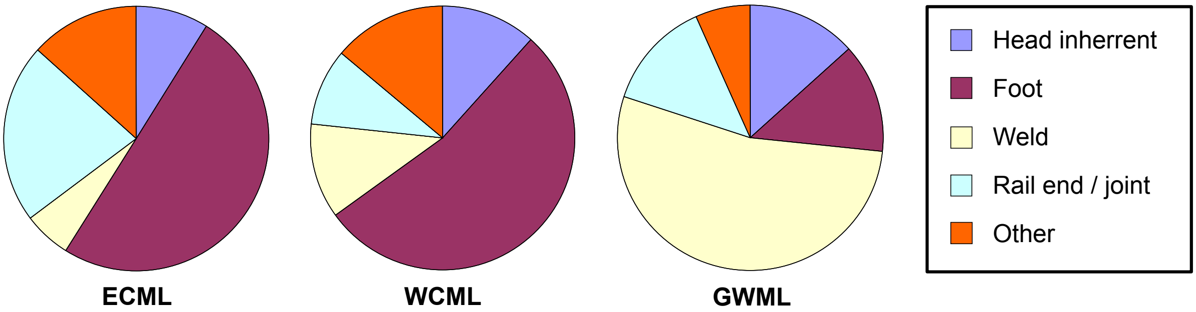

Figure 28: Distribution of rail break types

Rail foot breaks

64 The mechanism causing rail foot breaks is illustrated by the Corby Glen rail break (paragraphs 9 to 15). The following factors make rail breaks of this type more likely (not all factors are necessarily present at every rail foot break):

- Degradation or missing rail pads resulting in:
  - loss of the cushioning effect intended to reduce the short term (impact) loads which can occur when rails transfer wheel loads onto sleepers;
  - high stresses in the rails at the points where they impact against the rough surface of concrete sleepers.
- Degradation or missing rail pads resulting in loss of support to the rail at one sleeper and thus increased tensile stresses on the underside of the rail because the rail is required to transfer load to adjacent sleepers.
- Degradation of rail pads which results in corrosion due to water accumulating within pad debris and thus in contact with the underside of the rail.
- Older welds resulting in a dip in the rail head which causes a bouncing effect on wheels as they pass over and thus localised increases in vertical wheel loadings, with an increased rail break risk, a short distance after the weld.

65 Network Rail standard NR/L2/TRK/001(modules 3 and 5) requires replacement of rail pads where necessary with section managers (track) being responsible for identifying missing or ineffective pads during their quarterly visual inspections of the track. However, although missing pads can be observed during inspections, degraded pads cannot always be identified as the area visible to inspection staff can appear to be intact (figure 29) when the area beneath the rail is degraded. Network Rail is investigating whether equipment, already fitted on the UTU to assess the shape of, and any movement of, the rail head, can be used to identify areas where the rail has moved from its expected position. Such movement can be due to lack of support from worn or missing pads. Replacement of pads forms part of Network Rail's plan to deal with the relatively high level of rail breaks on the ECML (paragraphs 128 and 129).

66 As older rails are more likely to contain defects for reasons explained at paragraph 84, replacement and repair of the older welds associated with dip defects forms part of Network Rail's plan to deal with the relatively high level of rail breaks on the ECML (paragraphs 128 and 129).

67 Fatigue cracking in the foot of the rail is often a precursor to a rail foot break but the position of these cracks means that their detection is beyond the capability of current routine UTU testing and is not required by the Network Rail standards relating to the UTU. The reasons for this are given in paragraph 96 and possible enhancements allowing detection of rail foot cracks by the UTU are described in paragraph 129. Pedestrian ultrasonic test equipment, pushed along the track by a walking operator, is capable of finding cracks in the central part of the rail foot, but most track is not routinely tested in this way (paragraph 90).

Figure 29: Rail pads in (a) new condition, (b) worn condition and (c) fitted beneath rail

Rail end/joint breaks

68 Rail end breaks occurred at both Copmanthorpe and Hambleton (paragraphs 16 and 27) and the differing crack patterns at these locations illustrate how the the exact failure mechanism can vary between different locations. The common factors which increase the risk of rail end breaks are:

- loss of support from ballast underlying sleepers leading to *dipped joints* and thus increased stresses on the rail joint (management of dips is discussed at paragraph 72);
- rail joints, particularly joints bolted together on site, having the potential to work loose allowing differential movement between components, with associated impact loadings when components hit each other; and
- corrosion pits acting as stress concentration features (a feature which can govern the exact location at which cracking starts).

69 Fatigue cracking is often a precursor to rail end breaks but cannot normally be seen during a visual inspection because the cracks are small and often obscured by fishplates. The cracks are sometimes too small to be detected by ultrasonic means (paragraph 94). However, the joint movement which causes many of these cracks can often be detected (paragraph 72).

70 Insulated block joints can be made up on site or under factory conditions. If made off site, two short lengths of rail are joined together in carefully controlled conditions to form a joint which is stronger than one made on site (reasons for this include a greater accuracy when drilling bolt holes, better preparation of metal surfaces by grit blasting, including a cold expansion process when forming bolt holes, and control of both temperature and humidity while adhesive cures). Factory made joints are now generally preferred by Network Rail and are installed by replacing a length of existing rail, or an existing joint, with the factory made component. The outer ends of this component are welded to the adjacent sections of track giving a robust connection (figure 30).

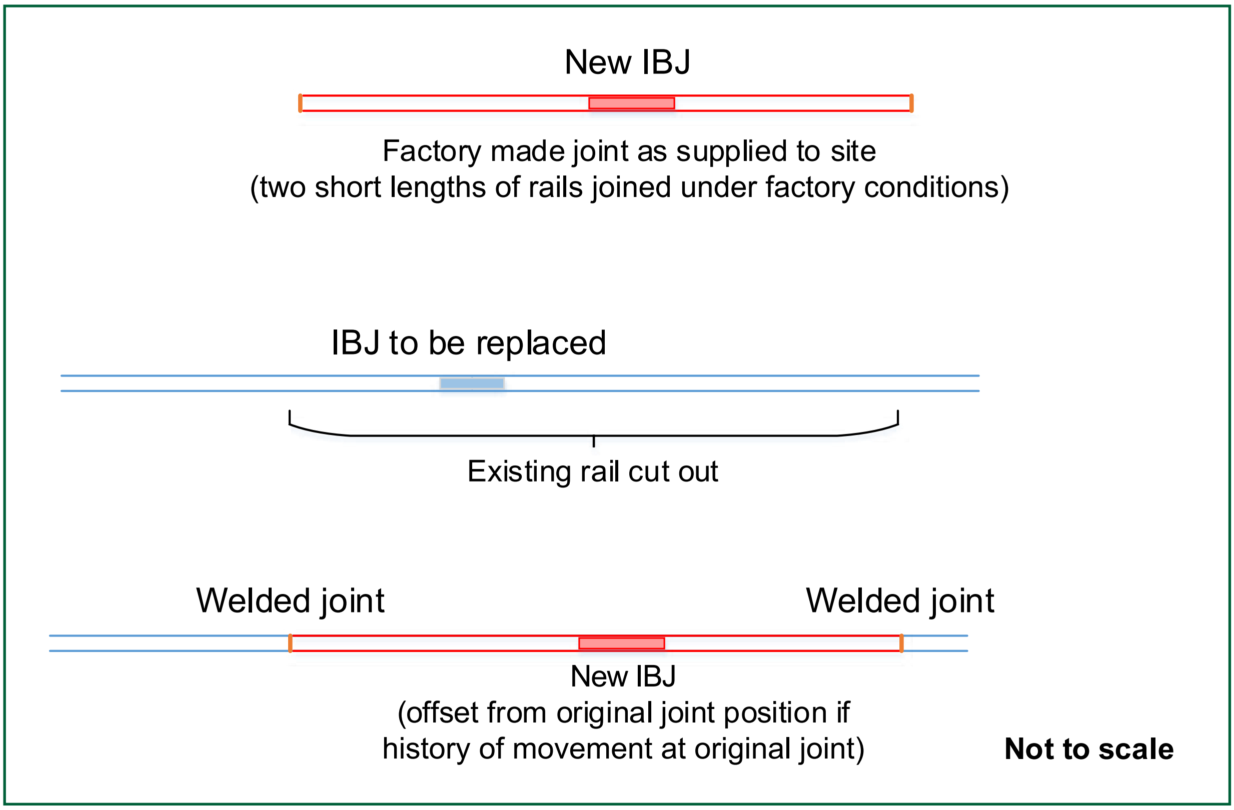

Figure 30: Installing factory made insulated block joint (IBJ)

71 Replacement of site made joints with factory made joints, and elimination of unnecessary joints such as the Hambleton insulated block joint (paragraph 28), forms part of Network Rail's plan to deal with rail breaks on the ECML (paragraph 128).

Managing joint dip

72 Effective track maintenance regimes should reduce the likelihood of poor support from underlying ballast. Monitoring joints for deformation due to lack of support (commonly known as joint dip) provides early warning of the potential for rail breaks. Network Rail considers such monitoring to be more effective than ultrasonic testing as a means of preventing rail breaks near joints. However, the Copmanthorpe and Hambleton incidents show that dip values at which action is required by Network Rail standard NR/L2/TRK/001 do not always achieve the intervention needed to rectify joint dip before a rail break occurs. A post-accident modification to this standard introduced requirements which, if correctly implemented, would have prevented the Copmanthorpe incident (paragraph 79).

73 Network Rail standard NR/L2TRK/L2/001/mod11, ‘Inspection and maintenance of permanent way’, version 5 was applicable at the time of all three incidents detailed in this report. This, and version 6 which applied from 2 February 2013, require the actions shown in table 2 to be taken in response to dips found on track with a maximum line speed of 90 mph and above (the line speed category applicable at all three incidents). Dips are measured as shown on figure 31.

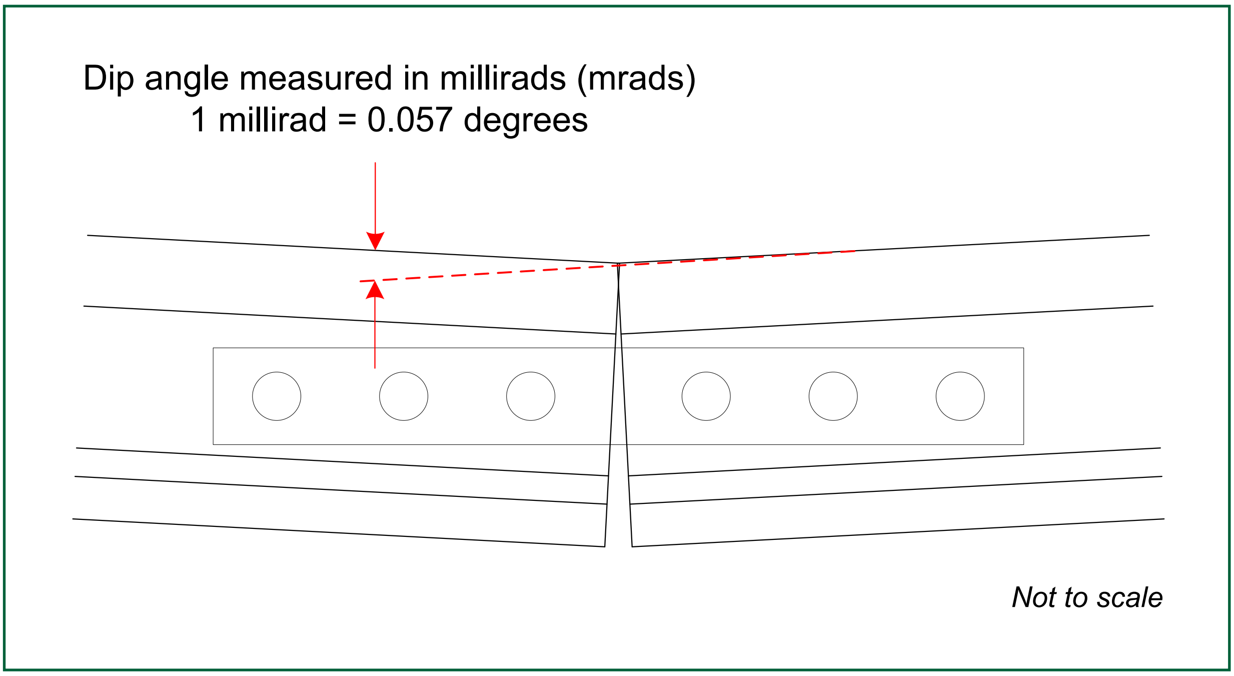

Figure 31: Dip angle measured at dipped joint

74 Joint dip angles at Copmanthorpe and Hambleton were generally recorded by the track geometry recording train at four weekly intervals before the broken rails were discovered. The recording intervals were in accordance with Table 1 of Network Rail standard NR/L2/TRK/001/mod11 which requires a ‘normal planning interval’ of four weeks and a ‘maximum interval’ of ten weeks. The results are shown on figure 32.

