Rail Accident Investigation Branch

Rail Accident Report

Derailment at Grayrigg
23 February 2007

Department for Transport

Report 20/2008
v5 July 2011

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	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.

Change control	Date	Paragraph no(s).	Description of change
v2	21/01/09	App F para 7	Amendments to para 7
v3	20/10/09	27, 154, 159, 160, 180, 181, 284, 515	Allowance made for extremities of wheelset dimensional tolerances.
v4	07/01/11	Table 1, 136, Table 6, App F para 4	The range of likely residual switch opening in 2004 changed to reflect results of further detailed analysis undertaken by Omnicom on 18/02/10. This involved an enhancement to the accuracy of measurement.
		Table 1, 27, 134, 136, 154, 159, 160, 180, 284, 289, 515	Clarification of likely residual switch opening and flange-back contact values. The single value of likely residual switch opening immediately before start of final degradation has been replaced with the range found during testing. A representative value of 8 mm has been used to assist in understanding of the change in flange-back contact for the tolerance range of train wheelsets.
		27, 154, 181	Revised to reflect wheelset tolerances and the full range of test results for the residual switch opening.
		73, 139, 148	Minor typographical errors corrected.
		136, App F para 7	Minimum free wheel clearance on 12 February clarified to be “no greater than 40 mm”.
		136	Correction to align minimum free wheel clearance figure with the value in Appendix F, paragraph 15.
v5	14/07/11	569	Change in text. Ref to ‘left-hand corner’ corrected to ‘right-hand corner’

Note: None of these changes affect the conclusions and recommendations of the report

This page is left intentionally blank

Derailment at Grayrigg, 23 February 2007

Contents

Preface

1 The purpose of a Rail Accident Investigation Branch (RAIB) investigation is to determine the cause of an accident or incident, with the aim of preventing future accidents and incidents, and of improving railway safety.

2 The RAIB does not consider or determine blame or liability, or carry out prosecutions.

General terms used in the report

3 This report is about the derailment of an express passenger train which occurred on 23 February 2007 near Grayrigg in Cumbria, on the West Coast Main Line (WCML). The general orientation of the WCML is on a north-south axis. However, at the location where the derailment occurred, trains running from London to Glasgow are travelling in an easterly direction. For the purposes of consistency, the terms 'north' and 'south' are used in this report when referring to infrastructure or events on the Glasgow and London side of the derailment respectively.

4 The geographical location on the WCML in the area of Grayrigg is established by the distance from a 'zero' datum at Lancaster station, measured in miles and *chains*.

5 At various places in this report, reference is made to the 'right' or 'left' side of the train or track. In all cases, this refers to the perspective of a person facing north in the direction the train was travelling, from London to Glasgow.

6 The location of the derailment was at Lambrigg *emergency crossover*, in the vicinity of the village of Grayrigg. In this report the derailment is referred to as being at Grayrigg, the nearest location of note, but the crossover and points are referred to as Lambrigg.

7 Throughout the report the term *Switches and Crossings* (S&C) is used to describe all means of intersection of railway lines, including diamonds, slips, and other more complex layouts. The term '*points*' is used when specific reference is made to points or the points at Lambrigg.

8 Appendix A to this report contains explanations of acronyms and abbreviations and Appendix B explains technical definitions that are shown in italics the first time that they appear in the report.

Summary of the report into the derailment at Grayrigg on 23 February 2007

<u>Key facts about the accident</u>

9 On 23 February 2007 at 20:12 hrs, an express passenger train derailed at *facing points*, known as Lambrigg 2B points, located near Grayrigg in Cumbria (Figure 1). The train, reporting number 1S83, was the 17:15 hrs service from London Euston to Glasgow, operated by West Coast Trains Ltd, part of Virgin Rail Group (referred to as 'Virgin Trains' in the remainder of this report), and was travelling at 95 mph (153 km/h). All nine vehicles of the Class 390 *Pendolino* unit derailed (Figure 2). Eight of the vehicles subsequently fell down an *embankment* and five turned onto their sides.

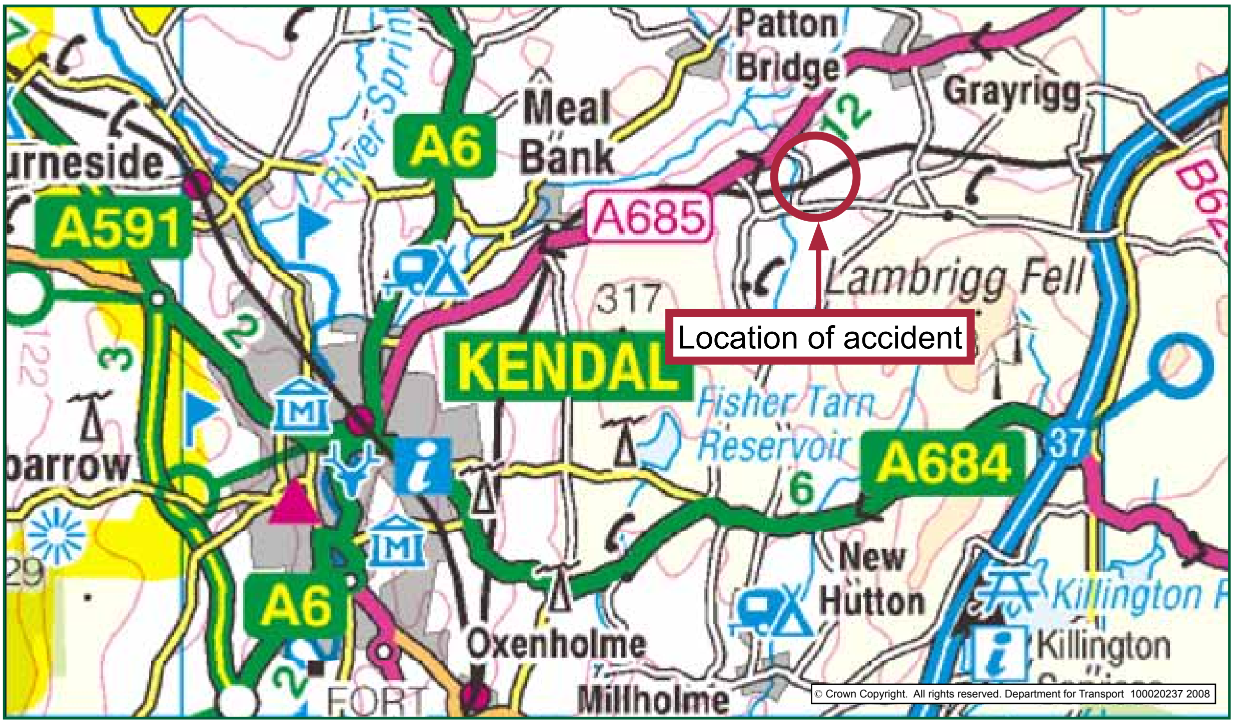


Figure 1: Extract from Ordnance Survey map showing location of accident

Figure 2: Aerial view of derailed train

10 The train was carrying four crew and at least 105 passengers at the time of the accident.

11 One passenger was fatally injured; 28 passengers, the train driver and one other crew member received *serious injuries* and 58 passengers received *minor injuries*. The remaining 18 passengers and two crew members were not physically injured in the derailment.

12 The railway line through the area remained closed until 12 March 2007. Initially this was for the rescue of the injured, then solely for accident investigation, then (in parallel) for accident investigation, vehicle recovery and repairs to the infrastructure, and finally to complete the repairs to the infrastructure.

Summary of the derailment and its causes

13 The train derailed as it passed over 2B points which were in an unsafe state. A combination of failures of *stretcher bars* and their joint to the *switch rails* allowed the left-hand switch rail to move, under its natural flexure, towards the left-hand *stock rail*. The left-hand wheels of either the first or second *bogie* on the leading vehicle (it is not clear which) passed the wrong side of the left-hand switch rail and were forced into the reducing width between the switch rails. The wheels then derailed by climbing over the rails. All the other vehicles of the train derailed as a consequence. Figures 3 and 4 show the key details of the points.

14 This situation arose at 2B points because of a combination of three factors. These were:

- the failure of the bolted joint connecting the third *permanent way stretcher bar* to the right-hand switch rail;
- incorrect set up of the points with excessive *residual switch opening*; and
- the omission of the scheduled weekly inspection on 18 February 2007.

All three were necessary for the accident to occur.

15 The bolts holding the third permanent way stretcher bar to the right-hand switch rail became loose, and subsequently completely undone. As a result of this, and the excessive residual *switch* opening, the left-hand switch rail was struck by the inner faces of passing train wheels, giving rise to large cyclic forces. As a consequence, rapid deterioration of the condition of the remaining stretcher bars and their *fasteners* occurred. This led to the left-hand switch rail becoming totally unrestrained.

16 This deterioration took place over a period of at least eleven days prior to the accident. An inspection, scheduled for 18 February, which should have detected the degradation, was omitted.

17 There were a number of shortcomings in Network Rail's safety management arrangements which were underlying factors in this accident.

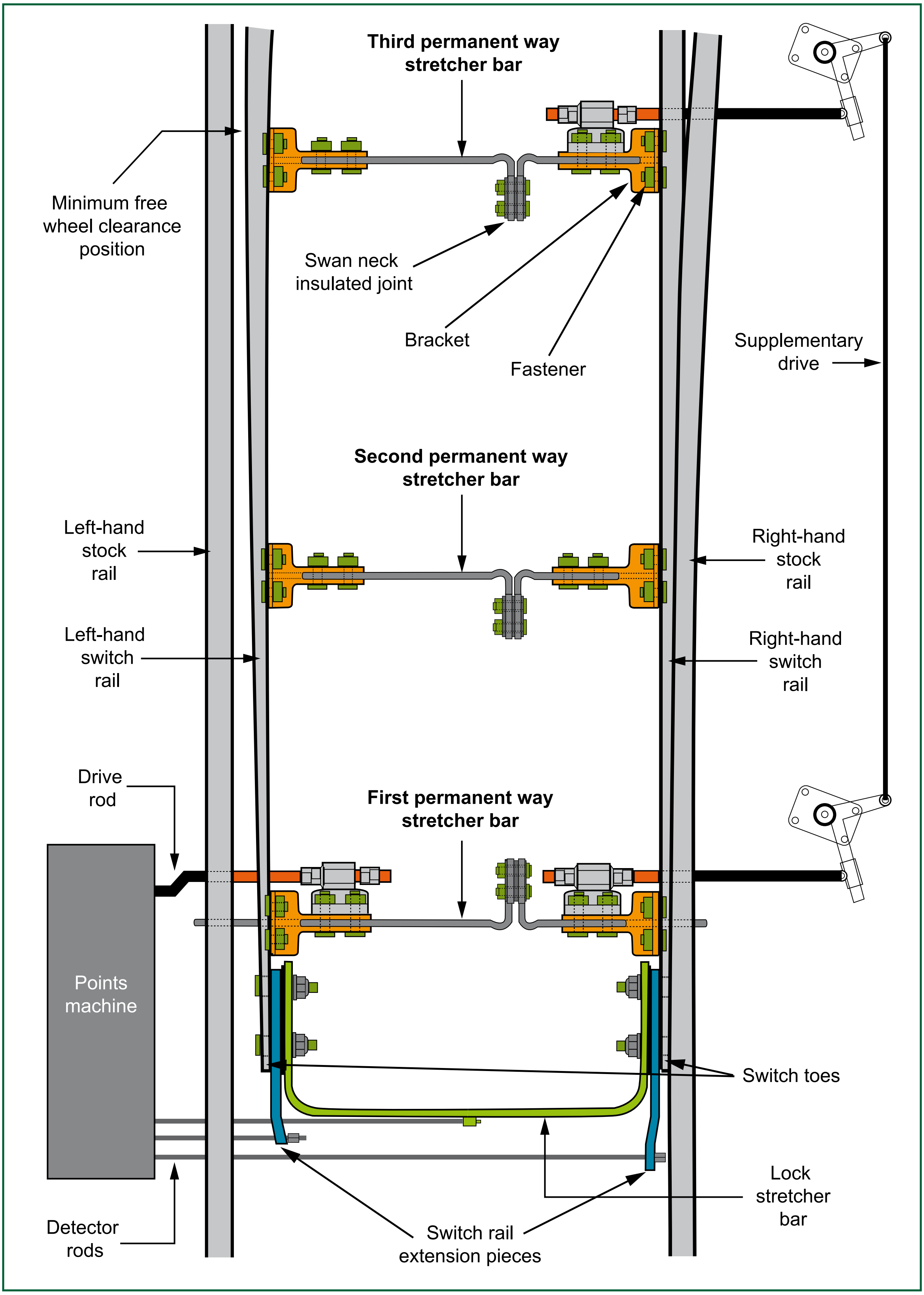


Figure 3: Layout of points showing switch and stock rails and stretcher bars

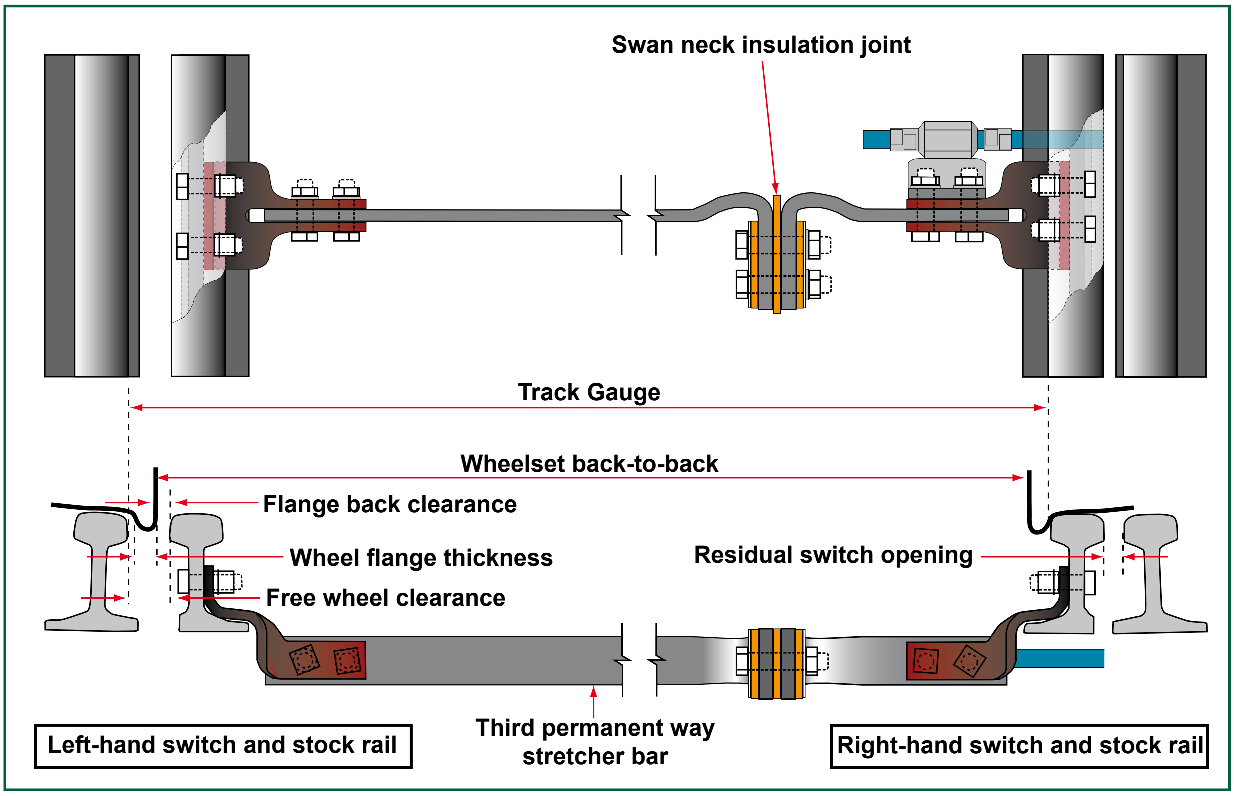


Figure 4: Schematic section of points showing key terms

Date	State, intervention and activity on 2B points
April 2004	Residual switch opening between 4 and 8 mm.
2 December 2006	Tamping activity to restore track alignment.
17 December 2006	Joint Points Team 3 monthly maintenance visit.
7 January 2007	3rd Permanent way stretcher bar right-hand bracket joint had failed and the fasteners were found fully unwound - bracket joint fasteners renewed. Post-accident reconstruction indicated the residual switch opening was likely to have been between 7 and 10 mm.
10 January 2007	New Measurement Train ran - six foot scanner showed free wheel clearance is normal.
12 February 2007	Structure Gauging Train ran - scan data showed position of stock rail relative to switch rail - dimensions indicated flange back contact happening. 3rd Permanent way stretcher bar had to have fractured and the fasteners had to have failed for this to happen.
18 February 2007	Missed basic visual inspection - nothing reported.
21 February 2007	Images from New Measurement Train showed 2nd Permanent way stretcher bar joints were missing - severe flange back contact.
between 21 February 2007 and 23 February 2007	Failure of 1st Permanent way stretcher bar and lock stretcher bar.
23 February 2007	Derailment.

Table 1: Simplified timeline of events

18 Since the accident, Network Rail has carried out extensive checks of similar points on the network. None have been found with the same degree of degradation as 2B points. However, Network Rail has found points in earlier stages of degradation.

19 Network Rail reports that it has taken steps to address the *causal factors* to the derailment, including:

- the introduction of improved instructions, management and checks on basic visual inspections;
- surveying the amount of residual switch opening on what it perceives as the higher risk points on its system;
- a programme of rectification of residual switch openings, starting with what it perceives as its highest risk points, which is still in progress; and
- commencing the analysis of the loads and forces in its *non-adjustable stretcher bar* assemblies so that it can review the design, and if necessary, upgrade them.

20 These actions by Network Rail have been monitored by the safety regulator, the *Office of Rail Regulation* (ORR).

Consequences of the derailment

21 It was dark at the time, and the driver of the train was unable to see anything untoward before the accident. He was thrown out of his seat by the initial derailment and was unable to make a brake application. However, the brakes were applied automatically four seconds after the derailment began, when the leading vehicle separated from the rest of the train.

22 The rear of the leading vehicle, and the front of the second vehicle, jack-knifed to the right so that for a period they were running derailed close to the *up* line. The leading vehicle then broke away and turned completely around, and the second vehicle came to rest at right angles to the railway; both vehicles rolled onto their sides. The rest of the train remained approximately in line, although the third, fourth and fifth vehicles also rolled over. The fatal and serious injuries occurred in the first five vehicles, where many of the occupants were thrown out of their seats.

23 The train crew, passengers, and local residents called the emergency services. It took some time to establish the exact location of the accident, which was in a remote area of rural Cumbria, and the first ambulance and fire crews reached the site at 20:46 hrs, 34 minutes after the accident. The last person was removed from the train by 22:47 hrs, and all the injured passengers and crew were removed from the site by helicopter and road ambulances by 00:11 hrs the following morning and taken to a number of hospitals in Cumbria and Lancashire.

24 The other passengers were taken to a reception centre at Grayrigg village school, from where arrangements were made for them to continue their journeys by alternative transport.

The condition of 2B points

Initiating joint failure

25 The fasteners in the third permanent way stretcher bar joint failed by unwinding. This occurs when the applied load exceeds the *clamping force* on the joint. The RAIB has concluded that, in this case, such loadings were a result of the passage of trains. Since the third permanent way stretcher bar joint had performed without any recorded incidents from installation in 2001 up to early 2007, either the clamping force provided by the joint exceeded the loads from traffic during most of that period, or, if the clamping forces were exceeded by the loads from traffic, the routine maintenance activities that were carried out on the joint compensated for this. However, tightening of fasteners during maintenance visits is not a recorded activity in Network Rail's systems, so there is no record of how often, if at all, the fasteners were, in fact, tightened in maintenance.

26 There is insufficient evidence to establish conclusively what led to the deterioration of the points at the start of 2007. Various possible causes are explored in the report. There is no evidence of any abnormal load being applied to the points. However, calculations and modelling undertaken during the investigation have indicated that the joint design cannot guarantee sufficient clamping force to withstand normal service forces similar to those that the RAIB concludes existed at Lambrigg 2B. It has not been possible to conclude whether it was an increased load, or a change in the maintenance activities, that led to the failure. Nevertheless, the common factor in both scenarios is the inability of the joint to provide sufficient clamping force in all circumstances.

Excessive residual switch opening

27 While the third stretcher bar was still complete and connected to the switch rails, the closing of the residual switch opening by the action of wheels acting on the right-hand rail also moved the left-hand switch rail due to its connection via the rear stretcher bar. This action prevented *flange-back* contact occurring for most wheelsets (the degree of flange-back contact is dependant upon the specific dimension of a wheelset – see Appendix D). After the failure of the joint between the third permanent way stretcher bar and the right-hand switch rail, the left-hand switch rail relaxed towards its adjacent stock rail until restrained by the supplementary drive (Figures 3 & 4). The left-hand switch rail was now in a position to be contacted by the rear of many more of the flanges of left-hand wheels of trains traversing the S&C. Had the residual switch opening been set to the defined value of 1.5 mm specified in the maintenance documentation, rather than the 7 to 10 mm likely present before the failure of the joint (Table 1), the left-hand switch rail would, in the event of the joint failing, have relaxed to a position less far to the left. In this case flange-back contact would have occurred for fewer wheelsets.

28 Had there been no flange-back contact between the left-hand switch rail and the flange backs of passing train wheels after the initiating joint failure, the rate at which the remaining stretcher bars broke or became detached would have been slower. In this case subsequent basic visual inspections, the next of which was scheduled three days after the derailment, could possibly have detected the degradation.

Omission of the scheduled inspection on 18 February

29 A supervisor carrying out a scheduled basic visual inspection of the track on Sunday 18 February 2007 did not include 2B points. He had originally only intended to carry out a supervisory inspection, but then agreed, on 12 February 2007, the Monday preceding the inspection, also to perform the basic visual inspection, which extended further north to include the points. During the week he forgot that he had agreed to extend his inspection to cover the extra length. As a result, the opportunity for a basic visual inspection to discover the degraded points, and for remedial action to be taken was lost.

Engineering safety management

30 The construction of 2B points at Lambrigg was to a standard design that has been in widespread use for over 35 years. Network Rail estimate that there are currently some 13,500 switches of this design in use in signalled routes across its system. The non-adjustable stretcher bars used in this design were introduced in earlier types of S&C over 50 years ago. The RAIB has concluded that the design of the joint between the permanent way stretcher bar bracket and the switch rail at 2B points, and of other similarly configured points, was such that it could have been subjected to forces beyond its design capability and therefore the points system had significant reliance on regular inspection and maintenance to maintain safe operations. This reliance was increased if the residual switch opening was incorrectly set.

31 Within Network Rail's organisation there was no systematic overview of the performance of S&C at appropriate individual component level, or any process for the analysis of the requirements for, and performance of, its inspection and maintenance.

32 The RAIB concludes that this incomplete understanding of the performance of S&C with non-adjustable stretcher bars, and the relationships between its design, usage, loadings, inspection and maintenance, led Network Rail to consider that the risk associated with the design was low and was being adequately controlled. This also resulted in an absence of clear and properly briefed standards for the setting up and adjustment of S&C.

Factors eliminated by the investigation

33 The following had no causal relevance to the derailment:

- the way in which the train was driven;
- the design and condition of the Pendolino train;
- the weather or the time of day;
- the actions of the signaller at Carlisle power signal box;
- the signalling system, including the points machine;
- track geometry on the approach to, and over 2B points, including alignment, *cant*, *gauge* and squareness of the switch *toe*s, but excluding the position of the switch rails;
- rail condition, including *sidewear* and rail clip condition; and
- the condition of the earthworks on and around the derailment site.

Severity of consequences

34 The number of casualties, the extent of their injuries and the amount of damage were affected by the speed of the train and the location of the derailment, which was close to an embankment where the derailed train came to rest.

35 In spite of the severity of the accident, damage to the windows was limited, and all but two of the passengers and all the crew were contained within the train as it came to rest. Consequently, the casualties resulted largely from people and objects being thrown around within the vehicles.

36 In the leading vehicle, all the reading light panels became detached because their locks were unable to withstand the accelerations of the vehicle during the accident. These panels were probably responsible for some of the injuries. In addition, five rows of double seats in the second vehicle became detached, because their mountings were overloaded by the deformation of the vehicle bodyside. This created a risk of injuries, although there are no reports of anyone having been injured by the detachment.

37 While objective comparisons cannot be made because of the different trains, speeds and forces involved, overall, the *crashworthiness* performance of the class 390 Pendolino avoided, almost completely, a number of hazards. These include multiple ejections through windows, *loss of survival space* and penetration of the passenger compartment by external structures, all of which have been known to cause fatal and serious injuries in the recent past.

38 Features which were of particular value in minimising passenger injury in this accident were:

- laminated windows which largely contained passengers within the train;
- robustness of the *couplers* which generally kept the vehicles together;
- the anti-roll bar links which ensured that most of the bogies remained attached to the train;
- penetration resistance of the bodyshell; and
- roll-over strength of the bodyshell.

Summary of actions reported as already taken

39 The RAIB issued a report of its immediate findings, on 26 February 2007, and a progress report on 3 October 2007.

40 The RAIB issued *urgent safety advice* (USA) documents to the industry relating to the design, inspection and maintenance of S&C on 6 June 2007 and to the inspection of S&C and fastener performance on 26 November 2007.

41 Network Rail and Virgin Trains carried out a joint investigation into aspects of the derailment, and released a report on 4 September 2007. This investigation differed in scope from that carried out by the RAIB.

42 Following a review of Network Rail's track inspection regime, the ORR served an *Improvement Notice* on Network Rail on 12 December 2007, stating that the system for planning and monitoring the basic visual inspection of track required improvement to ensure serious defects, that could affect the safety of trains, are identified so that appropriate action can be taken. A further Improvement Notice was issued on 9 June 2008 relating to the joint between non-adjustable stretcher bar brackets and switch rails and arose from the RAIB's second urgent safety advice. At the time of publication, this second notice is subject to an appeal at an Employment Tribunal. It is beyond the scope of this report to examine whether Network Rail has taken actions necessary to meet the requirements of these notices, which is a matter for Network Rail and the ORR.

