



Rail Accident Investigation Branch

Rail Accident Report



Locomotive derailment at Ordsall Lane Junction, Salford, 23 January 2013

Report 07/2014
March 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.

© Crown copyright 2014

You may re-use this document/publication (not including departmental or agency logos) free of charge in any format or medium. You must re-use it accurately and not in a misleading context. The material must be acknowledged as Crown copyright and you must give the title of the source publication. Where we have identified any third party copyright material you will need to obtain permission from the copyright holders concerned. This document/publication is also available at www.raib.gov.uk.

Any enquiries about this publication should be sent to:

RAIB	Email: enquiries@raib.gov.uk
The Wharf	Telephone: 01332 253300
Stores Road	Fax: 01332 253301
Derby UK	Website: www.raib.gov.uk
DE21 4BA	

This report is published by the Rail Accident Investigation Branch, Department for Transport.

Locomotive derailment at Ordsall Lane Junction, Salford, 23 January 2013

Contents

Summary	5
Introduction	7
Preface	7
Key definitions	7
The accident	8
Summary of the accident	8
Context	9
Events preceding the accident	12
Events during the accident	13
Events following the accident	14
Locomotive fire	14
Key facts and analysis	15
Background information	15
Identification of the immediate cause	26
Identification of causal factors	27
Observations	33
Summary of conclusions	34
Immediate cause	34
Causal factors	34
Observations	34
Previous RAIB recommendations relevant to this investigation	35
Actions reported as already taken or in progress relevant to this report	37
Recommendations	38
Appendices	40
Appendix A - Glossary of abbreviations and acronyms	40
Appendix B - Glossary of terms	41

This page is intentionally left blank

Summary

At 14:34 hrs on 23 January 2013 a class 47 diesel electric locomotive derailed on a small radius curve, approaching Ordsall Lane Junction in Salford, and caught fire. The locomotive derailed to the outside of the curve. It was being hauled on the rear of an empty train, which was formed of another class 47 locomotive and five coaches.

The cause of the derailment was that the lateral forces acting at the wheel-rail interface, as the locomotive negotiated the curve, were sufficient to cause the leading right-hand wheel to climb the rail. Despite being required by standards, there was no check rail on the curve. This safeguard would have restricted the lateral displacement of the wheels and prevented the derailment.

The RAIB found that the following factors had resulted in the lateral forces being high enough to initiate wheel climbing conditions:

- The dry and clean state of the inside face of the outer rail on the curve that enabled high levels of wheel-rail contact friction to be established; recently-modified arrangements for lubricating the rails did not prevent this.
- Machining work that had recently been undertaken to restore the wheel profiles on the locomotive; this removed any pre-existing lubricant and contaminant from the locomotive wheels that would otherwise have helped reduce wheel-rail contact friction levels.
- The relatively low angle of contact between the wheel and rail associated with the newly-restored wheels on the locomotive; this reduced the locomotive's ability to resist the climbing forces acting at the wheel-rail interface.
- The wider than normal distance between the rails (track gauge) that had developed on the curve.

The above combined to generate the conditions necessary for derailment, but none of these factors involved non-compliance with applicable standards.

Although it was found that the reprofiling of the wheels had left the wheel surface slightly rougher than specified, the RAIB decided not to investigate this factor any further. This was because the surface was only marginally non-compliant and there is contradictory evidence regarding its effect on wheel-rail friction.

The basic approach to managing the risk of derailment on small radius curves on the national network relies on vehicles and track complying with separate technical standards. However, because these standards do not require consideration of the worst possible combination of conditions, there remains a residual risk of derailment. It is generally recognised by the railway industry that the level of this residual risk is reduced by certain traditional features, such as check rails and trackside rail lubricators. Therefore, although not generally relied upon, RAIB observed that any change in the provision of such features has the potential to reduce the overall level of derailment safety.

The RAIB has directed three recommendations to Network Rail. They are concerned with:

- ensuring that non-compliances with currently prescribed requirements for check rails are identified and mitigated;
- understanding any changes to infrastructure management processes that have increased derailment risk on small radius curves, and the need to take actions to reduce this risk; and
- determining when it is necessary to bring existing track assets in line with latest design standards.

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 or railway industry.

Key definitions

- 4 All dimensions in this report are given in metric units, except speed and locations, which are given in imperial units in accordance with normal railway practice. Where appropriate the equivalent metric value is also given.
- 5 All mileages in the report are measured, via Weedon, Nuneaton, Crewe and Stockport, from a datum at London Euston station. The directions left and right are relative to the direction of travel of the train.
- 6 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.

The accident

Summary of the accident

- 7 At 14:34 hrs on 23 January 2013 locomotive 47500, which was being hauled on the rear of empty coaching stock train 5Z47¹, derailed on the small radius curve approaching Ordsall Lane Junction in Salford (figure 1). Train 5Z47, the 13:28 hrs booked departure from Ardwick train maintenance depot, Manchester, to Carnforth Steamtown, Lancashire, was travelling on the *Down Bolton* line. Locomotive 47500 had been at Ardwick depot for *wheel reprofiling*.

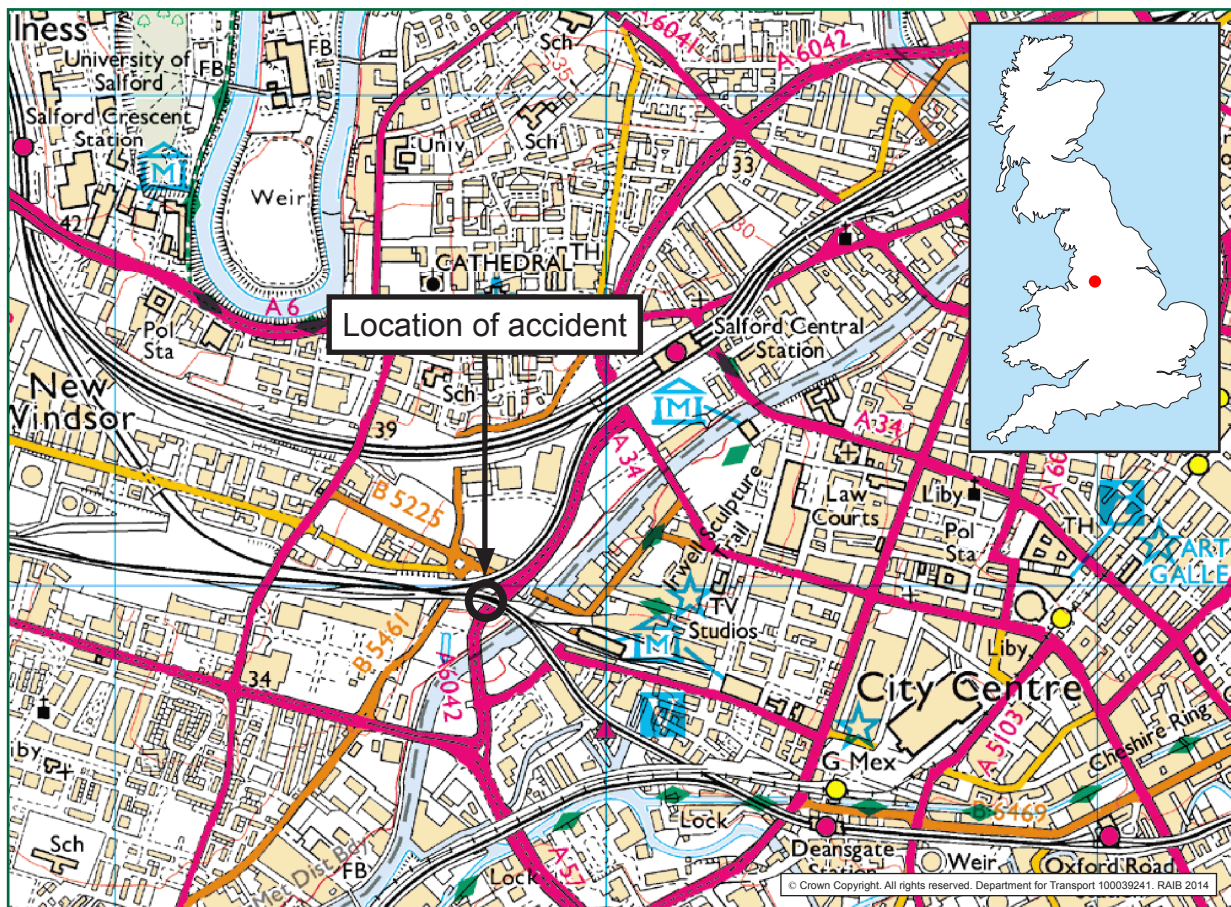


Figure 1: Extract from Ordnance Survey map showing the location of the accident

- 8 The train ran derailed for around 70 metres before coming to a stand. There was significant damage to the track and to the locomotive, which also caught fire. No-one was injured, but there was the potential for more serious consequences: for instance, if a passenger train had been passing on the adjacent *Up Bolton* line while the derailed train was infringing its path.

¹ The derailed train is referred to in the report by its reporting number, a four-character alphanumeric code that is used to identify it for operational purposes.

Context

Location

- 9 Ordsall Lane Junction is located west of Manchester in the city of Salford. Here the railway, running north from Manchester Piccadilly, via Castlefield Junction, to Bolton and the West Coast Main Line at Euxton Junction, crosses the lines running east-west between Manchester Victoria and Liverpool Lime Street. It comprises two tracks: the Up Bolton line and the Down Bolton line. Much of the original railway alignment in the area dates from the historic Liverpool and Manchester railway, which opened in 1830; there is a branch off the Up Bolton line that leads to the former Liverpool Road station - now part of the Museum of Science and Industry.
- 10 From Castlefield Junction (189 miles 67 chains), the railway runs elevated on a brick viaduct until it curves to the left and runs over three bridges. The first, bridge 130, crosses the River Irwell. The next, bridges 130A and 130B, date from the late 1980s and take the railway over the Manchester-Salford inner relief road. The minimum radius of the curve is 178 metres (paragraph 43). Shortly after, there is a *transition curve*, and the tracks become straight before reaching Ordsall Lane Junction (190 miles 28 chains). Figure 2 shows the general alignment of the railway.
- 11 The derailment occurred close to *milepost* 190¼. Locomotive 47500 had just crossed bridge 130B and was entering the transition curve. The permitted speed here is 30 mph (48 km/h), on both the Up Bolton and Down Bolton lines.
- 12 Network Rail has planned a programme of infrastructure investment in Manchester, known as the Northern Hub, to improve rail services between towns and cities in northern England². This includes building a new section of railway in the area, to be known as the Ordsall Chord, which will then connect Manchester Piccadilly, Manchester Oxford Road and Manchester Victoria stations. The work is scheduled to start in late 2014, or early 2015, and will involve the re-alignment of the Up Bolton and Down Bolton lines on bridges 130, 130A and 130B.

Organisations involved

- 13 Network Rail owns and maintains the railway infrastructure where the derailment occurred. It is part of its London North Western (North) route.
- 14 West Coast Railway Company Limited (generally known as West Coast Railways), an independent train operating company specialising in running charter trains, operated train 5Z47. It also owns and maintains the rolling stock involved and made arrangements for the wheel reprofiling at Ardwick depot.
- 15 Siemens owns and operates Ardwick depot³ and, for around three years, has provided a service to West Coast Railways for reprofiling the wheels on a variety of vehicles with the type of profile used on locomotive 47500.
- 16 All of the above parties freely co-operated with the investigation.

² Further information can be found at www.networkrail.co.uk.

³ Siemens built Ardwick depot for the maintenance of the Class 185 *diesel multiple unit* fleet. Class 350/4 electric multiple units are also maintained there.