Dip Angle (mrads)	*Inspect*	*Initial Action*	*Ultrasonic Test (bolt holes & rail ends only)*	*Remedial Action (version 5)*	*Remedial Action (versions 4 & 6)*
≥ 30	Within 14 days	Apply control measures [1]	Within 4 weeks	Repair [2A] / replace joint within 13 weeks	Repair [2B] / replace joint within 13 weeks
≥ 40	Within 7 days	Apply control measures [1]	Within 7 days	**Repair** [3,4] joint within 4 weeks	**Replace** joint within 4 weeks
≥ 50	Within 7 days	Apply control measures [1]	Within 7 days	**Repair** [3,4] joint within 14 days	**Replace** joint within 14 days

Notes:

1. These may include enhanced visual inspection, speed restriction or remedial maintenance such as lifting and packing.

2A. If dip angle exceedance is previously repaired joint, action should be replace.

2B. If the dip angle exceedance is a repeat fault, ‘replace’ may be the most appropriate option.

3. Network Rail’s briefing note for version 6 states that ‘repair’ (version 5) was changed to ‘replace’ (version 6) as a ‘clarification’. Version 4 had stated ‘replace’.

4. Options for repairing dips at insulated block joints were limited for reasons explained in paragraph 78.

Table 2: Dip action requirements (extracts from Network Rail standard NR/L2TRK/L2/001/mod11)

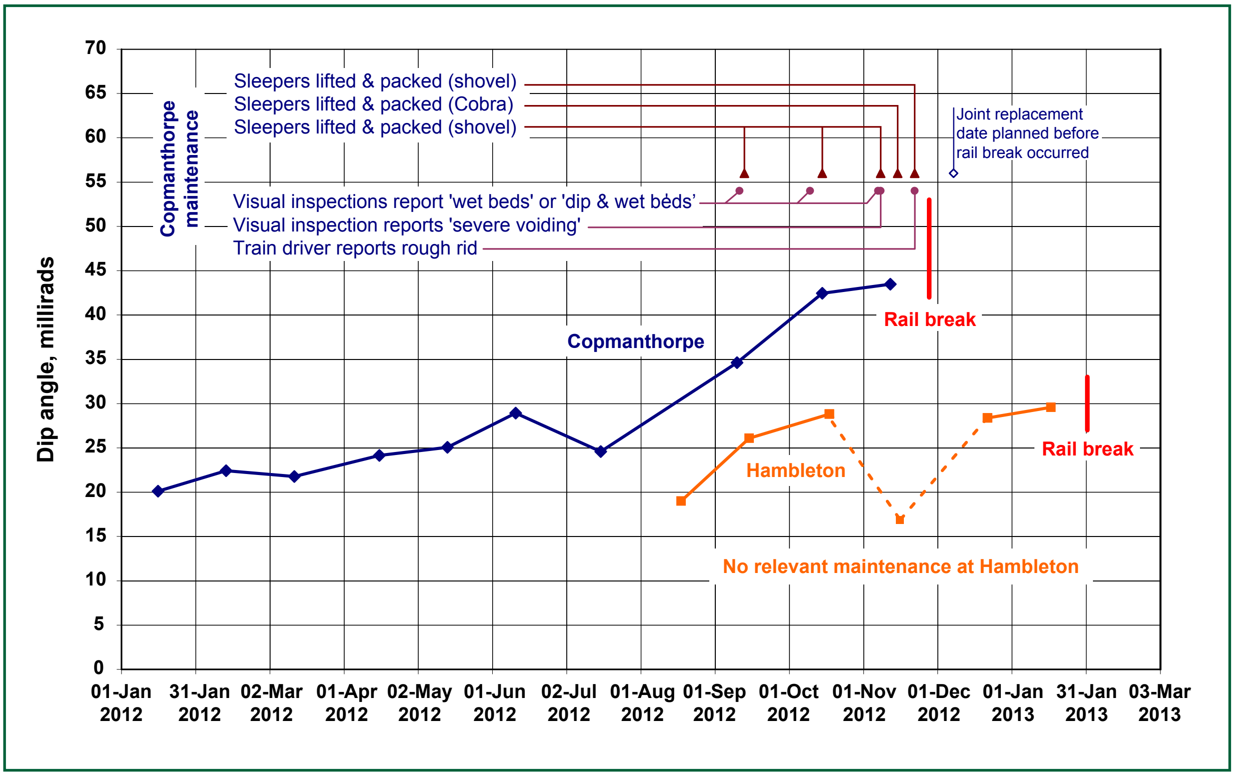

Figure 32: Dips at Hambleton and dips plus maintenance at Copmanthorpe

75 The dip values at Companthorpe exceeded the 30 mrads action limit when measured on 10 September, 15 October and 12 November, the last three occasions that measurements were taken before the broken rail was discovered. On each occasion, the track was lifted and packed within three days. The track was also lifted and packed on two other occasions in October and November after visual inspections identified the dip. All lifting and packing was carried out using shovel packing except one instance in November when powered hand tools were used (Table 1).

76 Lifting and packing entails raising the track with jacks and then using shovels to move pieces of stone forming the ballast under the sleepers. Depending on the condition of the ballast and the underlying ground, the rail alignment can then again deteriorate rapidly as the pieces of stone moved under the sleepers get pushed down under the weight of passing rail traffic. In this instance, repeated recurrence of the dip indicated that this type of movement was occurring at the joint with the associated risk of a rail break.

77 As a result of the joint dip measured by the track geometry recording train on 10 September 2012, maintenance staff ordered a replacement joint and planned to install this on 8 December 2012. The replacement joint was already on site when the broken rail was discovered ten days before the planned replacement date. Version 5 of standard NR/L2/TRK/001 was current at this time and required joints to be repaired within four weeks if the track geometry train measured a dip exceeding 40 mrads. The lifting and packing undertaken after each geometry recording train run reporting such dips met the requirements of the standard.

78 Witness evidence states that lifting and packing was the only practical repair option for the insulated block joint at Copmanthorpe. Rail straightening is permitted at some dipped joints but not at those with insulated block joints (standard NR/L2/TRK/001/mod04, version 5, section 9). When joints are replaced at locations where dip recurs due to damage to the ballast and formation, as at the Copmanthorpe site, this issue is dealt with by replacing the existing joint with continuous rail and providing a new joint nearby at a location where better support from the ballast is expected.

79 Version 5 of standard NR/L2/TRK/001 was current from 1 September 2012 to 1 February 2013. The previous and following versions both required joints to be replaced within four weeks if measured dips exceeded 40 mrads. If this requirement had been applied when the dip of 42 mrads was measured on 15 October 2012, the old joint would have been replaced before it broke. The reinstatement of ‘replace’ in version 6 is described in the Network Rail briefing note for version 6 as a ‘clarification’.

80 The magnitude of dip measured by the track geometry recording train at Copmanthorpe should have triggered ultrasonic testing of rail ends and bolt holes using pedestrian equipment in accordance with the Network Rail requirements shown in Table 2. This testing did not take place, but it is unlikely that it would have identified any cracks as they were probably about 2 mm in size and thus too small to be detected with the pedestrian equipment (cracks smaller than 5 mm are not reported for reasons explained at paragraph 94). The omission of this test is discussed at paragraph 112.

81 The dip values recorded at Hambleton (figure 32) did not exceed the 30 mrads at which action is required by standard TK/L2/001/mod11 and no action was taken. However, the dip readings do show a generally increasing trend in the four months preceding discovery of the broken rail. Dip values less than 20 mrads are not routinely reported and values between 20 mrads and 30 mrads are not reported as requiring action. The RAIB has reviewed all geometry recording train dip measurements from August 2012 when a dip of 19 mrads was recorded. This increased to 26 mrads in September and then, with the exception of a 17 mrads measurement in November, gradually increased to 29.58 mrads in January, two weeks before the broken rail was discovered. An increasing dip angle at a joint indicates on-going movement at the joint with an associated risk of a rail break.

82 Evidence from Copmanthorpe and Hambleton shows that dip measurement data sometimes provides indications of a potential break. For this reason an enhanced response to dip measurements forms part of Network Rail's plan to deal with rail breaks on the ECML (paragraph 128 and 129). An enhanced response to dip measurement (reducing the dip value at which action is triggered) was implemented on the WCML in 2011 and Network Rail has stated that this has contributed to the subsequent reduction of rail breaks on this line shown in figure 18.

Rail weld breaks

83 Breaks at locations where rails are joined by welds were relatively infrequent on the ECML between 2009 and 2013. The average annual rate of occurrence of weld breaks was 0.034 per billion tonne kilometres, about 6% of all ECML rail breaks. This average was comparable to the WCML (0.039) and considerably lower than the GWML (0.104). Although weld breaks are relatively infrequent on the ECML, they represented about 21% of all rail breaks across the Network Rail infrastructure in 2012/13, a proportion which had reduced steadily from 34% since 2009/10.

84 Given the relatively low occurrence of weld defects on the ECML, the RAIB has not considered these in detail but notes that Network Rail has stated that it is taking action to replace the older welds as these have the greatest likelihood of containing a significant defect (paragraphs 85, 128 and 129). Characteristics which encourage breaks at welds include:

- poor preparation of the rail faces to be welded;
- the presence of moisture in the materials used for welding (resulting in a porous, thus weak, weld);
- poor control of environmental conditions during welding (eg allowing rapid cooling); and
- inclusion of slag (a weak material) which results in stress concentrations in the surrounding weld material.

85 Modern welding techniques and quality control procedures aim to address these issues, so Network Rail's strategy for reducing the occurrence of rail breaks includes replacement of older welds. Replacement of older and defective welds also addresses the formation of dips at welds which can cause a bouncing effect on wheels as they pass over the dip. This effect causes localised increases in vertical wheel loadings, and thus an increased rail break risk, in nearby sections of rail (paragraph 64).

Rail head inherent breaks

86 ‘Rail head inherent’ is a category used by Network Rail for the purpose of analysing rail break data and comprises all breaks from defects in the head of the rail such as squats, *tache ovale* and transverse defects from *rolling contact fatigue*. This type of break represented about 9% of ECML rail breaks between 2009 and 2013. The average annual rate of occurrence was 0.051 per billion tonne kilometres; greater than both the WCML and the GWML (0.039 and 0.26 per billion tonne kilometres).

87 Some rail head inherent breaks are associated with high localised stresses at the rail-wheel contact and these can be reduced by grinding the rail head to maintain a rail profile compatible with train wheels. Grinding is also generally intended to remove any zones of surface material within which cracking has started to develop, and which could cause the stress concentrations which encourage the development of larger cracks.

88 Replacing existing rails with new rails manufactured using improved techniques reduces the likelihood of sub-standard material being found in the rail head. This, and routine grinding, are included within the processes Network Rail is using to address rail break issues on the ECML (paragraphs 128 and 129).

Ultrasonic testing

89 Ultrasonic test equipment uses high frequency sound waves to detect cracks in rails. A transmitter applies energy to the surface of the rail and this spreads through the rail as ultrasonic waves. These waves are reflected if they encounter a crack or other discontinuity such as the underside of the rail. A receiver detects any reflected waves and this information is used to determine the position of any crack or other discontinuity.

90 Network Rail uses train mounted ultrasonic equipment (the UTU) and ultrasonic equipment mounted on a small trolley pushed along the rail by a person (pedestrian equipment). These are illustrated in figure 33. On most track, the UTU is used to identify areas of concern and pedestrian equipment, which travels much slower, is used to evaluate these areas in detail. Pedestrian equipment is also deployed at *switches,* at *crossings,* on lines not tested by the UTU and to investigate some locations where the track geometry recording train has identified dipped joints.

91 The UTU uses nine probes to direct ultrasonic waves towards different parts of the rail (figure 34). Six of these, designated the 70 degrees probes, are primarily intended to detect cracks in the rail head. Two, designated the 37 degrees probes, are intended to detect cracks in the rail head and the upper part of the rail web. The ninth, pointing directly downwards and designated the 0 degree probe, responds to cracks in the rail head and rail web. It also detects the waves which are normally reflected from the rail bottom and this can be used as part of the process to verify that the UTU is operating correctly[5].