43 During the period of the investigation, Network Rail has:

- Removed the crossovers at Lambrigg: it does not intend to reinstate them.
- Undertaken a series of examinations of S&C across its system. The examinations focused on stretcher bars, stretcher bar fasteners, *free wheel clearance*, residual switch opening and track gauge.
- Repaired all defects that it has identified which were similar to those that caused the accident at Grayrigg, although none have been found with the same degree of degradation as 2B points.
- Renewed non-adjustable stretcher bars in those points it regarded as most high risk because of their similarity to 2B points.
- Revised its standards and maintenance specifications for the set-up, maintenance and fault reporting relating to S&C with non-adjustable stretcher bars, primarily to address the issues of residual switch opening and flange-back contact.
- Commissioned various studies, some of which are still ongoing, to enhance its understanding of the design and behaviour of S&C with non-adjustable stretcher bars and the fasteners of the stretcher bars.
- Revised its maintenance and engineering organisations in the light of the Grayrigg derailment to clarify the relationships between maintenance and engineering staff.
- Refined and developed its process for handling recommendations from accident investigations.
- Introduced a new assurance regime, which includes independent checks on the track and signalling assets.
- Issued instructions for standardised diagrams to be issued for basic visual inspections, to include location, resources and access.

<u>Summary of recommendations</u>

44 There are twenty-nine safety recommendations made in this report:

- Recommendation one is targeted at Network Rail and concerns a long term review of the design, inspection and maintenance of non-adjustable stretcher bars in S&C;
- Recommendations two to five are targeted at Network Rail and concern long term design, inspection and maintenance issues on all types of S&C.
- Recommendations six to twelve are targeted at Network Rail and concern actions that can be taken in the short and medium term to mitigate risk from S&C in advance of the implementation of the longer term recommendations.
- Recommendations thirteen to twenty are targeted at Network Rail and concern underpinning engineering and risk management issues.
- Recommendation twenty-one arises from an *observation*, and is addressed to the Safety Authority regarding the briefing of its annual delivery plan.
- Recommendations twenty-two to twenty-five are targeted at the Rail Safety and Standards Board (RSSB), or Virgin Trains and Angel Trains. They concern issues associated with the behaviour of the train as a consequence of the derailment.
- Recommendations twenty-six to twenty-eight are addressed to organisations involved in the rescue after the accident. They concern the rescue operation.
- Recommendation twenty-nine arises from an observation, and is targeted at Network Rail. It concerns research into any link between long work-hours and human error.

The Accident

This section describes:

- the parties involved in the accident;
- the location and infrastructure;
- the train; and
- the sequence of events before, during and after the derailment.

The Accident

The parties involved

Companies

45 Train 1S83 was operated by West Coast Trains Ltd, which trades as Virgin Trains.

46 The class 390 Pendolino *electric multiple unit* forming the train was owned by Angel Leasing Company Ltd. It had been constructed by Alstom Transport Ltd, and was maintained by Alstom Transport West Coast Traincare Ltd.

47 The railway infrastructure at Grayrigg was, and is, owned, operated and maintained by Network Rail.

Train crew

48 The driver of the train was an employee of Virgin Trains, based at Polmadie, Glasgow. He had been qualified to drive trains for five years, and regularly operated over the route past Grayrigg. He was familiar with the Class 390 Pendolino trains, having driven them regularly since their introduction on London-Glasgow services in 2004. His staff records indicate that Virgin Trains had assessed him as fully competent in the skills required for his scheduled activities that day. There were no concerns about his medical fitness to drive trains.

49 The driver had been on leave or *rest day*s for the three days leading up to the day of the accident. On 23 February 2007, he commenced work at 13:52 hrs at Polmadie depot. He drove a Pendolino train departing Glasgow Central for London Euston at 15:10 hrs as far as Preston, arriving there at 17:46 hrs. He had a scheduled break until 19:36 hrs when he took over train 1S83. There is no evidence that he was in any way fatigued as he drove the train.

50 The driver received serious injuries in the derailment and these rendered him incapable of using the emergency exit from the driving cab. The nature of his injuries meant that he had to be rescued from the cab, and he was subsequently hospitalised until 20 March 2007.

51 The *train manager* was an employee of Virgin Trains, based at Glasgow Central depot. He had been qualified to work on Pendolino services since 2005, and regularly travelled between Glasgow and Preston.

52 On 23 February 2007, he commenced duty at 14:55 hrs, and also worked the 15:10 hrs train from Glasgow Central to Preston, where he took a scheduled break. He took over train 1S83 at Preston. The train manager was not physically injured in the accident.

53 The *customer services manager* was based at Glasgow Central and had seven years experience with Virgin Trains. Three months before the accident he had attended a safety refresher course, which included emergency door opening and train evacuation. On 23 February 2007, he worked a train from Glasgow to Wigan before joining train 1S83 at 19:23 hrs. The customer services manager was not physically injured in the accident.

54 The *customer service assistant* worked for an agency, Adecco, who regularly supply Virgin Trains with temporary personnel. She had joined Adecco in December 2006, and had six days' training before working on trains: half a day of this was on safety matters. This included theoretical training on emergency door opening, and on the need, generally, to stay on board a train after an accident. On 23 February 2007, she travelled on an earlier service from Glasgow to Wigan and joined train 1S83 there. The customer service assistant was seriously injured in the accident.

<u>*Network Rail staff*</u>

55 Network Rail employed the signallers at Carlisle power signal box, the *electrical control room operators* at Crewe, and the staff who were responsible for inspecting, maintaining and repairing 2B points at Lambrigg *emergency ground frame*, together with their managers.

56 Lambrigg emergency ground frame was subject to an inspection and maintenance regime. The points were scheduled to be inspected every week by patrollers working for Network Rail's *infrastructure maintenance manager* for Lancashire and Cumbria, who is based at Preston. The examination of the points during the weekly basic visual inspections was undertaken by members of the Carnforth track engineering team, normally out-based at either the Oxenholme or Tebay depots. There was no single individual who undertook all or the majority of weekly basic visual inspections through the points; the work was shared between a number of people.

57 The maintenance of the switches and their associated control mechanism was the responsibility of a dedicated *joint points team* based in Carlisle. There were four permanent members of the team, two from the signal maintenance department and two from the track maintenance department. In the year leading up to the accident, there were a number of different people, as well as the permanent signal engineering department members, who were involved in the work of the joint points team, but no such substitution took place among the track engineering members because they were the only two people at the Carlisle depot qualified to undertake the specific duties.

<u>*Passengers*</u>

58 The *British Transport Police* (BTP) secured the names and addresses of a total of 105 passengers on the train. Details of injuries are given in paragraphs 91 to 94.

<u>Location</u>

59 Lambrigg emergency ground frame is located on the two-track London to Glasgow WCML, with the nearest stations being Oxenholme, approximately five miles (8 km) to the south, and Penrith, approximately 27 miles (43 km) to the north (Figure 1 shows the immediate area of Grayrigg).

60 A level crossing, controlled from a local signal box, existed at Lambrigg until April 1977. The site of the level crossing is now used as an access and egress point for railway maintenance staff working on the railway in this area. The site of the former level crossing was approximately 150 metres north of the location of 2B points.

61 On a typical weekday in February 2007 approximately 60 trains passed northbound through Lambrigg, including:

- 34 express passenger services provided by Class 390 'Pendolino' and Class 221 'Super Voyager' trains, both capable of tilting (paragraph 74), and by Class 220 'Voyager' trains;
- some 24 freight or *engineering trains*; and
- two overnight sleeper trains.

This compares with approximately 50 movements per day when 2B points were installed in 1971, the principal difference being the lower number of cross-country passenger services operated at that time.

Infrastructure

62 Train movements through Lambrigg are controlled by *four-aspect colour light signalling*, operated from Carlisle power signal box.

63 The line is electrified, using 25 kV AC *overhead line equipment*.

64 The maximum permitted line speed at Lambrigg on both the up and *down* lines is 95 mph (153 km/h) for tilting trains authorised to run at *enhanced permissible speed* (EPS), and 85 mph (137 km/h) for other trains. EPS was authorised in October 2005, and trains were timetabled to it from December 2005 as part of the upgrade to the WCML; before then, all trains were restricted to a maximum speed of 85 mph (137 km/h) or less.

Lambrigg emergency ground frame and 2B points

65 Lambrigg 2B points, the location of the derailment, were 24 miles and 12 chains from Lancaster.

66 When the WCML was resignalled in the 1970s, two crossovers were installed at Lambrigg because the signal box in the vicinity enabled local control of the points. The purpose of the crossovers was to allow single line working while engineering work was taking place on the WCML, or when only one line was available for traffic because of a train failure.

67 After the removal of the level crossing in 1977, the points at Lambrigg continued to be operated from the old signal box until 1993. Early in that year the signal box was removed and since then the points have been controlled from a *ground frame* cabin within the local relay room at Lambrigg; they required an *electrical release* by Carlisle power signal box before they could be operated. They could not be operated directly from the power signal box.

68 Each of the two crossovers at Lambrigg consists of two points. One crossover is in the facing direction while the other is trailing (Figure 5). A train travelling towards Glasgow on the down line first encounters 2B points in the facing direction and then 3A points in the trailing direction.

69 Normal UK signalling practice is that the position of a switch rail that is closed against the stock rail is detected, locked, and interlocked with the signalling, so that, if the switch rail is more than 3.5 mm away from the stock rail at the toe, it is not possible to signal a train through the points. The Lambrigg crossovers were controlled in accordance with this convention, allowing the signallers in Carlisle power signal box to be aware of the position of the points. There is no requirement to separately measure or detect the position of the open switch rail, although, under fault conditions, if it and its *detection equipment* were to move sufficiently, independently of the closed switch, it could result in a loss of *detection*. This would change signal aspects to *danger* and might be sufficient to stop a train passing over the points (depending on how close to the points the train was when the loss of detection occurred).

70 The designed track curve radius through Lambrigg emergency ground frame is 1487 metres with the track curving to the left in a *cutting*. The designed cant is 95 mm. Both figures are within the limits laid down by Network Rail's company standards.

71 At 3A points, the cutting ends in a short section of level ground at the site of the former level crossing. Continuing towards Glasgow, the railway is carried on an embankment which is 15 metres high at its maximum point on the down side. Part way along the embankment a *transition curve* reduces the *left-hand curve* radius until the track is straight. The derailment happened in the course of the left-hand curve, and in the cutting.

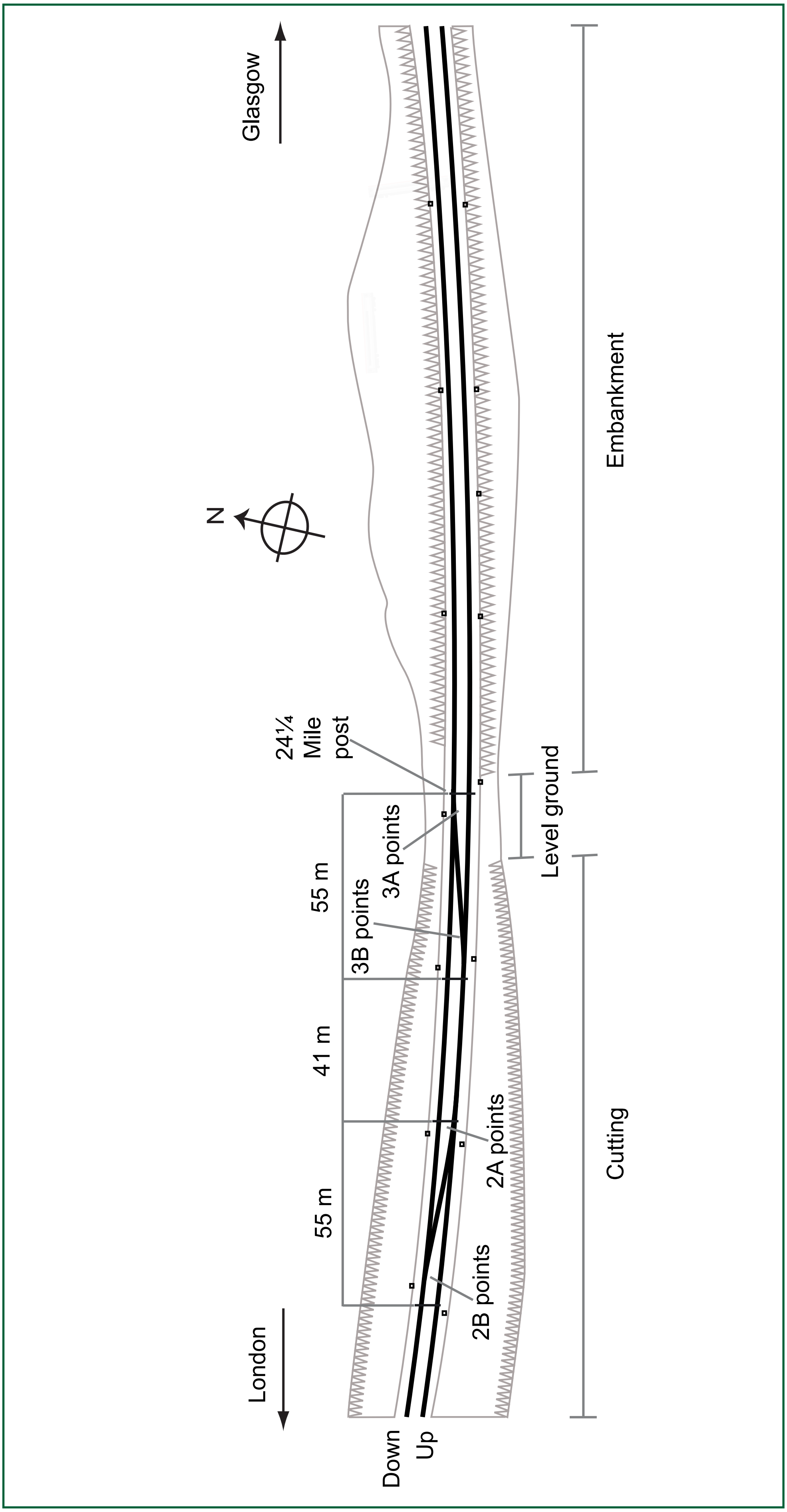


Figure 5: Layout of Lambrigg crossovers

72 The *speed restriction* when the route was set over the crossover from one line to the other (points set *reverse*) was 10 mph (16 km/h). Normally, the points were set, locked and detected for the main route, and line speed (paragraph 64) was permitted across them. Points 2B were of a *contraflexure* configuration, with a right-hand *turnout* on a left-hand curve.

Running Order/ RAIB Designation	Coach Designation	Vehicle Type	Vehicle No.
One	Coach A	Driving motor (standard)	69233
Two	Coach B	Intermediate motor (standard)	69933
Three	Coach C	Pantograph trailer (standard)	69833
Four	Coach D	Intermediate motor (standard)	69733
Five	Coach E	Trailer (standard)	68833
Six	Coach G	Intermediate motor (first)	69633
Seven	Coach H	Pantograph trailer (first)	69533
Eight	Coach J	Intermediate motor (first)	69433
Nine	Coach K	Driving motor (first)	69133

Table 2: Composition of Pendolino train 390 033

<u>The train</u>

73 The train which derailed was a nine-car Class 390 'Pendolino' electric multiple unit. It was designed and manufactured by Alstom Transport Ltd, and was maintained by Alstom Transport West Coast Traincare Ltd. This class of train first entered passenger service in July 2002. The train involved in the derailment was numbered 390 033; Table 2 lists the order in which they were travelling.

74 Class 390 Pendolinos were designed for a maximum operating speed of 140 mph (225 km/h) and run on, among other routes, the WCML between London Euston and Glasgow Central. They began operating on this route in January 2004. The design features a tilt system to maintain a comfortable passenger environment while the train is negotiating curves at higher speeds than conventional rolling stock.

75 The original design and construction were certified by a *Vehicle Acceptance Body* as compliant with the relevant *Railway Group Standards*, using the *Engineering Acceptance* procedure. Additionally, possible hazards resulting from the operation of the train were identified and addressed through the progressive submission of safety cases for approval for operation by a *Rolling Stock Acceptance Board*. The train was also approved for service by *Her Majesty's Railway Inspectorate* (HMRI) under the Railways and Other Transport Systems (Approval of Works, Plant and Equipment) Regulations 1994 (ROTS), and the Railways (Interoperability) (High Speed) Regulations 2002.

<u>External circumstances</u>

76 It was dark and raining at the time of the accident, with moderate winds, and there was no ambient light in the vicinity of Lambrigg emergency ground frame. The weather played no part in the events leading up to the accident, but did affect the rescue of the injured, as explained later in the report.

Events preceding the accident

77 Train 1S83 commenced its journey from London Euston on 23 February 2007 on time at 17:15 hrs. The journey north to Preston was uneventful, other than flooding in the kitchen area in the ninth (rear) vehicle because of an equipment fault, which led to it being emptied of passengers for the journey beyond Preston, although the train manager was in that vehicle when the accident happened.

78 At Preston there was a scheduled change of driver. The train departed at 19:40 hrs with the next scheduled stop being Carlisle. The driver used the speed set feature on the Class 390 to control the train speed at or just below the line speed limit, and applied the brakes on the approach to Oxenholme for the 90 mph (145 km/h) speed restriction through the station. After passing through Oxenholme, the driver accelerated the train to the permitted maximum line speed of 95 mph (153 km/h) before engaging speed set again.

79 As the train approached Lambrigg crossovers it was running at 95 mph (153 km/h) with its tilting system active and no faults recorded on the *Train Management System*.

Events during the accident

80 As the leading vehicle passed through 2B points, it derailed as described in detail in paragraphs 538 onwards. All the other vehicles of the train derailed as a consequence.

81 The driver recalled that the train 'leapt in the air' as it derailed. He was unable to react before the motion of the derailed train propelled him out of his seat.

82 Vehicle one became detached from the rest of the train when its coupling to vehicle two failed and, after rotating through 190 degrees horizontally, and rolling down the side of the embankment, it came to rest at the foot of the embankment's northern slope, facing opposite to the original direction of travel. Vehicle two came to rest at right angles to the direction of travel with its trailing end at the foot of the embankment and the leading end overhanging the track.

83 The front of vehicle three closely followed the trailing end of vehicle two, and it, and the remainder of the vehicles, ran derailed mainly on the down line, eventually deviating over the edge of the embankment and onto the slope. They came to rest at various positions along the down (left-hand) slope of the embankment and in the down *cess*.

84 The train came to rest within a distance of 320 metres from the toes of 2B points by the combined retardation effect of derailed bogies ploughing through trackwork, *ballast*, earthworks and vegetation, the train's emergency braking still effective on those vehicles yet to derail, and the collision of some vehicles with overhead line electrification masts and their foundations.

Events following the accident

85 As a result of the damage and disruption to the signalling system, all signals in the immediate vicinity on both lines automatically reverted to danger and approaching trains were stopped before they reached the site of the accident.

86 The driver of the Pendolino had been rendered unconscious during the derailment. Upon regaining consciousness, he, despite extensive injuries, had the presence of mind to use the only communication equipment he could reach, his personal mobile phone, to call an off-duty employee of Virgin Trains (whose number was programmed in that phone) to relay a message to Virgin Trains operations control asking for trains to be stopped on the up line.

87 The train manager also called Virgin Trains operations control to report that the train was derailed, but was unable to give a precise location. The train manager, customer services manager and customer service assistant provided information to the emergency services about the train and the number of passengers on board. They then assisted the passengers and the emergency services, although none of them was able to move fully throughout the train, and the customer service assistant was seriously injured.

88 Staff in the Network Rail electrical control room at Crewe, and the signaller at Carlisle, were both immediately aware that something was wrong in the Lambrigg area from indications on their display panels, but they did not know what had happened. They implemented procedures to secure the safety of the accident site – *emergency isolation* and switching all signals so they would remain set to danger.

89 The emergency services were notified of the accident by a number of passengers on the train using their mobile phones, and also by two local residents who heard the sound of the accident. One of the local people who called the emergency services gave details of the location and his postcode (paragraph 624).

90 The emergency services mobilised staff to site, and declared a *major incident* when they realised the extent of the accident. The first ambulance and fire crew, from Kendal, located the train at 20:46 hrs. After a considerable exercise involving many agencies, the last person was removed from the train by 22:47 hrs, and all the injured were removed by ambulance or helicopter by 00:11 hrs the following morning. The passengers and crew were either taken to hospital or continued their journey onwards by road.

<u>Consequences of the accident</u>

91 Eighty percent of the people in the train were injured to some extent. Table 3 below shows the distribution of physical injuries for both passengers and train crew.

	Injury severity				
	Fatal	***Serious**	**Minor**	**No injury**	**Total**
Passengers	1	28	58	18	105
Train crew	0	2	0	2	4

[* As defined in the Railways (Accident Investigation and Reporting) Regulations 2005]

Table 3: Summary of physical injuries on train 1S83

92 Mrs M Masson, an 84-year old passenger, was fatally injured as a result of the accident. She was travelling in the leading vehicle of the train, was rescued from it by Ambulance and Fire & Rescue services personnel, and airlifted to hospital, but died en-route.

93 The most serious injuries were sustained by those travelling in the leading four vehicles; 55 passengers and two crew were treated in hospital, and a total of 86 passengers and two crew were physically injured. The RAIB has not attempted to capture or quantify the level of any psychological trauma suffered by passengers or crew.

94 The majority of the hospitalised passengers, at least 40, were released within 24 hours, but some were kept in hospital for up to several weeks.

95 The train was substantially damaged by the accident though there was no significant loss of passenger or crew survival space. Details of the damage to the train are given in paragraphs 548 to 561. Subsequently it has been written off.

96 The derailment caused major damage to the track, signalling, and overhead line equipment of both the down and up lines. All four sets of points of the emergency crossovers at Lambrigg (2A, 2B, 3A, 3B - Figure 5) were severely damaged as were the earthworks of the down-side slope of the embankment.

97 As a result of the damage, the railway was completely blocked at Lambrigg and remained so for sixteen days during recovery and reconstruction. The line reopened to traffic at 19:45 hrs on 11 March 2007.

98 Road closures and traffic restrictions were imposed on the A685 and local minor roads in the vicinity of Grayrigg village for ten days after the accident in order to facilitate the access of the rescue and recovery operations to the site.

This page is left intentionally blank

The Investigation

This section describes:

- the investigation process; and
- the sources of evidence;

The Investigation

Investigation process

99 The BTP, the ORR and the RAIB all mobilised to the site. They agreed early on 24 February 2007 that the RAIB would take the role of lead investigative agency as there was no 'clear indication that the railway accident or incident had been caused by serious criminality'[1].

100 The RAIB managed and co-ordinated the gathering of evidence during the on-site phase of the investigation:

- The BTP provided inner cordon security, search team members, a photographic record of evidence taken and an evidence log. They also provided details of who was on the train, where they were, and, where possible, what injuries they had suffered.
- The ORR collected documentary evidence from off-site locations relating to the signalling system, train operations, and infrastructure maintenance and inspection.
- The RAIB carried out all other aspects of evidence collection.

101 Following detailed on-site surveying, photography, measurement of the track under unloaded and loaded conditions, examination of the signalling system, taking of forensic samples and recovery of detached items of evidence in the vicinity, the whole switch section of 2B points (Figure 6) was secured for transport and removed as a complete panel to a secure laboratory for testing and analysis.

Figure 6: Points 2B switch section in laboratory

[1] Memorandum of understanding between the RAIB, the BTP, the Association of Chief Police Officers and the ORR for the investigation of rail accidents and incidents in England and Wales, para 38.

102 Similarly, following an initial examination on site to record and secure perishable evidence, all nine vehicles of the derailed train were recovered separately and removed to secure covered storage.

103 The RAIB withdrew from site, having completed the site evidence gathering phase of its investigation, in the evening of 4 March 2007.

104 The scope of the RAIB investigation has differed from that of the industry's in that it has:

- established the sequence of the failure of 2B points, sharing this with Network Rail for input into the industry investigation;
- established the probable factors that underpinned the initial failure of the points;
- looked at the design of points and the management of maintenance both at national and local level to identify broader issues;
- investigated the pre-derailment condition of the train, its post-derailment trajectory, crashworthiness performance, injury causation and egress; and
- reviewed the performance of the industry and the emergency services during the rescue phase immediately following the derailment.

105 The RAIB investigation has focused on three main areas:

- establishing how and why 2B points at Lambrigg came to be in a state which led to the derailment, and whether the factors that led to this may also be present elsewhere on the network;
- establishing the behaviour of the train as and after it derailed, and in particular how the casualties were injured; and
- reviewing the rescue of the passengers and crew from the train until they were clear of the site.

106 Access was freely given by the ORR, the BTP, Network Rail, Virgin Trains, Alstom, Cumbria Police, Cumbria Fire and Rescue Service, North West Ambulance Service, Mountain Rescue teams, and the Royal Air Force Search & Rescue and Mountain Rescue teams to their staff, data and records in connection with the investigation.

Sources of evidence

107 The RAIB has collected the following evidence in addition to that specified in paragraphs 101 and 102:

- components of the other three points at Lambrigg crossovers (2A, 3A and 3B points);
- permanent way stretcher bars from 622B points at Grayrigg freight loops, 1¾ miles (2.8 km) north of Lambrigg;
- detailed surveys of the interior and exterior of each vehicle of the derailed train;
- site photographs taken by the RAIB and by other agencies, including an aerial photographic and video survey taken by the Lancashire police helicopter;
- site surveys;
- witness testimony;
- data from Network Rail's track recording trains;
- train information consisting of maintenance records and downloads from the *On Train Data Recorder* (OTDR), Train Management System, internal Closed Circuit Television (CCTV), and the tilt actuation and control systems;

- reports from Alstom Transport West Coast Traincare Ltd relating to data downloaded from the OTDR, the Train Management System and other train systems;
- train design and certification documentation supplied by Alstom Transport West Coast Traincare Ltd;
- documents and records supplied by the ORR;
- documentation and records supplied by Network Rail relating to operation of the infrastructure locally in the Lancashire and Cumbria Area;
- documentation and records relating to the design, commissioning, maintenance, inspection and repair of the infrastructure nationally and locally in the Lancashire and Cumbria Area. This includes information from the Network Rail Engineering Support Centre at Derby, which collects data from the various monitoring systems installed on trains and at the lineside;
- standards, procedures and drawings supplied by Network Rail relating to design, commissioning, inspection, and maintenance of the infrastructure; and
- information on previous and subsequent incidents that had relevance to the accident at Grayrigg.