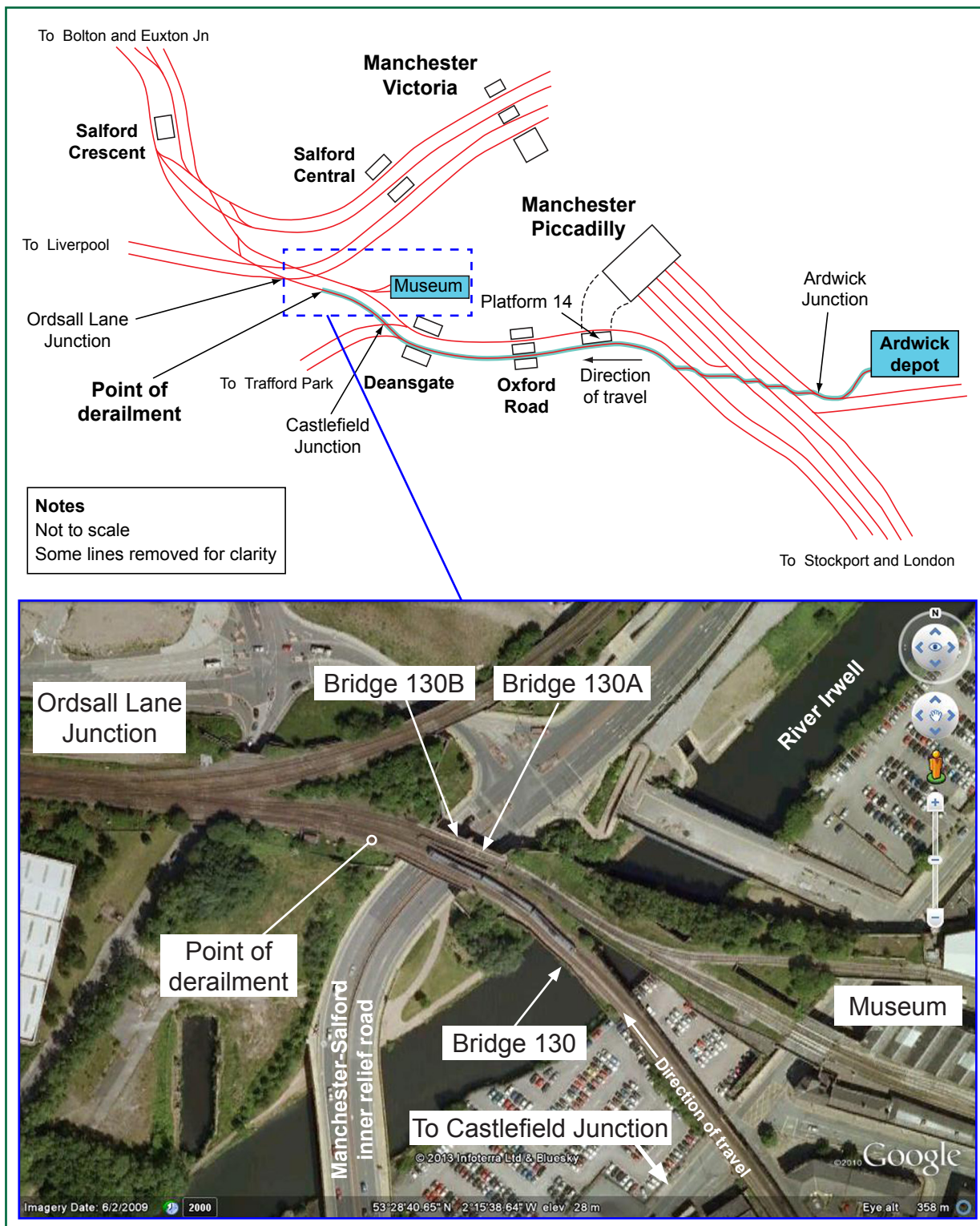


Figure 2: Diagram of the railway between Ardwick train maintenance depot and Ordsall Lane Junction

Train involved

17 Another class 47 diesel electric locomotive, 47854, headed train 5Z47. Coupled to it were five ex-British Rail coaches and, at the rear, locomotive 47500.

- 18 West Coast Railways had identified the need for wheel reprofiling on locomotive 47500 because a *wheel impact load detector* (WILD) had detected wheel flats when it passed over the WILD site at Salfords in Surrey, on 8 December 2012. The wheel profiles were restored to the *P1 wheel profile*. Selected coach wheel profiles were also restored at Ardwick depot.
- 19 Class 47 locomotives were built for British Rail in the mid-1960s. Their running gear comprises two three-axle bogies, each with an overall wheelbase of 4.42 metres. The bogies are spaced 11.28 metres apart (figure 3).



Figure 3: Locomotive 47500 showing wheelbase and bogie spacing dimensions

- 20 West Coast Railways purchased locomotive 47500⁴ in 2009, overhauled it and, after examination in 2010, re-introduced it into service. Since then, West Coast Railways has maintained the locomotive in accordance with its maintenance instructions. It completed the last routine examination at its depot at Carnforth Steamtown on 15 January 2013; it found nothing untoward.

Track involved

- 21 The track on the curve, from bridge 130A through to the derailment site, comprises jointed *flat-bottom BS113A rail*, fastened with *pandrol clips*, to *pan 11 baseplates*. The baseplates are screwed into hardwood sleepers supported on stone ballast. Figure 4 shows a typical view of the track and its construction.
- 22 A team working for Network Rail's track maintenance engineer for north Manchester (Manchester North TME) inspects and maintains the track in the area. The last inspection of the track was the weekly basic visual inspection carried out on 20 January 2013, three days before the derailment (paragraph 47).
- 23 Witness evidence indicated that the last track renewal work on the down Bolton line was in 2008. The date of manufacture marked on the rails supports this; however, Network Rail was unable to supply the RAIB with any records of the work that was carried out (paragraph 78).

⁴ The locomotive was not in service when West Coast Railways purchased it. The freight operating company EWS was the last company to operate it. At that time it was numbered 47770.



Figure 4: The track on the Down Bolton line, looking from bridge 130B towards the derailment site

External circumstances

- 24 The air temperature recorded⁵ at the time of the derailment was 2°C and the wind was from the east-south-east with a speed of 11 km/h. There had been no precipitation for the preceding 36 hours; this is significant because a lack of moisture can result in a high level of friction on the rail, which increases the risk of a wheel *flange* climbing onto the rail and into derailment (paragraph 66).

Events preceding the accident

- 25 At 12:35 hrs on 23 January 2013, West Coast Railways' locomotive 47854 arrived at Ardwick depot to haul locomotive 47500 and the five coaches back to Carnforth Steamtown. It had travelled from Carnforth Steamtown with some other vehicles that needed wheel reprofiling. There was a crew of four West Coast Railways' staff on the incoming train: two drivers (the second driver was required to help with the shunting necessary at Ardwick depot), a guard and a locomotive fitter.
- 26 After uncoupling the other vehicles from locomotive 47854, the train crew waited for the reprofiling work on locomotive 47500 and the five coaches to be completed. They then coupled them up onto locomotive 47854, shut down locomotive 47500 and completed a brake test of the train. They also did a check to confirm that, in light of the recent wheel reprofiling work, the wheels on locomotive 47500 rotated freely.
- 27 Train 5Z47 departed Ardwick depot at 14:24 hrs, and was routed via Ardwick Junction, over the lines that lead into the terminal platforms at Manchester Piccadilly station, and onto the line passing through platform 14 (figure 2). Both drivers travelled in the front cab of locomotive 47854; the guard and a fitter travelled in the rear cab of locomotive 47854. There was no-one in any of the hauled vehicles.

⁵ Based on records for the weather station at Manchester Hulme Library, 1.5 km south-east of the derailment site.

Events during the accident

- 28 At 14:29 hrs, after passing Manchester Piccadilly (platform 14), Oxford Road and Deansgate stations, the train was routed onto the Down Bolton line at Castlefield Junction. The *colour-light signal* MP501 protecting Ordsall Lane Junction was showing a *single-yellow aspect* as the train approached at 18 mph (30 km/h).
- 29 Shortly after crossing bridges 130A and 130B, the driver in charge stated that the train came to a gentle stand just as he was about to apply power to traverse the junction. Because his cab indications did not show why it had stopped, he looked back along the train. He saw smoke coming from a fire on locomotive 47500 and immediately pressed the emergency call button on the train radio; the other driver in the cab then spoke with Network Rail's *route control*. The driver of another train stopped at the junction also saw the fire; he alerted the signaller at Manchester Piccadilly on a *signal post telephone*. The fitter in the rear cab of locomotive 47854 felt a longitudinal movement through the train and, on looking back, also saw the smoke. Both he and the guard immediately got out to investigate. They found locomotive 47500 derailed, with both bogies straddling the right-hand rail (figure 5). Analysis of the *on-train data recorder* showed that the locomotive was travelling at 14 mph (23 km/h) when it derailed.
- 30 Route control made an emergency broadcast stopping all trains in the area, and the signaller replaced the signals to danger. The assisting driver on 5Z47 subsequently placed *track circuit operating clips* on the adjacent lines, providing additional protection. The fire service was alerted at 14:38 hrs.



Figure 5: Derailed locomotive (main photograph courtesy of Greater Manchester Fire and Rescue Service)

Events following the accident

- 31 The locomotive fitter and the guard made an initial attempt to extinguish the fire but soon realised that it was too intense. They retreated to the front of the train and waited for the fire service. Fire crews were reported to be at the scene by 14:43 hrs.
- 32 Network Rail closed the railway for recovery of the rolling stock and repair of the track. It was reopened at 15:38 hrs on 25 January 2013.

Locomotive fire

- 33 Closed-circuit television images of train 5Z47 passing through Deansgate station at 14:33 hrs (around a minute before the derailment) did not show any sign of a fire on locomotive 47500. The RAIB has judged that, even if the fire had started immediately after passing the station, there was insufficient time for it to have resulted in enough structural damage to have caused the derailment. Furthermore, there was evidence that the locomotive fire was a consequence of the derailment: West Coast Railways' post-incident examination of locomotive 47500 found that a fuel pipe had ruptured near one of the derailed bogies, and close to where a live electrical cable had been severed.

Key facts and analysis

Background information

Post-derailment examination of the track

- 34 The RAIB inspected the track and found two sets of marks on the outer rail of the curve on the Down Bolton line that were consistent with the flanges of the right-hand wheels of locomotive 47500 climbing onto the railhead and then dropping into the *six-foot* (figure 6). The first set (which contains the RAIB designated point of derailment) started at 14 metres after the end of bridge 130B; the second set started 22 metres further on.

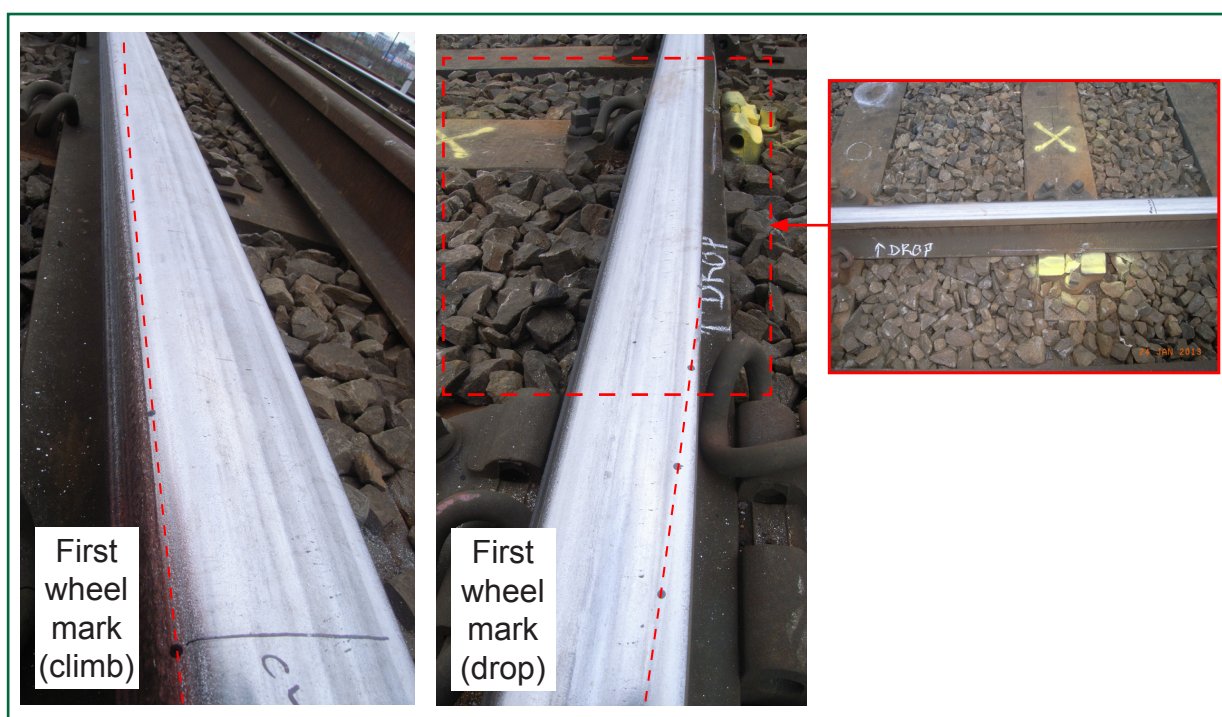


Figure 6: First mark showing evidence of a wheel flange climbing over the railhead

- 35 The *gauge face*, where the wheel flange had been in contact with the railhead of the outer rail, was dry, clean and shiny, with no evidence of naturally-occurring metal oxides, lubricants or other contaminants. There were also signs of aggressive *sidewear* on the railhead, with metal particles deposited on the ballast and sleepers below (figure 7).
- 36 The RAIB measured sidewear readings of between 8 and 10 on the outer rail in the vicinity of the derailment. These measurements were made using the Network Rail NR4 stepped sidewear gauge⁶ (figure 8). The gauge readings range from 18, when the rail is new, to 0 when the rail needs to be replaced or transposed⁷.