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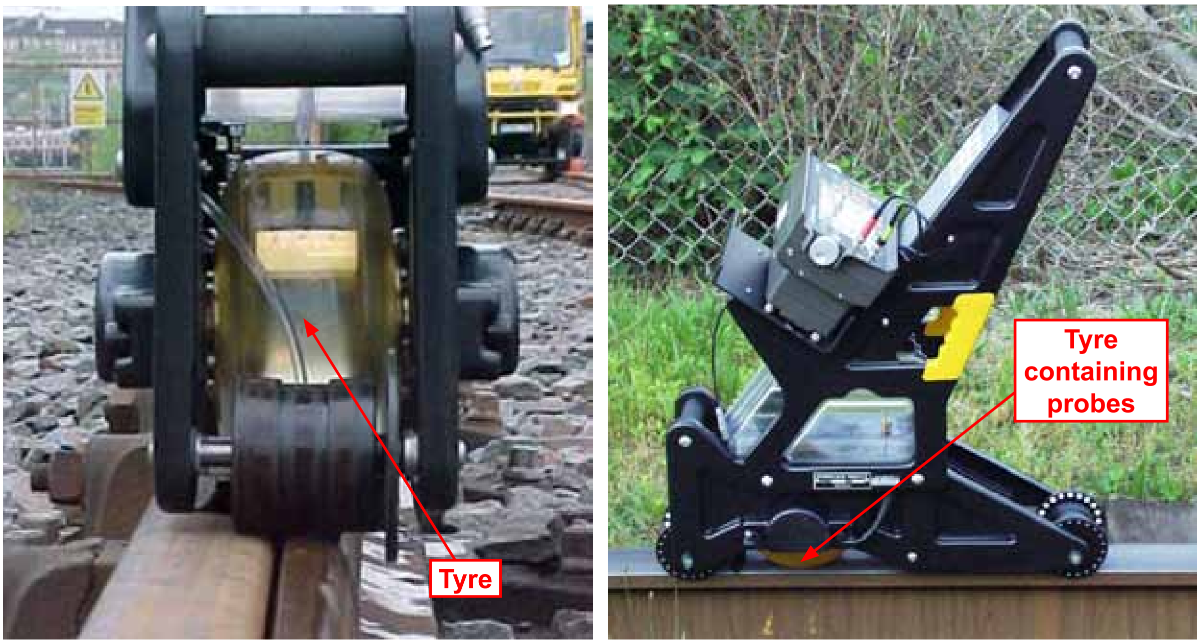
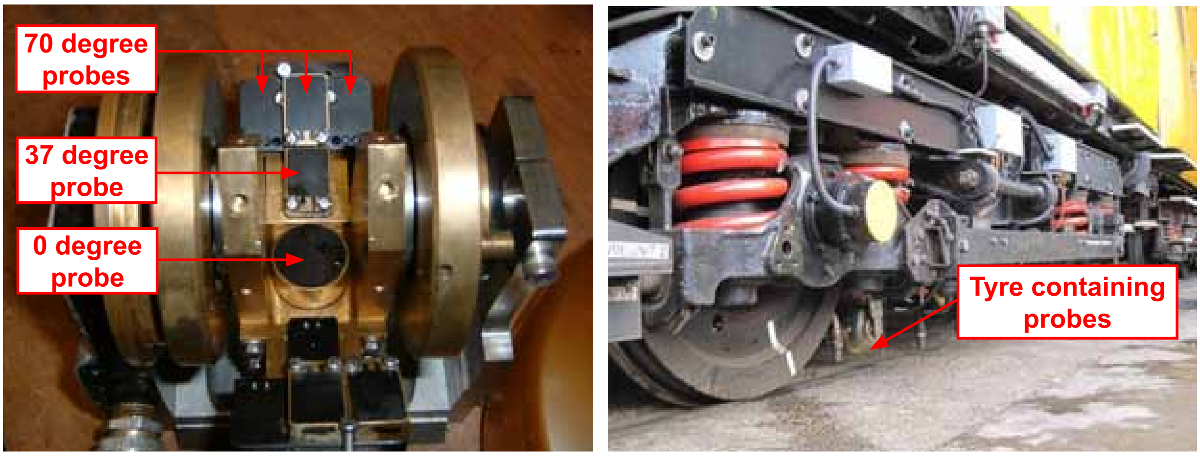
[5] This report describes equipment capabilities in the configuration and processes used on Network Rail infrastructure. Some of the test equipment could, under other conditions, provide additional capabilities.



Tyre (on equipment modified for use on switch blades)

Pedestrian equipment



Probes arrangement inside tyre (see figure 34 for detail)

Train mounted equipment: the Ultrasonic Testing Unit (UTU)

Figure 33: Ultrasonic testing equipment (images copyright Sperry)

92 Taken together the UTU probes should identify cracks (provided that they are of sufficient size) in any part of the rail except:

- at depths more than 123 mm below the rail head; a limitation which means that cracks are not found if they are in the lower part of the web or in any part of the foot (paragraph 96); and
- a zone immediately below bolt holes (where any cracks are unlikely to grow because stresses in the steel are relatively low).

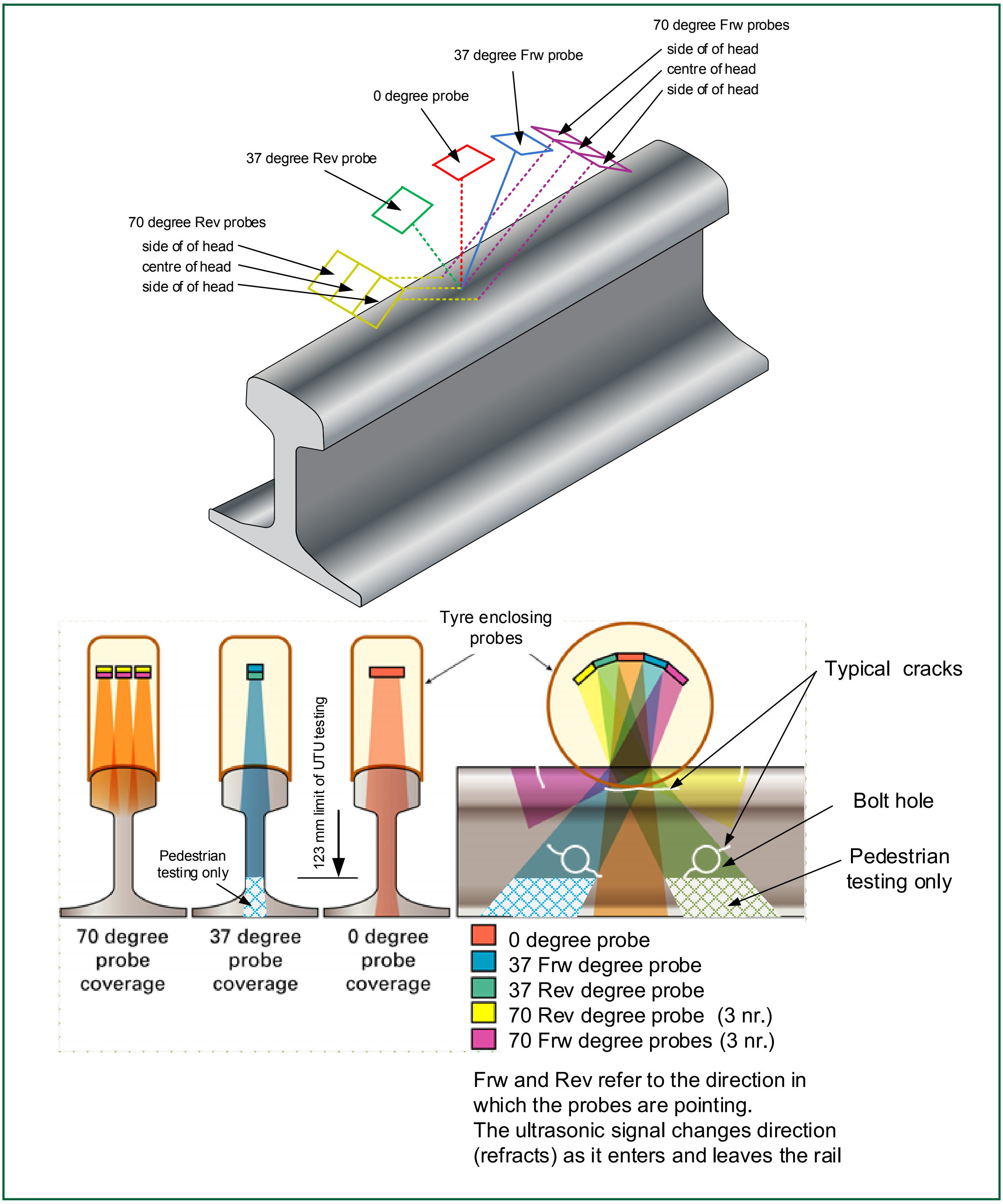


Figure 34: Ultrasonic probe arrangements (copyright Sperry)

93 Pedestrian equipment, used with Network Rail's routine cyclic testing procedures, identifies cracks (provided that they are of sufficient size) to a maximum depth of 123 mm below rail head. This can be increased to the full rail depth if an alternative Network Rail procedure is used. In all cases, cracks cannot be detected in:

- a zone immediately below bolt holes (where any cracks are unlikely to grow); and
- the outer parts of the rail foot (paragraph 95).

94 Network Rail and Sperry (the supplier of the ultrasonic testing equipment) have agreed reporting thresholds for the UTU which reflect the capabilities of the train mounted equipment. The minimum crack size to be reported is typically 5mm although the reporting threshold is larger for longitudinal cracks (cracks parallel to the rail). The pedestrian equipment is sometimes capable of detecting smaller cracks when used by a skilled operator who can adjust the testing process to suit particular site circumstances. However, Network Rail states that detection of smaller cracks by pedestrian means cannot be relied upon. Sperry has stated that crack detection can be less effective very close to joints when the rail ends have suffered from local deformation (batter) or vertical misalignment (dipped joint). In some instances, a rail break can be initiated from locations where fatigue cracking is smaller than can be reliably identified by processes currently used by Network Rail. Such incidents are, based on information obtained from Sperry, probably unusual but probably occurred at Copmanthorpe and Hambleton (paragraphs 21 and 31).

95 Cracks in the central part of the rail foot can, provided that they are large enough, be detected using the pedestrian equipment. Neither the pedestrian equipment, nor the enhanced UTU equipment (paragraph 129) can detect rail foot cracks outside the central part of the rail foot because the ultrasonic signal must pass through the rail web (figure 35).

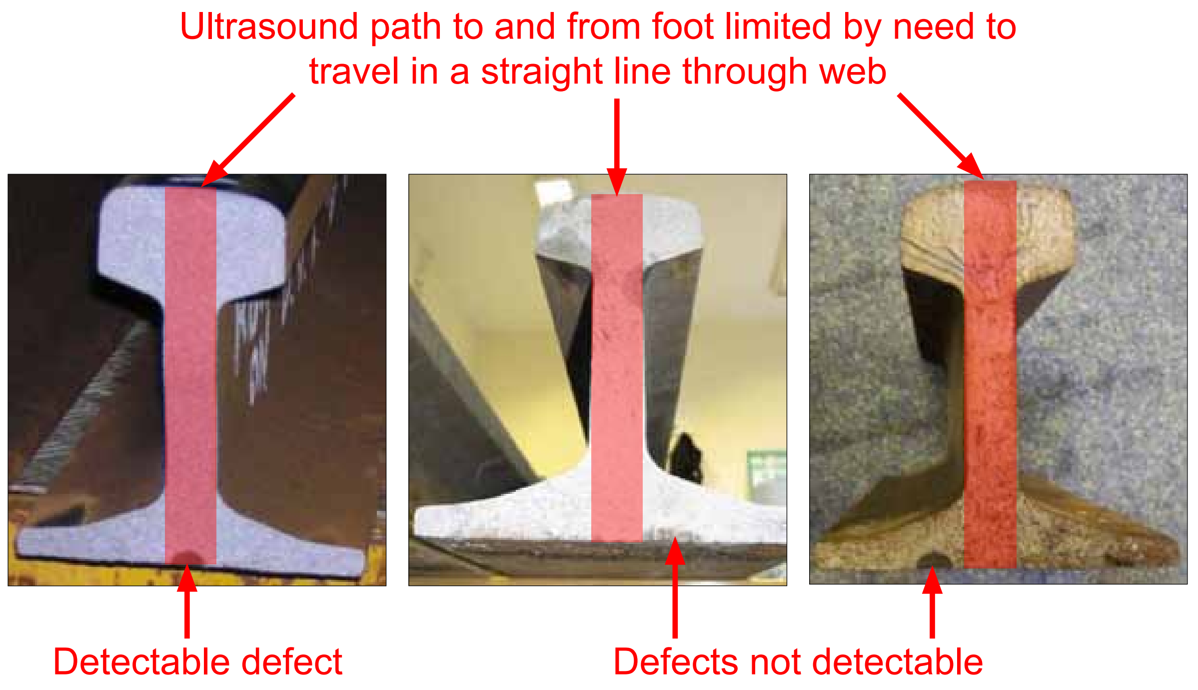


Figure 35: Limited extent of crack detection in rail foot

96 Cracks more than 123 mm below the rail head are not reported when using the UTU in accordance with current Network Rail procedures which permit the UTU to operate at speeds of up to 50 mph (80 km/h). It means that cracks in the bottom 36 mm of new BS113A rail, and within the bottom 49 mm of new CEN60 rail, are not reported.

97 It is possible to extend routine ultrasonic testing to the bottom of the central part of the rail foot. However, detection of cracks in this zone could be impractical because it could be impractical to differentiate between ultrasonic reflections from cracks and those from the surface irregularities found on the underside of some rails. Network Rail is currently undertaking tests in which ultrasonic responses are obtained from the full rail depth using a procedure which involves operating the UTU at reduced maximum speed. These tests are intended to determine whether it is practical to:

- establish an acceptably reliable means of distinguishing cracks from irregularities on the underside of the rail foot; and/or
- use reflections from surface irregularities to recognise areas where the extent of these irregularities means that there is a significant risk of them initiating fatigue cracking.