108 In the post-site investigation phase the RAIB has:

- recreated the switches of 2B points as closely as practicable to the configuration they were in at Lambrigg;
- undertaken testing of those switches;
- analysed and modelled the likely behaviour and failure modes of the switches of 2B points;
- conducted field tests to establish typical loadings in stretcher bars (in co-operation with Network Rail) on the operational railway;
- commissioned testing and analysis of the joint between the permanent way stretcher bar and the switch rail used in 2B points;
- modelled *fatigue* fracture behaviour of the failed stretcher bar components from 2B points;
- reviewed investigations into other similar incidents and accidents;
- reviewed the outcome of tests carried out by Network Rail on its S&C since the accident;
- reviewed the inspection and maintenance interventions into 2B points;
- reviewed Network Rail's management procedures as they affected the derailment;
- carried out bespoke analysis of the data from Network Rail's track recording trains;
- reviewed the internal and external damage to the derailed train;
- modelled the behaviour of the train, recreating its likely path from derailment to coming to rest;
- reviewed the injuries sustained in the derailment for severity, and causation;
- reviewed the evacuation of the train after it came to rest; and
- reviewed the response of the emergency services and other parties involved in the rescue of the passengers and crew from the train.

The Infrastructure: Evidence and Analysis

This section describes, under the following headings, the evidence and analysis relevant to the causes of the accident:

- the degradation of 2B points - the condition of 2B points' components following the accident, the sequence of failures and the technical causes;
- the inspection and maintenance regime – the activities of staff at Lambrigg, and the immediate supervision of those activities;
- other accidents and incidents involving S&C stretcher bars that have relevance to the derailment;
- Network Rail's management arrangements;
- safety regulation –the role of the safety regulator with regard to S&C, and to previous relevant accidents and incidents; and
- the timeline – a chart describing events leading to the accident.

The Infrastructure: Evidence and Analysis

Degradation of Lambrigg 2B points

Introduction

109 A generic description of the operation and key terms relevant to the type of points used at Lambrigg is presented in Appendix D. This includes a description of the relationship between residual switch opening and the onset of flange-back contact.

110 According to Network Rail standards, in a correctly set up condition the residual switch opening will be 1.5 mm and the open switch rail will not be subject to any flange-back contact.

The condition of the points after the derailment

111 Figure 7 shows the state in which the points were found immediately after the accident.

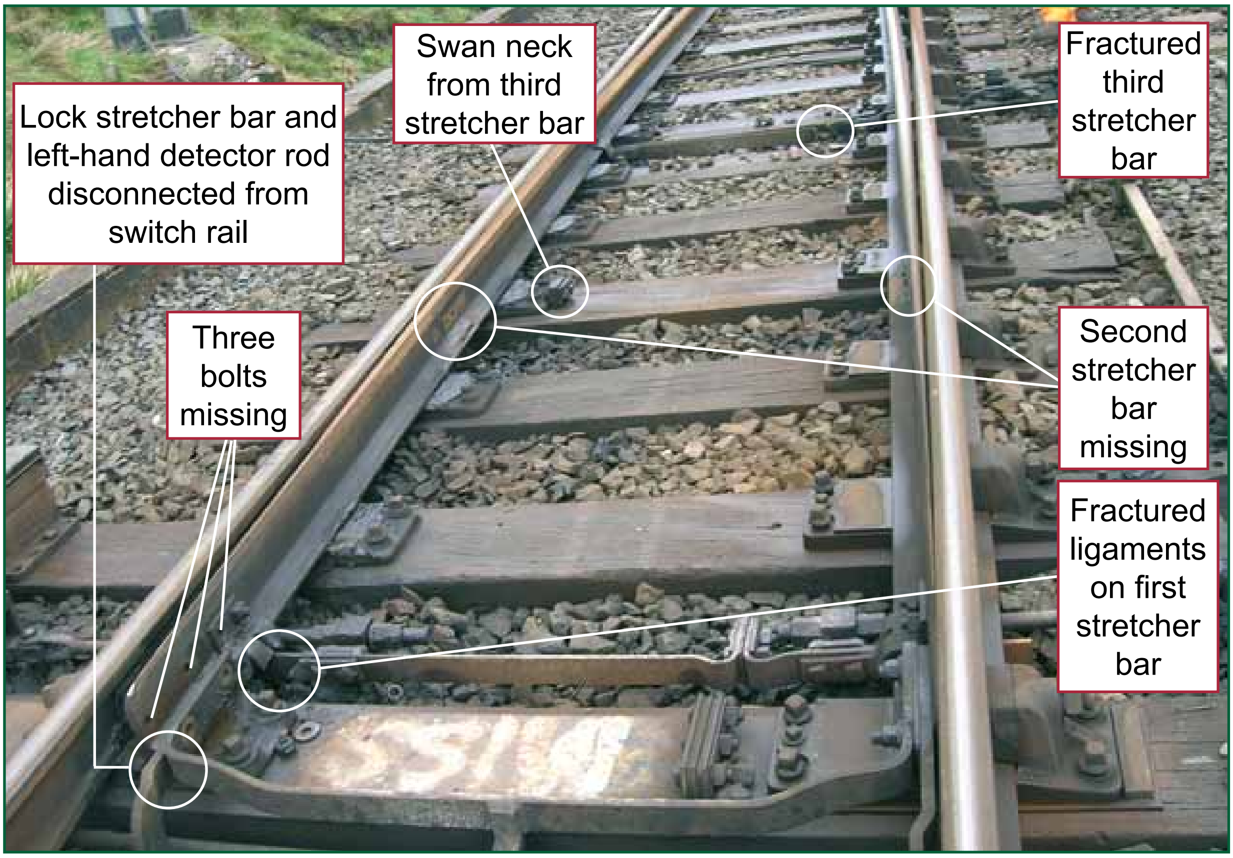


Figure 7: 2B points on 24 February 2007

Rails

112 The left-hand switch rail was found in a partially open position with no connections between it and the right-hand switch rail, because all of the stretcher bar assemblies had failed. The toe of the left-hand switch rail was standing open by 52 mm. The right-hand switch rail was also standing off from its stock rail by 22 mm at the third permanent way stretcher bar position. Additionally, the track beyond the *heel block*s of the points was distorted to the left. However, when 2B switches were removed from the track, both switch rails closed up to their stock rails. This suggested that the switch rails had not been significantly permanently deformed during the derailment. Comparative switch flexure tests on a new switch panel indicated similar behaviour to that exhibited by 2B points after the accident. Therefore, the subsequent tests on 2B points are likely to have been indicative of their behaviour before the accident.

113 There was bruising on the tip of the left-hand switch rail (Figure 8) caused by impact with more than one train wheel as the wheels passed to the *gauge-side* of the left-hand switch rail during the derailment. There were wheel marks on the *field-side* face of the left-hand switch rail starting close to the switch toe and running along it, through to and beyond the third permanent way stretcher bar position (Figure 9). There were no marks indicating that any wheels had passed between the right-hand switch and stock rails from the toe to the third permanent way stretcher bar. There were flange climb marks on both switch rails in the vicinity of the third permanent way stretcher bar, and three of the left-hand *slide chairs* had fractured during the derailment because of forces tending to widen the gauge.

Figure 8: Bruise to the tip of the left-hand switch rail

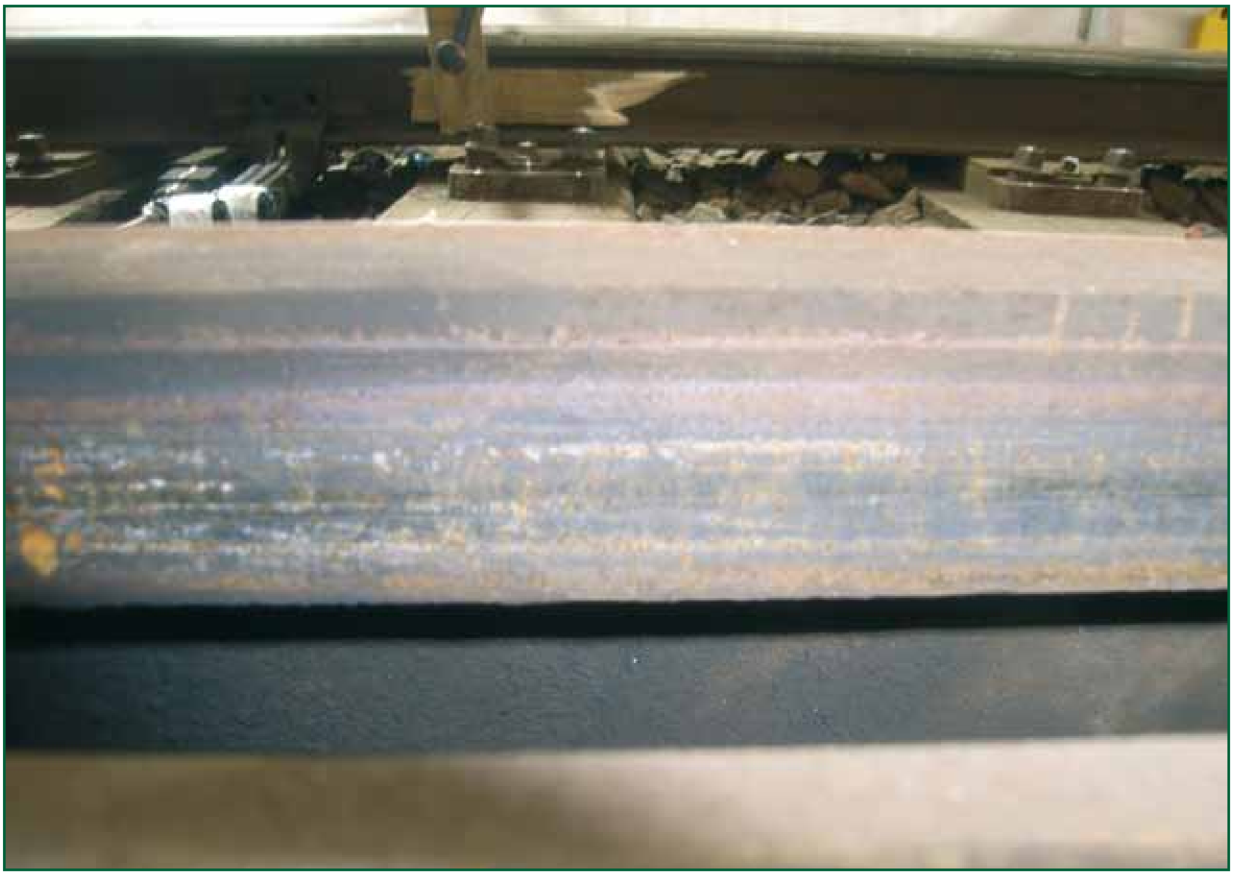


Figure 9: Wheel marks on the field side face of the left-hand switch rail

114 *Rail branding* was present on the *four-foot* side of the right-hand side switch rail where the second and third permanent way stretcher bar brackets had been attached (Figure 10). *Branding* was also present on the field-side of the left-hand switch rail where both bolt heads of the first permanent way stretcher bar and the north bolt head of the *lock stretcher bar* had been seated (Figure 11).

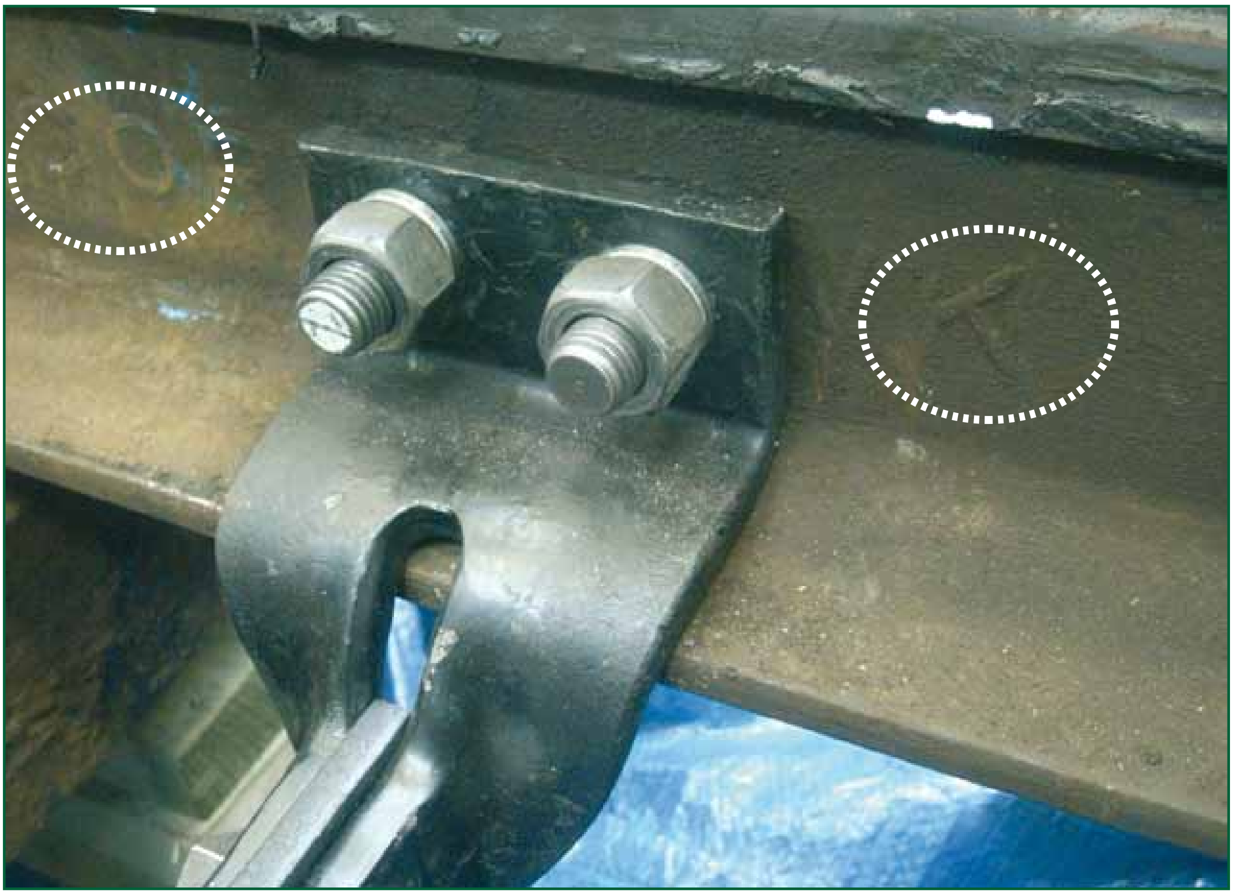


Figure 10: Rail branding on right-hand switch rail (Note: a new bracket has been added for testing purposes)

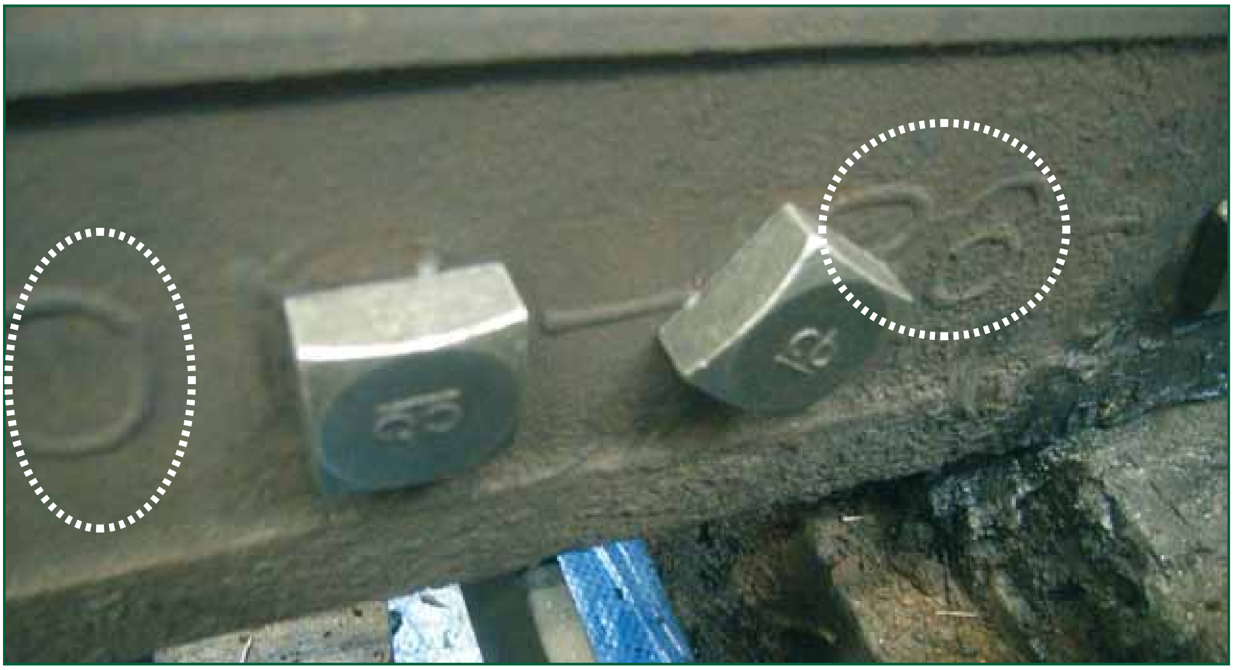


Figure 11: Rail branding on left-hand switch rail (Note: new bolts added for testing purposes)

Lock stretcher bar

115 The lock stretcher bar was detached from the left-hand switch rail because the two fasteners were not in place. These fasteners were ¾ inch Whitworth bolts with *prevailing torque* nuts. The bolts were made from mild steel, equivalent to grade 4.6 to British Standard 3692:2001, commonly known as black bolts, in accordance with Network Rail's specifications. All of the detached fastener components were lying in the vicinity of the switch toes, with the exception of one of the bolts which, despite an extensive search, was not found. The other lock stretcher bar bolt was recovered from the left-hand slide chair at the point toes, between the left-hand switch rail and its adjacent stock rail (Figure 12). There were markings on the bolt head (Figure 13), and the feet of both rails, consistent with the bolt having been trapped by the closing of the left-hand switch rail.

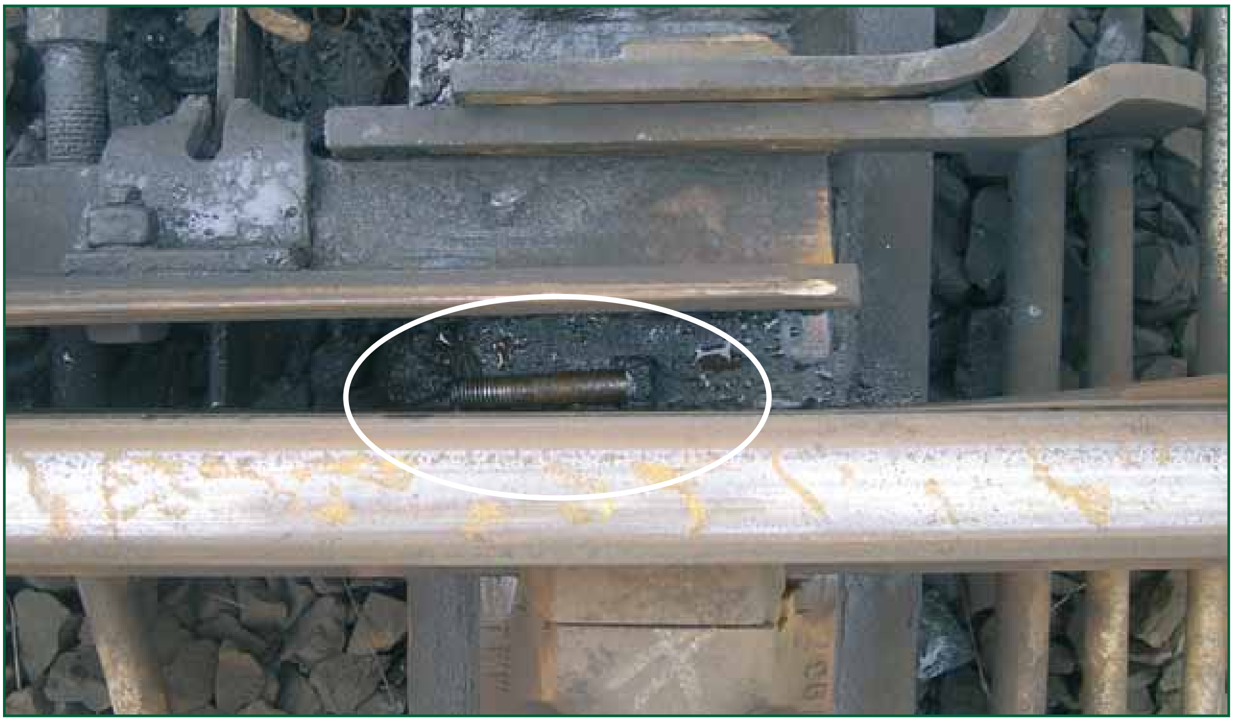


Figure 12: Lock stretcher bar bolt between left-hand switch and stock rail at toe

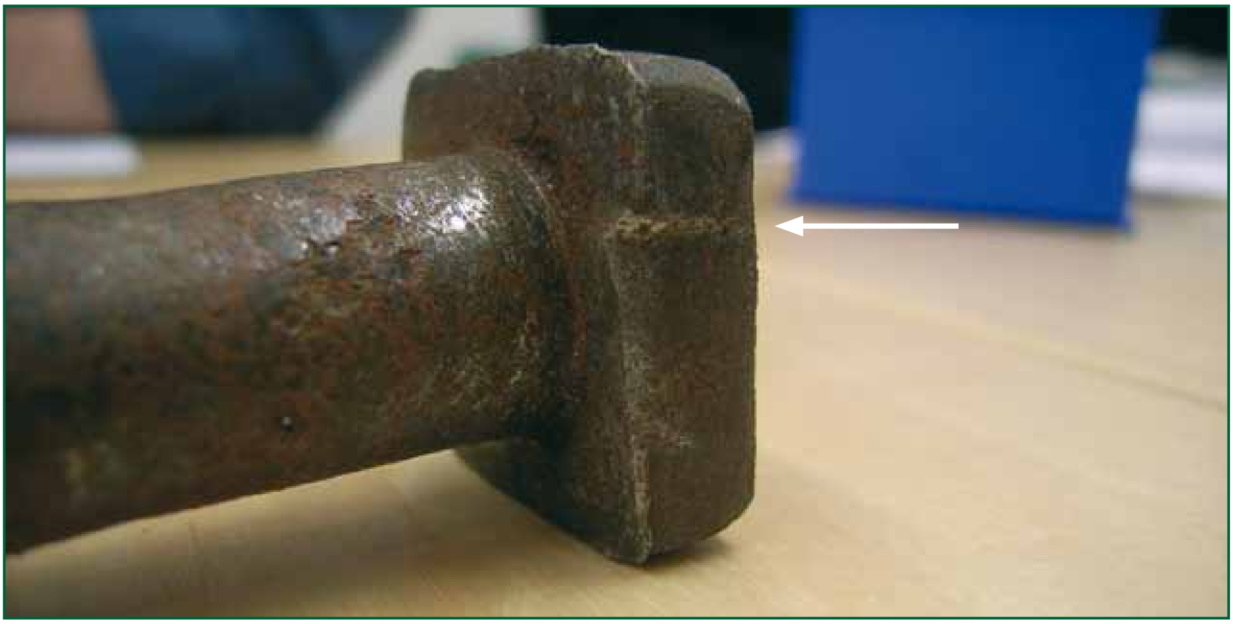


Figure 13: Indentation in lock stretcher bar bolt head

116 Examination of the one detached lock stretcher bar bolt (paragraph 115) indicated that the fastener had loosened and the nut had progressively wound off the bolt. The gradual unwinding of the nut is apparent from the decreasing flattening of the crowns of the threads towards the tip of the bolt (Figure 14).

Figure 14: Lock stretcher bar bolt showing progressive thread damage

117 The left-hand *switch rail extension piece* (Figure 15), to which the *detector rod* was attached, was also detached from the left-hand switch rail because its fasteners were common with those of the lock stretcher bar.

Figure 15: Left-hand switch rail toe showing switch rail extension piece (arrowed)

118 Measurement of the *torque* during disassembly of the intact lock stretcher bar joint at the right-hand switch rail showed that, once the joint was loosened, the prevailing torque nuts, although designed to resist unwinding, only exhibited a resistance similar to that of a plain nut. The threads of the nut, which are designed to be offset to increase the torque necessary to move the nuts, were distorted so that they gave no extra resistance.

119 The *bolt retaining plates* on the field-sides of both switch rails had not been fitted. These provide an aid to assembly of the bolted joints; they do not contribute to maintaining their integrity. Since the joints had remained secure for several years, the RAIB concludes that omission of the plates did not contribute to the accident.