⁶ The NR4 stepped sidewear gauge comprises a shaped profile, with jaws, and a stepped wedge-piece. The jaws are placed across the rail, with the straight jaw aligned to the outer face and the round jaw resting on the corner of the inner (gauge) face. The measurement is made by sliding the wedge-piece along the top of the rail in the slot between the jaws; the reading is the height (as marked on the wedge-piece) of the highest step that will just pass under (as shown on figure 8).

⁷ The maintenance action defined in Network Rail standard NR/L2/TRK/001, 'Inspection and maintenance of permanent way', for line speeds up to 80 mph (129 km/h).

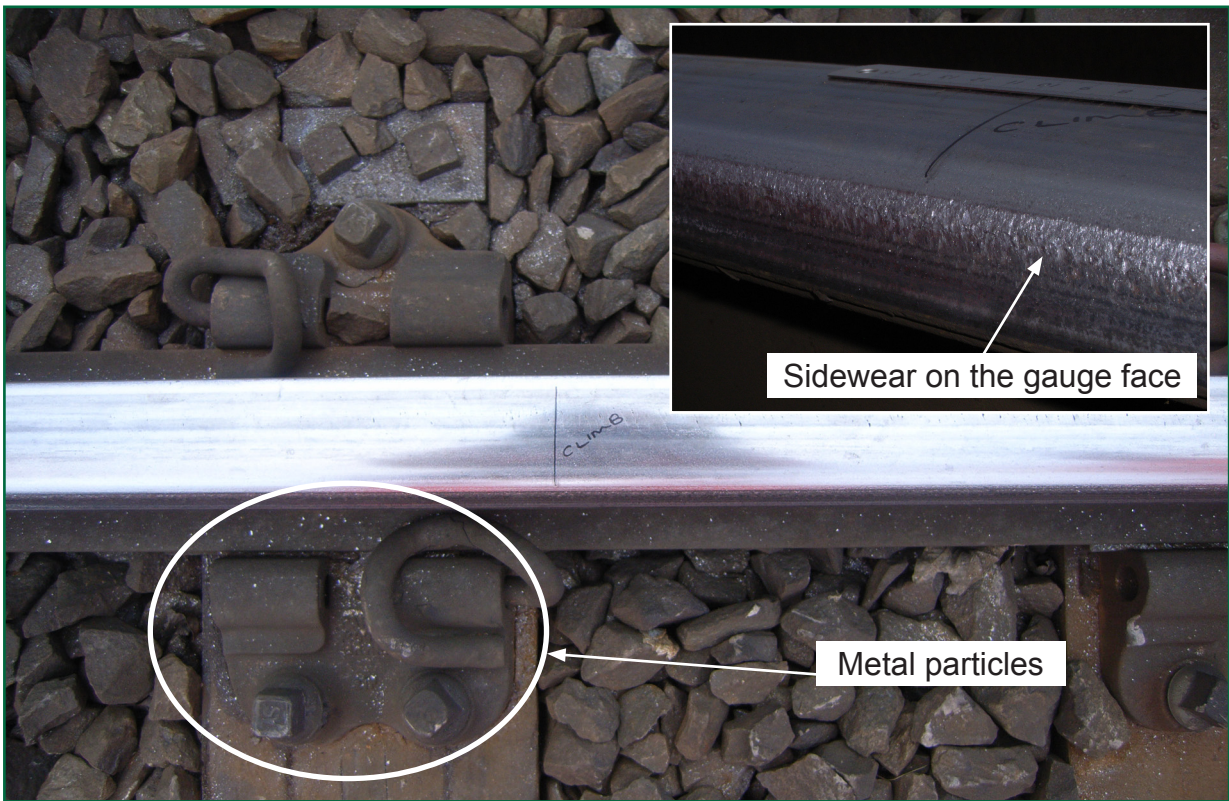


Figure 7: Condition of the gauge face of the outer rail of the curve and the deposits of metal particles

37 The RAIB also witnessed Network Rail’s survey of the track, which included recordings of the rail profiles and static measurements⁸ of the *track cant* and *track gauge*. The latter showed that the track gauge was significantly wider than nominal, but less than that at which unscheduled maintenance is required (paragraph 102).

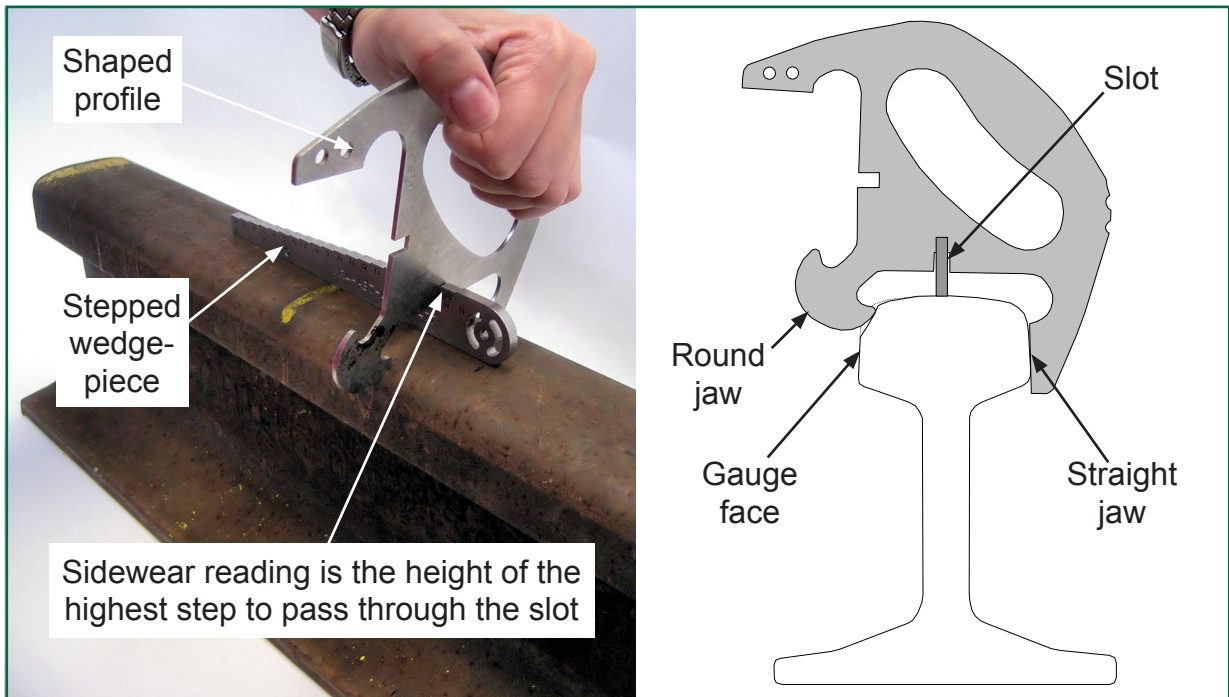


Figure 8: NR4 stepped sidewear gauge

⁸ These do not take into account the displacement of the track due to train loading.

Control of derailment risk on small radius curves

- 38 Following discussion with the Rail Safety and Standards Board (RSSB) and Network Rail, and a review of published standards, the RAIB concluded that the basic approach to managing the risk of derailment on small radius curves on the national network relies on two separate high level requirements. These are summarised below:
- Vehicles running on the national network must:
 - comply with Railway Group standard GM/RT2141 ‘Resistance of railway vehicles to derailment and roll-over’; or
 - for older vehicles such as the class 47 locomotive, have a proven history of operation.
 - The track must comply with the geometric limits defined in Railway Group standard GC/RT5021 ‘Track system requirements’.
- 39 The combination of these requirements does not guarantee derailment prevention; this is because the assessment of vehicle derailment resistance does not take into account the worst possible combination of track, operational and environmental conditions (for example, there is no allowance for very high levels of wheel-rail contact friction). Therefore, even when the vehicle and track are compliant with the high level requirements described in paragraph 38, there is a residual risk of derailment.
- 40 It is generally recognised by the railway industry that the level of this residual risk is reduced by the provision of certain track elements, such as *check rails* (paragraphs 41 and 42), and environmental factors that modify the wheel-rail contact friction, such as naturally-occurring moisture and metal oxides (paragraphs 24 and 35), and artificially-applied lubricants (paragraphs 61 and 62). Although these track elements and environmental factors do not form part of the railway industry’s basic approach to the control of derailment risk, they are features of the overall railway environment in which the above high level requirements have been applied (that is, they have become part of the ‘historic norm’ on the national network). Consequently, any change to the extent of the provision of such track elements, or arrangements designed to manage the wheel-rail contact friction, has the potential to reduce the overall level of safety.

Provision of check rails

- 41 A check rail is a rail that is fitted alongside a running rail at a specified dimension from the gauge face. When a railway vehicle with conventional bogies, such as a class 47 locomotive, negotiates a curve the flanges of the leading outer wheels on each bogie tend to be displaced towards the outer rail. On smaller radius curves the flanges can be forced into contact with the gauge face – the resulting lateral force increasing the risk of the wheel flange climbing onto the rail and into derailment (paragraph 66). A check rail fitted alongside the inner running rail of a curve restricts this lateral displacement, by bearing on the *flange backs* of the inner wheels, helping to prevent the flanges of the outer wheels climbing onto the outer rail. Figure 9 shows a check rail fitted to a typical small radius curve.