98 The 'merged' fatigue crack which had developed at Corby Glen before the rail broke was below the depth tested by the UTU (ie more than 123 mm below the rail head) but was more than 5 mm in size and was directly below the rail web (figures 3 and 35). It is therefore possible that this crack could have been detected before the rail broke if the UTU had been configured to detect rail foot cracks, or indicators of rail foot cracks, in the way now being tested by Network Rail. It is likely that testing with pedestrian ultrasonic equipment would have found the crack but Network Rail standards would only have required this type of testing at this location if the UTU had identified a defect.

Maintenance and renewal regimes

99 Maintenance practices have a significant effect on the prevention of rail breaks as these can, and should as far as reasonably practicable:

- recognise and remedy defects which can cause rail breaks; and
- recognise, and implement an appropriate response to, the small cracks which often precede rail breaks.

100 Examples of such maintenance activities include:

- replacement of degraded rail pads;
- correction of dipped joints;
- ultrasonic testing for cracks;
- maintenance of the trackbed, particularly ensuring effective drainage is provided where necessary;
- removal of insulated block joints which are no longer required and replacement of existing insulated block joints where better types of joints are available; and
- replacement of defective welds and use of modern techniques for new welds.

101 The effect of maintenance activities is apparent from track geometry and track defect data provided by Network Rail for the period from 2008 to 2013[6]. Network Rail has stated that the occurrence of poor track geometry and defects are affected by both weather conditions and changes to the equipment used for testing. These can have a significant effect on comparisons between different years but, depending on how weather conditions vary across the country, can have less significance when comparing the relative performance of routes. Some data is also affected by changes in the equipment used to monitor track geometry, a factor which affects comparison between successive years but not between routes. The data shows that:

- Track geometry faults per 100 kilometres[7] on all lines within the LNE route occurred at a broadly consistent rate from 2008/09 to 2012/13, typically 4% below the average rate for all routes; the rate on LNE was typically about 6% higher than on the LNW route and started about 6% lower than on the Western route but approximately matched this route in the final two years (figure 36).
- Track geometry faults per 100 kilometres for LNE/ECML primary and key lines rose by about 23% between 2008/09 and 2011/12 (later data is not available) compared to a 10% rise in the average for all primary and key lines; the fault rate on LNE/ECML lines was typically 20% less than the average for all primary and key lines, 18% less than those on Western/GWML tracks and 31% more than those on LNW/ WCML lines (figure 37).
- Defects per 100 kilometres requiring the immediate imposition of an emergency restriction on primary and key lines fell significantly between 2008/09 and 2012/13 with the LNE/ECML rate falling by 60% and the national average reducing by about 50%; the rate on LNE/ECML tracks was typically 30% below the national average, 25% less than on Western/GWML and 40% less than on LNW/ WCML (figure 38).
- The proportion of track on the LNE route with very poor geometry[8] rose by about 40% between 2008/09 and 2011/13 compared to a national rise of about 10%; the proportion on the LNE route rose from 15% below the national average to 10% above between 2008 and 2013 by when it was 46% higher than on the LNW route and 25% higher than on the Western route (figure 39).

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[6] Data provided by Network Rail to the Office of Rail Regulation and obtained from http://dataportal.orr.gov.uk/. Values triggering defect (fault) reports remained broadly constant from late 2009 onwards, earlier data has been adjusted by Network Rail to be consistent with post-2009 data.

[7] The number of faults is the number of discrete locations with a defect in the vertical alignment, horizontal alignment, gauge and/or twist. The numerical criteria for these defects are given in Network Rail standard NR/L2/TRK/001.

[8] Very poor geometry is defined in section 7 of Network Rail standard NR/L2/001/mod 11 and reflects irregularities in both the vertical and the horizontal alignment of rails.