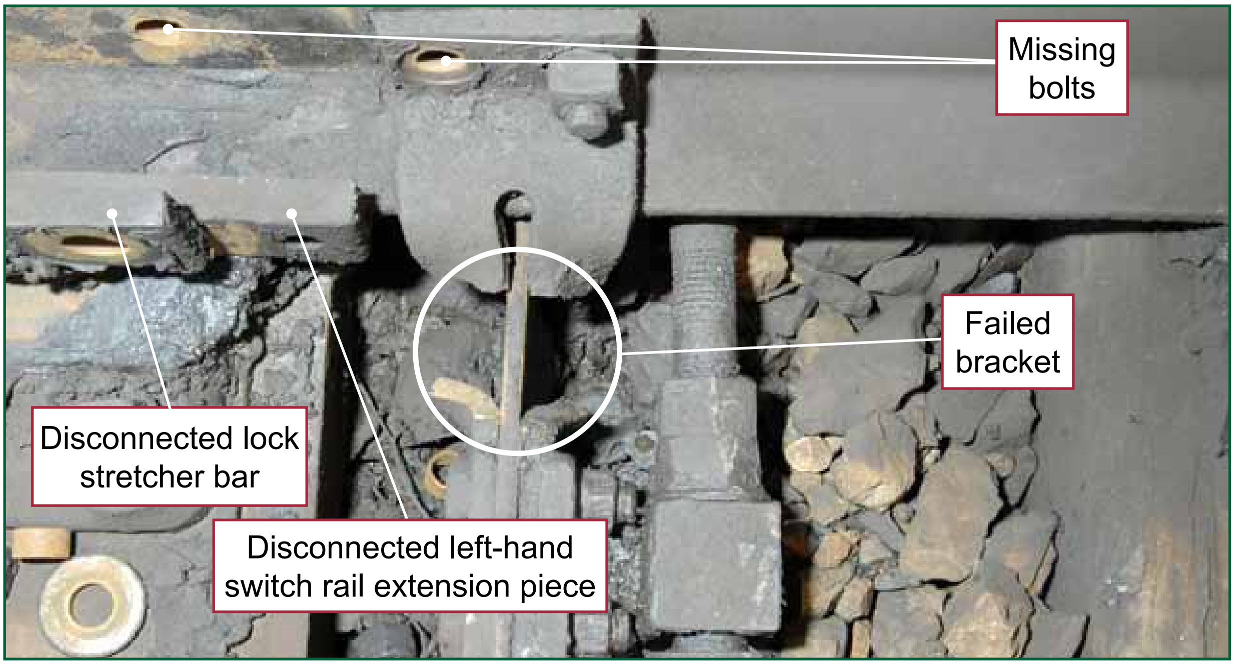


Figure 16: Failed bracket first permanent way stretcher bar

<u>First permanent way stretcher bar</u>

120 The first permanent way stretcher bar left-hand switch rail bracket was found to be broken on both *ligaments*, close to where it was bolted to the stretcher bar itself (Figure 16). All the fracture surfaces were free from corrosion, indicating that the fractures had occurred within a few days before the accident.

121 One of the fasteners between the bracket and the left-hand switch rail was not present; the other was in place, but only finger tight. A bolt, nut and *spring washer* from the bracket connection were found under the switch rail lying on the ballast.

<u>Second permanent way stretcher bar</u>

122 The second permanent way stretcher bar was missing from the points. All of its fastener components (bolts, nuts and spring washers) were present in the ballast in the vicinity of where the bar had been, with the exception of the right-hand switch rail bolts which were still within their attachment holes in the right-hand switch rail (Figure 17).

123 Two sections of stretcher bar (Figures 18 and 19) were found at two separate locations 50 metres and 150 metres north of 2B points. Their dimensions and metallurgy indicated that these were the sections of the second permanent way stretcher bar.

Figure 17: Right-hand switch rail at second permanent way stretcher bar position

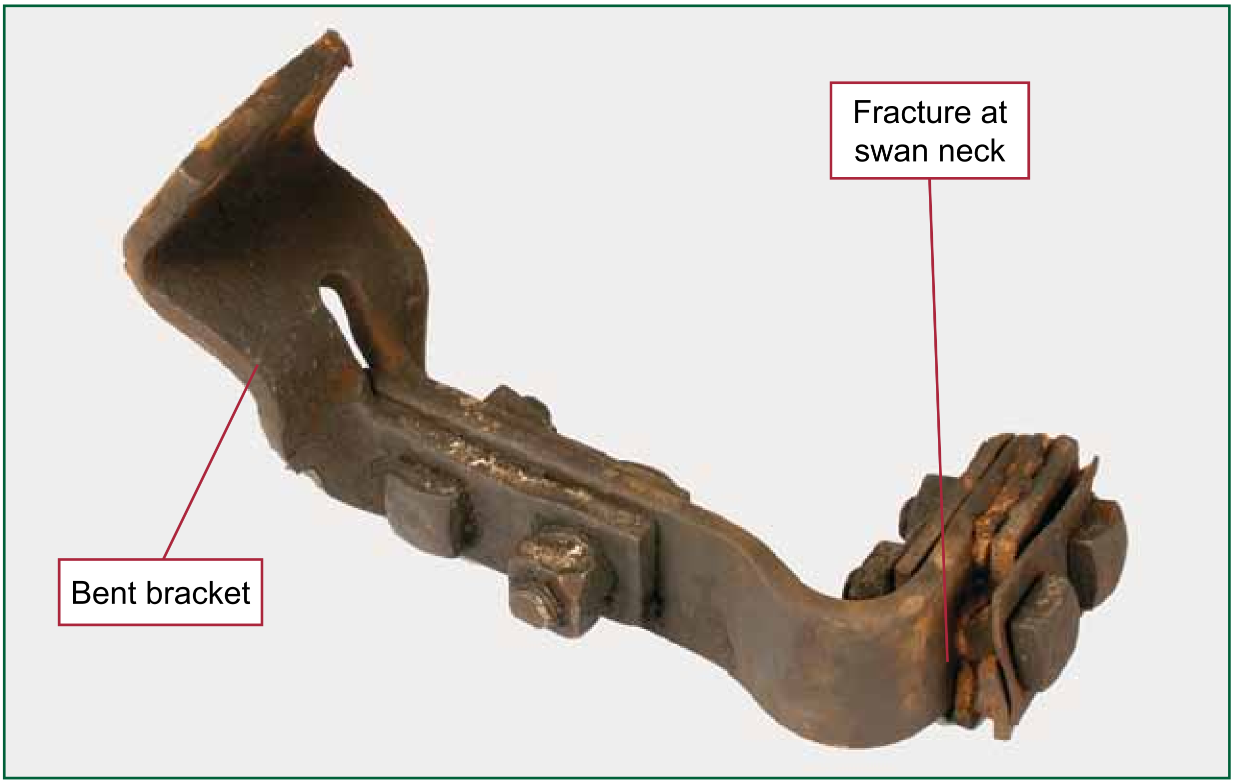


Figure 18: Short section of second permanent way stretcher bar

Figure 19: Long section of second permanent way stretcher bar

Third permanent way stretcher bar

124 The third permanent way stretcher bar was found in place but broken in two places (Figure 20). The *swan neck insulation* assembly was found on the third *bearer* from the point toes in the direction of travel close to the left-hand slide chair (Figures 7 and 21).

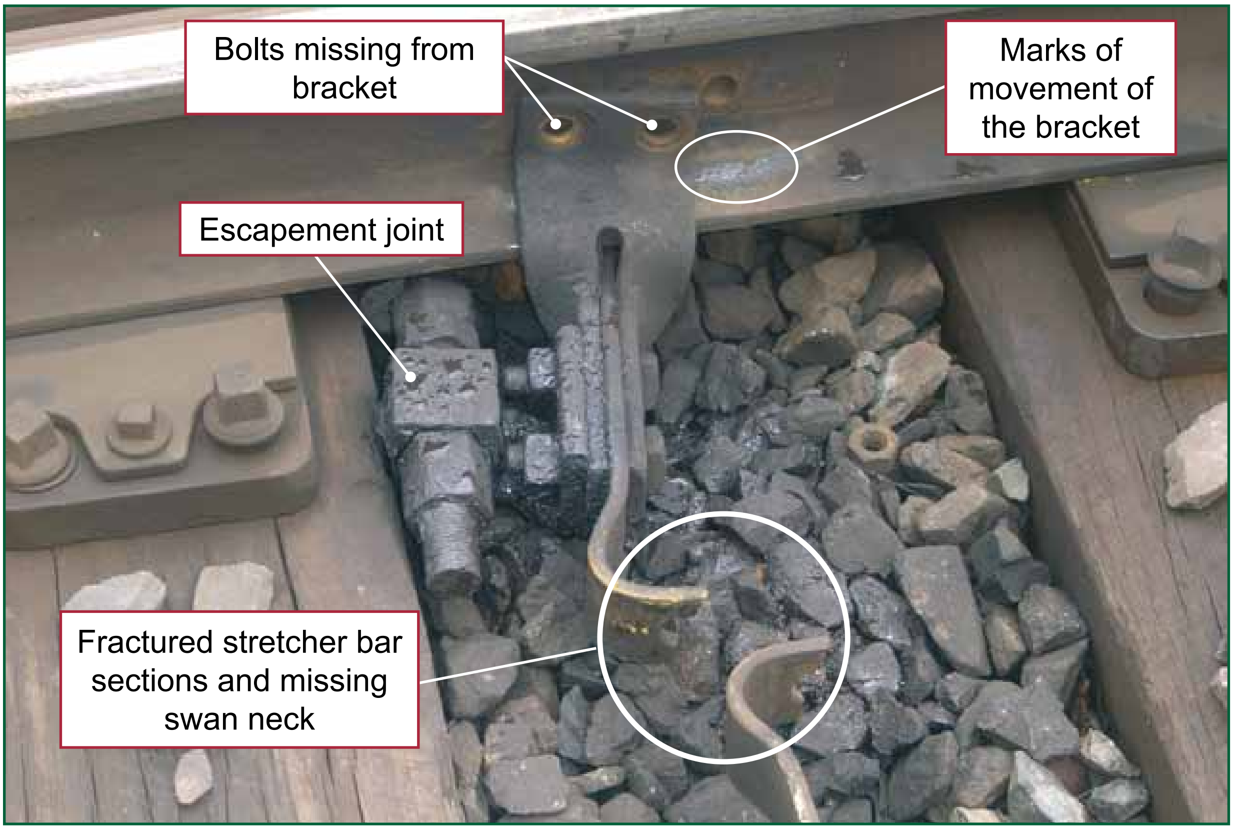


Figure 20: The third permanent way stretcher bar

Figure 21: The third permanent way stretcher bar swan neck insulation assembly

125 The broken components in the third permanent way stretcher bar swan neck insulation assembly had new, corrosion-free fracture surfaces. Additionally there was evidence of older fatigue. The four fracture surfaces in the swan neck insulation assembly are shown in Figure 22.

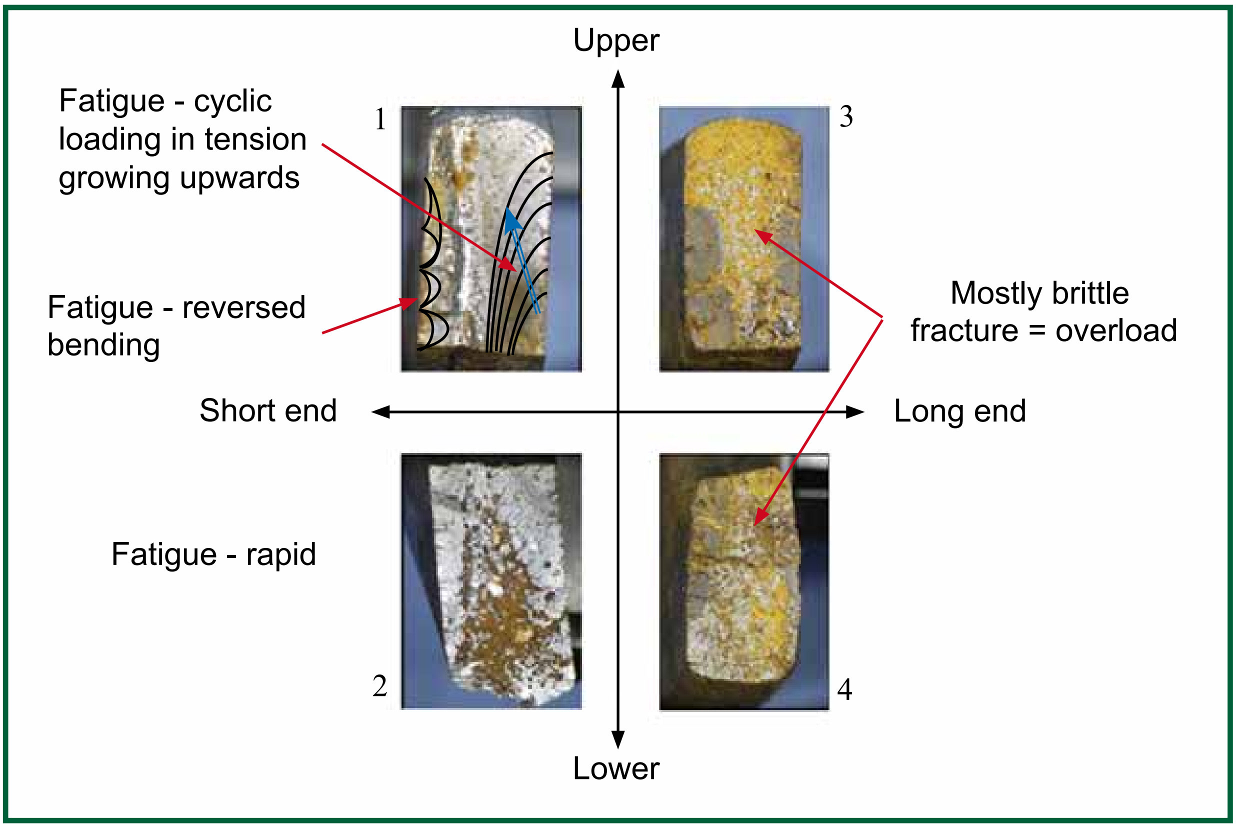


Figure 22: Fatigue surfaces within the swan neck assembly of the third permanent way stretcher bar

126 There were also cracks in the ligaments of both the left and right-hand switch rail brackets (Figure 23).

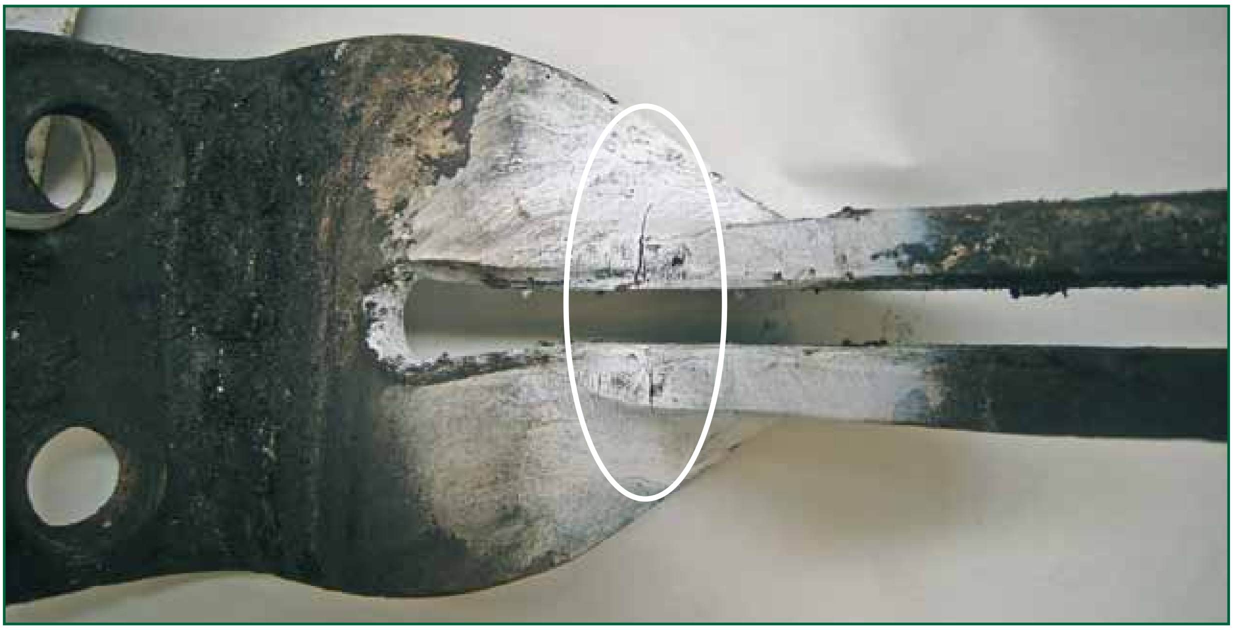


Figure 23: Cracks in the left-hand rail bracket of the third permanent way stretcher bar

127 The right-hand bracket of the stretcher bar was detached from the right-hand switch rail and was supported only by its connection to the supplementary drive (Figure 20).

128 Four bolts and four nuts (all ¾ inch Whitworth) and two single coil spring washers were found in close proximity to the third permanent way stretcher bar. All of the bolts exhibited signs of damage consistent with being loosely held within the switch rail holes prior to working free. Three of the bolts had sustained damage consistent with being trapped for a while between the closed right-hand switch and stock rails before falling free (Figure 24).

Figure 24: Damaged bolt from right-hand end bracket of third permanent way stretcher bar

129 There were indentations matching the rail branding (paragraph 114) imprinted into the mating face of the right-hand stretcher bar bracket (Figure 25).

Figure 25: Indentations imprinted into the mating face

Permanent way stretcher bar to switch rail fasteners

130 Each fastener between a switch rail and the stretcher bar bracket consisted of a ¾ inch Whitworth bolt, 65 mm long, fitted with a nut with a single coil spring washer. The bolts were made from mild steel, equivalent to grade 4.6 to British Standard 3692:2001, commonly known as black bolts, in accordance with Network Rail's specifications.

131 All of the permanent way stretcher bar fasteners were examined and were undamaged, with the exception of those from the third permanent way stretcher bar as described in paragraph 128. The lack of damage to the bolts and their threads indicated that the nuts had unwound from their bolts once each joint had initially failed by *slip* (Appendix E). Failure by fatigue, overload, thread stripping or any other mechanism would have resulted in visible damage to the bolts.

Supplementary drive

132 The supplementary drive is shown in Figure 26 and its role is described in Appendix D. The supplementary drive was complete and undamaged and all of its components were operating correctly.

133 Where the supplementary drive connects to the stretcher bar there is an *escapement joint*. Clearances within this joint, known as lost motion, isolate the supplementary drive and the toes of the switches from forces induced by the passage of trains. There was 16 mm of lost motion at the escapement joint at the third permanent way stretcher bar. Although this is above the maximum specified values[2], the amount of lost motion itself was not significant to the accident as it provided the necessary isolation of forces.

134 The position of the escapement joint's four-foot nuts was such that it allowed a residual switch opening in the range of 7 to 10 mm between the right-hand switch and stock rails.

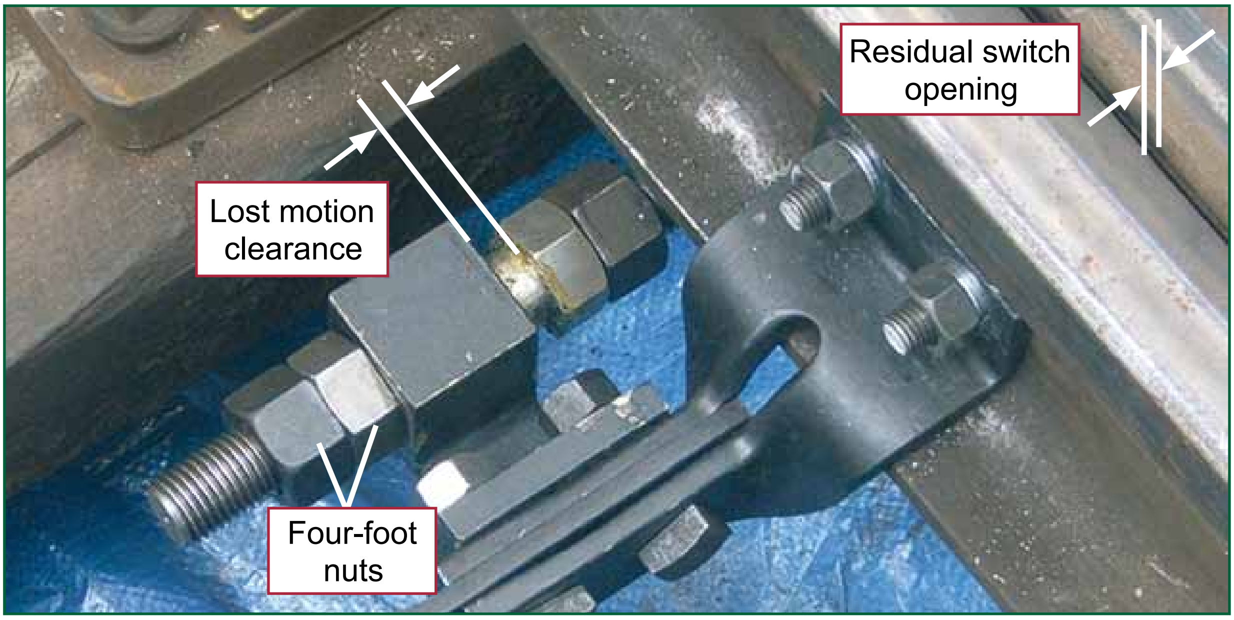


Figure 26: Escapement joint on a reconstructed stretcher bar

[2] Network Rail Signal Maintenance Specification NR/SMS/PF02 does not contain values for the amount of lost motion required. It refers both to Code of Practice NR/GN/SIG/11772 and Company Work Instruction NR/WI/SIG/00111. The former states a lost motion range of between 5 and 10 mm and the latter a range between 5 and 15 mm.

Analysis of the points' degradation

135 This section describes the probable sequence of failures within 2B points, as summarised in Figure 27, and their possible causes.

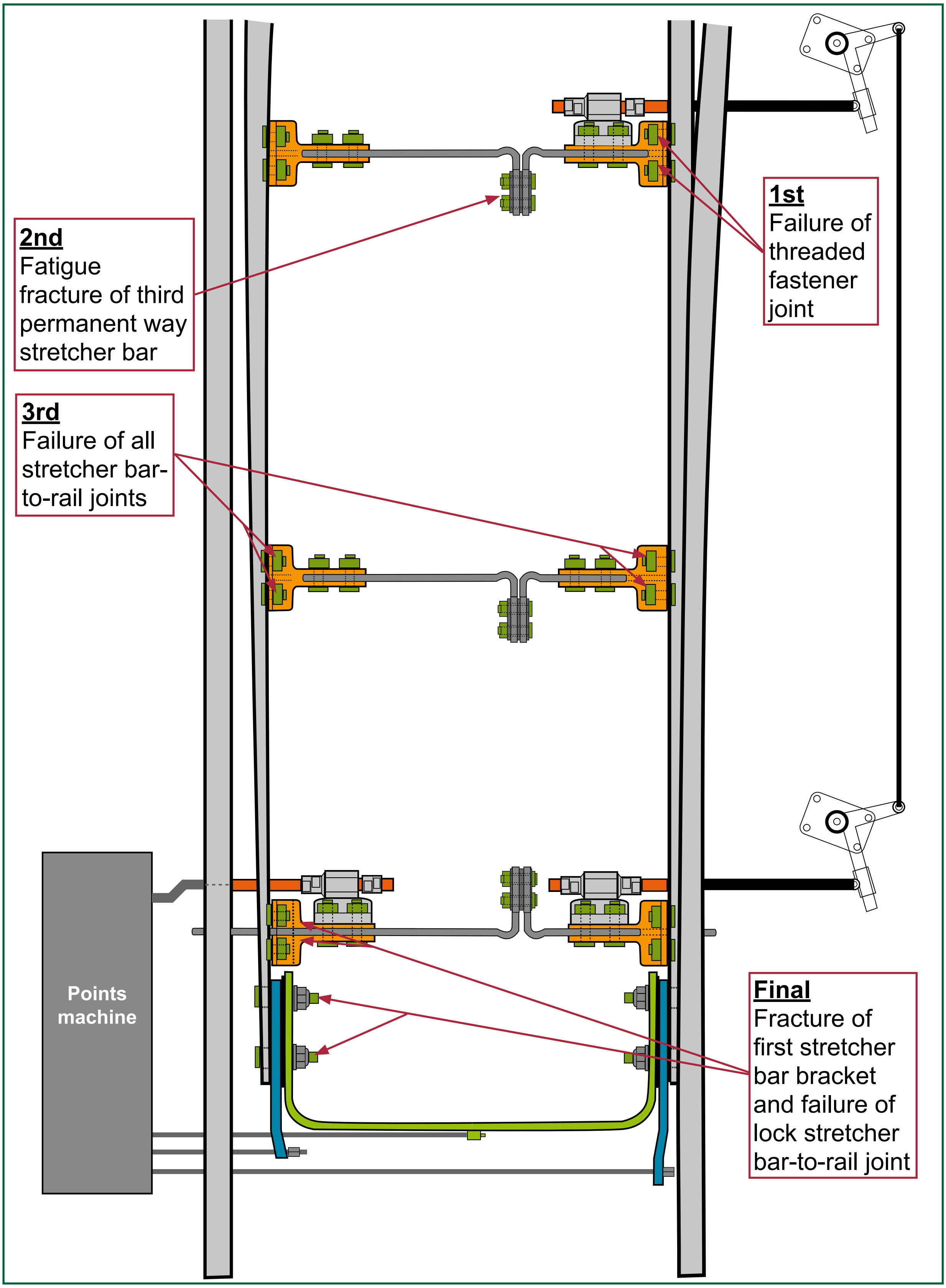


Figure 27: The sequence of failures - schematic diagram of points

136 The following list identifies what is known of the state of the points at dates preceding the accident. Reference is made to Network Rail's track recording trains and their systems which are described in detail in Appendix F. None of the train-based monitoring systems are designed to automatically detect and flag the type of defects found in 2B points. However, the RAIB has been able to analyse the output and extract relevant data, and the results in this report are from this bespoke, post-accident, analysis:

- In April 2004, *Omnisurveyor3D* photographs show that the residual switch opening was between 4 and 8 mm; there is no evidence that it was subsequently changed (paragraph 285).
- On 7 January 2007, both fasteners of the joint of the third permanent way stretcher bar right-hand bracket to switch rail were replaced following an earlier failure (paragraphs 265 - 267). Post-accident reconstruction indicated the residual switch opening was likely to have been between 7 and 10 mm.
- Analysis of data from the *New Measurement Train's* six-foot scanner, recorded on 10 January 2007, showed that on that date the minimum free wheel clearance was of the order of 60 mm in the vicinity of the third permanent way stretcher bar, confirming that the third permanent way stretcher bar was not fractured at that time. However, these measurements do not allow conclusions to be drawn about whether the stretcher bar to switch rail joints were loose or not.
- Information from the *Structure Gauging Train*, recorded on 12 February 2007, showed that on that date the minimum free wheel clearance was not greater than 40 mm. Subsequent laboratory tests on 2B points indicate that this dimension was commensurate with the third permanent way stretcher bar not providing any restraint to the left-hand switch rail.
- Photographs taken by the New Measurement Train, on 21 February 2007, showed that the second permanent way stretcher bar was missing and the minimum free wheel clearance was 16 mm.