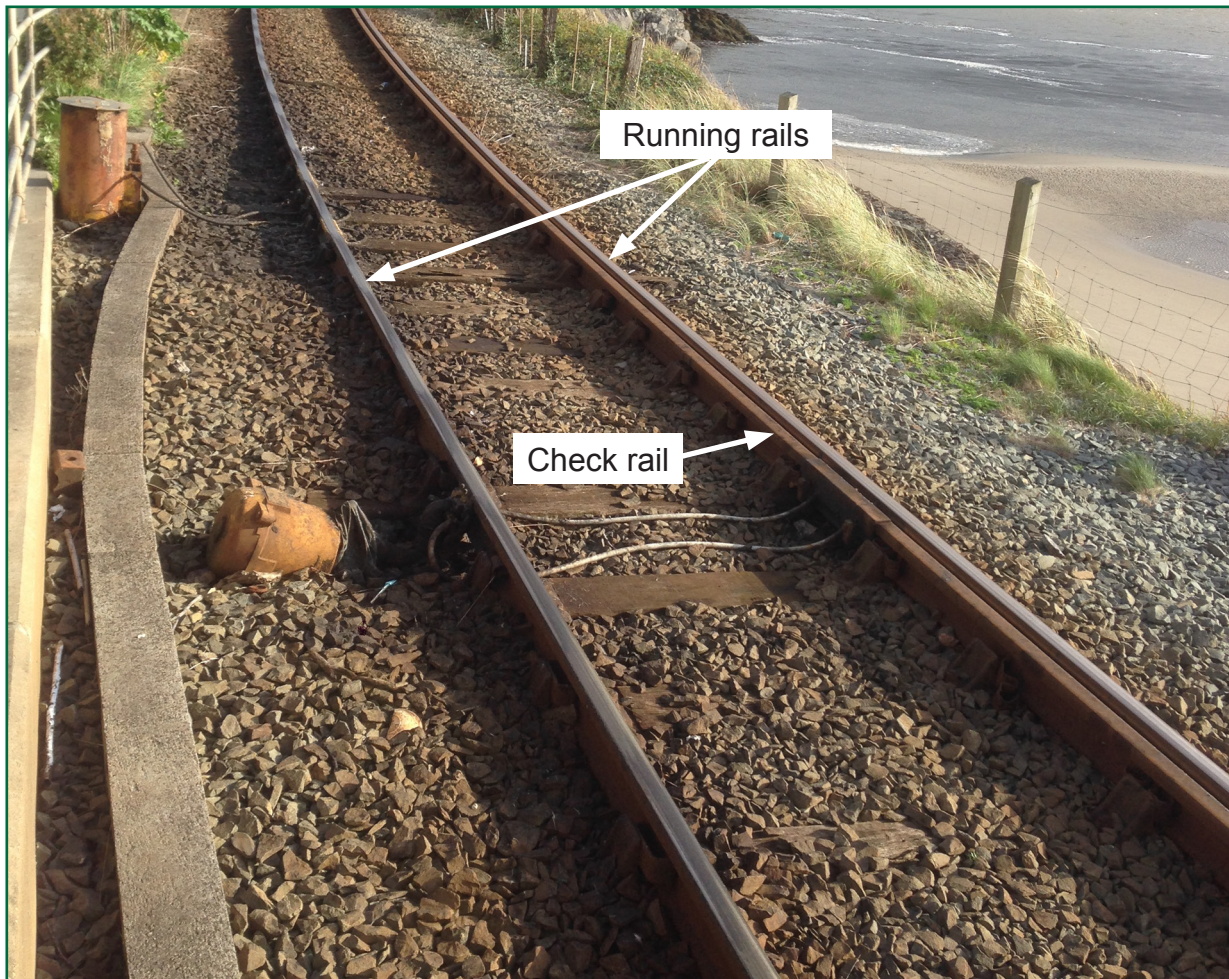


Figure 9: Check rail fitted to a typical small radius curve

- 42 Both Railway Group standard GC/RT5021 'Track system requirements', and Network Rail standard NR/L2/TRK/2102 'Design and construction of track', require that check rails are fitted on all passenger lines⁹ (and running lines close to passenger lines) where the track radius is less than 200 metres, and that they should extend at least 9 metres into adjoining sections of straighter track. The RAIB found evidence of equivalent requirements going back over 100 years¹⁰ (it noted however that there is no equivalent requirement in the applicable *Technical Specification for Interoperability* issued by the European Commission).
- 43 Network Rail's track geometry measurement train recorded the track curvature¹¹ along the line on 12 November 2012. The curve radius was at its minimum 30 metres before the point of derailment, where it measured 178 metres. Although the point of derailment was on the curve transition where the radius had increased to 209 metres, it had been less than 200 metres only 5 metres before. The track geometry at the derailment location therefore met the criteria for check rail fitment in both GC/RT5021 and NR/L2/TRK/2102. Figure 10 shows the measured track curvature.

⁹ NR/L2/TRK/2102 also requires check rails on passenger diversionary lines.

¹⁰ Various historic railway requirements refer to the need for check rails on curves of 10 chains (approximately 200 metres) radius or less, including the Ministry of Transport's 'Railway construction and operation requirements for passenger lines and recommendations for goods lines' dated 1950 and the Board of Trade's 'Requirements etc of the Board of Trade in regard to the opening of railways' dated 1892.

¹¹ Curvature = 1/radius.

- 44 There was no check rail fitted to the curve on the Down Bolton line approaching Ordsall Lane Junction at the time of the derailment.

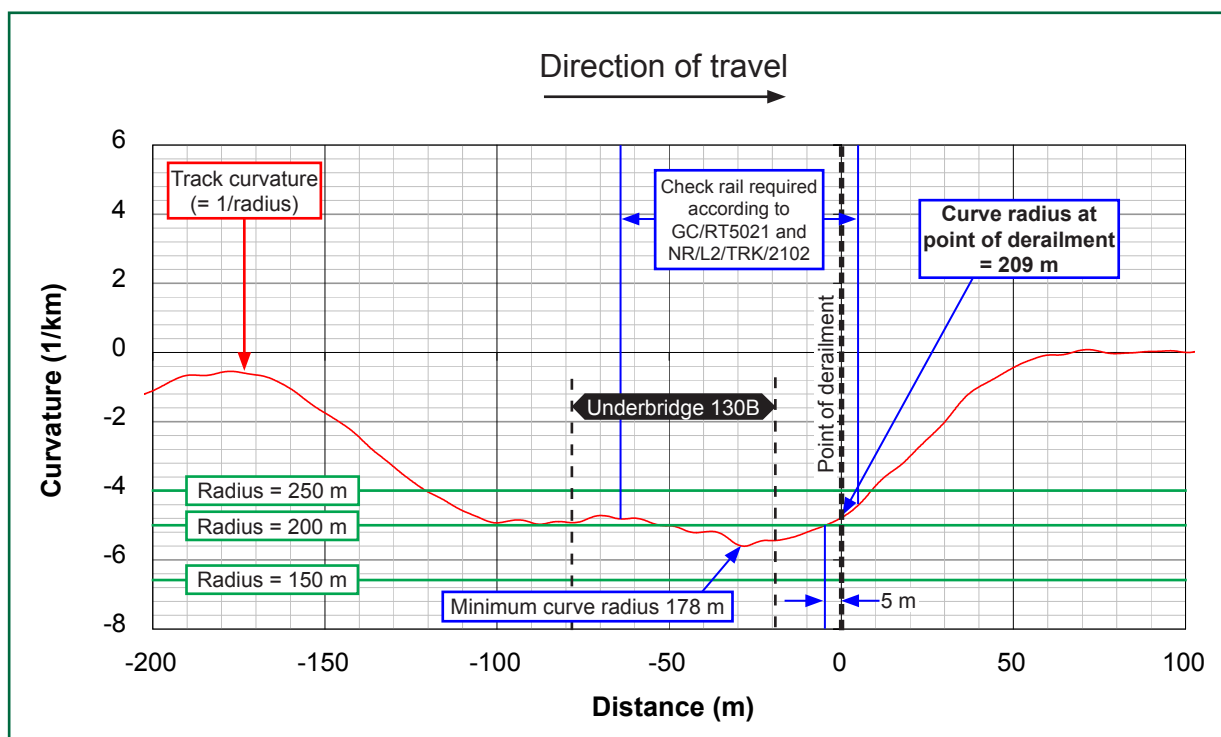


Figure 10: Track curvature in the vicinity of the derailment showing where a check rail was required

Inspection and maintenance of the track

- 45 Network Rail requires routine visual inspection of its track in accordance with its standard NR/L2/TRK/001, 'Inspection and maintenance of permanent way'. The frequencies of inspection depend on the type of track and the track category (which is determined from the line speed and the annual loading from trains that use it). The Down Bolton line approaching Ordsall Lane Junction consists of jointed track and was classed as track category 4. As a result, the application of NR/L2/TRK/001 required:
- a basic visual inspection by *patrollers* every week;
 - a *section manager* visual inspection every 13 weeks;
 - a track maintenance engineer (TME) inspection every two years.
- 46 Basic visual inspections are used to identify defects which could affect the safety and operation of the railway if they remain uncorrected before the next inspection. The Down Bolton line at Ordsall Lane Junction is inspected as part of a pre-planned inspection walk. It is done every Sunday morning as special arrangements are needed to protect staff working on the bridge and viaduct sections towards Castlefield Junction.

- 47 The basic visual inspection reports, for the three months prior to the derailment, showed that the overall frequency of inspection was compliant with Network Rail's requirement and that the only work identified in the vicinity of the derailment site was the regular need to tighten the screws securing the pan 11 baseplates (paragraph 21). The patroller who did the last inspection before the derailment (paragraph 22) found that four screws needed tightening. He observed nothing untoward regarding the dry and sideworn condition of the outer rail of the curve. Although Network Rail would have expected him to notice if the sidewear had been excessive, recent measurements - made by the section manager before the derailment and afterwards by the RAIB - showed that this was not the case (paragraph 36 and 49). He did not notice any metal particles on the ballast and sleepers under the railhead, which would have been an indication of the aggressive sidewear on the railhead, and therefore the high wheel-rail contact friction; he recalled that frost covered the ground.
- 48 The section manager visual inspections are used to decide how to respond to problems identified in the basic visual track inspection reports that did not require immediate attention. The section manager's inspections of the Down Bolton line were carried out every two months, exceeding Network Rail's required frequency, using the pre-planned inspection walk used for the basic visual inspection. The section manager told the RAIB that there had been recent maintenance work in the area, primarily addressing wide track gauge and track alignment issues. At the last inspection, undertaken on 9 December 2012, he reported the track to be in 'fair condition'.
- 49 The section manager took a Network Rail NR4 stepped sidewear gauge with him on 9 December 2012. He recalled taking sidewear readings of 12 and 14 on the outer rail of the curve, which were within permitted limits. He stated that he saw no evidence of metal particles on the ballast and sleepers.
- 50 The purpose of the TME's inspection is to check the performance of those that have carried out the basic visual and section manager visual inspections, to help develop the maintenance and renewal strategy for an area, and to identify safety issues that are likely to affect the railway in the longer term. The Manchester North TME last inspected the area on 5 August 2012. On the Down Bolton line, the inspection report focused on the work to control the wide track gauge in the area (paragraph 48). However, overall the TME reported the track to be in good condition. He recorded no issues regarding rail sidewear.
- 51 NR/L2/TRK/001 requires the TME and the section manager to supplement their visual track inspections with rides in the cab of trains. The last cab ride by the TME was on 9 February 2011. He identified concerns with the lateral alignment of the rail joints on the curve and the need for a long-term plan to re-rail and install a check rail. However, the TME recalled that he subsequently discussed this with the section manager and decided not to pursue it further as the track in the area was due to be re-modelled as part of the Northern Hub investment programme (paragraph 12). The last cab ride by the section manager was on 21 September 2012. He identified the need to address some rail joints, which were slightly dipped, but no issues with the track curvature or alignment.

- 52 NR/L2/TRK/001 also specifies a sidewear inspection regime, which is carried out by a separate inspection team in the TME's organisation. It involves the periodic recording of sidewear at pre-identified network locations¹², using a NR4 stepped sidewear gauge, and is used to help plan rail replacement. The inspection team had been monitoring rail sidewear once a year at six positions on the curve of the Down Bolton line approaching Ordsall Lane Junction. The last measurement was made on 10 July 2011; values between 15 and 14 were recorded. No recordings were made in 2012 because Network Rail considered the wear rate was low enough to extend the measurement interval to two years.
- 53 In addition to the above inspections, Network Rail routinely makes recordings of the track geometry, using its track geometry measurement train, in order to find geometry faults. The last track geometry measurements, made on 12 November 2012 (paragraph 43), identified no faults, according to Network Rail's standards, which needed to be addressed outside of routine scheduled maintenance. The RAIB particularly noted the lack of significant *track twist*, a common contributor to derailments. The recorded levels of twist (measured over a standard 3-metre base) in the vicinity of the derailment were only 50% of that at which any form of action is required.
- 54 Network Rail kept no record of the radius of the curve approaching Ordsall Lane Junction. The RAIB observed that this can be determined from curvature data recorded by the track geometry measurement train. Network Rail does not require its maintenance teams to review this curvature data in order to check the radii of individual curves, either periodically or after maintenance work.