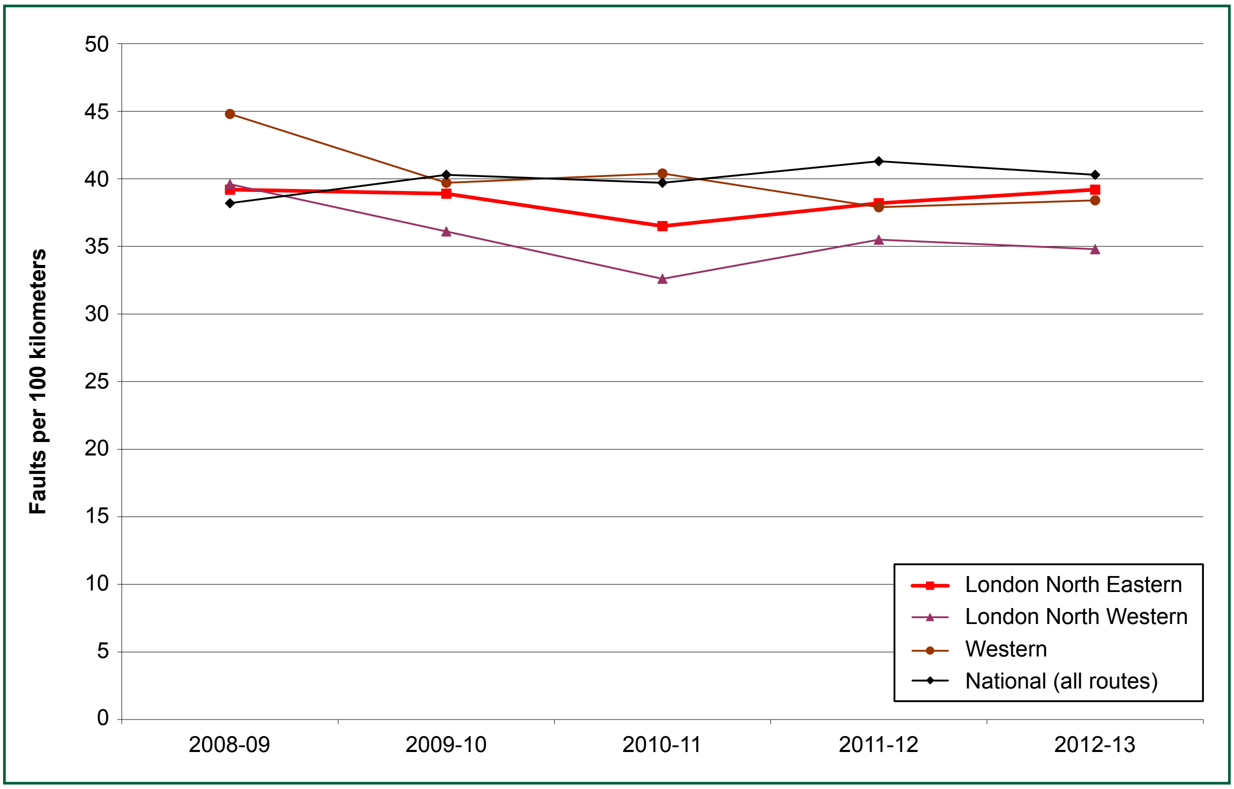

Figure 36: Track geometry faults 2008 to 2013, all lines

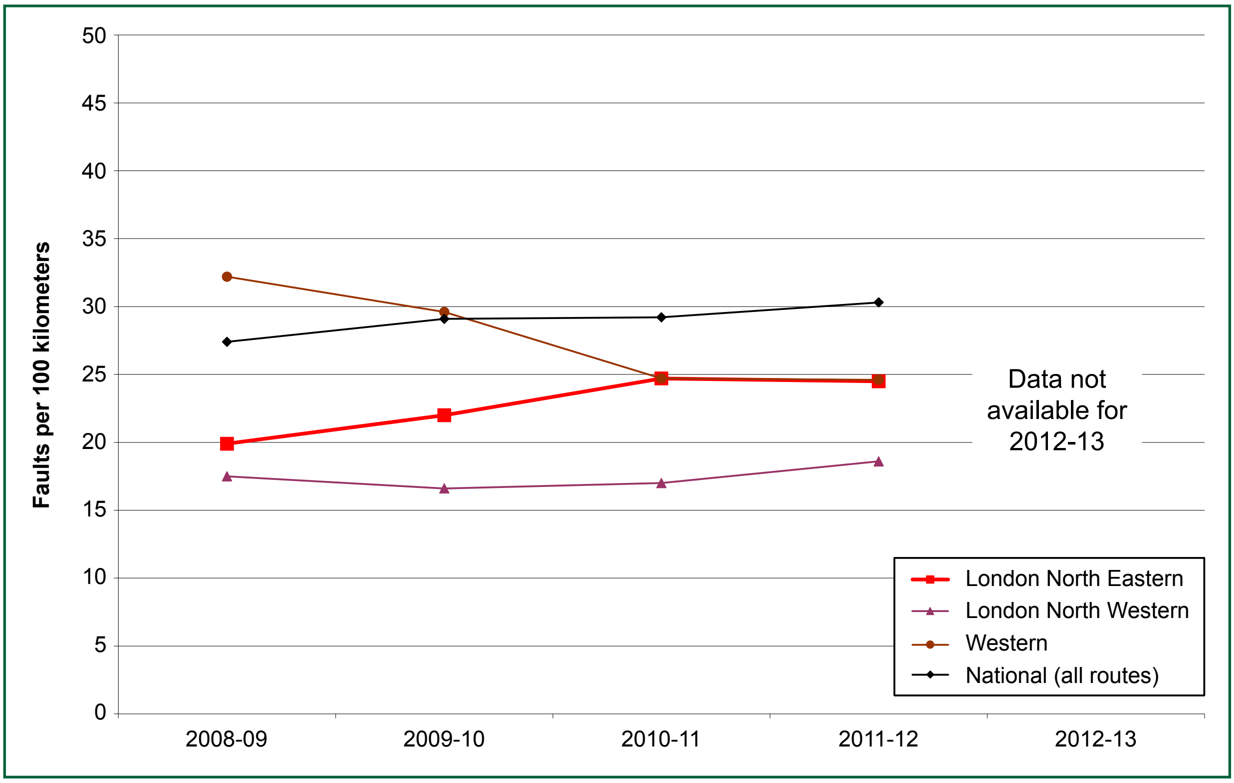

Figure 37: Track geometry faults 2008 to 2013, primary and key lines

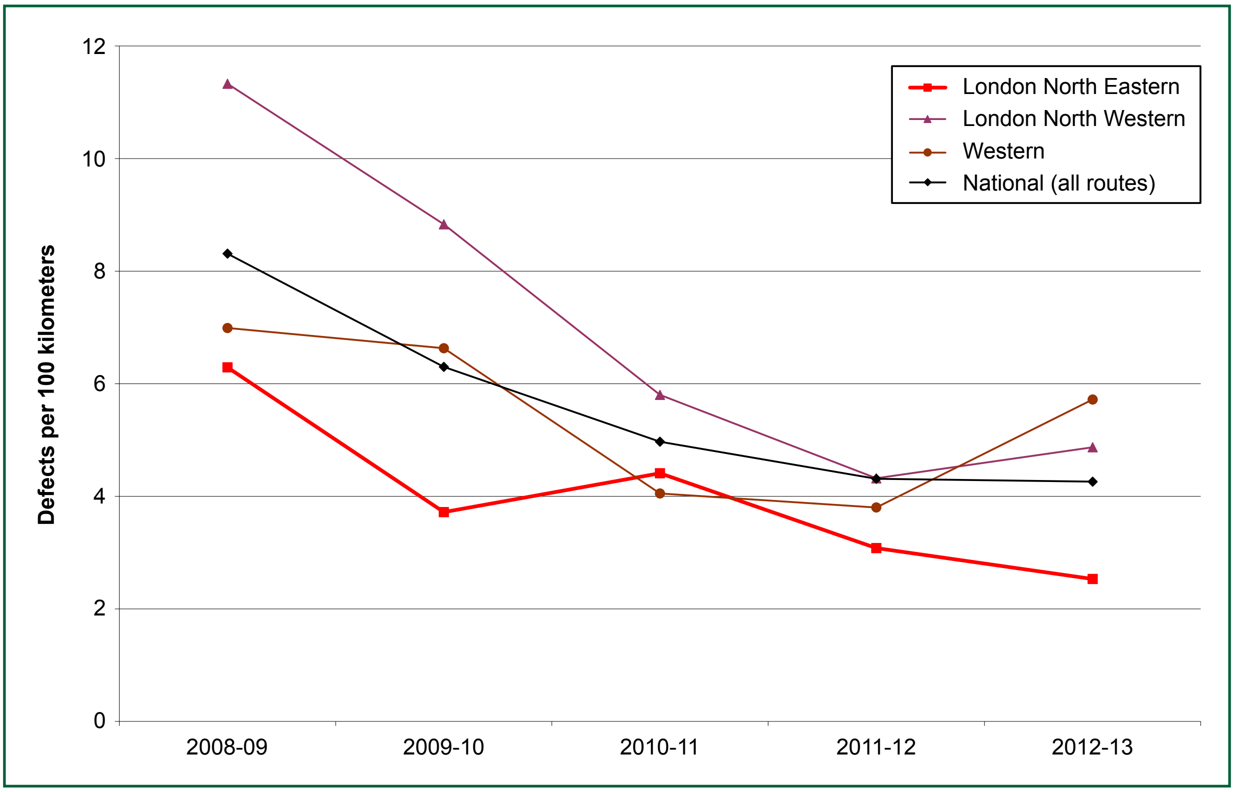

Figure 38: Immediate action defects, primary and key lines, 2008 to 2013

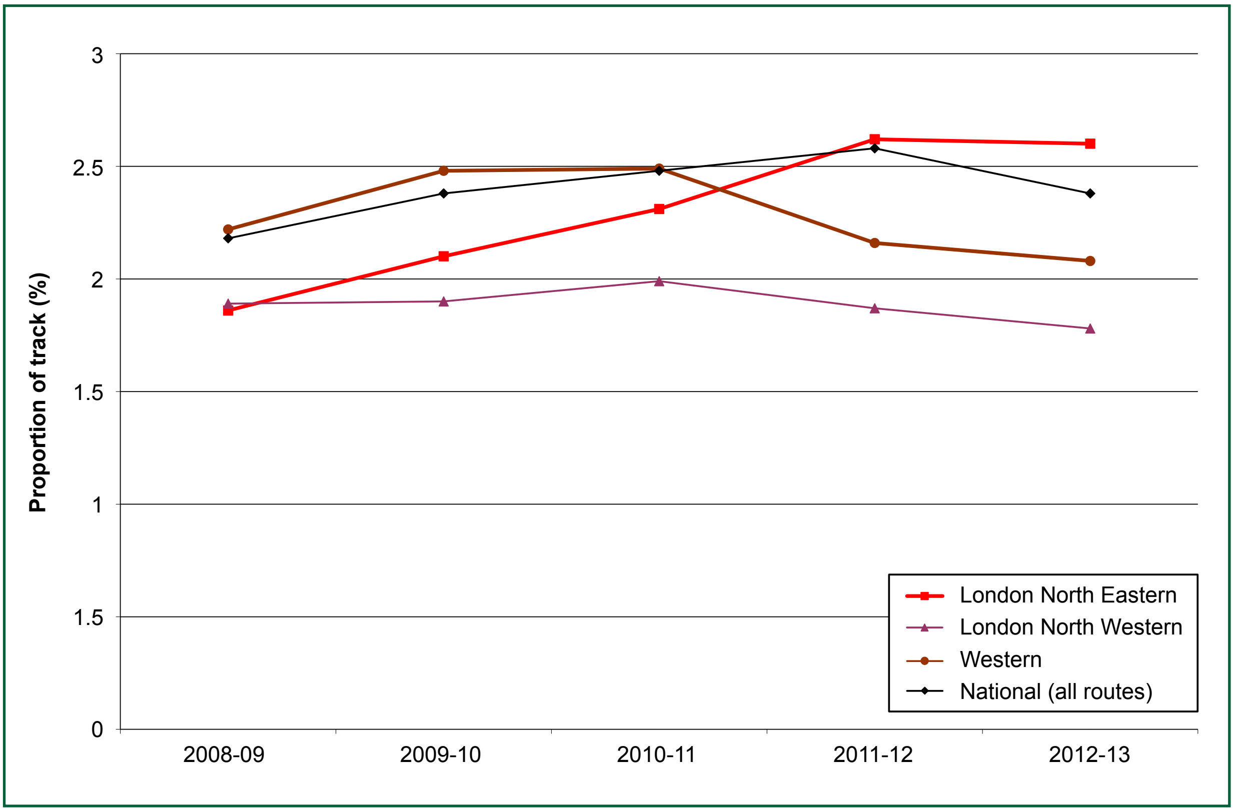

Figure 39: Very poor track geometry 2008 to 2013, all lines

102 Network Rail has stated that maintenance of the ECML has been undertaken in accordance with the standards which applied throughout its infrastructure. This statement is supported by the data for track geometry faults and defects requiring immediate imposition of an emergency speed restriction (figures 36 and 38). However, changes to maintenance practices cannot be ruled out as a possible cause of the significant deterioration in the proportion of LNE route with very poor geometry, and the increase in the occurrence of geometry faults, on the principal and key tracks (mainly the ECML) within this route (figures 37 and 39). The very poor geometry is relevant to rail breaks because it leads to increased dynamic loads from trains and thus an increased likelihood of rail breaks.

103 Although maintenance practices are a possible factor in the occurrence of rail breaks, it is probable that the age of trackwork has a significant effect on track geometry and is thus a factor in both deterioration of LNE track geometry and in the inferior geometry when compared to LNW and Western routes Trackwork age is also a probable factor in the increasing occurrence of geometry faults on principal and key tracks on the LNE route. The greater occurrence of pre-1987 rail, ballast and sleeper on the LNE route, compared with the LNW and Western routes, is shown in figure 40. This data reflects the low levels of rail replacement across the national rail network in the mid 1990s[9].

104 Although the RAIB has found no indications that non-compliance with Network Rail maintenance standards is a factor in the occurrence of rail breaks on the ECML, it appears that the maintenance regime was unable to prevent a deterioration of track geometry and an increasing occurrence of rail breaks between 2010 and 2013. This indicates a need for additional measures and Network Rail's approach to this is described in paragraphs 128 and 129.

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[9] Rail failure assessment for the Office of the Rail Regulator, Transportation Technology Center, Inc., October 2000.

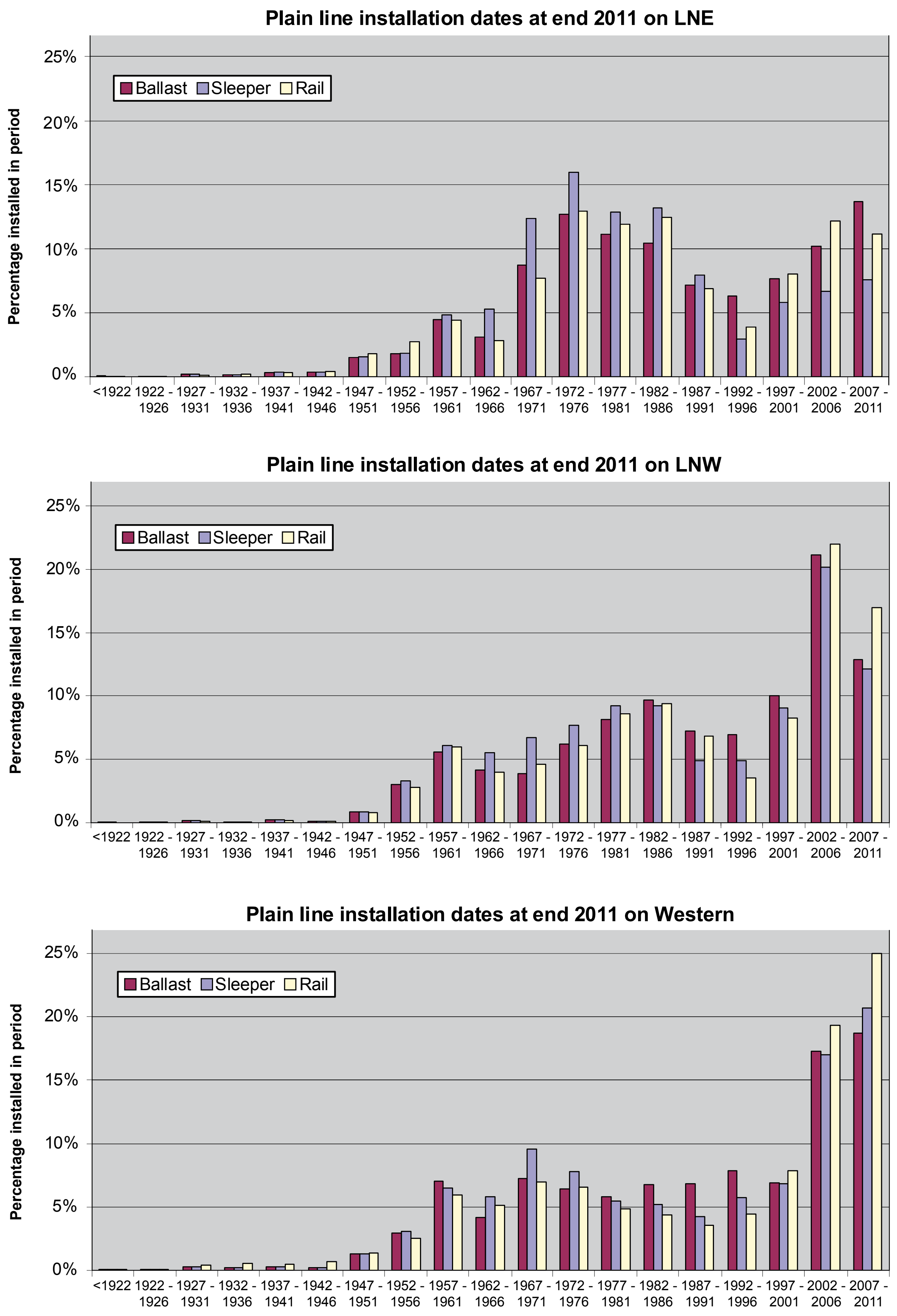


Figure 40: Plain line installation dates on selected routes

Observations[10]

Detecting track defects with the UTU

105 Although the UTU is only intended to detect rail cracks, the absence of a reflection from the bottom of the rail can be indicative of a track defect. The UTU data collected at the Copmanthorpe joint on 19 November 2012 shows that the reflected wave normally provided by the rail bottom (paragraph 91) was missing for a distance of about 75mm. Sperry has stated that, when this happened, the reflections measured by the other probes suggest that the test wheel tyre was in contact with the rail head and that it considers the UTU equipment was functioning correctly. It has suggested the following among possible causes for a loss of the rail bottom signal:

- An irregular rail foot surface, possibly due to corrosion, which results in a diffuse reflected wave which was too weak to be detected.
- The bottom of the rail in contact with water so the ultrasound passes into the water instead of being reflected.
- Imperfect rail alignment, or localised rail damage, meant that the test equipment was temporarily not receiving a complete return signal.

106 The RAIB considers that, in the particular circumstances at Copmanthorpe, it is likely that the rail bottom signal was lost due to rail distortion associated with the dip. This is because the rail break was caused by movement at the joint and this movement would probably have resulted in the rails being misaligned as the track geometry recording train passed over the joint. Contact with water, and corrosion caused by water, are unlikely explanations because the joint is between sleepers and so above an air gap (figure 4).

107 As all the possible causes given by Sperry indicate a possible track defect (including some defects which could lead to a broken rail), the loss of the rail bottom signal could be used as an indication of a site requiring inspection to determine whether a track fault is present. Current Network Rail standards do not require reporting of locations where the rail bottom signal is lost except as part of a recently introduced process for identifying longitudinal rail head defects (paragraph 128(i)). Network Rail has stated that, although the loss of the rail bottom signal is unusual on the ECML, it is relatively frequent on jointed track so any process for using loss of rail bottom as a trigger for track inspections would need to take this into account.

Identifying repeat faults

108 Network Rail standards (eg notes 2A and 2B on Table 2) recognise the importance of identifying defects which recur at the same location and which are often described as repeat defects. However, defect data is provided to track maintenance staff with location information which does not always provide a precise position for the defect. This makes it difficult for managers to recognise when repeat faults are occurring.

---

[10] An element discovered as part of the investigation which deserves scrutiny but which is not directly related to rail break issues investigated by the RAIB.

109 The difficulty of recognising repeat faults is apparent from the Copmanthorpe joint defect reports. Four track geometry recording train runs and four UTU runs were undertaken in the period from July to November 2012 and all identified the joint. The locations given by the geometry recording train and provided to track maintenance staff were spread over a distance of about 137 metres of track with a maximum distance of 134 metres from the actual position of the joint (figure 41). The UTU gave locations concentrated within a 15 metres zone but displaced from the joint such that the furthest location was 28 metres from the joint.