137 The RAIB concludes that the third permanent way stretcher bar bracket to right-hand switch rail joint failed for a second time some time after the bolts were renewed on 7 January 2007. The data from the Structure Gauging Train indicates that the third permanent way stretcher bar itself failed before or on 12 February 2007.

138 All other failures, as described in paragraphs 159 to 162, occurred between 12 and 23 February 2007, with the final failure being either the joint failure on the lock stretcher bar or the fractures of the first permanent way stretcher bar.

<u>First failure – loss of integrity of the right-hand switch rail joint of the third permanent way stretcher bar</u>

139 The Structure Gauging Train evidence shows that the third permanent way stretcher bar had fractured by 12 February 2007, as the amount of free wheel clearance was less than would be the case if the left-hand switch rail had still been connected to the supplementary drive via the permanent way stretcher bar. Metallurgical analysis (paragraph 155) indicated that the fracture arose from a recent change in loading. The most likely cause of this was the introduction of flange-back contact as a result of the failure and separation of the joint between the stretcher bar and the right-hand switch rail. The RAIB concludes that the failure of the joint was the first failure.

140 The lack of damage to the fastener components indicated that the joint failed because the clamping force[3] was exceeded by the load imposed on the joint, leading to joint slip and subsequent unwinding of the nuts from the bolts.

141 The following paragraphs present a summary of an assessment of the performance of a permanent way stretcher bar-to-rail joint against the loads that it can experience. The term adopted in this analysis for the type of joint failure is slip. Slip occurs when the load on the joint exceeds its clamping force and allows the joint surfaces to separate or move relative to each other. The occurrence of slip leads to a reduction in clamping force and therefore further slip will occur under lower successive loads, eventually leading to a complete loss of clamping force. Once clamping force has been lost, a plain nut will be loose and free to unwind off the bolt under dynamic conditions. The RAIB has focused upon the mechanism of first failure, ie slip, and has not investigated the number of applications of load before the nuts become free to unwind.

142 Because neither a *load case* nor a design analysis of the permanent way *stretcher bar assembly* was available, the RAIB requested that Network Rail measure the forces in stretcher bars on points. Three sets of points, including two sets on the WCML with similar configuration[4] and traffic loading to 2B points were tested. Measurements were taken of the axial forces in the third permanent way stretcher bar caused by the passage of train wheels. In a correctly set up condition with 1.5 mm residual switch opening and no flange-back contact, it was found that 20 % of the axial stretcher bar forces measured under traffic were between 2 and 4 kN and 80 % were less than 2 kN.

[3] The working of a bolted joint and the terms used in the following paragraphs are presented in Appendix E.

[4] All the switches tested were classified CV. Switch length classification is explained in Appendix D.

143 Resolving a 4 kN force in the third permanent way stretcher bar to that experienced by the fasteners, and assuming that the load is shared equally between the two fasteners, indicates that a clamping force of 18.5 kN is required in each fastener. Therefore each fastener needs to be tightened to a *preload* that will achieve a clamping force of at least this value to prevent joint slip.

144 Tightening of the fastener extends the portion of the length of the bolt which is within the joint, known as the *joint length*.

145 However, *plastic deformation* can also occur in the components of the joint reducing the joint length and therefore the bolt extension. This results in a reduced preload and associated clamping force. The proportional loss of preload, with a bolt of similar diameter and material, is greater for a shorter joint length than a longer one since the bolt extension of the former would be less. These effects lead to the design of joints with larger joint length-to-bolt diameter ratios. For example American engineering guidance is that the ratio should, where practical, be of the order of 4 to 1 or more[5]. The switch rail to stretcher bar joint has a ratio of 1.7 to 1.

146 One element of plastic deformation of a joint is the embedding of the mating surfaces (Appendix E). Embedding is the microscopic deformation of the surfaces in the joint under installation and service loads, leading to a loss of bolt extension and preload and hence clamping force. Therefore the fastener requires additional preload so that after embedding has taken place the required clamping force is still present. The amount of embedding is dependent on the number of surfaces in the joint and surface finishes; it does not change with the length of the bolt. Therefore comparing joints of similar materials and with the same diameter of bolt, one with a shorter joint length will experience a greater percentage loss in preload from embedding than one with a longer joint length.

147 Engineering guidance[6] predicts that, for the materials used in this joint, the embedding loss due to surface roughness effects will be of the order of 23 μm. RAIB tested five joints[7] constructed from actual rail and stretcher bar bracket samples clamped together with a fastener tightened to a torque of 250 Nm[8]. This was loaded to represent the passage of train wheels. This indicated a total reduction of joint lengths due to all plastic deformation effects of between 50 μm and 200 μm. These values include effects such as plastic deformation due to lack of surface flatness as well as embedding. Since the samples were taken from similar batches the surface finishes were likely to be very similar; the variability in results was therefore likely to be due to differences in flatness of the joint surfaces. The testing therefore validates the use of 23 μm as a reasonable value of embedding loss in the analysis.

148 Calculations demonstrate that this amount of embedding results in a loss of preload in each fastener of 12.5 kN. Thus to ensure sufficient clamping force to prevent joint slip, the preload in each fastener must exceed the sum of this value and the 18.5 kN referred to in paragraph 143, ie 31 kN (Figures 28a and b). No attempt has been made to predict the loss of preload due to other plastic deformation, and therefore this calculation indicates the minimum preload requirement.

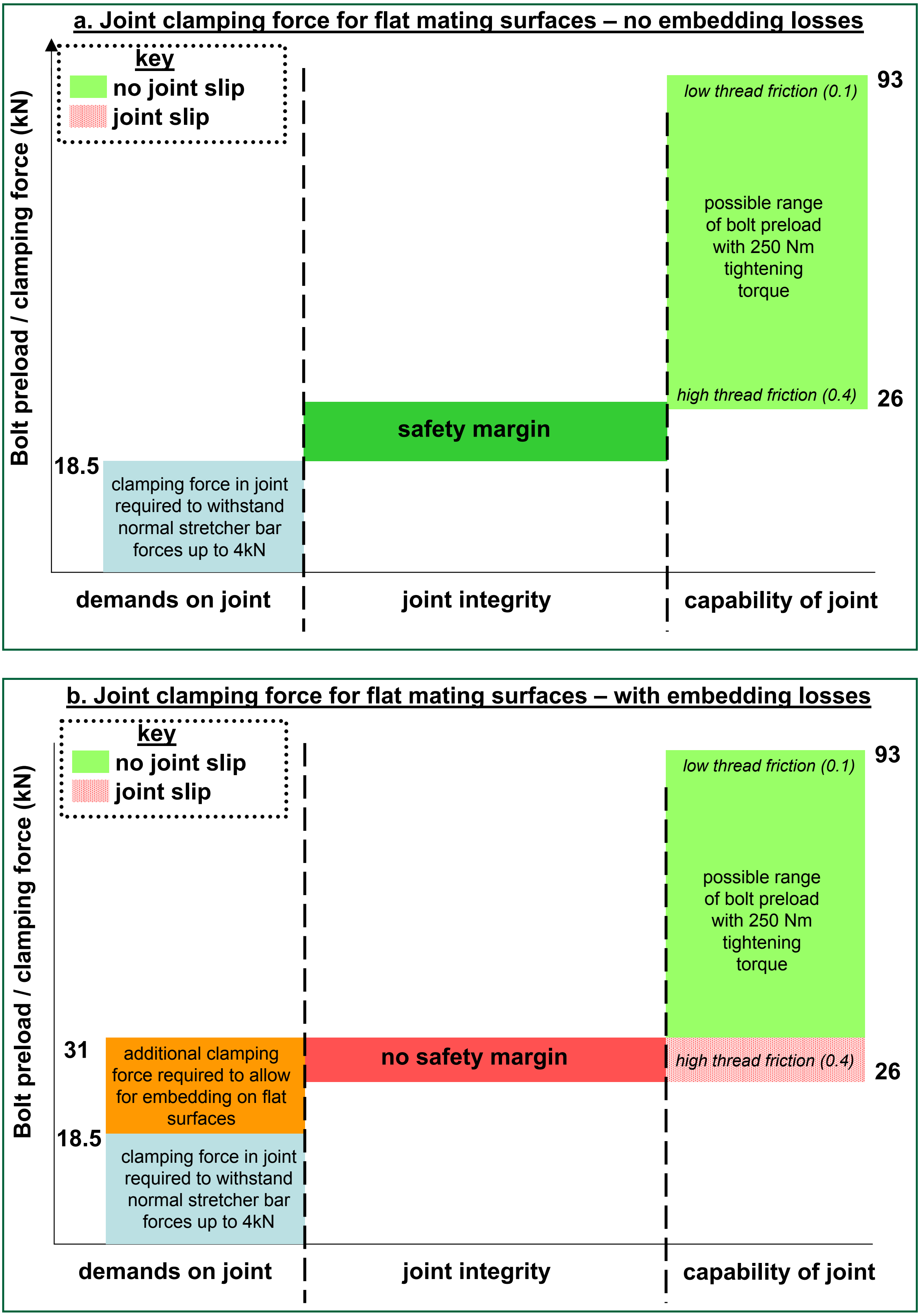
---

[5] Machinery's Handbook, 27th Edition, 2004, Industrial Press Inc.

[6] Analysis based on VDI 2230 – Systematic calculation of high duty bolted joints. Verein Deutscher Ingenieure, 2003.

[7] A grade 10.8 bolt was used in the tests to ensure that there was no plastic deformation of the bolt under the applied loads.

[8] This value is from Network Rail maintenance standards applicable before April 2006 (see Appendix I).



Figures 28a and 28b: The relationship between clamping force required to withstand realistic service loads and the clamping force achieved

149 The range of preloads achievable by the fastener was calculated to be between 26 kN and 93 kN. This was based on the 250 Nm tightening torque and a realistic range of friction (Appendix E). The relationship between the 31 kN minimum clamping force required to resist slip and the range of achievable clamping forces is shown in Figure 28b. This shows that for points of a similar configuration and traffic loading as 2B points, even if fully tightened, a safety margin cannot be guaranteed between the as-designed joint's clamping force and the forces it can experience in normal service, ie without any flange-back contact.

150 This analysis is based on the nominal design, ie, flat mating surfaces, and the specified torque of 250 Nm. Other factors that may lead to plastic deformation of the surfaces and reduce the clamping force still further over time are described below (Figure 28c):

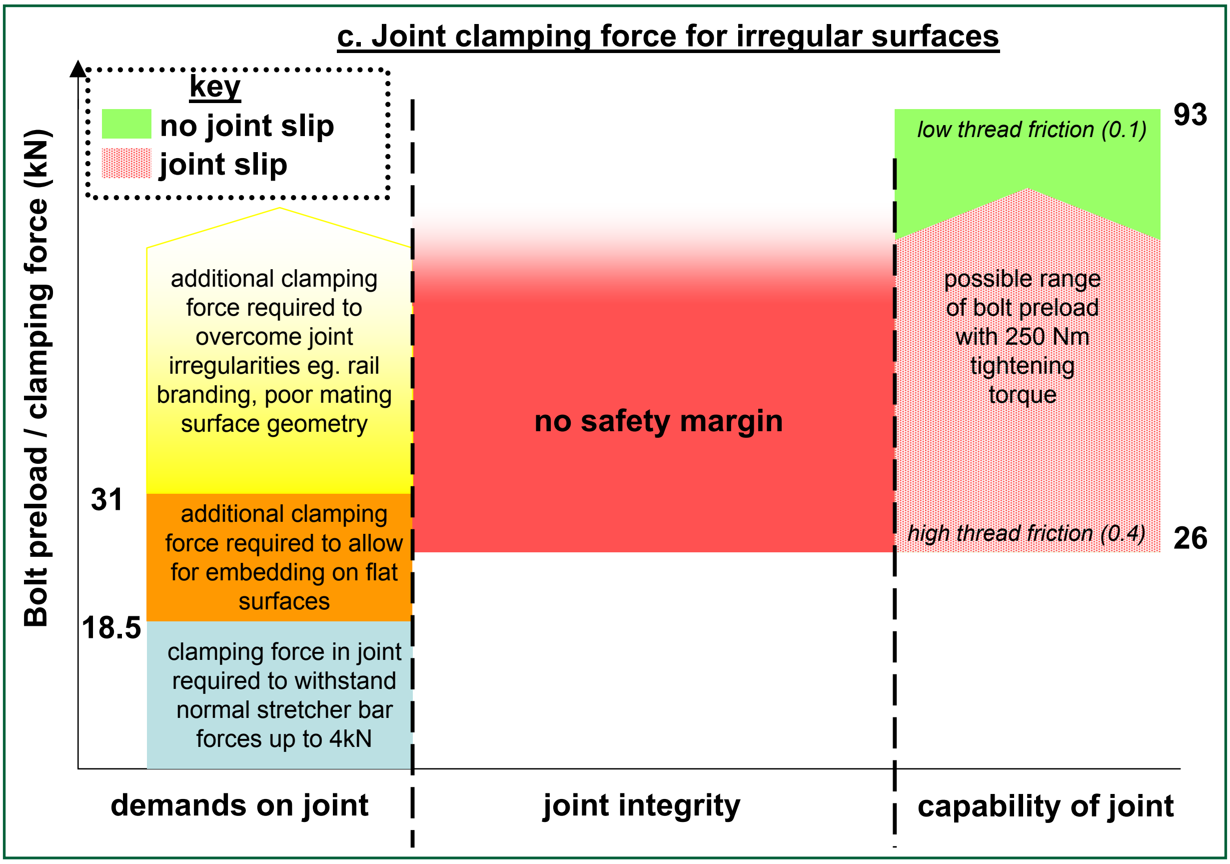
- Increased contact stresses can arise from reduced contact areas as a result of concavity or convexity of mating faces between the bracket and rail. Although it was not possible to determine the actual degree, if any, of such on 2B points, the design specification did not control the flatness of the bracket's mating face.
- Similarly, any contact between the top of the rail foot and the underside of the bracket could also increase contact stresses. Although at 2B points there was no contact between the rail foot and the bracket underside, the design specification does not ensure that these localised contact points cannot occur.
- Raised branding on the switch rail under the bracket, as was the case with 2B points, also reduces the contact area and leads to increased contact stresses. Indentation of the mating surface of the bracket indicated that this was the case on 2B points (paragraph 114).

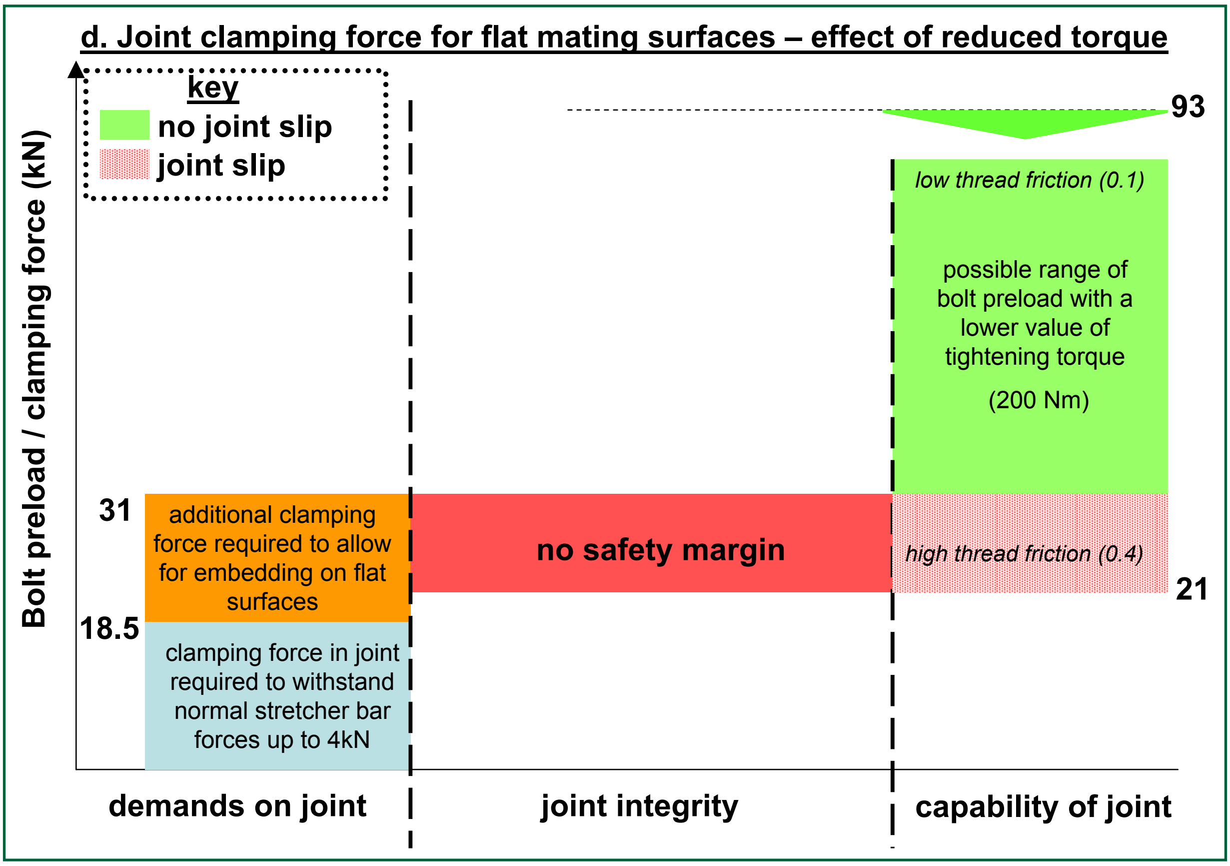
151 Testing and analysis by the RAIB has indicated that with the specified torque and low thread friction conditions, it is possible that the grade of bolts as used in 2B points could be permanently deformed as the stress in the bolt can exceed its elastic limit. It is unlikely that this was the case on this joint, because:

- it is difficult to achieve 250 Nm torque with a short spanner;
- the bolts' thread friction was unlikely to have been low enough, because of the retightening of the original bolts during maintenance (Appendix E) and the manner in which the replacement bolts, installed on 7 January 2007, were stored before use;
- the bolts' mechanical properties would have needed to be towards the lower limit of the strength distribution defined by standards for this material grade.

152 The RAIB's analysis has shown that for the nominal design, the permanent way stretcher bar-to-switch rail joint is unable to withstand the full range of service loads for points of a similar configuration and traffic loading to 2B points. The other factors described in paragraphs 150 and 151 will further reduce the available preload and therefore the capability of the joint. The RAIB has not analysed the performance of joints for points with different configurations and traffic loadings to 2B points.

153 Tests undertaken by the RAIB on similar fasteners on other points found fastener torques as low as 20 Nm. The low torque indicated that there were significant reductions in the clamping forces in these joints, and an associated reduction in their resistance to slip failure (Figure 28d).





Figures 28c and 28d: The relationship between clamping force required to withstand realistic service loads and the clamping force achieved

Second failure – fracture of the third permanent way stretcher bar

154 Following the loss of the clamping force within the joint the nuts were free to rotate off the bolts and the left-hand switch rail relaxed towards its adjacent stock rail until restrained by the supplementary drive as explained in Appendix D. Trains passing over the points closed the residual switch opening between the right-hand switch rail and its adjacent stock rail. Post-accident reconstruction found the residual switch opening to have been between 7 and 10 mm[9] prior to any failures and subsequent analysis was based upon a representative value of 8 mm, ie within this range. (The degree of flange-back contact would have been up to 1 mm less for a residual switch opening of 7 mm, and greater had the residual switch opening been more than 8 mm).

- *Prior to the failure of the bolted joint:*
  Trains passing over the points closed the residual switch opening and this action pulled the left-hand switch rail open further via its connection to the third permanent way stretcher bar. For a wheelset in the middle of its permissible tolerance range and a residual switch opening of 8 mm there would have been no flange-back contact. (For the extreme case of wheelset tolerance[10] there may have been up to 2 mm of contact).

- *Following the failure of the bolted joint:*
  The closing of the residual switch opening no longer acted to open the left-hand switch rail as the direct connection between the switch rails via the stretcher bar had been lost. For a wheelset in the middle of its permissible tolerance range and a residual switch opening of 8 mm there may have been up to 6 mm of flange-back contact. (For the extreme case of wheelset tolerance there may have been up to 12 mm of contact).

The degree of flange-back contact on the left-hand switch rail was related to the size to which the residual switch opening had last been set. Had the residual switch opening been set at the nominal specified value of 1.5 mm rather than a value of between 7 and 10 mm, there would have been no flange-back contact for any wheelset within its tolerance range prior to the joint failing. It is unlikely that there would have been any contact with a wheelset in the middle of its permissible tolerance range once the joint had failed.

155 The second failure was the complete fracture of the short section of the third permanent way stretcher bar in the swan neck insulation assembly. Metallurgical examination of the fracture surfaces indicated a high rate of fatigue crack growth and the lack of corrosion of this fracture showed that this was recent. The onset of the flange-back contact is the only mechanism which could have introduced this high cyclic load. The right-hand switch rail joint of the third permanent way stretcher bar therefore failed before the stretcher bar itself fractured.

156 At the RAIB's request Network Rail commissioned computer modelling of the permanent way stretcher bar assembly. Analysis of forces recorded from network tests on similar points with a similar degree of flange-back contact indicated axial stretcher bar forces of up to 20 kN in the third permanent way stretcher bar, compared with up to 4 kN without flange-back contact. The modelling predicted a greatly reduced stretcher bar life from that expected under normal service forces, from tens of years to the order of weeks. Additionally, the modelling predicted that the highest stresses under these loading conditions were in the swan neck, where the failure on 2B points' third permanent way stretcher bar actually occurred. This modelling work supported the RAIB's conclusion that the failure of the swan neck of the third permanent way stretcher bar was because of flange-back contact.

[9] The range of residual switch opening is due to differences in switch flexure and frictional effects between the indiviual reconstruction tests.

[10] The degree of flange-back contact is dependent upon the specific dimensions of a wheel set - see Appendix D.

157 As the joint between the stretcher bar bracket and the right-hand switch rail had failed before the basic visual inspection on 7 January 2007, it is likely that the stretcher bar had been subject to flange-back contact at this stage leading to fatigue crack growth. However, it has not been possible to determine the degree of growth before and after 7 January 2007.

158 Although not relevant to the subsequent collapse of the points, a second fracture of the third permanent way stretcher bar occurred through a bolt hole in the swan neck of its long section (paragraph 124). Metallurgical examination indicated that this was an overload failure caused by impact with the short section due to the ongoing flange-back contact, which had increased as explained in the following paragraphs.

Subsequent failures leading to the collapse of 2B points and the derailment

159 Following the fracture of the third permanent way stretcher bar, the retention by the supplementary drive was lost and the left-hand switch rail closed further towards its stock rail. This increased the level of flange-back contact up to 22 mm for a residual switch opening of 8 mm.

160 Testing in the laboratory demonstrated that the forces in the remaining stretcher bars increase following the loss of the third permanent way stretcher bar. Testing on the network and in the laboratory indicated that greater flange-back contact resulted in an increase in forces experienced by the remaining stretcher bars. The magnitude of these forces was sufficient to overcome the clamping force on both rail bracket joints on the second permanent way stretcher bar. The failure of these joints resulted in a further increase in flange-back contact to a level of up to 37 mm for a residual switch opening of 8 mm. This led to the failure of the left-hand joints of the lock and first permanent way stretcher bars. While the left-hand switch rail continued to be struck, the left-hand switch rail bracket of the first permanent way stretcher bar failed at both of the ligaments where it joins the stretcher bar itself. The northerly fracture was by fatigue and the southerly by *brittle overload* (Figure 29). The RAIB has not been able to determine the order in which the final failures occurred.

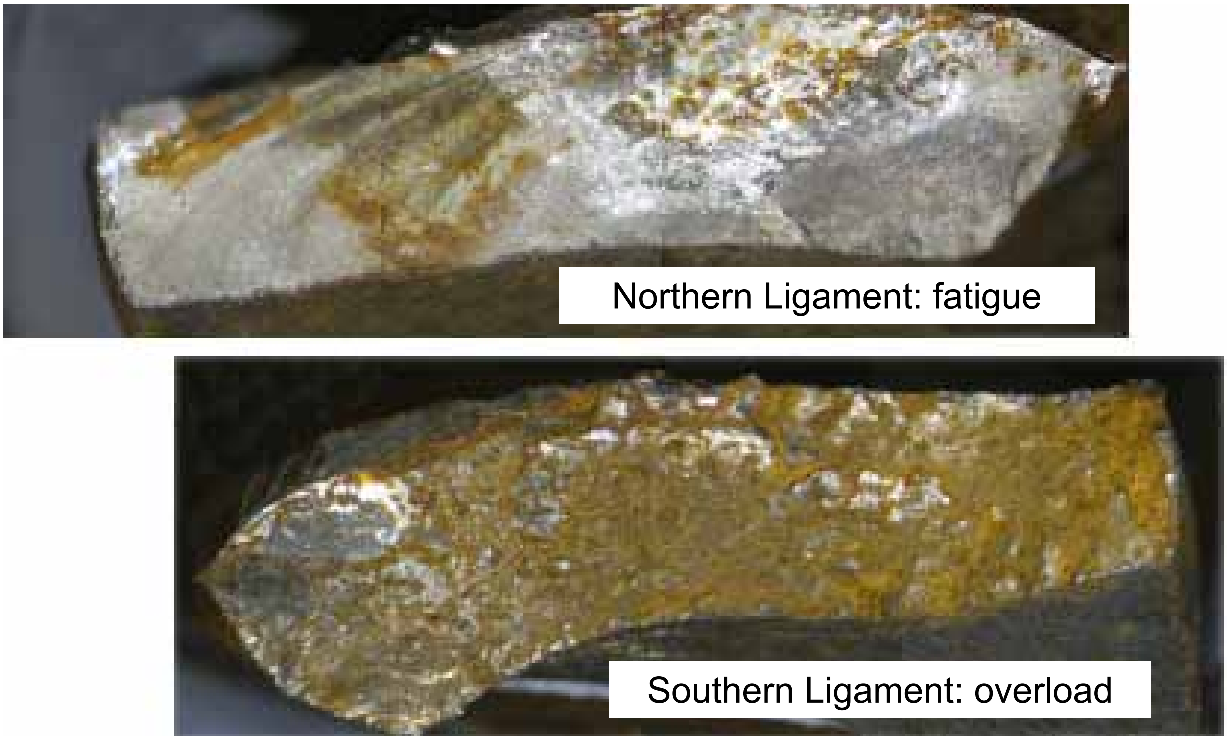


Figure 29: Fatigue and mechanical failure surfaces in ligaments of first stretcher bar bracket

161 Vibration from the wheelsets of either train 1S83 or the preceding train, the loss of restraint from the stretcher bars, its natural flexure, and the effect of gravity on the canted track, allowed the left-hand switch rail to close to within 22 mm of its adjacent stock rail; full switch rail closure was prevented by one of the lock stretcher bar bolts being trapped between the two rails (paragraph 115). However, the switch rail closed sufficiently to allow more than one of the train's wheelsets to run into the narrowing track gauge between the two switch rails, as evidenced by the bruise on the toe of the left-hand switch rail (paragraph 113). These wheels then derailed by flange climb over the heads of the switch rails, and the derailment caused the lateral distortion of the track (paragraph 112). The subsequent behaviour of the derailed train is described in the section of the report about the train from paragraph 538 onwards.