Examination of the derailed train

- 55 The RAIB examined locomotive 47500 after the derailment and identified that the underframe and the leading bogie were twisted in a way that could unload the leading right-hand wheel, thereby increasing the risk of flange climbing. However, given that there was no significant wheel load variation recorded on recent passes over WILD sites (Salfords (paragraph 18) and Cheddington in Buckinghamshire, on 3 January 2013), these twists are most probably a consequence of the derailment, locomotive fire or handling during recovery and transportation. The RAIB concluded that they are not significant to the cause of the derailment.
- 56 The RAIB's survey of the various primary and secondary suspension clearances (for instance between the bogie frame and the axle boxes) revealed nothing unusual in the set up of the bogies that may have adversely influenced the ability of the locomotive to negotiate the curve approaching Ordsall Lane Junction.
- 57 The RAIB's measurements showed that the wheels on locomotive 47500 had been correctly reprofiled to the P1 wheel profile. Figure 11 shows the measured profile of the leading right-hand wheel compared to the specified design. It also shows the differences with the worn shape of the leading right-hand wheel profile on locomotive 47854.

¹² NR/L2/TRK/001 requires monitoring at all locations where sidewear occurs. The section manager visual and TME inspections are used to identify any new sites that need to be included in the monitoring regime.

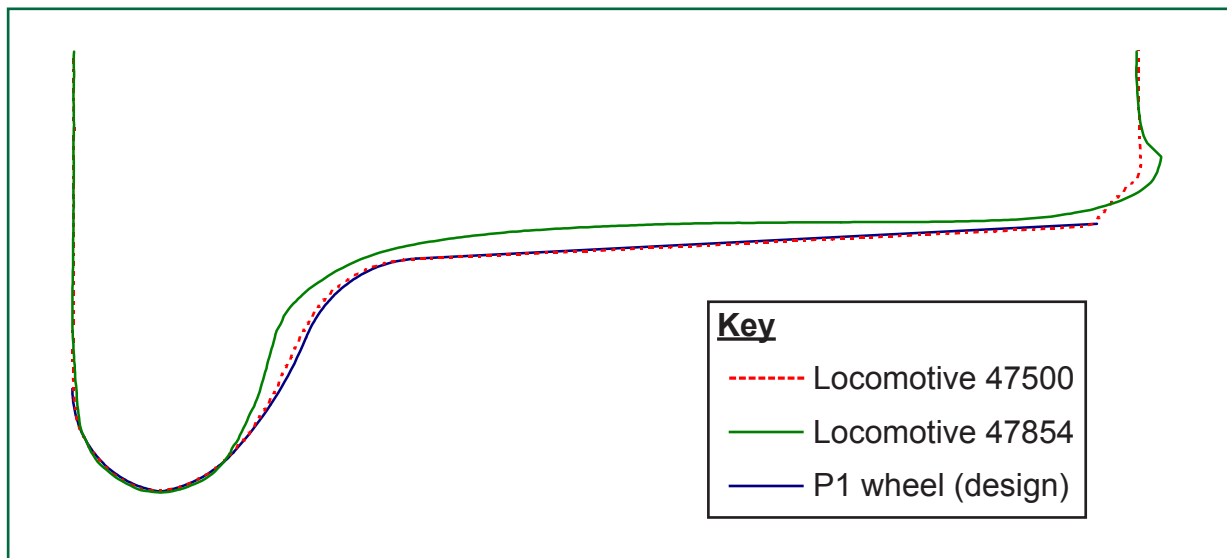


Figure 11: Comparison of the measured profiles on the leading right-hand wheels of locomotive 47500 and 47854

Wheel reprofiling at Ardwick depot

- 58 Staff at Ardwick depot undertake wheel reprofiling work for West Coast Railways in accordance with an in-house procedure and an agreed customer specification (the 'Contract control form' (CCF)) - the latter detailing the specific requirements for the particular vehicle type. The work is carried out on a computer-controlled underfloor *wheel lathe* (figure 12). Coarse cuts are carried out first to remove the bulk of the unwanted material. The lathe operator then manually sets the feed rate necessary to achieve the specified *surface finish* on the final finishing cut, taking into account the condition of the cutting tool and other factors. In common with other maintenance depots, the machining process that Siemens uses does not require a lubricant or cutting agent.
- 59 On the CCF for class 47 locomotives, West Coast Railways specified that the wheel reprofiling should be done in accordance with Railway Group standard GM/RT2466 'Railway wheelsets', and supporting guidance note GM/GN2497 'Guidance on wheelset tread, gauging and damage identification'. On the CCF, it also specified a surface finish of N10¹³, which is consistent with the requirement in GM/GN2497 that states 'a roughness no coarser than 12.5 μm (N10)', and a maximum difference of 0.25 mm between the diameters of two wheels on a wheelset.
- 60 The maximum wheel diameter difference recorded on a wheelset on locomotive 47500, after wheel reprofiling, was 0.108 mm. The wheel lathe procedure requires operatives to regularly monitor the surface finish during wheel reprofiling by visual comparison with a roughness specimen machined to a range of finishes from N5 to N12 (figure 13). There was no requirement to record the results of the comparison. However, from an inspection of the post-derailment condition of the wheel surface the RAIB estimates that a surface finish of between N10 and N11 was achieved, which was marginally rougher than the value of N10 that was specified (paragraph 93).

¹³ The surface finish was specified in terms of the *roughness average* (R_a), which is often also expressed using a system of N-classes; N10, for instance, is equivalent to an R_a value of 12.5 μm .



Figure 12: Wheel lathe at Ardwick depot (inset shows the control used to manually set the feed rate on the finishing cut)



Figure 13: Surface finish sample gauge against a typical newly-reprofiled wheel

Rail lubrication

- 61 Network Rail uses *rail lubricators* to apply lubricant to the gauge face on curves. The devices work by detecting the passage of a train and then applying a quantity of grease to the passing wheels via *grease delivery units* (GDUs) located on the rail. There are three main types:
- mechanical lubricators, which rely on the train wheels depressing a plunger to directly activate the grease pump supplying the GDUs;
 - hydraulic lubricators, which rely on the passing wheels depressing a plunger that hydraulically operates the grease pump; and
 - electric lubricators, which use electronic sensors to detect wheel passage and then deliver grease by means of an electrically-operated pump; manufacturers claim electric lubricators are more controllable and can be configured to treat longer track distances.
- 62 In 2011, Network Rail issued a new standard concerning rail lubrication, NR/L3/TRK/3510/A01, 'Lubrication of plain line running rails, check rails and S&C'. This requires rail lubricators to be provided at all locations where high lateral forces between wheel and rail are 'known or observed to exist', and further details the characteristics of such sites: for instance, curves of less than 1000 metres radius. It also describes where the different types of lubricator should be used. For instance, on longer sequences of curves (800 to 6400 metres long) electric lubricators are required.
- 63 The rail lubricators in the Manchester area are inspected and maintained by a team that report to Network Rail's rail management engineer (Manchester RME¹⁴). In 2012, the team, supported by the local *route asset management* organisation, began a project to rationalise the rail lubrication equipment that it was responsible for¹⁵. Prior to this there were around 590 lubricators, mainly of the hydraulic and mechanical type, in the Manchester area. Many of these lubricators were on long sequences of curves. The plan was therefore to identify and review such sites and replace groups of mechanical and hydraulic lubricators with a single electric lubricator, in accordance with the criteria defined in NR/L3/TRK/3510/A01. By the end of the project, Network Rail intended to reduce the total number of lubricators in Manchester to around 200. One of the anticipated benefits was reduced maintenance workload.

¹⁴ The Manchester RME is responsible for a range of other issues relating to rail management including rail grinding and ultrasonic rail defect detection. He reports to the TME responsible for the track maintenance in the east of Manchester. However, his rail management responsibilities extend across Manchester and include where the derailment occurred.

¹⁵ The route asset management team was supporting similar initiatives with other maintenance teams on the London North Western (North) Route.

- 64 As part of the project, Network Rail gave priority to locating a new electric lubricator on the approach to platform 14 of Manchester Piccadilly. It was installed on 7 July 2012, and by 4 August 2012 Network Rail had removed all five hydraulic lubricators which previously treated the Down Bolton line, and its approaches, up to Ordsall Lane Junction 2.7 km away (figure 14)¹⁶. The lubricant coverage expected from the new electric lubricator¹⁷ was such that lubricators beyond Ordsall Lane Junction, and on the other line branching off at Castlefield Junction, could also be removed.
- 65 Although rail lubrication is primarily focused on long-term infrastructure asset maintenance (paragraph 87), it is also beneficial in reducing the risk of derailment.

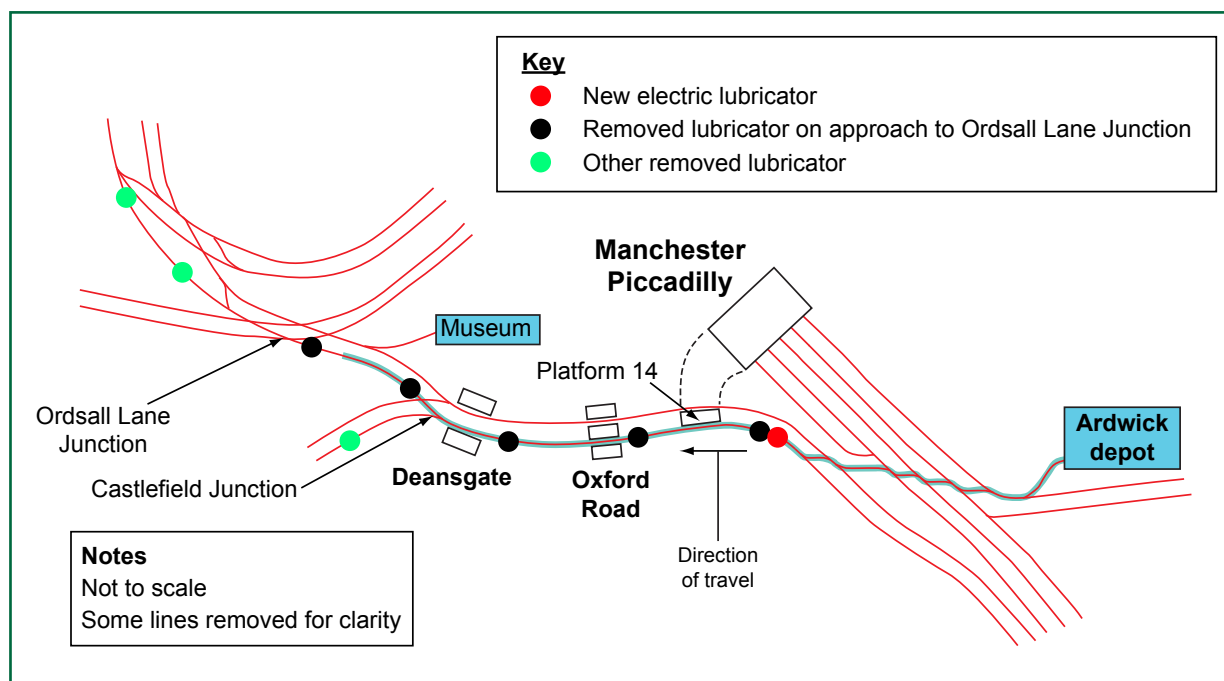


Figure 14: Map showing the location of the lubricators that were removed after the new electric lubricator was installed on the approach to platform 14 at Manchester Piccadilly

Vehicle dynamics study

- 66 The witness marks from the locomotive wheels showed that the mechanism of the derailment was flange climbing of a right-hand wheel of locomotive 47500 (paragraph 34). There is a risk of derailment by flange climb when the ratio of the lateral force of the wheel flange on the rail (Y) to the vertical wheel load (Q), known as the Y/Q derailment quotient, exceeds a critical limit value. The critical limit value is dependent on the level of wheel-rail contact friction and the *flange contact angle*; the higher the friction (or the lower the flange contact angle) the lower the critical limit, and therefore the greater the risk of derailment.

¹⁶ There is witness evidence that the installation of the new lubricator was not subject to approval by the route asset management organisation as NR/L3/TRK/3510/A01 requires.

¹⁷ Network Rail used values from NR/L3/TRK/3510/A01 (derived from manufacturer's data and service experience) as the basis of the distance that an electric lubricator could treat.