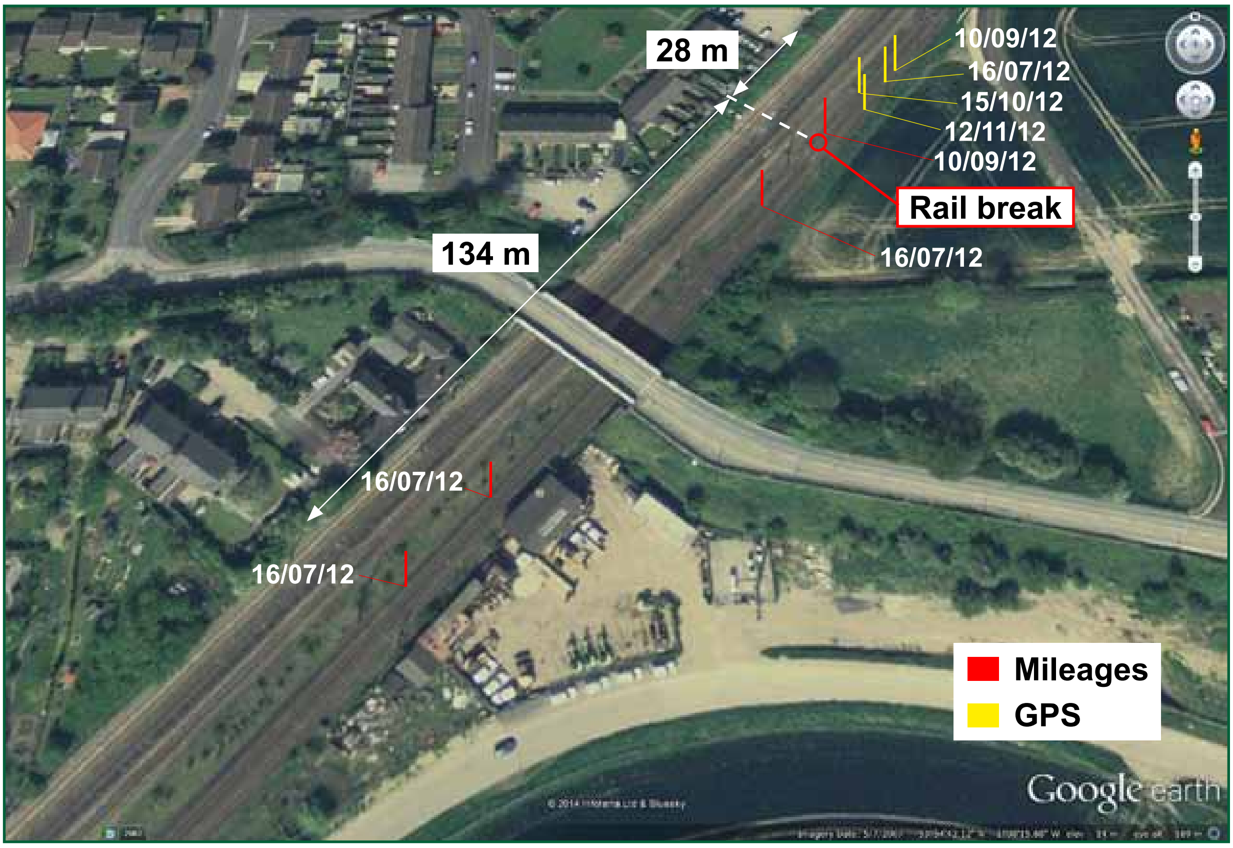


Figure 41: Copmanthorpe dipped joint locations from track geometry recording train output

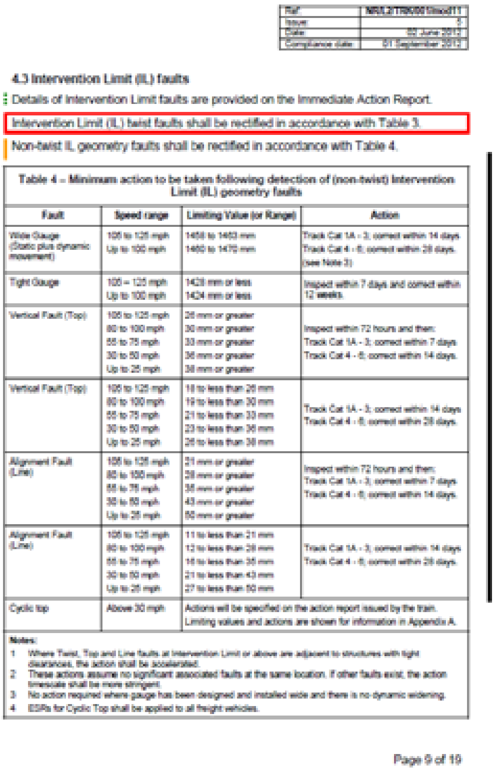
110 The locations given by the track geometry recording trains and by the UTUs are usually sufficient for staff to find the defect on site, in part because these staff can look for areas where track deformation is apparent. However, track maintenance managers have no practical means of determining any imprecision in the locations given and this can result in them planning a defect response without recognising that they are dealing with a repeat defect. There is no process for staff attending site to update Network Rail records with precise defect locations.

111 Although imprecise location data was not a factor at Corby Glen, Copmanthorpe or Hambleton, it has been a factor in previous accidents. It was a factor in a derailment at Bordesley Junction, Birmingham on 26 August 2011 (RAIB report 19/2012) because imprecise location data from train mounted recording equipment led to remedial work being carried out in the wrong place, leaving an uncorrected track defect. The lack of precise information about the location of track defects was also a factor in a derailment at Stanton, near Foreign Ore Branch Junction, Scunthorpe on 25 January 2008 (paragraph 125).

Disseminating changes to Network Rail standards

112 The Track Maintenance Engineer and the Section Manager (track) responsible for the Copmanthorpe joint had not appreciated, before the broken rail was found, that they should have arranged ultrasonic testing of the joint using pedestrian equipment in response to the track geometry recording train measuring dip angles exceeding 30 mrads in September, October and November 2012 (paragraph 80). The requirement for this test had been introduced on 1 September 2012 when version 5 of Network Rail standard NR/L2/TRK/001 became effective. There was no similar requirement in version 4 of this standard. This is not a factor in the incident because it is unlikely that any cracks in the rail would have been large enough to be detected by the pedestrian equipment.

113 Both the Track Maintenance Engineer and Section Manager (track) had been briefed on changes introduced by version 5 of the document. The new version introduced a significant number of changes and a non-standard process was used to brief these. The briefing documentation did not highlight the new ultrasonic testing requirement. This had been added in a part of the standard where old requirements were being presented in a new format (a flow chart had been changed to a table). The additional requirement was marked only by a thickening of the linework within part of the new table. Unlike other changes in the standard, there was no margin mark to highlight the change (figure 42).



Ref:	NR/L2/TRK/001/mod11
Issue:	5
Date:	02 June 2012
Compliance date:	01 September 2012

4.3 Intervention Limit (IL) faults

Details of Intervention Limit faults are provided on the Immediate Action Report.

Intervention Limit (IL) twist faults shall be rectified in accordance with Table 3.

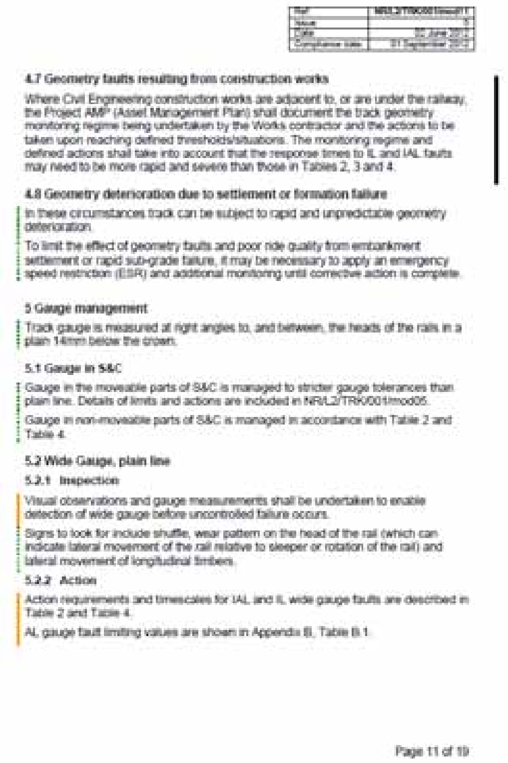
Non-twist IL geometry faults shall be rectified in accordance with Table 4.

Table 4 – Minimum action to be taken following detection of (non-twist) Intervention Limit (IL) geometry faults

Fault	Speed range	Limiting Value (or Range)	Action
Wide Gauge (Static plus dynamic movement)	105 to 125 mph Up to 100 mph	1458 to 1463 mm 1460 to 1470 mm	Track Cat 1A - 3; correct within 14 days. Track Cat 4 - 6; correct within 28 days. (see Note 3)
Tight Gauge	105 – 125 mph Up to 100 mph	1428 mm or less 1424 mm or less	Inspect within 7 days and correct within 12 weeks.
Vertical Fault (Top)	105 to 125 mph 80 to 100 mph 55 to 75 mph 30 to 50 mph Up to 25 mph	26 mm or greater 30 mm or greater 33 mm or greater 36 mm or greater 38 mm or greater	Inspect within 72 hours and then: Track Cat 1A - 3; correct within 7 days. Track Cat 4 - 6; correct within 14 days.
Vertical Fault (Top)	105 to 125 mph 80 to 100 mph 55 to 75 mph 30 to 50 mph Up to 25 mph	18 to less than 26 mm 19 to less than 30 mm 21 to less than 33 mm 23 to less than 36 mm 26 to less than 38 mm	Track Cat 1A - 3; correct within 14 days Track Cat 4 - 6; correct within 28 days.
Alignment Fault (Line)	105 to 125 mph 80 to 100 mph 55 to 75 mph 30 to 50 mph Up to 25 mph	21 mm or greater 28 mm or greater 35 mm or greater 43 mm or greater 50 mm or greater	Inspect within 72 hours and then: Track Cat 1A - 3; correct within 7 days. Track Cat 4 - 6; correct within 14 days.
Alignment Fault (Line)	105 to 125 mph 80 to 100 mph 55 to 75 mph 30 to 50 mph Up to 25 mph	11 to less than 21 mm 12 to less than 28 mm 16 to less than 35 mm 21 to less than 43 mm 27 to less than 50 mm	Track Cat 1A - 3; correct within 14 days. Track Cat 4 - 6; correct within 28 days.
Cyclic top	Above 30 mph	Actions will be specified on the action report issued by the train. Limiting values and actions are shown for information in Appendix A.	

Notes:
1 Where Twist, Top and Line faults at Intervention Limit or above are adjacent to structures with tight clearances, the action shall be accelerated.
2 These actions assume no significant associated faults at the same location. If other faults exist, the action timescale shall be more stringent.
3 No action required where gauge has been designed and installed wide and there is no dynamic widening.
4 ESRs for Cyclic Top shall be applied to all freight vehicles.

Page 9 of 19



Ref:	NR/L2/TRK/001/mod11
Issue:	5
Date:	02 June 2012
Compliance date:	01 September 2012

4.7 Geometry faults resulting from construction works

Where Civil Engineering construction works are adjacent to, or are under the railway, the Project AMP (Asset Management Plan) shall document the track geometry monitoring regime being undertaken by the Works contractor and the actions to be taken upon reaching defined thresholds/situations. The monitoring regime and defined actions shall take into account that the response times to IL and IAL faults may need to be more rapid and severe than those in Tables 2, 3 and 4.

4.8 Geometry deterioration due to settlement or formation failure

In these circumstances track can be subject to rapid and unpredictable geometry deterioration.

To limit the effect of geometry faults and poor ride quality from embankment settlement or rapid sub-grade failure, it may be necessary to apply an emergency speed restriction (ESR) and additional monitoring until corrective action is complete.

5 Gauge management

Track gauge is measured at right angles to, and between, the heads of the rails in a plain 14mm below the crown.

5.1 Gauge in S&C

Gauge in the moveable parts of S&C is managed to stricter gauge tolerances than plain line. Details of limits and actions are included in NR/L2/TRK/001/mod05.

Gauge in non-moveable parts of S&C is managed in accordance with Table 2 and Table 4.

5.2 Wide Gauge, plain line

5.2.1 Inspection

Visual observations and gauge measurements shall be undertaken to enable detection of wide gauge before uncontrolled failure occurs.

Signs to look for include shuffle, wear pattern on the head of the rail (which can indicate lateral movement of the rail relative to sleeper or rotation of the rail) and lateral movement of longitudinal timbers.

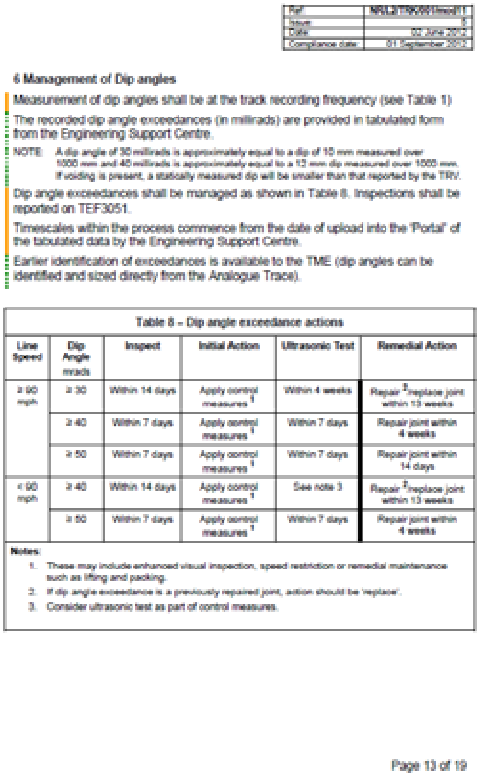
5.2.2 Action

Action requirements and timescales for IAL and IL wide gauge faults are described in Table 2 and Table 4.

AL gauge fault limiting values are shown in Appendix B, Table B.1.

Page 11 of 19

Margin marks showing changes (above)



Ref:	NR/L2/TRK/001/mod11
Issue:	5
Date:	02 June 2012
Compliance date:	01 September 2012

6 Management of Dip angles

Measurement of dip angles shall be at the track recording frequency (see Table 1)

The recorded dip angle exceedances (in millirads) are provided in tabulated form from the Engineering Support Centre.