162 The loss of the fasteners common to both the lock stretcher bar and the switch rail extension piece (paragraph 117) led to the closing of the left-hand switch rail being undetected by the signalling system.

Other issues found

163 Network Rail undertook a series of special inspections on points with full-depth, flat-bottom rail switches with non-adjustable permanent way stretcher bars across the network following the accident (Appendix O). Analysis of the data from nearly 30% of such switches on Network Rail's infrastructure has identified that many points had loose fasteners as defined by Network Rail's criteria, residual switch openings greater than 1.5 mm were prevalent and many points were subject to flange-back contact. However, Network Rail has not found any other points with the same degree of degradation as 2B points. The actions taken in response to these findings are described from paragraph 670 onwards.

164 The RAIB has calculated that the preload achieved by tightening of the permanent way stretcher bar fasteners to a torque of 250 Nm arises from a bolt extension of up to 129 µm, depending on the thread friction assumed. This extension and all of the preload will therefore be lost by the nut unwinding by 1/19 of a complete turn. It is observed that 'loose' as defined by Network Rail (Appendix O) is between ⅛ and ¼ of a turn. Therefore the findings from Network Rail inspections will not necessarily have identified the full extent of fasteners with a loss of preload.

165 RAIB undertook load deflection testing on spring washers similar to those used in the 2B points permanent way stretcher bar joints. This demonstrated that the load to compress the spring washers was very low (0.65 kN) compared to the clamping forces required of up to 31 kN (paragraph 148) and therefore contributed little to the resistance to unwinding of the fastener. Research undertaken by the automotive[11] industry in the 1980s also indicated that spring coil washers are ineffective as a means of preventing the loosening of fasteners.

166 At the time of the Grayrigg derailment there were no Network Rail standards or procedures regarding the reuse of threaded fasteners. Evidence from witnesses indicates that re-use was taking place. Reuse generally leads to an increase in thread friction and therefore reduces clamping force on each successive tightening[12]. In addition, reuse of prevailing torque nuts also reduces the effectiveness of the mechanism preventing the nut from unwinding[13], once the clamping force has been overcome. Tests on the fasteners on the intact right-hand lock stretcher bar joint indicated that the prevailing torque resisting the unwinding of the nut was as low as that of a plain nut (paragraph 118).

[11] Eccles, W., *Re-use of Electro-Zinc Plated Nuts and Bolts.* Fastener Technology International, 2005. October 2005.

[12] Comparison of locking devices on Grade 8.8 Screwed Assemblies, British Leyland Engineering Department Report 83/1096-50-11. 1983.

[13] BS EN ISO 2320-1998; Prevailing torque type steel hexagon nuts – Mechanical and performance requirements.

167 Metallurgical examination undertaken by Network Rail of 78 stretcher bars from other points found 37 fatigue cracks in ligaments of the brackets or the bars themselves similar to those found in the third permanent way stretcher bar of 2B points (paragraph 126).

168 Separate computer modelling, commissioned both by Network Rail (paragraph 156), and by the RAIB, has shown that stretcher bars on correctly set points have a long, but finite, life when subjected to normal service forces (in the order of tens of years). The modelling has shown that even without flange-back contact there is a relationship between increased residual switch opening and a reduction in fatigue life to a value in the order of years, as increasing the opening leads to increased movement of the stretcher bar under traffic. The predicted areas of highest stress (Figure 30) include around the bolt hole, where the fractures in the third stretcher bar at 2B points occurred. Network Rail records indicate that 60 to 70 stretcher bars are replaced per month across all territories; some of these are repeat replacements.

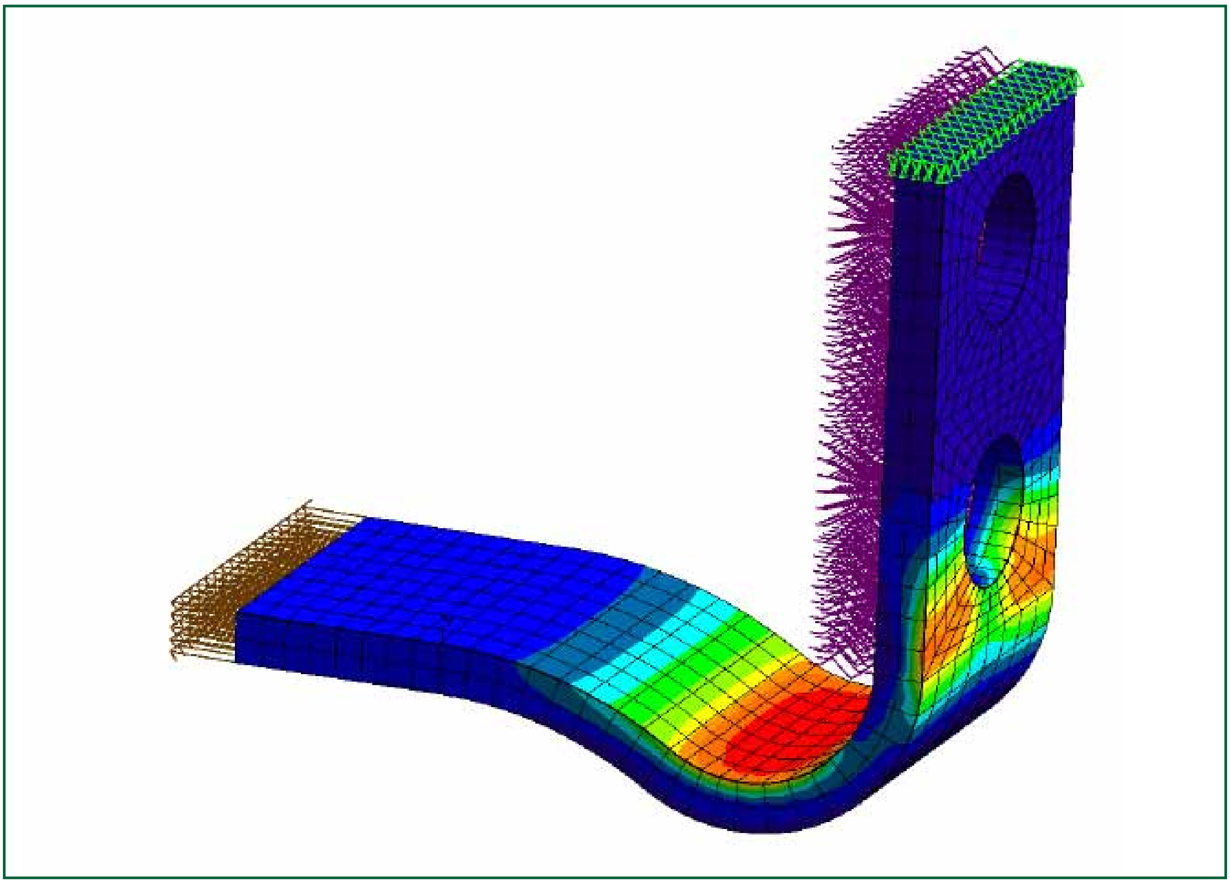


Figure 30: Stress contour plot of swan neck assembly

169 All of the cracks within the swan neck assembly were found to be growing outwards from the bolt holes. Therefore these cracks cannot be detected by visual inspection until the section has fully fractured.

170 The loosening of nuts on the permanent way stretcher bar bracket to rail joint may not be immediately identifiable by visual inspection. This is because of two factors:

- Firstly, the joint will have to have lost all its clamping force before any gap appears.
- Secondly, as the third permanent way stretcher bar was in tension the nuts will have had to have unwound sufficiently to allow the switch rail to relax such that a gap appears between the bracket and the nut. Any gap between the bracket and the rail would have been difficult to see because it is obscured by the head of the switch rail.

171 Because the switch rail separated from its detector rod due to the failure of the common fasteners (paragraph 117), any opportunity to detect the closure of the switch rail (paragraph 69) was lost.

172 Testing and analysis indicated that the forces seen by permanent way stretcher bars are significantly affected by geometric features such as flatness and squareness between mating parts, lengths of bars when installed and connections to other components such as the points machine and supplementary drive.

Tamping on 2/3 December 2006

173 *Tamping* was undertaken through the points at Lambrigg emergency ground frame on the night of 2/3 December 2006. This tamping work was to address an alignment issue on the up line which had resulted in an 80 mph (129 km/h) speed restriction being imposed on that line. The extent of the tamping covered the whole 2A/2B crossover, and involved tamping and realigning both the up and down lines. The presence of *through timbers* which support both lines made it necessary to realign both tracks of the crossover. The main issue addressed was the horizontal alignment which was adjusted to bring it into the position defined by the *absolute track geometry* for this location. The adjustments made to the down line involved moving the switch toes of 2B points 13 mm towards the *six foot*, and the crossing 25 mm towards the cess. This realignment would have changed the pattern of lateral loading applied to the track by passing trains, though the exact amount is not known. The change to the alignment was evident from comparison of the alignment traces from the track recording runs of 24 November 2006 and 20 December 2006. The possible effects of the tamping are described in paragraph 179.

Conclusion of the investigation into the points' degradation

174 The accident at Grayrigg was due to sequential failures of the permanent way and lock stretcher bar assemblies at 2B points allowing the left-hand switch rail to move to an unsafe position.

Joint failure at the third permanent way stretcher bar

175 The first failure, leading to the degradation of 2B points, was the failure of the joint on the third permanent way stretcher bar at its connection to the right-hand switch rail. This occurred because the clamping force was insufficient to withstand the forces imposed by traffic. Calculations and modelling by the RAIB have indicated that the joint design cannot guarantee sufficient clamping force to withstand all normal service forces for points of a similar configuration and traffic loading to 2B points.

176 There is no recorded evidence of previous failures of the joint before 7 January 2007 and witness evidence suggests that the joint had not been a persistent problem. However, given the difficulty that patrollers undertaking the weekly visual inspections would have had in being able to identify loosened fasteners (paragraph 170) and that any retightening of the fasteners during the 3 monthly maintenance visits would not have been recorded (paragraph 261), it cannot be assumed that the preload had not been reduced or lost on previous occasions. The absence of recorded joint failures at 2B points can be explained by:

- all the loads experienced by the joint being less than its clamping force; or
- some of the loads experienced being greater than its clamping force and inspection and maintenance activities compensating for the deficiencies in the joint design before joint failure.

177 The joint therefore failed by January 2007 for reasons or combinations of reasons related to the imposed loads from traffic, and inspection and maintenance intervention on the joint. These possibilities are explored in paragraphs 275 - 276.

178 The RAIB has also found no evidence to suggest that any significant change in traffic took place at 2B points in the six months before the accident. The introduction of EPS for tilting trains is known not to have caused any significant increase in loads above those already exerted by trains not operating at those higher speeds.

179 The RAIB has also considered the effect that the tamping of the up and down lines at 2B and 2A points on 2/3 December 2006 may have had on the stretcher bar loads. It has concluded that though the alignment at 2B points had changed as a result of the tamping, the accelerations measured by the New Measurement Train were little changed between the runs before and after the tamping, and the limited changes tended to show a smoother ride. The geometry of, and irregularities in, the track after tamping were in accordance with the accepted design intent and with NR/SP/TRK/001. The RAIB has no evidence of routine tamping of S&C, either within its designed alignment and technical standards or in any other circumstances, ever affecting the integrity of S&C. Similarly, the RAIB has no evidence that the change to the track alignment arising from the work on 2/3 December 2006 resulted in the imposition of forces on the track at a magnitude known to exceed expected or permitted values.

Acceleration of the failure of the points due to the magnitude of the residual switch opening

180 The residual switch opening of between 7 and 10 mm allowed flange-back contact to occur for most wheelsets once this joint had failed. The flange-back contact significantly increased forces in the third permanent way and other stretcher bars, causing their failure and the collapse of the points.

181 The RAIB's modelling indicates that points with non-adjustable stretcher bars can withstand forces from degraded conditions where flange-back contact occurs for a limited period of time only. Depending on the degree of flange-back contact, this time may only be a matter of days. In the case of 2B points the maximum period could not have exceeded 36 days, if the joint had failed immediately after the fasteners were replaced on 7 January 2007.

182 The following features were causal factors in the derailment:

- the failure of the switch rail to stretcher bar joint, on the right-hand side of the third permanent way stretcher bar, because of its inability to withstand normal service loads in all circumstances; and
- the excessive residual switch opening.

183 Results from Network Rail inspections (Appendix O) indicate that loose fasteners and stretcher bar defects occurred in all territories across the network.

Inspection and maintenance

General evidence

Track design considerations

184 Since the points at Lambrigg were installed in curved track, the radius, installed cant and permitted *cant deficiency* (see Appendix G) determined the overall maximum possible speed of operation of trains. Prior to the introduction of EPS in October 2005 (paragraph 64), the permitted speed was set at 85 mph (137 km/h).

185 The *West Coast Route Modernisation* project adopted an EPS of 95 mph (153 km/h) through Lambrigg, and this kept the cant deficiency below 4° (105 mm) on the curve of 1487 metres radius, and within the 4¼° (110 mm) permissible limit for track with discontinuities[14], for example, through S&C. The project concluded that no special maintenance instructions were required for the crossovers at Lambrigg, other than the maintenance of absolute track geometry.

186 Before their introduction in 2002, Class 390 'Pendolino' and Class 221 'Super Voyager' tilting trains were required by the then infrastructure owner, Railtrack plc, to demonstrate compliance with the track force requirements set by railway group standard GM/TT0088 'Permissible Track Forces'. This standard defined limits for lateral and vertical wheel forces and maximum impact forces at discontinuities. The loads imposed by a Class 55 locomotive, a type introduced in the early 1960s, running at 100 mph (161 km/h), were used as a reference. There is no evidence of classes of locomotive or unit designed against these criteria causing excessive track damage. The design of Class 390 and 221 tilting trains used the basic premise of being able to operate at higher cant deficiencies than conventional trains without exceeding the permissible force criteria by virtue of a low overall mass, lower axle loads and enhanced suspension characteristics. Measurement of the forces exerted on the rails by these trains during testing and acceptance trials showed that they were less than those generated by a Class 55 locomotive. This assessment included a review of data obtained from instrumented test trains, railhead wear and track recording data.

Inspection and maintenance requirements

187 Network Rail classifies its routes in accordance with the speed of trains operating over them and the annual tonnage carried. The section of line between Oxenholme and Penrith is designated Category 1. Network Rail Company Standard NR/SP/TRK/001 'Track Maintenance Standards' dictates the minimum inspection frequencies for each track category, together with the intervention requirements and risk controls for particular track defects. Points 2B were subject to the defined S&C inspection and maintenance regime with responsibility for the different aspects being split between Network Rail's signal engineering (formerly signalling & telecommunications) and track engineering (formerly permanent way) department. Table 4 summarises the key elements of the inspection regime and identifies which department carried out the work.

188 For *plain line* and S&C, NR/SP/TRK/001 and its associated work instruction NR/WI/TRK/001 'Track Inspection Handbook' detailed the requirements for a basic visual inspection (patrol). This was to identify defects which required rectification before the next planned inspection. Where possible, the patroller was required to rectify minor defects, including the replacement of missing clips, tightening of bolts (but not stretcher bar bolts in S&C) etc, where this could be done safely. There was also a requirement to identify and report other defects, and where a patroller believed that there was a need to measure gauge or other dimensions, this was to be reported to the supervisor.

[14] Railway Group Standard GC/RT5021 'Track System Requirements'.

The patroller was not required to make measurements directly. For Category 1 track, inspections were required weekly with a maximum interval between inspections of eight days. The inspection reports were required to include the date, the person undertaking the inspection, details of the lines and mileages inspected, and to positively record when no defects were found.

189 Specifically for S&C, a patroller was required to walk through each section of track in the four-foot and observe the condition of the components. This included the observation and identification of loose, distorted, broken or disconnected stretcher bars and loose or missing bolts. The patroller was also required to observe rail condition, the presence of obstructions, the position and security of *check rails*, track geometry and track support. NR/WI/TRK/001 further required that all visual inspections included the requirement to assess the free wheel clearance within S&C, and report for correction within 36 hours if less than 45 mm. However, NR/SP/TRK/001 stated that no measurements were required as part of basic visual track inspections.

190 The basic visual inspection was supplemented by a 'supervisor's inspection', undertaken by the *track section manager* or his nominated deputy. NR/SP/TRK/001 defined the supervisor's inspection as identifying work to be planned and carried out, reviewing trends in condition, identifying items to be proposed for renewal and checking that basic and special track inspections, maintenance and renewal work were effective. The supervisor's inspection included the measurement of gauge and the 50 mm flangeway gap between the switch and stock rails (ie the free wheel clearance).

191 The track section manager[15] also had to determine and prioritise the actions needed to address defects identified, and then arrange entry of those defects that required remedial work into Network Rail's work scheduling system, *Ellipse*.

192 Category 1 track required a supervisor's inspection of S&C every two months and of plain line inspection every three months. The track section manager was allowed to delegate one in two inspections to a competent person approved by the *track maintenance engineer*. He should therefore personally inspect each set of S&C within his area at least once every four months. NR/SP/TRK/001 clause 9.2.2 allowed for the track section manager's inspection to be used to substitute for the basic visual inspection. The on-foot inspections were supplemented by cab-riding (refer to Table 4).

193 The supervisory inspections were supplemented by an 'engineer's inspection' by the track maintenance engineer once every two years. The track maintenance engineer was also required to carry out an inspection by means of a cab ride every three months. The purpose of the track maintenance engineer's inspection, as defined in NR/SP/TRK/001, is to 'review condition, trends, work sufficiency, proposals for renewals work, quality of maintenance and renewal work and check that other inspections are adequate and effective'.

194 Network Rail standard RT/E/S/10660 'Implementation of *Signalling Maintenance Specification*s' and RT/E/S/10661 'Signalling Maintenance Task Intervals' detailed the inspection and maintenance of points to be undertaken by signalling maintenance technicians from the signal engineering function, and their inspection and maintenance frequencies. This comprised a four-weekly test and three-monthly inspection and servicing visits as detailed in Table 4; the standard also gave details of actions to be implemented as a result of 'late' or 'missed' maintenance. RT/E/S/10660 also contained a large number of signal maintenance specifications covering all types of signalling equipment found on Network Rail's infrastructure. The last revision of the signal maintenance specification before the accident was in April 2006 and before that in February 2005.

---

[15] See paragraph 304 for details of the relationship of the posts in Network Rail's organisation.

Responsible Department	Scheduled Periodicity	Summary of Scope
Signal Engineering	Four weekly*	*Facing point lock* (FPL) *test* (note: this frequency can vary between 4, 6 and 13 weeks depending on the location and the inherited practices from the previous *infrastructure maintenance contractor*.)
	Three monthly*	General condition check including: ▪ free movement of points (adequate lubrication of moving components and no obstructions); ▪ points machine and connections to points including *back drive*; ▪ points detection; ▪ stretcher bars including fixings and insulation; ▪ the tightness and positioning of nuts and locking nuts to be checked using an appropriate spanner; ▪ clearances at switch toe and in vicinity of back drive including flangeway clearance and closed switch opposite; ▪ facing point lock test.
	Annual	Point inspection to NR/SMS/PC41. Points machine Westinghouse style 63.
	Two yearly	Inspection by signal supervisor.
	Five yearly	Inspection of a representative sample of assets at each site by area signalling engineer.
Track Engineering	Weekly	Basic visual inspection including: ▪ general condition check (alignment faults, twist faults, gauge errors, condition of components such as stretcher bars, *sleeper*s and *baseplate*s and missing or broken bolts and fasteners); ▪ no requirement to take measurements.
	Two monthly	Supervisor's S&C inspection including: ▪ general condition check (alignment faults, twist faults, gauge errors, condition of components such as stretcher bars, sleepers and baseplates and missing or broken bolts and fasteners); ▪ measurement of track gauge; ▪ measurement of flangeway gap and toe opening as appropriate; ▪ check clearances within points including those at switch toe and in vicinity of back drive (flangeway clearance).
	Two monthly	Cab ride by track section manager.
	Three monthly*	Condition check of switch blades and adjacent stock rails and their inter-relationship.
	Three monthly	Ultrasonic inspection of rails (examination for defects in metal).
	Three monthly	Cab ride by track maintenance engineer.
	Biennial	Inspection by track maintenance engineer.
	As required	Inspection by area track engineer.
	As required	Inspection following mechanised *tamping* of points.
	As required	Inspection to identify general maintenance including provision of additional ballast, hot weather precautions, etc.
Network Rail Headquarters	Three monthly	Track geometry check using mechanised equipment carried on board a dedicated measurement train to identify track and geometry defects in the loaded condition.

[* At Lambrigg, these activities were undertaken by a Joint Points Team comprising personnel from the signal and track engineering functions.]

Table 4: Key elements of the inspection regime for S&C applicable to Lambrigg emergency ground frame

Track Access

195 Appendix H explains the history of how access to the track between Carnforth and Carlisle was reduced as the West Coast Route Modernisation project was implemented, and the steps taken by local management to address the issues arising. The effect of these changes was that the only time available for inspection and repair of track on the WCML from south of Lancaster to just south of Carlisle was from first light to approximately 10:00 hrs on a Sunday morning, with the inspections taking place in a *green zone*. Inspections could only be carried out in darkness if a concession was agreed to permit inspections using artificial light. No such arrangements had been proposed and no approval had been sought from the Territory Engineer (Track) for Carnforth depot's section of the WCML.

196 In March 2006 a local staff representative alerted HMRI to the issue of restricted access. An inspector investigated the issue, and was advised that local management had plans in place to tackle the problem. The inspector sought and received assurances from the Lancashire and Cumbria area management that the access restrictions were not having an adverse impact on the maintenance backlog. The impact of the reduced access on maintenance is described in paragraph 244.

197 Network Rail specification NR/SP/OPS/031 'Risk assessment and briefing of timetable change', described a process for evaluating the effect of timetable changes; this was a cross functional responsibility between Network Rail's Maintenance, Engineering and Operations & Customer Services departments. However, the process did not include consideration of the impact of timetable changes on access for inspection. NR/SP/TRK/001 defined the impact on inspection frequency of changes in the speed of trains or the tonnage of traffic. NR/SP/OPS/031 mandated the territory maintenance manager (or his/her representative) to provide advice of the effects of timetable change on infrastructure maintenance requirements. NR/SP/OPS/031 was supported by guidance note NR/GN/OPS/030, 'Risk assessment of timetable change'. This identified that the main issue associated with the effect of timetable change on infrastructure maintenance was additional wear and tear on the track. NR/GN/OPS/030 also indicated that this might lead to a higher frequency of broken rails or greater exposure of track workers to injury. It did not identify that timetable changes might lead to greater difficulty for maintenance and inspection staff in gaining access to the track.

Maintenance organisation for the Lancashire and Cumbria area

198 The Network Rail generic structure for an area maintenance organisation is shown in Figure 32 (following paragraph 305) and described in Appendix K.

199 The infrastructure maintenance manager held overall responsibility for ensuring that patrolling, inspection, examination, and maintenance on the WCML through Grayrigg was in accordance with Network Rail company standards and procedures. The points at Lambrigg were the responsibility of the track section manager at Carnforth and the *signalling maintenance assistant* based at Carlisle.

200 The track section manager's workload was increased by a vacancy in one of Carnforth's three assistant track section manager posts carried throughout 2006, with a junior member of staff filling the post on an occasional basis. In January 2007, a member of staff who had occasionally filled the post in an acting capacity was permanently appointed assistant track section manager.

201 Until 2004, an *infrastructure maintenance contractor* was responsible for the inspection and maintenance of the points at Lambrigg. The infrastructure maintenance contractor had established joint points teams within its contracted areas of responsibility to cover all the signal and track engineering examination and maintenance requirements at points. It was thought that joint working would be more efficient and improve the reliability of points. When Network Rail took over the maintenance of the national railway network from the infrastructure maintenance contractors they initially retained all the existing processes, procedures and organisational arrangements and sizing, including the joint points team that covered Lambrigg.

202 Although the Carnforth track section manager was responsible for all aspects of track associated with the points at Lambrigg, some of the inspections and maintenance were carried out by others. The joint points team which performed the inspection and maintenance of the points at Lambrigg was within the signal engineering function and normally consisted of two signal technicians (the senior of whom was the leader of the team) and two staff from the track engineering function. All these staff were based at Carlisle and were managed on a day-to-day basis by the signalling maintenance assistant at Carlisle, although the track engineering staff in the joint points team were part of the Carlisle track section manager's team. Similarly, some other inspections, for example the ultrasonic examination of rails, were carried out by staff who did not report to the track section manager. However, any deficiencies associated with the track elements of 2B points were reported to the Carnforth track section manager for action. The differing track and signalling boundaries resulted in a division of technical responsibility for the points at Lambrigg; the Carnforth track section manager was responsible for track engineering, and the Carlisle signalling maintenance assistant for signal engineering. The Carlisle track section manager provided labour for the track S&C activity that was carried out by the joint points team, but was not responsible for the track.