- 67 Many factors affect the Y and Q forces acting at the wheel-rail contact point. The RAIB commissioned a vehicle dynamic study, using computer simulation, to investigate their significance in this derailment. The computer model of locomotive 47500 was assembled and developed from a combination of historic design information, *bogie rotation tests* undertaken on other class 47 locomotives and the wheel loads recently recorded at WILD sites (paragraph 55). The computer model of the track focussed on the conditions at the point of derailment. It was created from a combination of measurements made at the derailment site (paragraph 37) and geometry recorded by the track measurement train on 12 November 2012 (paragraph 53).
- 68 The computer simulations looked at the sensitivity of the following factors on the Y/Q derailment quotient:
- wheel and rail profile geometry;
 - the level of friction at the wheel-rail contact;
 - train speed;
 - track geometry: lateral alignment, track gauge and track twist;
 - lateral track stiffness; and
 - the effect of forces from the coupled vehicles.

Identification of the immediate cause¹⁸

69 The immediate cause of the accident was that the lateral forces acting at the wheel-rail interface, as locomotive 47500 negotiated the curve approaching Ordsall Lane Junction, were sufficient to cause the flange of the leading right-hand wheel to climb the outer rail. Nothing was provided to limit the lateral displacement of the wheelset and prevent it crossing over the railhead into derailment.

- 70 The following evidence supports this:
- The two sets of witness marks on the track (paragraph 34) and the final position of the locomotive (paragraph 29), which are consistent with the right-hand wheel flanges climbing the outer rail of the curve and into derailment.
 - The computer simulations from the vehicle dynamics study, which showed that the flanges of the leading right-hand wheels on both bogies were at a risk of climbing the outer rail of the curve under high wheel-rail friction conditions. They further showed that, close to the point of derailment, a coefficient of friction of 0.55 was necessary to result in wheel-rail contact forces that exceeded the Y/Q critical limit value for long enough for these wheels to lift the full depth of the flange (and therefore be high enough to cross over the railhead) - the leading wheel flange on the locomotive climbing first. Given the variables involved, it is not possible to precisely determine the actual friction levels at the time of the derailment. However, a technical literature review¹⁹ confirmed that a coefficient of 0.55 (or more) was credible, considering the clean and dry wheel-rail contact conditions that were observed (paragraphs 24 and 35).

¹⁸ The condition, event or behaviour that directly resulted in the occurrence.

¹⁹ A variety of literature sources were considered, including a revision draft of European Standard EN14363 (dated June 2013), which reports friction measurements made by British Rail, and a guidance note published by the RSSB: GM/GN2642, 'Guidance on wheel/rail low adhesion'.

- The lack of any evidence of significant track twist (paragraph 53) or uneven wheel loading (paragraph 55), which showed there was no significant reduction in vertical wheel load (Q). Therefore, lateral forces must have been dominant in raising the Y/Q derailment quotient (paragraph 66) above the critical limit value.
- The absence of a check rail on the curve, which would have otherwise restricted the lateral displacement of the leading wheelset and prevented the right-hand wheel flange climbing onto, and over, the railhead (paragraph 44).

Identification of causal factors²⁰

- 71 The absence of a check rail on the curve approaching Ordsall Lane Junction was causal to the accident. Railway infrastructure operators in Great Britain have long been required to provide this safeguard at such locations (paragraphs 42 and 43) and its fitment would have prevented the derailment.
- 72 The vehicle dynamics study established that the following four factors were all necessary to additionally make the Y/Q derailment quotient high enough at the leading right-hand wheel:
- the state of the gauge face of the outer rail of the curve, which was a pre-condition for high wheel-rail contact friction;
 - the state of the wheel flanges of locomotive 47500, which was also a pre-condition for high wheel-rail contact friction;
 - the relatively low flange contact angle associated with the newly-reprofiled wheels; and
 - the wider than normal track gauge that had developed on the curve.

The individual conditions associated with these four factors were all within expected bounds or required maintenance limits (with the exception of the surface finish of the wheel, which was marginally rougher than that specified (paragraph 93)). The above factors only presented a derailment risk because they acted in combination and there was no check rail. It is likely that the derailment would have been prevented by improving any of these: reduced friction on the wheel or the rail (paragraph 81); an increased wheel flange contact angle (paragraph 100); or reduced gauge-widening (paragraph 105).

- 73 The RAIB found no evidence that any other effects, such as the way the train was being driven, irregularities in the track alignment or forces from coupled vehicles, were significant to the cause of the derailment.

²⁰ Any condition, event or behaviour that was necessary for the occurrence. Avoiding or eliminating any one of these factors would have prevented it happening.

Check rail provision

74 There was no check rail installed on the curve approaching Ordsall Lane Junction although its location and radius met the criteria for fitment. Without a check rail there was nothing to prevent the lateral wheel-rail forces tending to cause the right-hand wheel flanges to climb the outer rail and into derailment. This was a causal factor.

75 The curve on the Down Bolton line approaching Ordsall Lane Junction was on a passenger line and had a radius of less than 200 metres. Railway Group standard GC/RT5021 therefore required that a check rail should have been fitted (paragraph 43); earlier equivalent documents had the same requirement (paragraph 42).

76 The radius of the curve has been less than 200 metres since at least the late 1980s:

- track geometry measurement train runs since 2005 have consistently recorded the minimum radius to be around 178 metres;
- a survey drawing prepared in November 2005 in connection with proposed *kinematic gauge* clearance work records the minimum radius as 150 metres; and
- British Rail's scaled setting out drawing from 1987 for the installation of bridges 130A and 130B shows the curve radius at approximately 170 metres.

The RAIB found no record that a check rail had been fitted at any time before or after this time.

77 The introductory part of Network Rail's standard for track design, NR/L2/TRK/2102 (paragraph 42), which also defined the need for a check rail, states that it specifies the 'minimum standards' for 'relayed' as well as new track.

78 Infrastructure alterations, like the installation of bridges 130A and 130B, or the renewal work in 2008 (paragraph 23), were therefore opportunities to bring the track back into compliance. The RAIB did not seek to establish why a check rail was not fitted in 2008, but it did find that Network Rail held no records of the work that was planned or undertaken.

79 Network Rail was unable to find and provide any formal records of the design of the track geometry in the area. Furthermore, it does not routinely review the curvature information recorded on track geometry measurement train runs (paragraph 54). Both of these may have highlighted that the radius of the curve was below 200 metres, and therefore that a check rail was required.

Conditions on the rail for wheel-rail contact friction

80 The dry, clean and uncontaminated state of the gauge face of the outer rail of the curve approaching Ordsall Lane Junction enabled a high level of wheel-rail contact friction to be established. Although not relied upon by Network Rail to manage derailment risk, the rail lubrication arrangements in the vicinity did not prevent this, and inspection processes did not identify that this had happened. This was a factor in the derailment.

81 While the vehicle dynamic study showed that a high coefficient of friction of around 0.55 was necessary to cause the derailment, it also showed that a reduction of less than 10% would have prevented it.

- 82 The dry and uncontaminated state of the rail (paragraph 35) was necessary for high wheel-rail contact friction to occur; this is also the most likely explanation for the aggressive sidewear observed on the gauge face of the outer rail. It is therefore significant that the derailment occurred during a period of dry weather (paragraph 24) and that naturally-occurring contaminants, such as metal oxides, had been removed leaving the gauge face shiny and showing bare metal (figure 7).
- 83 Infrastructure maintainers often use artificially-applied lubricants, such as greases and oils, to avoid high wheel-rail contact friction conditions occurring at critical locations on the railway. Such lubricants are highly effective, and the presence of a grease or oil contaminant on the gauge face would have reduced the friction enough to have prevented the derailment. A guidance note published by the RSSB²¹ indicates an average coefficient of friction of only 0.12 for rail with oil on it.
- 84 Network Rail had extensive arrangements in place to lubricate curves in the Manchester area. However, because of the recent lubricator replacement project (paragraph 63), lubrication of the outer rail of the curve approaching Ordsall Lane Junction became reliant on grease applied by the new electric lubricator near platform 14 at Manchester Piccadilly (paragraph 64).
- 85 When the Manchester RME's team came to inspect and maintain this lubricator on 20 January 2013, they found that the battery voltage was low and that no grease was being delivered; the maintenance records show they planned to revisit it as soon as possible to investigate further. The RAIB was unable to determine how long the lubricator had been faulty because no routine inspection or maintenance had been planned, or made, since 4 August 2012 (around a month after the lubricator was installed) when it was reported to be working satisfactorily. The reason for this was that Network Rail omitted to enter the lubricator, and a number of others, as new assets on the database it uses to plan inspection and maintenance tasks.
- 86 Network Rail repaired and tested the new electric lubricator near platform 14 at Manchester Piccadilly station after the derailment. It found that lubricant did not transfer as far as it expected, and did not reach Ordsall Lane Junction²². However, it is unlikely that this finding is significant to the derailment; if the new lubricator had been working, the wheels on locomotive 47500 would almost certainly have picked up enough grease to reduce the friction by the small amount necessary to prevent derailment.
- 87 Network Rail's current standards indicate that it considers that rail lubrication is provided for the management of rail wear, noise and related concerns, and not for derailment protection, which would require more regular inspection and prompt rectification. For example, in NR/L3/TRK/3510/A01:
- although wear, *rolling contact fatigue* and noise are all referred to, there is no reference to derailment risk in the characteristics given for sites where lubricators are needed;

²¹ GM/GN2642 'Guidance on wheel/rail low adhesion'.

²² Network Rail explained that additional testing is currently being carried out to understand the reasons for this.

- lubricator inspection intervals on track category 4 lines, such as the Down Bolton line (paragraph 45), can be extended to as long as 13 weeks (although inspections are required every eight weeks for the first six months of operation); and furthermore
- a lubricator that has stopped delivering grease only requires rectification within a month (in NR/L2/TRK/001 three months is allowed).

The earlier standard on rail lubrication, NR/L2/TRK/8006 'Installation and management of rail mounted lubricators', referred to the role of lubrication in reducing derailment risk. However, Network Rail confirmed that it had decided to remove this reference when it issued NR/L3/TRK/3510/A01, as it wanted to emphasise that the primary purpose of rail lubrication was infrastructure asset protection.

- 88 Given the prescribed minimum inspection and rectification periods, the RAIB is unable to determine whether the RME's team would have identified and rectified the lubricator fault in time, if the new electric lubricator had been correctly included on Network Rail's maintenance database.
- 89 Neither the patroller nor the section manager identified any issues with the condition of the outer rail on the curve during routine track inspections (paragraphs 47 and 48). This is perhaps not surprising: they were unlikely to observe a lack of grease on rails so remote from the new electric lubricator (paragraph 64) and the rail sidewear was within permitted limits (paragraph 49). It is possible that the patroller did not see the deposits of metal particles on the last basic visual inspection because of ground frost (paragraph 47). However, the RAIB observes that similar metal deposits on other curves in the Manchester area were only identified as a result of special inspections made in response to the derailment.

Conditions on the wheels for high wheel-rail contact friction

90 The recent wheel reprofiling removed any residual lubricant and other contaminants from the wheels of locomotive 47500 that would otherwise have helped reduce the wheel-rail contact friction encountered. The clean and dry surface of the wheels following reprofiling was therefore a factor.

- 91 Rail vehicle wheels pick up lubricants and other contaminants from deposits on the railhead and the general environment. Contaminants can also form on the wheel surface as a result of natural oxidation. However, on locomotive 47500 such contaminants would have been removed during wheel reprofiling, which was undertaken using an un-lubricated machining process (paragraph 58), and the finished wheels would almost certainly have been left clean and dry. In line with European and Railway Group standards, Siemens' in-house processes do not require any lubricant to be applied to wheels after reprofiling.
- 92 There are no rail lubricators at Ardwick depot, and the train passed no others before it reached the defective electric lubricator on the approach to platform 14 at Manchester Piccadilly.