NOTE: A dip angle of 30 millirads is approximately equal to a dip of 15 mm measured over 1000 mm and 40 millirads is approximately equal to a 12 mm dip measured over 1000 mm. If voiding is present, a statically measured dip will be smaller than that reported by the TRV.

Dip angle exceedances shall be managed as shown in Table 8. Inspections shall be reported on TEF3051.

Timescales within the process commence from the date of upload into the 'Portal' of the tabulated data by the Engineering Support Centre.

Earlier identification of exceedances is available to the TME (dip angles can be identified and sized directly from the Analogue Trace).

Table 8 – Dip angle exceedance actions

Line Speed	Dip Angle mrads	Inspect	Initial Action	Ultrasonic Test	Remedial Action
≥ 90 mph	≥ 30	Within 14 days	Apply control measures ^{1}	Within 4 weeks	Repair ^{2}replace joint within 13 weeks
	≥ 40	Within 7 days	Apply control measures ^{1}	Within 7 days	Repair joint within 4 weeks
	≥ 50	Within 7 days	Apply control measures ^{1}	Within 7 days	Repair joint within 14 days
< 90 mph	≥ 40	Within 14 days	Apply control measures ^{1}	See note 3	Repair ^{2}replace joint within 13 weeks
	≥ 50	Within 7 days	Apply control measures ^{1}	Within 7 days	Repair joint within 4 weeks

Notes:
1. These may include enhanced visual inspection, speed restriction or remedial maintenance such as lifting and packing.
2. If dip angle exceedance is a previously repaired joint, action should be 'replace'.
3. Consider ultrasonic test as part of control measures.

Page 13 of 19

Ultrasonic testing changes marked only within table (left)

Figure 42: Change markings in version 5 of standard NR/L2/TRK/001

Summary of conclusions

Site specific

114 The rail break discovered at Corby Glen on 14 September 2012 occurred in a section of plain rail and was triggered by wear of the pad intended to separate the rail from the sleeper, and a dipped weld (paragraphs 11 and 12). It is probable that the wear was not apparent during visual inspections for reasons explained in paragraph 65).

115 The rail breaks found at Copmanthorpe on 28 November 2012, and at Hambleton on 1 February 2013, were both in the end of a rail at an insulated rail joint. Both were caused by movement of the joint due to inadequate support of sleepers (paragraphs 19 and 29).

116 Remedial action was being undertaken at Copmanthorpe in accordance with timescales permitted by the applicable Network Rail standard but this did not result in replacement of the joint before the accident (paragraphs 77 to 79). The need for remedial action at Hambleton had been noted during a visual inspection but the break occurred within the time period allowed by Network Rail for correcting the defect (paragraph 33). No remedial action had taken place at Hambleton in response to track geometry recording train measurements because the last recorded value was just less than that required to trigger action (paragraph 81).

Rail break analysis

117 The number of rail breaks on Network Rail infrastructure has reduced from more than 900 per year in the late 1990s to typically 160 per year in the period 2009 to 2013. Rail break risk represents about 0.05% of total railway safety risk excluding suicides and about 1% of the risk associated with train accidents (paragraphs 39 and 40).

118 The LNE route is the Network Rail route with the greatest number of rail breaks after allowing for differences in route length and the amount of traffic. The ECML has more rail breaks than the two most comparable lines (WCML and GWML), again after allowing for route length and the amount of traffic (paragraphs 47 and 48).

119 The most significant factor in the relatively high number of rail breaks on the LNE route and the ECML is that these lines have a relatively high proportion of older track infrastructure including rails, sleepers, fixings and ballast (paragraphs 51 to 56).

120 The RAIB has found no evidence that non-compliance with Network Rail maintenance standards is a factor in the occurrence of rail breaks on the ECML. It appears that the inspection and maintenance regime was unable to prevent deterioration of track geometry and increasing occurrence of rail breaks between 2010 and 2013 (paragraph 104).

121 The RAIB reviewed Network Rail's management of rail breaks with particular emphasis on the types of break found on the ECML. This review identified a number of explanations for the frequency of rail break occurrence on the ECML. The RAIB review identified that:

a. rail breaks are more common in older rail and this can be addressed by replacement of older rail with new rail (paragraphs 51 to 56 and 88, action in progress);
b. rail breaks can be triggered by worn and missing rail pads, a factor which can be addressed by replacement of rail pads (paragraph 65, action in progress, **Recommendation 3**);
c. rail breaks can occur at defective welds or be triggered by increased wheel loads due to bouncing effects initiated by dips at defective welds, both issues being addressed by replacement or repair of defective welds (paragraph 66 and 85, action in progress);
d. detection of small cracks, before they enlarge and cause a broken rail, is an effective means of mitigating rail break risk and it is possible that additional mitigation can be provided by implementation of enhanced crack detection techniques (paragraphs 67, 69 and 89 to 98, action in progress, **Recommendations 1 and 4**);
e. the relatively high risk of rail breaks at rail joints can be mitigated by installation of improved track joints and removal of unnecessary track joints (paragraph 71, action in progress); and
f. a dipped joint is often a precursor to a rail break at the joint so the likelihood of a rail break can be reduced by implementing an enhanced response to dipped joint measurements (paragraph 82, action in progress).

122 Network Rail is already taking, planning or considering actions intended to address many of the above findings (paragraphs 128 and 129).

123 The RAIB notes that some lessons learnt in respect of ECML rail breaks are likely to be applicable elsewhere on Network Rail infrastructure (paragraph 58, **Recommendation 2**)

Additional observations

124 Although not directly linked to the rail break events covered by this investigation, the RAIB observes that:

a. the UTU records when the signal from the rail bottom is lost, an indicator of possibly defective trackwork, but no action is taken in response to this information (paragraph 107, action in progress);
b. information relating to track defects is provided to track maintenance managers in a way which makes it difficult to identify defects which recur at the same location (paragraph 110, existing recommendation at paragraph 125); and
c. the process used to identify changes in Network Rail standards can result in changes being missed by staff responsible for their implementation (paragraph 113, **Recommendation 5**).

Previous RAIB recommendations relevant to this investigation and currently being implemented

125 The following recommendation was made by the RAIB as a result of a previous investigation relating to a derailment at Santon, near Foreign Ore Branch Junction, Scunthorpe on 25 January 2008 (RAIB Report 10/2009). It addresses the accurate reporting of defect locations (paragraph 110 of the present report) and has not been remade to avoid duplication of a recommendation which is reported as being implemented.

> Recommendation 6
>
> Network Rail should take measures to improve the accuracy of location information for track geometry faults recorded by all track geometry recording runs and inspection staff, and provide maintenance staff with the ability to use this information to precisely locate the identified faults.

126 The Office of Rail Regulation (ORR) reported to the RAIB in March 2014 that this recommendation had been implemented using GPS technology and a computer based Linear Asset Decision Support tool (LADS). Details provided by ORR state that Network Rail's track geometry recording trains have been fitted with *Global Positioning Systems* (GPS) and mobile phone technology with a GPS application has been introduced into track maintenance teams. ORR notes that maintenance engineers have reported that this GPS capability allows faults to be reliably located.

127 LADS provides a consolidated source of track defect data from engineering inspections and track geometry measurements within a computer system which allows this data to be displayed on a background of a site photograph. This is intended to allow staff to assimilate information from different sources when deciding how to manage a defect. ORR's March report states that roll out of LADS was in progress and expected to be complete in May 2014. Network Rail has subsequently confirmed to the RAIB that engineering inspection and track geometry measurement data was added to LADS in June 2014.

Actions reported as in progress, proposed or under consideration

128 Network Rail has stated that it has implemented the following actions on the ECML since 2012 with the expectation that they will reduce the likelihood of rail breaks (extension of these activities, and extension of the activities described in paragraph 129, forms part of **Recommendations 1 to 4**):

a. Undertaking pedestrian ultrasonic testing, usually within four weeks, if the track geometry recording train identifies dips exceeding 20 mrads.

b. Replacing joints where dips exceed 25 mrads, or exceed 20 mrads with an increase of at least 1 mrad since the last track geometry recording train run. These criteria were based on professional judgement, supplemented by some calculation of potential benefits, and are more onerous than those in current Network Rail standards. Originally introduced on the WCML and then extended to the ECML, these criteria are now being applied to other Network Rail high speed lines.

c. Replacing site-made insulated block joints with stronger joints, normally factory-made glued joints, on lines with permitted speeds of 90 mph and above.

d. Removing unnecessary (redundant) joints with all identified joints in the York area of the ECML now removed, and joints elsewhere being replaced when appropriate signalling schemes take place.

e. Implementing a programme for replacing life-expired rail on 48 km of track during 2013 using CEN56 or CEN60 rail laid on 10mm rail pads where possible and 7.5 mm pads elsewhere. The main driver for this work is control of rail foot breaks in older high tonnage rails, including some where the old pads were only 5 mm thick. A further 100 km of track replacement is planned for 2015/16.

f. Replacing older welds as part of rail replacement projects or if defects are detected by ultrasonic testing. In addition, although not affecting the ECML, Network Rail has reported that it has replaced about 300 of the older welds that it considered most likely to break on selected secondary and tertiary lines in LNE route. The older welds were of the *aluminothermic* type, *tri-metallic* welds at *cast crossings* and welds between rails of differing type. The lines are those where there has been an increase in rail breaks due to changes in traffic type, speed or tonnage.

g. Improving track drainage, by locating drains and introducing an enhanced maintenance regime. The decision to improve drainage was based on an appreciation that poor drainage was adversely affecting a range of assets including earthworks. The decision was taken before the deterioration in rail break performance on the ECML which is discussed in this report. However, one of the known benefits of improved drainage was to improve track support and thus reduce the likelihood of track geometry faults which can trigger rail breaks.

h. Introduced an additional (fourth) UTU, mainly to allow coverage of additional secondary lines, but also improving the resources available for main line testing when UTUs are being maintained or being used to install and test new equipment.

i. Introduced, in September 2013, a revised method of analysing UTU data which identifies longitudinal defects in the rail head. This is achieved by identifying locations where the rail bottom signal is lost at the same location on successive UTU runs.

j. Introduced the Linear Asset Decision Support tool (paragraph 127) to bring together, and thus aid assimilation of, maintenance information relating rail defects, dip angles, welds, track geometry and other important data streams with the intent of improving proactive management of track assets including recognition of the repeated geometry faults which can lead to rail breaks.

k. Implementing a programme for identifying, and then replacing, worn pads on 21 km of track during 2013 in addition to pads replaced during the rail replacement programme. Worn pads are normally identified by inspection of pads removed on a sample basis as in-situ inspection is generally difficult. This work is generally prioritised towards locations where pads are only 5 mm or 7.5 mm thick and have carried high tonnages of traffic. This prioritisation reflects the much greater service life expected from 10 mm pads compared to the thinner pads.

l. Replacing Corprotec coated rails at level crossings. The coating was intended to reduce rail corrosion, but experience showed that the coated rails were easily damaged. The new rails have a more robust coating.

129 Network Rail reports that the number of rail breaks on LNE route reduced from 54 in 2012/13 (figure 16) to 28 in 2013/14. The proportion of Network Rail infrastructure rail breaks occurring on LNE route in the same period reduced from 30% to 22%. The number of rail breaks on ECML reduced from 24 in 2012/13 to 14 in 2013/14 with the number of breaks at rail ends (the location where breaks are most likely to cause a derailment) reducing from 4 to 1 (figure 43). Although it is possible that external factors, for example weather conditions, contributed to the improved performance on LNE route and ECML, it is probable that part of the improvement is a consequence of implementing the measures described in paragraph 128. Network Rail has stated that it is currently taking the following actions which have the potential to reduce the likelihood of rail breaks:

a. Trialling equipment which has been installed on all four UTUs in order to test the full depth of the rail to identify rail foot defects, or indicators that there is a relatively high risk of such defects (paragraph 97).

b. Trialling eddy current based wheel probes which have been fitted to all UTUs to measure the length and depth of surface defects. It is intended to activate the equipment on all UTUs when appropriate action thresholds have been established from trials currently involving one UTU. It is anticipated that this will automate a current procedure which relies on pedestrian visual and ultrasonic procedures.

c. Procuring mobile maintenance units (trains which incorporate a mobile covered area with lighting and storage facilities) to allow more efficient implementation of on-track work including pad replacement.