<u>Training and competence</u>

203 Network Rail inherited a variety of competency management processes from the ex-infrastructure maintenance contractors and has since introduced a standard competence management system across the maintenance function. A key aspect of this was a new procedure known as '*assessment in the line*'. The track section manager was required to manage the competence of track engineering staff at Carnforth depot to this new procedure from December 2006. Prior to this the track section manager had begun a process of establishing what competencies were held within his team as nothing was in place to identify this before he joined the depot in January 2006. From this, the track section manager compiled a training needs analysis in accordance with the Network Rail training system. This document identified all the training required at the depot, but this had not been delivered by 23 February 2007.

204 The eight patrollers who carried out basic visual inspections of the Lambrigg crossovers between 24 December 2006 and 11 February 2007 had a range of patrolling experience in carrying out this type of inspection of between one and 34 years. All eight patrollers had been trained, but in five cases their certificate of competency had lapsed, in one case by more than eight years. Network Rail investigated post-accident and were satisfied that, while none of the patrollers had a working knowledge of NR/SP/TRK/001, they were aware of the contents of associated work instruction NR/WI/TRK/001 and had access to that document.

205 Network Rail's policy for signal engineering staff was that they should be licensed by the Institution of Railway Signal Engineers (IRSE). Network Rail mandated this under standard NR/SP/SIG/10160 'Signal Engineering: Implementation of IRSE Licensing Scheme – The Route to Competence'. The IRSE issues licences covering specific work activities following an assessment of the competence of the person concerned. The work activities covered design, installation, testing, maintenance and engineering management and were generic in nature (rather than equipment specific). However, Network Rail had issued a notice authorising a temporary non-compliance with standard NR/SP/SIG/10160. The notice identified the immediate controls and measures required to achieve compliance with the standard.

206 To supplement the IRSE licensing scheme, Network Rail operated a competence management system covering specific signalling equipment. Staff undertaking work on signalling equipment were required to be issued with an '*Authority to Work*' document each year, following a review of a person's continuing competence using assessment in the line. Staff were only to be issued with an Authority to Work if they were still in possession of a valid IRSE licence for the appropriate licence category.

207 The signal engineering staff involved in recent interventions at Lambrigg before the accident had valid Authority to Work documents at the time of their visits.

208 Network Rail introduced a supplementary drive course, available from 2004, primarily to improve the performance of S&C. Its content included instructions that there should be a gap of 1.5 mm between the closed switch and stock rail at each supplementary drive position (ie the residual switch opening). The joint points team signal engineering team members were scheduled to attend this course, which would have included the setting up of the supplementary drive and the residual switch opening, but the courses (at the end of 2005, and then again at the end of 2006) were cancelled. The RAIB could not establish why these cancellations took place. The joint points team signal engineering team members had not previously been trained in the setting up of supplementary drives.

Audits

209 Between June and September 2006, the track maintenance engineer undertook a maintenance compliance audit at Carnforth depot in accordance with Standard NR/SP/ASR/036, 'Network Rail audit manual' (Appendix J). The audit addressed 32 items, and this included supervisor and basic visual inspection arrangements. For supervisor's inspections, the method for recording when and where walking inspections were carried out was deemed acceptable, as were the depot's weekly '*plan-do-review*' meetings as a means of making the contents of Network Rail's Ellipse system, more accurate. Problems affecting the data included information such as basic visual inspection boundaries which did not match those actually in use, and frequency of point-oiling, which exceeded the maintenance requirements and which the track section manager had been unable to get corrected. This resulted in a discrepancy between the information generated by Ellipse and the work required on the ground, and led to difficulties in closing out completed activities. The audit identified issues with the quality of reporting by those in acting positions, although the basic visual inspections, their frequency and the sign-off arrangements were considered to be acceptable. The auditor's report acknowledged the benefit of having the same patrollers inspecting the same section of track all of the time, but this had not been actioned at the time of the accident. Details of other relevant audits are given in Appendix J.

Evidence relating to track inspection and maintenance

Inspection practice

210 The section of the WCML maintained by Carnforth depot was divided into sections identified by the letters A to J for the purpose of organising basic visual inspections. Lambrigg emergency ground frame was at the northern end of basic visual inspection H. The lengths of basic visual inspections ranged between 2 miles 1320 yards and 6 miles 880 yards. The variation in length was a result of aiming to make each inspection of approximately equal duration, given the variety of track layout complexity, the location of access points (Figure 31) and the overall access constraints. Basic visual inspection H covered the 5 miles 440 yards from Oxenholme Station, 19 miles north of Lancaster, to Lambrigg at 24 miles 440 yards, and comprised a double track section of line constructed from continuous welded rail on concrete *sleeper*s. The crossovers at Lambrigg were the only other track feature within this section.

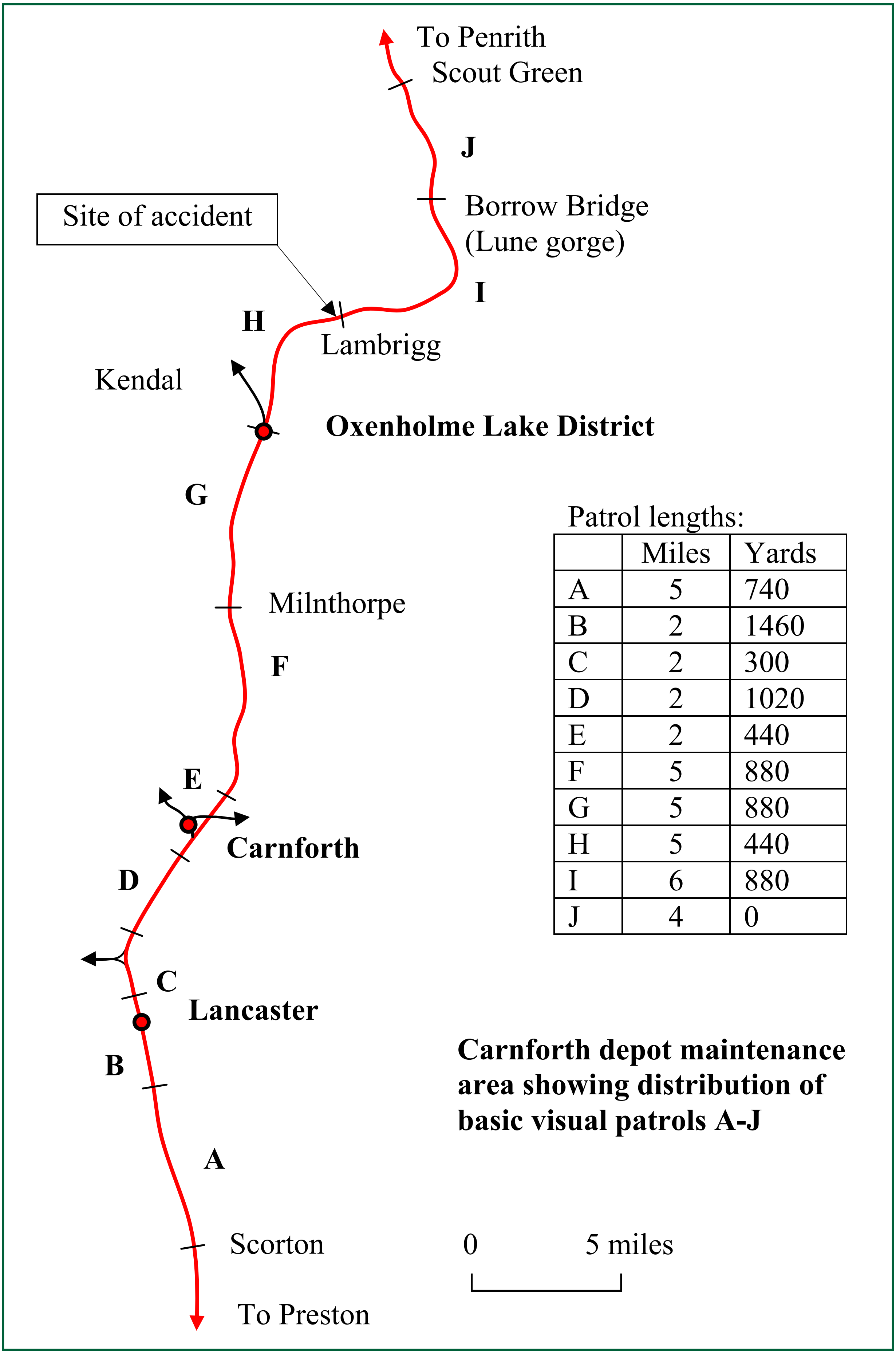
211 The Carnforth depot timekeeper assisted the track section manager by allocating rostered and volunteer staff to the various basic visual inspection lengths as a weekly duty. While staff from the Oxenholme and Tebay gangs were most frequently allocated to cover inspection H, 14 different patrollers from the depot undertook this duty during the year preceding the accident, and this included nine different patrollers during the preceding ten weeks. The Carnforth depot timekeeper maintained records of inspections reported as completed.

212 Patrollers on the Carnforth section gave evidence that normal practice was to record all defects in their own note books or on paper as they walked through the length and then transfer the findings afterwards to the official inspection record sheets when back at their depot. In many cases, the patrollers disposed of the notes made during the inspection once the formal record sheet had been completed as there was no requirement to retain them, and the RAIB has not seen any evidence of the information recorded by this means.

213 The patrollers varied, both in the extent that they identified defects, and in how they recorded these defects on the inspection record sheets. Some patrollers recorded all faults found, including those that might already have been in Ellipse, whereas others only recorded defects they regarded as being new or requiring special attention. After the supervisor had evaluated and prioritised this information, clerical staff entered it onto Ellipse. Patrollers who completed repairs to defects during or immediately after completion of the inspections recorded nothing on the inspection sheet as the work was completed. The inspection record sheets do not therefore provide a reliable guide to the extent of the defects observed by patrollers during their inspections.

214 Patrolling was undertaken on Sunday mornings as a consequence of access constraints (Appendix H). Some of the patrollers were rostered on a pattern that meant that the Sunday inspection was part of their basic week. In addition, a considerable amount of overtime for non-rostered staff was necessary to provide the numbers required to do and provide *lookout*s for all the inspections.

215 The RAIB has examined the records for inspection H for the 12 months preceding the accident. The average number of defects recorded per patroller ranged between one and nineteen, with an average across all patrollers of ten. Although some patrollers consistently reported more defects than others, no relationship was found between the number of defects recorded and the number of inspections undertaken.



Patrol lengths:

	Miles	Yards
A	5	740
B	2	1460
C	2	300
D	2	1020
E	2	440
F	5	880
G	5	880
H	5	440
I	6	880
J	4	0

Figure 31: Patrol map

216 Supervisory inspections took place at the laid down frequencies, although the track section manager delegated more than the maximum of one in two inspections (allowed by NR/SP/TRK/001), to assistants. The most recent supervisory visits are discussed in the section below.

217 The track maintenance engineer responsible for the section of route through Grayrigg was acting in accordance with the requirements of NR/SP/TRK/001 (Table 4). He had last walked through the section including the points at Lambrigg on 8 September 2005 and was not therefore required to do so again until September 2007.

218 There was no specific requirement for the more senior area-based area track engineer to undertake the inspection of assets at a particular frequency. The area track engineer had been in post for two years and had not visited Lambrigg emergency ground frame during that time, although he had ridden over it in the track inspection saloon.

219 In addition to the inspections outlined above there was a requirement for track staff to oil the points at Lambrigg. This activity took place on a Sunday morning, and was required to take place every thirteen weeks. Previously the frequency had been weekly, and this was still the frequency entered on Ellipse. The track section manager's organisation signed this item off as complete each week to prevent an artificial backlog within the Ellipse system, even when no work was carried out. The RAIB's witness and documentary evidence indicates that no-one was rostered to oil the Lambrigg points on either 11 or 18 February 2007, and the basic visual inspections were the only activities planned at Lambrigg on those dates. Other evidence indicates that oiling may have been carried out, but by the patrollers during the basic visual inspection, hence meaning that no other visits were made to the points.

Track inspection and maintenance activities 1 December 2006 to 23 February 2007

220 A supervisor's inspection on Sunday 1 December 2006 recorded loose check rail bolts within the Lambrigg crossovers. Maintenance activity to rectify this defect took place during the overnight possession on Saturday 6 to Sunday 7 January 2007, but this activity was not related to the loose stretcher bar bolts discovered later on the same day.

221 On Sunday 7 January 2007, a patroller observed a defect with the third permanent way stretcher bar at 2B points and reported it directly to Network Rail's *infrastructure fault control* at Birmingham at 09:10 hrs. A signal engineering department fault team was dispatched from Carlisle to rectify the defect, details of which are given in paragraphs 265 - 267.

222 Records for basic visual inspections H dated 14 January, 21 January, 28 January and 4 February do not identify any defects relating to the points at Lambrigg. The RAIB is not able to verify the actual status of the points on those dates.

223 On Thursday 25 January 2007, an assistant track section manager from Carnforth undertook a supervisor's inspection of the points at Lambrigg. The inspection was undertaken outside of a possession, and the supervisor was not accompanied by a lookout, despite *red zone* working with *unassisted lookout protection* being prohibited at this location. To ensure his safety, he needed to look up from his work every few seconds. He was aware of the need to take measurements during a supervisor's inspection, but in these circumstances the use of gauges was impractical. The related inspection report listed two defects, neither of which related to 2B points.

224 On Sunday 11 February 2007, four patrollers from the Tebay gang were allocated to undertake inspections H, I and J between Oxenholme and Scout Green, inspection I being divided into two parts during the winter period as it was over six miles in length and daylight access was limited. Each patroller was provided with a lookout and the group also had a driver, making a total of nine staff. The senior member of the group was allocated to inspection H and 'booked-in' his three colleagues with the Person in Charge of Possession (PICOP) by telephone. He did not inform the PICOP that the group was intending to sub-divide into five inspections rather than four in order to split inspection H as well.

225 The northern section of inspection H, which included 2B points, was inspected by the fifth person, who was actually rostered as the lookout for inspection I. He was qualified as a patroller and was reassigned to inspection H by local arrangement within the Tebay gang, leaving two inspections without lookouts. The fifth person had recorded two defects on his previous inspection, in October 2006, against an average of ten faults for all other patrollers in the 12 months preceding the accident. On 11 February 2007, the fifth person did not report any new defects or sign the record sheet for the section of inspection H which he undertook. In particular, he did not report any defects in points at Lambrigg.

226 The RAIB's analysis of the output from the Structure Gauging Train (paragraph 136) shows that the failure of the joint at the right-hand end of the third permanent way stretcher bar and the subsequent fracture of the stretcher bar had both occurred by 22:17 hrs on 12 February 2007.

227 On Monday 12 February 2007, a weekly 'plan-do-review' meeting was held at Carnforth depot, to finalise arrangements for the following weekend's activity. The meeting was attended by the track section manager together with other supervisory staff and the depot timekeeper, and considered the patrolling arrangements for Sunday 18 February 2007. The track section manager volunteered to cover inspection H at the same time as undertaking a supervisor's inspection of the plain line section between Oxenholme and Docker, south of Lambrigg. The purpose of this substitution was to release two members of staff to undertake maintenance work at Morecambe South Junction near Lancaster because this could not be done during the week.

228 Following the 'plan-do-review' meeting, a roster sheet was issued to patrollers, but as a consequence of the substitution, no patroller was rostered to undertake inspection H. The track section manager did not normally receive a copy of the roster sheet and was therefore not reminded that he had agreed to undertake inspection H in addition to his plain line inspection on the following Sunday.

229 Time records show, and the track section manager reported, that to keep on top of his workload, he usually worked 50 to 60 hours a week, over five days, including Sundays when rostered. He was not managing to achieve all the inspections that he was required to do personally (see Table 4), although they were being carried out by his assistants. During the latter part of the week preceding the possession on 18 February 2007, the track section manager attended a training course in Preston and responded to a track alignment fault between Oxenholme and Lambrigg, introduced by defective tamping during an overnight possession on 14/15 February 2007. An emergency speed restriction was imposed and remedial tamping was arranged for the following night. The track section manager visited the site on the morning of Friday 16 February 2007 to check the alignment. He was able to remove the emergency speed restriction and restore the track to line speed.

230 The track section manager began his inspection on 18 February 2007 with two specific objectives in mind: to re-check the site of the remedial tamping and to inspect a section of track where severe rail head wear was occurring on a curve. He commenced his inspection mid-way between Oxenholme and Lambrigg at 22 miles 440 yards and walked northwards to 23 miles 680 yards to inspect the sidewear before returning southwards to Oxenholme station. Consequently, a 1520 yard section of track between the limit of his inspection and the northern end of inspection H at 24 miles 440 yards, which included the points at Lambrigg, was not inspected on Sunday 18 February 2007. The track section manager stated after the derailment that in the course of the week he had forgotten that he had agreed to carry out inspection H as well as his own inspection.

231 On Monday 19 February the inspection records schedule was updated by the depot timekeeper at the next 'plan-do-review' meeting. Notes from the meeting confirm that all work was considered complete; no-one present identified the omitted section of inspection H, which included 2B points. The track section manager was not rostered to be in work on that day, but was present at this meeting, although he did not participate fully as he was simultaneously preparing for a staff briefing that afternoon. The timekeeper was in the practice of inserting a sheet into the relevant inspection file to record substituted inspections whenever these occurred, but unlike the inspection records, these sheets were not signed by the track section manager. The track section manager produced the report for his inspection, using a template which referenced the supervisory inspection boundary at 23 miles 1320 yards as the northern limit of his inspection, even though he had stopped 640 yards south of this point. The track section manager initialled and dated a separate sheet used to monitor supervisor's inspections, but did not insert a tick to indicate that a full inspection had been done as he was aware he had not reached the northern limit, and intended to pick it up at a later date. The track section manager submitted his report to the track maintenance engineer, who signed it off on the 20 February 2007. However the track maintenance engineer would not have known that the supervisor's inspection was incomplete, or that the track section manager had also intended to carry out the basic visual inspection, and hence he had no visibility of the omission of the section that included 2B points.

232 A team of ultrasonic rail flaw detector operators examined the plain line in the vicinity of Lambrigg emergency ground frame before daybreak on Sunday 18 February 2007. A rail flaw was detected on the up line approximately 22 metres (25 yards) south of 2B points and a team of track engineering department staff subsequently attended site to fit rail clamps before the end of the possession. Staff attending this incident did not observe any problem with 2B points on the down line.

Analysis relating to track inspection and maintenance

Inspection prior to and including 11 February 2007

233 Network Rail's records indicate that inspection and maintenance activity was undertaken at the specified frequency (Table 4), but was of varying quality, which affected the reliability of the outcome. In particular, the supervisor's S&C inspections covering Lambrigg on 1 December 2006 and 25 January 2007 were both undertaken outside of possessions, and without the required measurements being recorded.

234 The number of defects identified and recorded during inspections by individual patrollers who covered inspection H during the year preceding the accident ranged between an average of one and nineteen. This suggests a wide variability in the reporting by staff of defects observed, or in the reconciliation of this information against data within Ellipse. The RAIB has not investigated this issue in detail as it falls outside of the causal chain, but it is noted that reasons may include:

- effect of the weather on patrolling;
- effect of having to look out for trains, particularly if patrolling unaccompanied;
- lack of individual capability to observe defects;
- lack of competence in detecting defects, due to lack of training or instruction on what is required;
- lack of competence due to not understanding the requirements; and
- lack of supervision or monitoring of the process.

235 The connection between the stretcher bar and the switch rail is obscured by the rail head, making the initial loosening of the fasteners difficult to observe from a standing position. This increased the possibility of it being missed by more than one inspection before 18 February 2007. The last report associated with 2B points was made during the assistant track section manager's S&C inspection on 25 January 2007, when he confirmed that tamping had been completed. The most recent report of a component defect was made on 7 January 2007 – six weeks and four days before the accident. Despite a requirement within NR/SP/TRK/001 for positively recording when no defects are found, it was local custom and practice not to do this.

236 The patrollers stated that they split inspections and used lookouts as patrollers (when qualified to do so) in order to ensure that an inspection could be completed in winter in the limited time available between first light and when the possession had to be given up. Patrolling without lookouts, even in a possession, is contrary to the requirements of the *rule book* if *engineering train* movements are planned. Based on timings used by Network Rail for the planning of basic visual inspections (ie 30 minutes per mile for continuously welded plain line and 5 minutes per unit of S&C in good condition), it would have been difficult to complete the relatively long inspection H (5 miles 440 yards), including the four units of S&C comprising the crossovers at Lambrigg, during the winter months without splitting the inspection. By late December, dawn in Carlisle was at 08:37 hrs, giving approximately two hours for patrolling before the possession needed to be handed back. However, by 11 February 2007, dawn in Carlisle was at 07:43 hrs and the possession was handed back at 10:35 hrs. Neither the supervisors nor more senior managers had identified that split inspections or patrolling without lookout protection were occurring. However, the RAIB cannot find evidence linking these irregular practices, or the lack of supervisory knowledge of them, to the causal chain of the derailment.

237 The RAIB's analysis of the Structure Gauging Train recording showed that by the evening of 12 February 2007 the third permanent way stretcher bar of 2B points had failed (paragraph 226). The joint between the stretcher bar bracket and the right-hand switch rail had previously failed prior to the basic visual inspection on 7 January 2007; there is no clear evidence as to when it failed again between that date and 12 February 2007. There were inspections, and other visits to the points, on a regular basis, as detailed earlier in this report. However, none required the application of a spanner on the stretcher bar bracket to switch rail joints, so it could not be readily established by visual inspection whether or not the fasteners were loose at any of them.

238 The basic visual inspection on 11 February 2007 took place 37 hours before the Structure Gauging Train recording. There is no record of any problem with the fasteners, but the short period of time means that consideration must be given to the possibility that the failure of the joint might have happened, and flange-back contact commenced, before the time of the inspection. The patroller who carried out the inspection appeared to record, in general, fewer defects than the other patrollers. However, given that there is no physical evidence by which the RAIB can confirm the status of the points on 11 February 2007, it is not possible to reach any conclusion with regard to the relationship between the inspection on 11 February 2007 and the accident on 23 February 2007.

Track access

239 The changes in access in 2005 and 2006 meant that the number of daylight hours available for patrolling was restricted, particularly in winter, when the time available was only just sufficient to complete inspection H (ie 3 hours based on standard timings). Network Rail experienced difficulty in rostering enough track staff on a Sunday morning, when mandatory inspections needed to be completed, and the system for completing inspections relied upon members of the team volunteering to work their rest days and do additional hours as required. The depot's focus on patrolling absorbed most of the experienced staff and restricted its ability to undertake routine maintenance on the main line.

240 From early 2006 the track section manager and his team repeatedly raised concerns to their management regarding the limited track access, and the lack of resources and training (paragraphs 200 and 204).

241 If inspections cannot be accommodated within the normal traffic pattern then provision should be made for regular possessions within the '*Rules of the Route*'. However, the restrictions on access imposed as a result of the *hazard directory* changes were not a factor that was taken into account when the Rules of the Route were developed for this section of the WCML. The Rules of the Route took account of the need to provide significant blocks of time during which normal train operations were suspended to allow engineers to undertake maintenance and renewal of the railway at weekends. They did not take into account the requirement to undertake routine inspection of the railway, as it was expected that this could be accommodated during normal traffic hours or accommodated within periods when the railway was closed for other maintenance.

242 The infrastructure maintenance manager attempted to find ways of managing the situation between autumn 2005 and the time of the accident, and at least five different and substantial initiatives were tried over this period.

243 Ultimately none of these initiatives offered a sustainable solution to the problem of access. During that period, the impact on maintenance was variable, with concerns being raised by the track section manager on the growing backlog of maintenance work. Had the update to the hazard directory been completed in time to provide an input to the Business Plan, the project and the infrastructure maintenance manager would have had an additional 18 months before the implementation of EPS in which to consider how the problem could be addressed. Steps could have been taken to enable track inspection to be achieved compliantly, in particular during the winter period when restricted daylight hours made the inspection of the infrastructure in the time available difficult.

244 Witness evidence, correspondence, and the Ellipse database indicate that the effect of the access problems on the condition of the infrastructure varied throughout the year. Although there was an adverse impact on the maintenance backlog, witnesses stated that during the summer of 2006 the effect was limited by drier weather, which stabilised the ballast and helped to slow the deterioration in track condition. At the end of August 2006, authority was given by local management for the procurement of the services of an eight - member agency gang to undertake maintenance activity that would otherwise have been undertaken on Sunday mornings by staff who were now required for patrolling or lookout duties. Despite this, the backlog worsened during the autumn of 2006 due to the wetter weather, and by the end of that year the critical maintenance backlog was reaching levels that management at local and territorial level deemed unacceptable. A major effort was made at the beginning of 2007 to reduce the backlog, and more resources were introduced in the form of contract staff to manage possessions, thereby releasing supervisors and other staff to spend more time on basic duties, and providing management focus on the critical backlog items in the 'plan-do-review' meetings. As a result a downward trend was seen through the first two months of the year.

245 The track section manager and his assistants were frequently involved in supervising maintenance activities at the weekend. Their supervisory inspections of the track were sometimes undertaken in the week by individuals working on their own (paragraph 223), despite a prohibition on red zone working with unassisted lookout protection through Lambrigg. This practice is not permitted by the rule book. The difficulties were exacerbated by staff shortages and rostering difficulties (paragraphs 200 and 239), and the introduction of assessment in the line which increased the supervisor's workload and created an environment where his team were hard-pressed to achieve the mandated supervisory inspections.

246 The RAIB concludes that the constraints on access were a *contributory factor* to the track section manager's decision to combine inspections on 18 February 2007, and hence to the derailment on 23 February 2007.