- 93 A review of published standards showed that the N10 surface finish that West Coast Railways specified (paragraph 59) is common practice; it is referred to in Railway Group standard GM/GN2497, European standard EN13262²³, 'Railway applications – wheelsets and bogies – wheels – product requirement', British Standard BS 5892-5²³ 'Railway rolling stock materials: specification for wheelsets for traction and trailing stock', and the historic British Rail standard MT/288 'Wheelset tread standards & gauging'. Post-derailment inspection of the wheels indicated that the actual finish of the wheels on locomotive 47500 was marginally rougher than this (paragraph 60) and therefore a potential factor in the derailment.
- 94 The RAIB commissioned a review of published literature concerning the wheel surface finish and wheel-rail contact friction following reprofiling to further understand this. This found that the relationship is complex and there is contradictory evidence as to whether a rougher surface finish may necessarily result in a higher level of wheel-rail contact friction. Some reports infer that higher levels of friction should be expected with a rougher surface. However, more recent research has shown that the level of friction is actually lower on initially rough reprofiled wheels, but then increases when the surface becomes smoother as machining marks are removed during early running. Recognising this, and that the surface finish non-compliance was only marginal, the RAIB has not sought to quantify the precise degree to which the condition of the wheel surface played a role. Therefore, while surface finish remains a possible factor in the derailment, the RAIB equally recognises that it may have actually reduced the risk of the wheel flange climbing onto the rail.

Wheel flange contact angle

- 95 **The relatively low flange contact angle associated with the new, and as yet to become worn, P1 wheel profiles of locomotive 47500 reduced its ability to resist derailment by flange climbing. This was a factor in the derailment.**
- 96 The wheel profile defines the shape and dimensions of the cross-section of the part of the wheel that runs on the railhead. The P1 wheel profile design originates from the 1930s. It is used on a wide range of ex-British Rail vehicles built before 1970 that are still permitted to run on Network Rail infrastructure.
- 97 A comparison of the measured profiles of the outer rail and the new P1 wheel profiles on locomotive 47500 showed that the peak flange contact angle was around 62° at the point of derailment²⁴. Modern wheel profile designs comply with the *flange angle*²⁵ requirement of 68-70° defined in clause 2.5.1 of Railway Group standard GM/RT2466: for example the *P8 wheel profile*, which became widely used after the class 47 locomotives were built in the mid-1960s. The peak flange contact angle for the P8 wheel profile on the same rail was found to be around 70°.

²³ As the equivalent R_a value, 12.5 μm .

²⁴ The flange contact angle increases to around 65° running on a new rail. However, the effect that the rail profile has on reducing the derailment risk is less than the shape of the wheel profile, and the computer simulations still indicated significant wheel lift would have occurred, and therefore derailment was a possibility, even if the rail on the curve had been unworn.

²⁵ This angle is associated with the geometry of the flange alone and, therefore, unlike the flange contact angle, is not affected by the shape of the rail.

- 98 A low flange contact angle increases the risk of derailment because it reduces the Y/Q critical limit value (paragraph 66). Calculations show that, on the outer rail of the curve, the Y/Q critical limit value associated with a new P1 wheel profile is 25% less than that for a P8 wheel profile²⁶.
- 99 However, as P1 wheel profiles wear in service, the associated flange contact angle increases. The peak flange contact angle associated with the worn P1 wheel profiles on locomotive 47854 (paragraph 57), for instance, was around 72°.
- 100 The vehicle dynamic study looked at the significance of the wheel profile geometry. The computer simulations indicated that locomotive 47500 would not have derailed if the wheels had worn and become like those on locomotive 47854. It would also not have derailed if the wheels had been machined to the P8 wheel profile²⁷.

Track gauge

101 Although within the prescribed limits of Network Rail's standards, the wide track gauge that had developed on the curve approaching Ordsall Lane Junction increased the risk of derailment. This was a factor in the derailment.

- 102 The track maintenance team was aware of historic problems with wide track gauge on the Down Bolton line and the need to control it within the limits prescribed in NR/L2/TRK/001 (paragraph 50). Records from both the track measurement train on 12 November 2012 (paragraph 53) and the post-derailment track survey (paragraph 37) showed that it was being achieved. However, in the vicinity of the derailment the level of gauge widening was significant, and within the range at which routine scheduled maintenance work needs to be considered.
- 103 Figure 15 shows the recorded variation of the track gauge from the nominal value of 1435 mm for straight track (as specified in Network Rail standard NR/L2/TRK/2102), and the limits requiring consideration of routine scheduled maintenance, corrective action within specified timescales and the line to be blocked.
- 104 The vehicle dynamic study found that the derailment risk was sensitive to track gauge variation. This was because of the consequent increase in the clearance between the wheel flange and gauge face allowed additional bogie rotation within the track gauge, therefore increasing the *angle of attack* of the leading right-hand wheel and, as a result, the lateral (Y) force on the rail (paragraph 66).
- 105 Network Rail standard NR/L2/TRK/2102 specifies a nominal track gauge of 1438 mm on curves with a radius of between 200 and 178 m. The computer simulations indicated that the derailment could have been avoided if it had been possible to maintain the track gauge close to this nominal value.

²⁶ Based on Nadal's formula (see Railway Group standard GM/RT2141) and a friction coefficient of 0.55.

²⁷ The RAIB considered operation with P8 wheel profiles for comparison purposes only. It recognises that a change of wheel profile involves the consideration of many complex factors, and therefore draws no conclusion whether a P8 wheel profile, or any other alternative, is suitable for use on a class 47 type locomotive.

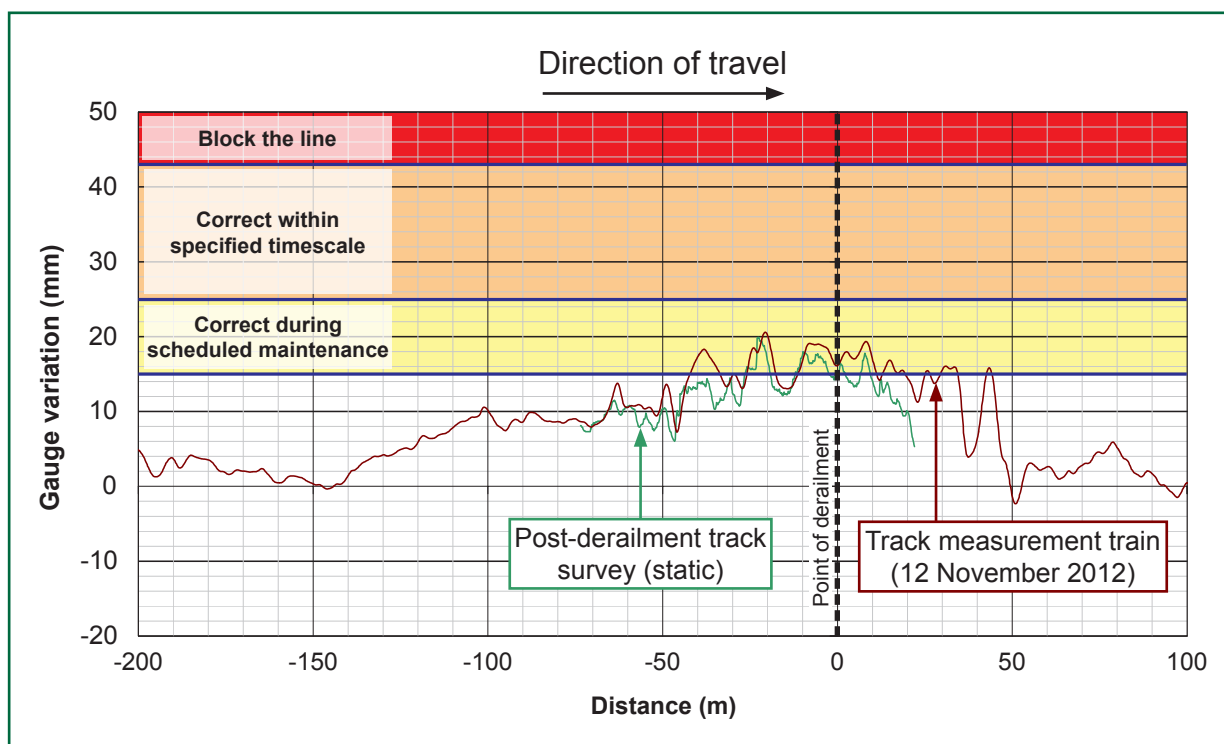


Figure 15: Track gauge measured in the vicinity of the derailment showing the relevant maintenance limits

Observations²⁸

Locations where check rails are not required

- 106 The vehicle dynamic study looked at the theoretical effect of increasing the radius of the curve on the approach to Ordsall Lane Junction, with all other parameters representing the established derailment conditions. This predicted that the derailment would still have occurred if the minimum radius on the curve had been 200 metres.
- 107 While compliance with Network Rail's current requirements for check rail provision would have prevented this accident, the locomotive remained at risk of derailment on curves of slightly larger radius, where a check rail would not have been required.
- 108 Check rails are only required on lines that passenger trains run over, or run close to (paragraph 42). Locomotive 47500 was therefore also at risk of derailment on other types of running line that it could have run on.

²⁸ An element discovered as part of the investigation that did not have a direct or indirect effect on the outcome of the accident but does deserve scrutiny.

Summary of conclusions

Immediate cause

109 The immediate cause of the accident was that the lateral forces acting at the wheel-rail interface, as locomotive 47500 negotiated the curve approaching Ordsall Lane Junction, were sufficient to cause the flange of the leading right-hand wheel to climb the outer rail. Nothing was provided to limit the lateral displacement of the wheel and prevent it crossing over the railhead into derailment (**paragraph 69**).

Causal factors

110 The causal factor was:

- a. A check rail had not been installed on the curve approaching Ordsall Lane Junction, although its location radius met the criteria for fitment. Without a check rail there was nothing to prevent the lateral wheel-rail forces tending to cause the right-hand wheel flanges to climb the outer rail and into derailment (**paragraph 74, Recommendations 1, 2 and 3**).

111 The following factors were necessary to make the Y/Q derailment quotient high enough to cause the leading right-hand wheel flange to climb the outer rail:

- a. The high friction conditions that had been established on the gauge face of the outer rail of the curve approaching Ordsall Lane Junction. Rail lubrication arrangements did not prevent this occurring, and inspection processes did not identify it (**paragraph 80, Recommendations 1 and 2**).
- b. The recent wheel reprofiling removed any residual lubricant and contaminant from the wheels of locomotive 47500, which would otherwise have helped reduce the high wheel-rail contact friction; it is also possible that the resulting changes to the surface finish had a similar detrimental effect (**paragraphs 90 and 94, Recommendations 1 and 2**).
- c. The relatively low flange contact angle associated with the new P1 wheel profiles reduced the ability of locomotive 47500 to resist derailment by flange climbing (**paragraph 95**).
- d. The wide track gauge increased the risk of derailment on the curve approaching Ordsall Lane Junction (**paragraph 101**).

Observations

112 Although not linked to the accident on 23 January 2013, the RAIB observes that:

- a. While Network Rail's current requirements for check rail provision should have prevented this accident, locomotive 47500 remained at risk of derailment on curves of slightly larger radius and on other types of running line, where a check rail would not have been required (**paragraphs 107 and 108, Recommendation 2**).

Previous RAIB recommendations relevant to this investigation

- 113 The RAIB has investigated other train derailments having similar characteristics:
- Epsom station, 12 September 2006 (RAIB report 34/2007²⁹). The fourth vehicle of a two four-car *electric multiple unit* train derailed on a right-hand curve on the approach to Epsom station. The wheels of the trailing bogie climbed over the outer left-hand rail close to a misaligned rail joint where there was significant sidewear. There were no injuries and only minor damage.
 - Wigan North Western station, 25 August 2009 (RAIB report 14/2010). The 12th wagon of a 40 bogie-wagon container train derailed on a left-hand curve on the approach to Wigan North Western station. The leading right-hand wheel of the leading bogie climbed over the outer rail at a point where the rail changed section. There were no injuries, but minor damage was done to signalling cables and one of the lines in the station remained closed while repairs were completed.
- 114 Both of these derailments occurred on curves without check rails that had a minimum radius close to 200 m. In the case of the derailment at Wigan North Western, the design radius of the curve was 175 m (the site survey showed that the radius had actually reduced to 140 m at the point of derailment). Although the track had been re-laid between 2003 and 2004, the RAIB was unable to determine why design checks had not identified the need to fit a check rail.
- 115 The investigation of the derailment at Epsom found problems with rail lubrication arrangements that had resulted from recent lubricator asset changes. In this case, a mechanical lubricator near the start of the curve into Epsom station was removed after it was confirmed that grease was reaching Epsom station from a new electric lubricator 7.3 km away (near Motspur Park station). The new electric lubricator was not working at the time of the derailment and, because of organisational issues with the track maintenance, no remedial action had been planned. At the derailment site there was evidence of metal particles on the track, similar to those deposited at Ordsall Lane Junction (paragraph 35), and very little grease on the rail.
- 116 The RAIB has made the following recommendations that have relevance to this investigation.