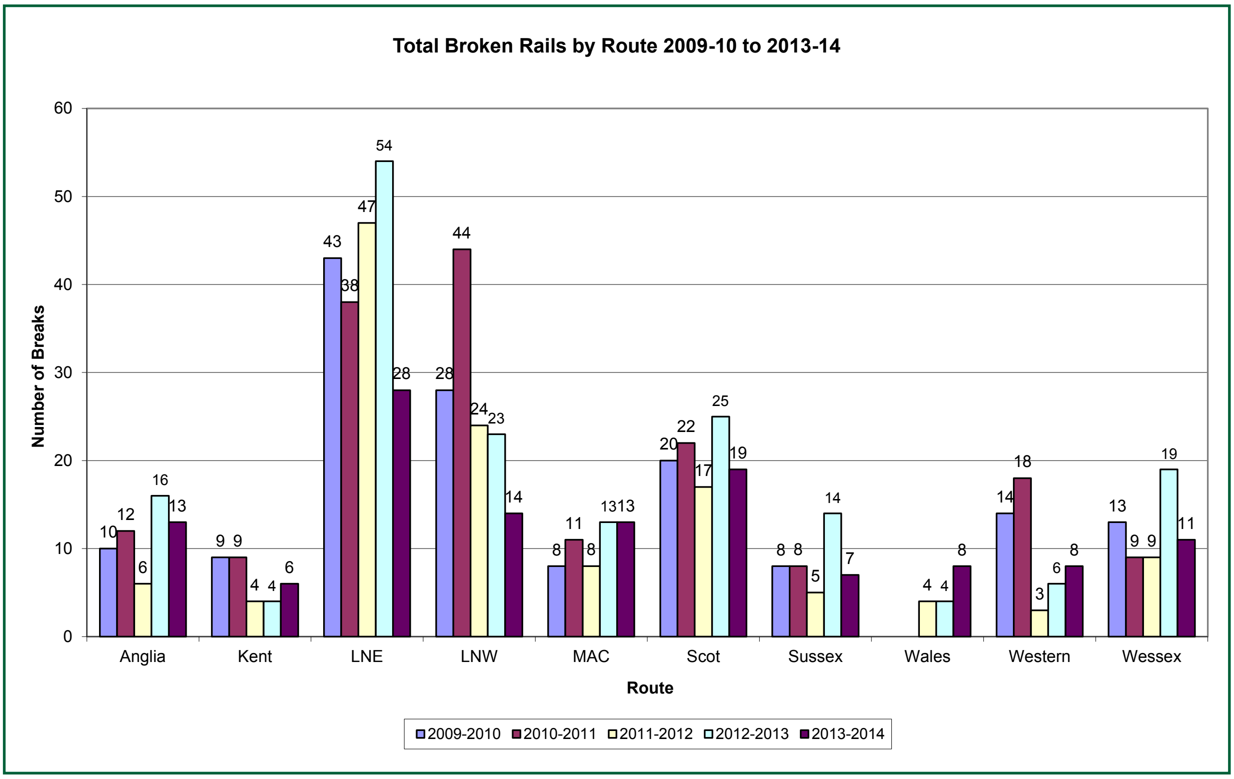


Figure 43: Total broken rails by route 2009-10 to 2013-14

d. Planning to fit instrumented wheels on a bogie beneath one of the track geometry recording trains in the second half of 2014 to record the vertical and lateral forces experienced by the wheels as the train responds to track geometry defects. Network Rail intends to correlate this information with track geometry measurements and so gain a greater understanding of the relationship between measured track defects and the forces transmitted between the track and the train.

e. Developing a means of linking video images with track geometry data as a means of identifying loose or cracked components before these fail resulting in a rail break.

f. Considering extending the areas in which maintenance intervention is triggered at reduced dip angles (paragraph 128b).

g. Considering introducing differential dip action limits dependent on location (eg whether on plain track or near points).

h. Considering whether it is practical to identify welds requiring replacement by measuring the irregularity that develops when wear or a defect means that the top of the weld is lower than the adjacent rail head. This may be practical because the shape of the irregularity has some similarities to a dipped joint so can be measured in a similar way.

i. Implemented a process for reporting repeated loss of rail bottom signal so that these locations can be inspected for possible defects. The process is currently being implemented on all higher speed/higher tonnage lines. The possibility of extending this process to other lines is now being considered.

Recommendations

130 The following recommendations are made[11]:

1 *This recommendation is intended to reduce the risk of rail breaks by taking advantage of technological developments in the UK and elsewhere, not restricted to ultrasonic techniques, to allow detection of smaller cracks in rails.*

Network Rail should undertake or commission research to identify any opportunities for reducing the size of cracks and defects which can be identified in rails in circumstances likely to be associated with rail breaks. The research should be targeted at providing reliable information using equipment capable of operating routinely throughout its infrastructure (paragraph 121d).

2 *This recommendation is intended to ensure that all parts of Network Rail obtain the maximum benefit from knowledge gained by work intended to reduce the risk of rail breaks on the East Coast Main Line and is a formalisation of a process which Network Rail states is already in progress.*

Network Rail should review the actions already being taken to reduce the incidence of rail breaks on the East Coast Main Line (including those described in paragraphs 128 and 129) in order to identify whether similar actions would provide significant safety benefits elsewhere on its infrastructure. If such benefits are identified, Network Rail should modify its processes so that they are applied more widely (paragraph 123).

3 *This recommendation is intended to reduce the risk of rail breaks due to the deterioration of rail pads.*

Network Rail should establish a process throughout its infrastructure for inspecting parts of rail pads beneath rails (on a sample basis) and, if necessary, replacing rail pads outside rail replacement projects in areas where this is justified by benefits, including benefits from reducing rail break risk (paragraph 121b).

continued

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[11] Those identified in the recommendations, have a general and ongoing obligation to comply with health and safety legislation and need to take these recommendations into account in ensuring the safety of their employees and others.

Additionally, for the purposes of regulation 12(1) of the Railways (Accident Investigation and Reporting) Regulations 2005, these recommendations are addressed to the Office of Rail Regulation to enable it to carry out its duties under regulation 12(2) to:

(a) ensure that recommendations are duly considered and where appropriate acted upon; and

(b) report back to RAIB details of any implementation measures, or the reasons why no implementation measures are being taken.

Copies of both the regulations and the accompanying guidance notes (paragraphs 200 to 203) can be found on RAIB's website www.raib.gov.uk.

4 *This recommendation is intended to reduce the risk of rail breaks by improving the ability of existing Ultrasonic Testing Unit (UTU) equipment to detect initiator cracks and other defects in the lower part of the rail.*

Network Rail should complete the current test programme to establish the practicability of extending current UTU testing and analysis to identify defects throughout the full depth of a rail and/or defects on the underside of a rail. If the test programme shows that this offers a reasonably practicable means of improving the detection of initiator cracks and other defects associated with potential rail breaks, Network Rail should introduce equipment and processes to implement this improved testing and analysis (paragraph 121d).

5 *This recommendation is intended to reduce the risk that railway maintenance staff fail to appreciate that an important change has been made to Network Rail standards.*

Network Rail should modify existing document preparation processes to ensure that markings intended to show changes to standards and other safety critical documents clearly indicate the change that has occurred (paragraph 124c).

Appendices

Appendix A - Glossary of abbreviations and acronyms

ECML	East Coast Main Line
EMGT	Equivalent million gross tonnes (of rail traffic)
EMGTPA	Equivalent million gross tonnes per annum (of rail traffic)
FWI	Fatalities and weighted injuries
GPS	Global Positioning System
GWML	Great Western Main Line
LADS	Linear Asset Decision Support (tool)
LNE	London North Eastern (route)
LNW	London North Western (route)
ORR	Office of Rail Regulation
RAIB	Rail Accident Investigation Branch
UTU	Ultrasonic Test Unit

Appendix B - Glossary of terms

All definitions marked with an asterisk, thus (*), have been taken from, or adapted from, Ellis's British Railway Engineering Encyclopaedia © Iain Ellis. www.iainellis.com.

Aluminothermic (weld)	A welding process using the chemical reaction between aluminium and iron oxide to produce both iron and the heat needed to melt the iron to form a joint between two lengths of rail.
Ballast (track ballast)	Crushed stone, nominally 48 mm in size and of a prescribed angularity, used to support sleepers, timbers or bearers both vertically and laterally.
Brittle fracture	Component failure where there is little or no deformation of the material prior to its breakage.*
Cast crossing	A monolithic component that permits the passage of wheel flanges across other rails where tracks intersect.*
Continuous welded rail	Track formed by welding together sections of rail to give a long length of continuous rail, generally longer than 37 metres (120 feet).
Corrosion pits	Depression in the surface of a metal surface caused by corrosion of the metal.
Coronet joint	Proprietary insulated fishplate jointing system illustrated on figure 5.
Crossings	An assembly that permits the passage of wheel flanges across other rails where tracks intersect.*
Dip angle	Defined in figure 31.
Dipped joint	Generally a fishplated rail joint that is displaying signs of distress, but can be used to describe a weld displaying similar defects* Illustrated in figure 6.
Down (as applied on the ECML)	The direction of trains travelling away from London.
Equivalent Million Gross Tons Per Annum	Measure of the amount of rail traffic described in paragraph 45 and in appendix D.
Fatigue crack	A crack caused by repeated bending or compression / tension cycles.*
Fishplate	Specially cast or forged steel plates used in pairs to join two rails at a fishplated rail joint.*
Flat bottom (rail)	A rail section having a flat based rail foot.*
Global Positioning System	A means of determining geographical location using signals from satellites.

Insulated block joint	A joint between two rails incorporating insulation to provide the electrical separation needed between adjacent track circuits.
Lifted & packed	The action of raising the track to its designed level and adding compacted ballast beneath the sleepers. The term is normally associated with a manual operation involving ratchet jacks and shovels, but can include tamping.*
mrad	One thousand of a rad (equivalent to approximately 0.057 degrees).
Pad (rail pad)	A resilient layer of rubber or similar material fitted between a rail and bearer or rail and baseplate.*
Rail breaks	An unintended separation of a rail due to cracking.
Rolling contact fatigue	Collective term for all rail defects directly attributable to the rolling action of a rail wheel on the rail.*
Residual Stress (in the context used in this report)	Stresses which remain in metal after completion of manufacture.
Sleepers	A beam made of wood, pre- or post-tensioned reinforced concrete or steel placed at regular intervals at right angles to, and under, the rails. Their purpose is to support the rails and to ensure that the correct gauge is maintained between the rails.*
Stress concentration	An zone in which relatively high stresses occur for reasons explained in paragraph 60.
Switch	An assembly of two movable rails (the switch rails) and two fixed rails (the stock rails) and other components used to divert vehicles from one track to another.*
Tache ovale	This describes a rail defect in the form of a fatigue crack propagating laterally from an internal defect in a rail.*
Track circuit	An electrical or electronic device used to detect the absence of a train on a defined section of track using the running rails in an electric circuit.*
Track geometry	The horizontal and vertical alignment of the track, including cant.*
Tri-metallic (weld)	A means of joining components made from differing types of steel which cannot be directly welded to each other. A small gap between the components is bridged using a material compatible with both components.
Ultrasonic Test Unit	A multiple unit train equipped with ultrasonic rail flaw detection equipment*

Ultrasonic testing (in the context used in this report)	The use of ultrasonic waves passed through rails to locate cracks within the rail.
Up (as applied on the ECML)	The direction of trains travelling towards London.
Weld	A means of jointing metal using heat to fuse the metal.
Wet beds	An area of ballast contaminated with slurry. Such wet spots spread under the action of passing traffic.*

Appendix C - Key standards

NR/L2/TRK/001 (modules 1 to 19): ● Version 4 valid until 31 August 2012 ● Version 5 valid from 1 September 2012 until 1 February 2013 ● Version 6 valid from 2 February 2013	Inspection and Maintenance of Permanent Way
NR/L2/TRK/2102	Design and construction of track

Appendix D - Equivalent million gross tonnes per annum (EMGTPA)

Network Rail has stated that equivalent million gross tonnes per annum (EMGTPA) is obtained by multiplying actual annual tonnage of traffic by factors allowing for axle weight and speed. The calculation is performed separately for unpowered passenger vehicles, freight and traction units; these components are then added together to give EMGTPA. The axle weight factor is adjusted for freight wagons equipped with bogies designed to reduce track wear. Additional details are given below:

$$\text{EMGTPA} = (T_{pass} \times K_{pass} \times S) + (T_{freight} \times K_{freight} \times S) + (T_{traction} \times K_{traction} \times S)$$

where:

T_{pass} = actual annual tonnage of unpowered passenger vehicles (assuming all passenger seats occupied)

$T_{freight}$ = actual annual tonnage of freight vehicles (including loads)

$T_{traction}$ = actual annual tonnage of locomotives and powered passenger vehicles (assuming all passenger seats occupied)

K_{pass} = coefficient dependent on axle load (0.8 for axles not exceeding 11 tonnes, 1.0 for heavier axles)

$K_{freight}$ = coefficient dependent on axle load (1.15 if all axles are less than 20 tonnes rising to 1.45 if most axles are between 22.5 tonnes and 25.5 tonnes; with a reduction factor of 0.1 for bogies designed to give low track forces)

$K_{traction}$ = coefficient dependent on axle load and power applied by traction unit (0.80 for axles less than 11 tonnes on vehicles having a power of less than 0.5 MW, rising to 1.80 for axles of 20 tonnes or more on vehicles have a power of 1.6 MW or more)

S = coefficient dependent on speed, eg 1.00 for speeds less than 40 mph (64 km/hr) and 1.55 for speeds from 76 mph to 100 mph (122 km/hr to 161 km/hr).

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Any enquiries about this publication should be sent to:

RAIB
The Wharf
Stores Road
Derby UK
DE21 4BA

Telephone: 01332 253300
Fax: 01332 253301
Email: enquiries@raib.gov.uk
Website: www.raib.gov.uk