Epsom station

- 117 Recommendation 3 of report 34/2007 reads:

Network Rail should review Company standard NR/SP/TRK/8006³⁰ to provide improved guidance on the use and siting of remote rail lubricators, and the action to be taken in the event of lubrication failure, to reduce the risk of potential derailment.

- 118 The Office of Rail Regulation (ORR) has advised the RAIB that it has assessed the progress that Network Rail has reported, and has confirmed that the recommendation has been implemented.

²⁹ RAIB reports are available at www.raib.gov.uk.

³⁰ Later designated NR/L2/TRK/8006, see paragraph 87.

Wigan North Western station

119 Recommendation 2 of the report 14/2010 reads:

Network Rail should check, on a risk basis, other sites where WCRM S&C Alliance³¹ has installed track to verify that it has been designed and installed correctly and should implement corrective action where necessary.

120 In response to this recommendation, the ORR reported to the RAIB on 31 May 2013 that Network Rail had undertaken a review of all 36 sites where the WCRM S&C Alliance had installed track and identified 15 with curve radii less than 200 metres. Network Rail confirmed that a check rail was not required at these locations, mainly because the curve radii were the result of using a standard design of track for *switches and crossings*. In concluding that Network Rail had implemented this recommendation, the ORR has subsequently explained that there were no instances where curve radii below 200 metres extended into adjacent plain line and that it accepted that it is not reasonably practicable to fit check rails in certain switch and crossing areas (the RAIB notes that GC/RT5021 specifically exempts the need for a check rail where 'the design of S&C prevents this from being provided'). Although not relevant to this investigation, the RAIB is concerned that Network Rail's review was limited to the provision of check rails and did not consider whether other elements of the track were designed and installed correctly.

121 Network Rail also reported that it had done work to increase radius of the curve at Wigan North Western station so that a check rail was not required.

³¹ The WCRM S&C Alliance was an organisation originally formed by partnership between Railtrack, GEC Tarmac Rail Maintenance Ltd and Central Track Renewals Ltd (but later between Network Rail and Carillion) to do work on the *West Coast Route Modernisation project*. The organisation no longer exists.

Actions reported as already taken or in progress relevant to this report

122 Network Rail has now fitted a check rail on the curve where the derailment occurred and has also installed additional rail lubricators in the area.

123 In response to the derailment, Network Rail has also:

- issued a safety bulletin alerting its track engineers to the circumstances of the derailment and highlighting the importance of effective rail lubrication in reducing derailment risk;
- conducted a review of its rail lubricator assets in the Manchester area in order to identify any other associated deficiencies; and
- commenced a review of the curves on the London North Western (North) route; this has so far identified another eight sites that do not comply with the company's requirement for check rail provision.

124 Siemens has made changes to its processes for reprofiling wheels. Wheel lathe operatives are now required to check every first wheelset that they reprofile on a shift in order to confirm and record that the resulting surface finish and wheel profile geometry complies with the relevant specification (paragraph 60). It has also specified that operatives use a finer feed rate on the final cut (paragraph 58).

Recommendations³²

- 125 Locomotive 47500 derailed at Ordsall Lane Junction because a set of individually permitted conditions combined to make the Y/Q derailment quotient at the leading right-hand wheel high enough (paragraph 72). Although the basic approach to managing the risk of derailment on small radius curves does not inherently guard against this (paragraphs 38 and 39), the RAIB also observes that the supplementary requirement to fit a check rail at this particular location should have mitigated the resulting residual risk and prevented derailment occurring. However, locomotive 47500 was at risk of derailment at locations that are similar, but where a check rail is not required: on curves of slightly larger radius (paragraph 106) and lines that passenger trains do not run over or near (paragraph 108).
- 126 The RAIB has considered the need for a fundamental review of the basic approach to managing derailment risk on small radius curves. However, given the outcome of the accident at Ordsall Lane Junction, and that the derailment required extreme levels of wheel-rail contact friction to coincide with a number of other factors, the RAIB has decided that such a review would not be proportionate. Instead it has chosen to focus its recommendations on two traditional features of the national network that are often associated with small radius curves: check rails and rail lubrication. These recommendations therefore recognise the significance of their role in helping to minimise derailment risk and the need to take this into account when considering changes that may affect the 'historic norm'.

³² 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 web site www.raib.gov.uk.

127 The following recommendations are made:

- 1 *The intent of this recommendation is to reduce the risk of derailment on small radius curves by ensuring that non-compliances with currently prescribed requirements for check rails are identified and mitigated.*

Network Rail should identify all curves that are non-compliant with Railway Group standard GC/RT5021 and Network Rail standard NR/L2/TRK/2102 in respect of the need to fit a check rail. For each identified curve, Network Rail should implement measures to adequately mitigate the risk of derailment. These may include one or both of the following methods, although other means of mitigation may also be appropriate (paragraph 110a, 111a and 111b):

- installing a check rail on the curve; and
- managing rail lubrication on the curve to a suitable level of availability.

Implementation of this recommendation may require Network Rail to review curvature information recorded on track geometry measurement train runs (paragraph 79).

- 2 *The intent of this recommendation is that Network Rail should understand any changes that it has introduced to infrastructure management processes that have had a detrimental effect on their ability to control derailment risk on small radius curves (paragraphs 63, 64 and 80 - 89) and take actions to reduce the risk so far as is reasonably practicable.*

Network Rail should review its approach to managing changes that may affect the friction on small radius curves to understand whether any alterations to infrastructure and/or management arrangements, have resulted in higher levels of friction.

At locations where it is considered that the rail friction is greater than that which applied previously, actions should be taken to reduce the corresponding increase in derailment risk so far as is reasonably practicable. These actions may include (paragraph 110a, 111a, 111b and 112a):

- improvements to the rail lubrication equipment that is provided and/or the associated management processes; and/or
- the provision of a check rail.

- 3 *The intent of this recommendation is to improve compliance with current design standards when track renewal or major maintenance work is undertaken.*

Network Rail should develop and implement (paragraph 110a):



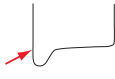
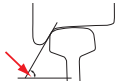
- criteria for when it is necessary to formally assess the need to bring existing track assets in line with current design standards; and
- a process to record the findings of such assessments.

Appendices

Appendix A - Glossary of abbreviations and acronyms

CCF	Contract control form
GDU	Grease delivery unit
ORR	Office of Rail Regulation
RME	Rail management engineer
RSSB	Rail Safety and Standards Board
TME	Track maintenance engineer
WILD	Wheel impact load detector

Appendix B - Glossary of terms

Angle of attack	The angle of the wheel relative to the rail when viewed from above.	
Bogie rotation test	A test to measure the torque generated between the bogie and vehicle underframe as the bogie rotates about a vertical axis (yaw rotation).	
Check rail	An additional rail mounted alongside the inside rail of a curve to restrict the lateral movement of the wheels.	
Colour-light signal	A railway signal which conveys its message by means of coloured lights.	
Diesel multiple unit	A self-contained diesel-powered train comprising one or more vehicles that can be coupled to other compatible diesel multiple units to form longer trains.	
Down	The name generally given to lines used by trains travelling in the direction away from London.	
Electric multiple unit	A self-contained electrically-powered train comprising one or more vehicles that can be coupled to other compatible electric multiple units to form longer trains.	
Flange	The extended portion of a rail wheel that provides it with direction guidance.	
Flange angle	The angle, relative to the horizontal, of the coned part of the flange on a rail wheel that faces the railhead.	
Flange back	The inside face of the flange of a rail wheel.	
Flange contact angle	The angle, relative to the horizontal, of the plane that passes through the point at which the flange (of a rail wheel) contacts the railhead.	
Flat-bottom BS113A rail	A type of flat-bottomed rail which weighs 113 lbs/yard.	
Gauge face	The side of the railhead that faces towards the opposite running rail.	
Grease delivery unit	The rail-mounted component part of a rail lubricator that delivers grease to the interface between the gauge face and the wheel flange.	
Kinematic gauge	The envelope described by the cross-section of a rail vehicle including displacements due to motion, load and tolerance effects.	

Milepost	A post placed at quarter-mile intervals along the railway indicating the mileage from a zero datum (in this case London Euston station).
On-train data recorder	A data recorder fitted to a train that records information on the operation of a train and the status of on-board equipment, including speed and brake applications.
P1 wheel profile	A standard wheel profile in use on rail vehicles built prior to 1970, having a tread based on a 1 in 20 cone.
P8 wheel profile	A wheel profile based on a worn P1 wheel profile, which has been commonly used on vehicles since 1970.
Pan 11 baseplates	A type of track component that is used to support flat-bottom rail on timber sleepers.
Pandrol clips	A type of proprietary rail fastening.
Patroller	A competent person whose duties are to carry out a visual inspection of the track.
Rail lubricator	A device for applying grease to the gauge face of the railhead. It typically consists of a grease reservoir, pump, rail-mounted actuator or wheel sensor, rail-mounted grease delivery units and all interconnecting hoses and couplings.
Rolling contact fatigue	Collective term for rail defects directly attributable to the rolling action of a rail wheel on the rail.
Roughness average	A measure of the average distance (in micrometres) between the median line of a machined surface and its peaks and troughs.
Route asset management	The roles and responsibilities associated with the custodianship of the railway infrastructure on a Network Rail route, for instance the track, civil works and signalling.
Route control	An office that monitors, reports and makes decisions on a day-to-day basis on the operation of the railway on particular Network Rail route.
Section manager	The local Network Rail manager directly responsible for maintaining the track and ensuring that it remains safe for operational use.
Sidewear	The reduction in railhead width due to wear caused by flange contact with the rail.
Signal post telephone	A telephone located at or near a railway signal that allows a driver, or other member of staff, to speak with the controlling signal box.

Single-yellow aspect	An indication of a single yellow light on a colour-light signal, warning the driver to expect that the next signal will be showing red.
Six-foot	A term defining the area between the two lines on a double-track railway.
Surface finish	The characteristics of the surface of a component produced by a machining process, such as turning or grinding. It is sometimes referred to as surface texture.
Switches and crossings	Track that allows a train to move from one line to another.
Technical Specification for Interoperability	The technical standards for railway subsystems (such as infrastructure and rolling stock) that are required to satisfy the essential requirements that the European Commission has defined in order to promote a single market in the European rail sector.
Track cant	The elevation of one rail above another in a curve.
Track circuit operating clip	A safety device carried on trains. Train crew can connect this to the track in an emergency in order to operate train detection circuits and make railway signals show red.
Track gauge	The distance between gauge faces of the running rails.
Track twist	The change in cant along the track, measured over a specific distance.
Transition curve	A curve of continuously varying radius, which connects a curve of constant radius to a straight, or to a curve of a different constant radius.
Up	The name generally given to lines used by trains travelling in the direction of London.
West Coast Route Modernisation project	A major renewal and enhancement programme on significant parts of the West Coast Main Line between London and Glasgow including routes to Liverpool, Manchester and Birmingham.
Wheel impact load detector	A rail-mounted system used to monitor the wheel-rail forces from passing trains in order to detect excessive wheel loads and wheel flats.
Wheel lathe	A special type of metal cutting machine that is used remove defects from rail wheels, such as cracks, cavities and flats, and to restore the profile to that specified.
Wheel reprofiling	The machining process used to restore the profile of rail wheels to that specified.

This page is intentionally left blank

This report is published by the Rail Accident Investigation Branch,
Department for Transport.

© Crown copyright 2014

Any enquiries about this publication should be sent to:

RAIB	Telephone: 01332 253300
The Wharf	Fax: 01332 253301
Stores Road	Email: enquiries@raib.gov.uk
Derby UK	Website: www.raib.gov.uk
DE21 4BA	