The basic visual inspection of 18 February 2007

247 As a result of the access problems, and the need to ensure that enough staff were available on Sunday mornings to undertake inspection and maintenance activities, the track section manager decided to combine his supervisory inspection with a basic visual inspection on 18 February 2007 so that the two staff could be released to carry out maintenance work elsewhere. In the event, the evidence from the track section manager is that he subsequently forgot that he was to carry out a basic visual inspection as well as a supervisory inspection. This led to the omission of 2B points because the supervisory inspection did not include them. The omission of the inspection of 2B points on 18 February 2007 is a causal factor of the accident.

248 At the end of the week before the missed inspection and while on a training course, the track section manager had to deal urgently with a track alignment fault between Oxenholme and Lambrigg and its aftermath, requiring him to arrange for the track to be tamped that night and for the lifting of the emergency speed restriction the following day. Combined with no system to remind him otherwise, this unplanned work might have contributed to the track section manager forgetting that he was due to carry out the basic visual inspection on 18 February 2007.

249 Workload and extended working hours were both factors that might have contributed to the track section manager forgetting to do the inspection. His workload had been increased by the introduction of assessment in the line and he had been unable to do all the inspections that he was required to do personally.

250 The findings of a literature review, carried out by the Health and Safety Laboratory for the *Health and Safety Executive* in 2003[16], concluded that there was a possible link between long working hours and fatigue. However the evidence they found relating to there being a link between long hours and performance was not conclusive. The report concluded that the relationship of long hours with performance was complex, and was also affected by individual characteristics, the environment and the type of occupation. The report recommended further research in this area.

251 On 19 February 2007, the 'plan-do-review' meeting did not recognise that there was an omission in the length of the inspection, and this meant that no action to reinstate the inspection was taken. This was a contributory factor to the derailment. NR/SP/TRK/001 defines the maximum interval between patrols (ie no more than eight days for a weekly patrol), and requires the supervisor to elevate the issue to the track maintenance engineer if a missed patrol is identified. The supervisor is also required to arrange to undertake the patrol at the earliest opportunity, taking steps to assess the risk and apply appropriate controls (which may include closing the line) until this is done. Evidence from witnesses and Network Rail suggests that if it is identified that a patrol has not been completed, then steps are normally taken to resolve the position in the laid down timescales.

252 By the time of the accident, 2B points had not been the subject of a visual inspection for twelve days.

[16] 'Working Long Hours' HSL/2003/02

Evidence relating to signalling equipment inspection and maintenance

Inspection and maintenance requirements

253 The standards applicable for carrying out signalling maintenance are given to staff in filofax© format. Details of the sections that are relevant to the derailment at Grayrigg are given in Appendix I.

Inspection and maintenance practice

254 The joint points team based at Carlisle was responsible for the maintenance of the points at Lambrigg (paragraph 202). The signalling members of the team carried out the actions specified in the signalling maintenance specifications. The main responsibility of the track engineering staff in the joint points team was to carry out the detailed inspections of the switch blades and their interface with the stock rails as required by Network Rail standard NR/SP/TRK/053 'Inspection and repair to reduce the risk of derailment at switches'. None of the track engineering responsibilities included any work on the stretcher bars.

255 In order to provide staff in the joint points team with a reminder of what tasks should be done at three-monthly visits, a form entitled 'PA11 Joint Point Inspection Form' (referred to as the 'PA11 form') had been produced by the former infrastructure maintenance contractor (paragraph 201). This form, which did not carry an issue date, listed in two columns the signal engineering items on one side of the form and the track engineering items on the other side. Each item was accompanied by a tick-box and there was room to write details of any work not corrected at the time on the rear of the form. It was to be signed off by each of the senior signal and track engineering members of the joint points team.

256 In 2003, Network Rail decided, and communicated, through a process of briefing and written instructions, that the maintenance of stretcher bars was the responsibility of the signal engineering function. However, Network Rail, who had taken maintenance in house from the infrastructure maintenance contractor in 2004, did not update the PA11 form to reflect this or other subsequent changes to the signalling maintenance specifications.

257 At the time of the accident the PA11 form still listed the maintenance of stretcher bars on the track engineering side of the form and stretcher bars were commonly referred to as 'permanent way stretcher bars'. It could not be determined which members of the joint points team actually checked the stretcher bars as the only evidence given was that they all worked together on the various maintenance tasks.

258 The originals of completed PA11 forms produced by the Carlisle joint points team were retained by the team, while copies were sent to the relevant signalling maintenance assistant and track section manager. The joint points team followed a practice of photocopying previously completed PA11 forms and erasing the signatures with correction fluid before signing them anew. Any work arising recorded on a PA11 form was noted by the signalling maintenance assistant on a defect form and prioritised for action. The work arising was also entered into the Ellipse system.

Inspection and maintenance activities 1 December 2006 to 23 February 2007

259 The last intervention by the signal engineering function at Lambrigg before the accident was the *facing point lock test* carried out by the joint points team on 31 January 2007. This resulted in no reported faults. The facing point lock test contained no requirement to check the integrity of the stretcher bars or their fasteners, but the members of the joint points team stated that they did visually examine them.

260 Before the accident, the last three-monthly inspection and maintenance by the joint points team at Lambrigg took place, during darkness, between 05:00 hrs and 08:25 hrs on 17 December 2006. On this occasion, only the signal engineering members of the team were present as the normal track engineering members were not available, having been allocated to other work. As a consequence, the track engineering section, including the items covering stretcher bars, of the PA11 form was not completed, was struck through, and was not signed off for any of the points at Lambrigg on that date. The track engineering elements of the inspection were not carried out.

261 The signal engineering members of the joint points team who were present on 17 December 2006 stated that they had carried out the required inspection of the stretcher bars. All the team members stated that when both signalling and track engineering staff were present, members of either function would check the stretcher bars; the task was not restricted to one function within the joint points team, although Network Rail policy was clear that this was a signalling responsibility. It could not be confirmed which function might have done the task as the individual tasks were neither initialled nor signed by the staff concerned on the PA11 forms (there was no requirement for the staff to do so). Given the lack of any ticks or overall signature on the track side of the PA11 form, there is no way of confirming the witness evidence.

262 The joint points team stated that their normal method of checking the tightness of stretcher bar fasteners was to use adjustable spanners and carry out any tightening found to be necessary by using torque spanners to the values given in Appendix I, paragraph 4. Before April 2006 signalling maintenance specification SMS PF01 had required that these fasteners were tightened to a torque of 250 Nm with a torque spanner. This requirement was removed from PF01 after that date, and there was then no requirement to measure, and no control on, the torque applied to the fasteners. This revised requirement applied to the maintenance visits to 2B points in June, September and December 2006, and the fault team's visit on 7 January 2007.

263 The previous three-monthly inspection and maintenance at Lambrigg by the joint points team was on 17 September 2006 and they generated a PA11 form as a record. It was signed by both the senior signal and track engineering members of the joint points team, but otherwise it was an exact photocopy of the PA11 form arising from the preceding inspection on 18 June 2006 (paragraph 258).

264 The size of residual switch opening was specified in the signalling maintenance specifications until April 2006, and in separate instructions thereafter (Appendix I, paragraphs 8 and 9). The joint points team stated that they would only consider the residual switch opening if the supplementary drive needed to be adjusted to obtain the required free wheel clearance, and that they did not check it otherwise because they were unaware of any maintenance requirement to do so. The signalling maintenance assistant and the signal maintenance engineer responsible for the Carlisle area also stated they were unaware of a requirement to check the residual switch opening during routine maintenance. The PA11 form contained no reminder to check the residual switch opening.

The failure of stretcher bar fasteners detected at Lambrigg on 7 January 2007

265 As described in paragraph 221, on Sunday 7 January 2007, a patroller reported to the infrastructure fault control that he had found that two nuts that should have secured the third permanent way stretcher bar right-hand side bracket to the switch rail were missing at 2B points at Lambrigg. The infrastructure fault control dispatched a signal engineering fault team from Carlisle who stated that they found both bolts were missing, but the nuts were present and lying in the ballast. It has not been possible to resolve the inconsistency between the patroller's original report and that of the fault team.

266 The cause of the failed fastenings was not investigated as required by SMS PF01, Points Fittings (Appendix I, paragraph 6).

267 The fault team fitted replacement nuts and bolts obtained from a stock in their vehicle and tightened them using adjustable spanners (witness evidence being that these were either 15 inch or 18 inch size). They did not use torque spanners (there was no requirement to do so (Appendix I, paragraph 5)) and had no access to any at the site. As the stretcher bar was not changed, the free wheel clearance was not measured. The fault team left the original bolts and nuts in the ballast under the location of the joint from which they had originally been removed.

268 The replacement nuts and bolts might never have been used before or might have been second hand, as it was custom and practice that nuts and bolts could be reused. Even if new nuts and bolts had been used it is likely, based on examples seen by the RAIB, that they would have suffered surface corrosion and thread contamination during storage in the fault team's vehicle before use.

Briefing of signal maintenance specification requirements

269 Appendix I details the relevant changes to the signalling maintenance specifications which were made as part of the April 2006 revision. These were not briefed to the relevant signalling maintenance assistant or the staff under his control, although the signalling maintenance engineer did attend a high level briefing on the changes at Network Rail's HQ. He was also present when the area signal engineer delivered a high level briefing based on briefing notes produced by Network Rail's HQ to a group of signal engineers on 28 April 2006. The briefing notes were not thought to give sufficient information to technicians and the meeting concluded that they should be briefed at a separate one day briefing. However, this did not take place, although front-line staff did receive the briefing notes. In the absence of a comprehensive briefing, they could do no more than identify the changes for themselves, and note any altered requirements. There was no separate verification that staff had done this, or evidence that they had done so.

Surveillance of signal engineering activities

270 Network Rail standard NR/SP/SIG/10028 'Inspection and Surveillance of Signal Engineering Activities' mandated surveillance to ensure signal engineering staff were competent, that maintenance standards were being met, the correct tools and equipment were being used, and that records were being kept correctly.

271 The signal maintenance engineer was to monitor staff under the surveillance regime at least annually to a plan approved by the area signal engineer. At the time of the accident, the plan had not been approved by the area signal engineer, but was considered by the area signal engineer not to be materially different to the previous one.

272 NR/SP/SIG/10028 also prescribed a system of visual and physical inspections of infrastructure assets (such as a relay room or junction area known as a 'site'). Under the standard, each supervisor was to inspect each site for which they were responsible every two years. The signal maintenance engineer was to carry out annual spot inspections to a plan approved by the area signal engineer, and the area signal engineer, or his or her representative, was to visit each site once every five years. At the time of the accident, the signal maintenance engineer's inspection plan had also not been approved by the area signal engineer.

273 The signalling maintenance assistant said he had visited the joint points team at work six times during the year before the accident and had also visited the fault team, although written records were not available confirming this. He last visited the installation at Lambrigg during October/November 2006, although it is not clear whether any staff were working there at the time. The signal maintenance engineer had been to Lambrigg once during the previous six years in connection with a staff accident (rather than to inspect the asset). He was behind with his checks and gave the difficulty in gaining access to the WCML when open to traffic as the reason.

274 The area signal engineer estimated that only 5 % of available time was spent on compliance issues and that most of that time was spent in checks on paperwork rather than asset condition. The area signal engineer had been given additional responsibilities by the infrastructure maintenance manager, including purchasing of materials for the area and also deputised for the infrastructure maintenance manager. The area signal engineer's inspection plan scheduled a visit to Lambrigg in June or July 2007.

Analysis relating to signal inspection and maintenance

Failure of the stretcher bar fasteners at Lambrigg detected on 7 January 2007 - the role of the joint points team

275 For the nuts on the third stretcher bar, right-hand side to have come off, on or before 7 January 2007, there must have been insufficient clamping force in the joint relative to that needed to withstand the loads imposed by traffic (paragraph 175). The RAIB's view is that the insufficient clamping force could only have arisen from either a change in the imposed loads affecting the joint or as a result of a change in the maintenance intervention to that joint. The RAIB found no evidence of abnormal imposed loads (paragraph 178).

276 The following are all possible scenarios relating to the actions of the joint points team on 17 December 2006. It has not been possible to confirm which scenario occurred; all are possible causal factors:

- The stretcher bar fasteners might have been found in need of tightening after being checked using a short spanner. The tightening might then have been carried out using the short spanner rather than a torque spanner and failed to achieve the pre-April 2006 specified torque of 250 Nm. The use of a short spanner makes achieving the full preload more difficult to achieve than with a torque spanner, depending particularly on the physique of the person involved. After the April 2006 revision of the SMS, there was no instruction covering how any bolts found in need of tightening should be tightened and therefore, although the joint points team had a torque spanner issued, its use was no longer mandated in these circumstances, and hence there was no control on the torque applied (Appendix I, paragraphs 4 and 5).
- The fasteners either might not have been found in need of tightening or they were tightened using a torque spanner to the pre-April 2006 specified level of 250 Nm, but high thread friction from the corrosion present, or repeated re-tightening at previous maintenance visits, rendered the tightening insufficient to generate the clamping force needed to withstand the loads imposed by traffic.
- The tightness of the stretcher bar fasteners might not have been checked. The lack of documentation means that there is an area of doubt, and there is no independent information available to confirm or deny the evidence of the signal engineering members of the joint points team, that they did examine and tighten the fasteners.

Failure of the stretcher bar fasteners at Lambrigg detected on 7 January 2007 - lack of investigation

277 The fault team that attended 2B points on 7 January 2007, in response to the report of nuts wound off (paragraph 265), did not carry out an investigation as to why this happened. The requirement to investigate, introduced in the April 2006 SMS PF01 (Appendix I, paragraph 6), had not been implemented locally through briefing and instruction.

278 The lack of an investigation extended to those supervising and managing the fault team, and was not at variance with expectations from engineers at Network Rail's HQ, who did not perceive the failure of non-adjustable stretcher bars to be an immediate significant risk (paragraphs 406 to 408). Neither the local signalling maintenance assistant nor the local signal maintenance engineer required any follow up action, although they were aware of the failure. They expressed the view, consistent with that of senior management, that it would take a repeated failure to trigger some form of investigation.

279 If an investigation had been carried out immediately after 7 January 2007, and prompted improved local vigilance, it is possible that the accident could have been prevented on 23 February 2007. However, given the short times between the two events, this is uncertain.

<u>Failure of replacement stretcher bar fasteners fitted at Lambrigg on 7 January 2007</u>

280 After the fitment of replacement fasteners to the third permanent way stretcher bar on 7 January 2007, it is known that the replacement fasteners failed on or before 12 February 2007 (paragraph 226). There was therefore insufficient clamping force in the joint to withstand the normal forces and this insufficient clamping force has already been identified as a *causal factor* of the derailment on 23 February 2007.

281 The activities of the fault team on 7 January 2007 at Lambrigg must be viewed within the context of the design of the joint. The following were possible causal factors to the derailment on 23 February 2007 (and may have acted in combination):

- The fault team might have tightened the replacement fasteners to an adequate torque, but high thread friction from the corrosion present on the nuts and bolts rendered the tightening insufficient to reach and generate the preload needed to resist the normal loads imposed by traffic. As explained at paragraph 276, the use of a short spanner makes achieving the full preload more difficult and there is no control over what preload is achieved.
- The fault team might have installed the fasteners with sufficient preload initially, but this was subsequently lost due to traffic loads overcoming the clamping force of the fasteners.
- The fault team might have installed the fasteners with sufficient preload initially, but this was subsequently lost due to embedding in the surfaces of the joint.
- The fault team might have installed the fasteners with sufficient preload initially, but this was subsequently lost due to further plastic deformation between the branding on the switch rail web and the surface of the bracket of the stretcher bar assembly.
- The fault team might have installed the fasteners with sufficient preload initially, but this was subsequently lost due to the existence of past plastic deformation of the bracket over the branding on the switch rail web, and the slip of mis-seated components on the branding subsequent to the installation of the new fasteners.
- The fault team might have installed the fasteners with insufficient preload because they used adjustable spanners rather than torque spanners to tighten them. They did not have torque spanners available and there was no mandated requirement to use them.
- The condition of the bolt threads, and the use of a short spanner, make it highly unlikely that sufficient preload could have been developed to permit plastic deformation of the bolt to take place, despite the theoretical possibility of it in cases of very high torque and low friction (paragraph 151). This scenario is not considered further.

There is no evidence as to which of the above scenarios may have caused the loss of preload after 7 January 2007.

282 The RAIB considers that the various scenarios put forward in paragraphs 276 and 281 are all possible causal factors for the failure of the stretcher bar joint at 2B points. In all cases other than not checking the bolts on 17 December 2006, they involve either a change in imposed load or deviation from prescribed maintenance practices or both acting in combination. Even if no attention was given on 17 December 2006 the replacement bolts installed on 7 January were installed in accordance with Network Rail's guidelines at that time. Despite this the joint failed, which can only be as a result of the applied load exceeding the preload, and then the fastener wound fully undone. In paragraph 182 the RAIB stated that the inability of the design of the joint between the stretcher bar and the switch rail to withstand normal service loads in all circumstances was a causal factor to the derailment. The various scenarios put forward all resulted from the joint being to a design that was able to fail after a small change in its circumstances, and this single causal factor underpinned all of them.

283 So far as the stretcher bar fastener failure is concerned, there is only one scenario put forward where actions were not compliant with Network Rail's laid down practice, namely that the joint points team had not checked the tightness of the bolts on 17 December 2006. This would only have been corrected by surveillance had the supervisor been present at the time. Therefore, the RAIB considers it unlikely that the deficiencies in supervisory audit identified in paragraphs 271 to 274 would have affected the possible causal factors listed above.

<u>*Inspection and measurement of the residual switch opening*</u>

284 The setting of the residual switch opening of between 7 and 10 mm (paragraph 134) allowed flange-back contact by most wheelsets[9] to occur once the joint between the switch rail and the third permanent way stretcher bar had failed. The forces resulting from this flange-back contact accelerated the degradation of 2B points, reducing the chances that they would be detected by patrolling. The residual switch opening setting has already been identified as a causal factor of the derailment on 23 February 2007.

285 The residual switch opening measured at the right-hand switch rail at the time of the accident was probably the value set when the half-switches were renewed in 2001. The records from the *Omnicom* train showed that in 2004 the value of the residual switch opening was already in excess of 1.5 mm. The residual switch opening of the right-hand switch rail was not deliberately changed over this period.

286 The joint points team had not attended a supplementary drive training course (paragraph 208). The RAIB has reviewed the course material and found that if they had attended the course, they would have been told that the residual switch opening should be set to 1.5 mm. The course material does not include instructions that the residual switch opening required checking at the three monthly maintenance visits. However, given Network Rail's view on the residual switch opening and its purpose to avoid over-straining the supplementary drive (Appendix I, paragraph 8), it is possible that the joint points team would have gained the impression that the 1.5 mm was a minimum value for the residual switch opening, and that there was no maximum value.

287 The joint points team stated that they were unaware there was a requirement to routinely check the residual switch opening which was a specific work item in SMS PF02, 'Mechanical Supplementary Drives', from at least April 2002 until the April 2006 revision. After April 2006, there was no specific reference to checking the residual switch opening in the signalling maintenance specifications (Appendix I, paragraph 9). Staff then had to refer to separate instructions which were not as readily available to them as the signalling maintenance specification, and much of whose content related to installation rather than maintenance. Work Instruction NR/WI/SIG/00111 'Points General – Supplementary Drives – Mechanical' referred to from SMS PF02 stated in the installation section that the gap between switch and stock rail should be set to a sliding interference fit with a 1.5 mm gauge (Appendix I, Paragraph 9).

288 The RAIB has not been able to establish precisely why the joint points team (and their supervisor and local manager - paragraph 264) were apparently unaware of the requirement to check the residual switch opening. This could have arisen from a failure in the briefing process when the requirement to check it every three months was introduced, or from insufficient training. It could also have arisen from an impression strengthened by lack of specific instruction in SMS PF02 that the residual switch opening was only a matter to be considered during installation, or when other adjustments needed to be made, and that a value at least in excess of 1.5 mm (with no maximum value) was satisfactory.

289 In its discussions with a sample of signal engineers, both internal and external to Network Rail, the RAIB found a general misunderstanding that the setting for the residual switch opening was between 6 and 8 mm and that there was an assumption the supplementary detection setting contained in NR/GN/SIG/11772 (Appendix I, paragraph 11) was the residual switch opening value. Given this misunderstanding, it is possible that the impression was widespread among signalling maintenance staff that the correct residual switch opening value was between 6 and 8 mm, which was similar to the dimension found in 2B points after the accident (Table 1).

290 There was an absence of awareness throughout Network Rail (paragraph 264) of the importance of the residual switch opening and its relationship with flange-back contact, and of the need to check and rectify residual switch opening. This absence of awareness was an underlying factor of the derailment on 23 February 2007, and is further explored in a later section of this report.

Other accidents and incidents involving S&C stretcher bars

291 The derailment at Grayrigg was not the first incident involving non-adjustable stretcher bars, although it has had the most serious consequences that the RAIB has been able to identify. The permanent way stretcher bars that were used in 2B points at Lambrigg are of a long-standing design. It has not been possible to establish when this design was first used, but it is likely that it was just before the second world war, and it became the standard design in use by British Railways from the 1940s. Evidence from long serving permanent way engineers, and the current data from SIN 097 and SIN 099 surveys (Appendix O) indicate that incidents of non-adjustable stretcher bar fasteners coming loose have regularly occurred, and are still occurring, on the British railway network; the text book issued by the Permanent Way Institution, a professional institution for railway track in the UK, refers to the risks of stretcher bar fasteners coming loose, and of fatigue in the bars[17]. However, the RAIB is aware of only one accident involving this design of stretcher bar over the last fifty years, at Kingham in 1966, and this was not as a result of the failure of the stretcher bar or its fasteners.

292 Details of the Kingham accident, an accident at Potters Bar in 2002 involving a more modern design of stretcher bar, and six examples of failures to non-adjustable stretcher bars and associated fasteners are given below.

293 **Kingham derailment on 15 July 1966** – The last coach of an eight-coach train derailed on facing points at Kingham on the Oxford to Worcester line. The Railway Inspectorate[18] investigation of the derailment[19] indicated that the open switch rail had moved towards the adjacent stock rail because a nut securing the switch blade to the facing point lock stretcher bar and one nut from each of the two stretcher bars connecting the switch blades had been removed in preparation for the complete removal of the points. No other means such as clips or *scotches* had been provided to secure the points in the *normal* condition and the open switch had moved under the vibration of the passing train. The removal of the nuts was a deliberate act and the derailment at Kingham therefore has no causal similarity to events at Grayrigg.

294 **Potters Bar accident on 10 May 2002** – A train derailed at facing points at Potters Bar and seven people lost their lives. The immediate cause of the accident was the condition of the stretcher bars in the points, although the design of the stretcher bars was substantially different from that at 2B points. The relevance of the Potters Bar investigations and recommendations to the derailment at Lambrigg is discussed in paragraphs 430 to 441.

295 **Grangetown incident on 5 August 2002** – Following a loss of detection, maintenance contractor's staff found that the bolts, nuts and spring washers holding the short end of the third stretcher bar on a pair of facing points were lying in the ballast. A Network Rail Eastern Region local investigation found that there was a history of failures, at approximately annual intervals, of this stretcher bar. There was also evidence of bolts loosening over a relatively short period of time, and of flange-back contact causing compression in, and flexing of, the third stretcher bar. The underlying causes of the incident were found by Railtrack to be the wide gauge on the turnout and the failure to take action to address it, along with significant *hogging* of the left-hand switch rail, wear and tear on the bolts and nuts and an insufficiently robust process for installing new and replacement stretcher bars. The relevance of the Grangetown investigation and recommendations to the derailment at Lambrigg is discussed in paragraph 442.

[17] British Railway Track, (7th edition), published by the Permanent Way Institution, June 2002, volume 5, paragraph 7.15.2.16.

[18] The name by which HMRI was known at the time.

[19] www.railwaysarchive.co.uk/documents/MoT_Kingham1966.pdf

296 **Treeton incident (between Chesterfield and Rotherham) on 23 May 2006** – A signalling supervisor inspecting the line found a pair of points, of the same basic vertical design as 2B points at Lambrigg, in extremely poor condition, with the holes in a non-adjustable stretcher bar incorrectly drilled, resulting in the supplementary drive being out of position in the ballast as no fasteners were in place. The points had been clipped and scotched out of use, reducing the immediate danger from their condition, although Network Rail stated, in a briefing document, that they 'posed a significant risk of derailment'. The free wheel passage was only 30 mm, compared with the standard requirement of a minimum of 50 mm, and as a result there was evidence of flange-back contact. A single stretcher bar had failed and been replaced three times in the previous two and a half months. Network Rail's local investigation found that the cause of the final failure was that the stretcher bar was incorrectly drilled, and that this had not been previously identified or investigated.

297 **Wood Green (North London) incident on 5 July 2006** – Following a report of a rough ride from a train travelling at 95 mph (153 km/h), Network Rail staff found that all the stretcher bars on a pair of points, part of a trailing crossover in the down fast line at Wood Green of the same basic vertical design as 2B points at Lambrigg, had become disconnected and the switch rail was able to move freely. As the crossover was a trailing one, there was no risk of a derailment comparable to that at Lambrigg. That the stretcher bar bolts were loose had been identified by a basic visual inspection two weeks before, but the message requesting attention was lost, and no action was taken.

298 The Wood Green incident was the subject of an investigation undertaken by Network Rail staff based in the local maintenance area. The investigation had been undertaken in accordance with a remit set between the local *maintenance delivery unit manager* and his track and signal engineers. The investigation did not give detailed consideration to the suitability of the design, adjustment or maintenance specifications. The remit focused on the adequacy of patrolling and fault response activities, and did not address why the fasteners were coming loose. Recommendations, which had local application and were monitored by the local recommendations review panel, related to:

- enhancement of patrolling and fault management regimes;
- frequency of ground frame inspections;
- urgent inspection of S&C in the London North Eastern territory to assess condition;
- analysis of S&C with one or more broken or disconnected stretcher bars in the previous 12 months; and
- clarification of the steps to be taken (report, rectify and investigate) in the event of a broken stretcher bar.

299 **Shaftholme incident (north of Doncaster) on 26 July 2006** – Signalling staff found that two bolts in the second permanent way (non-adjustable) stretcher bar were missing, and that the stretcher bar and a bracket were fractured on the third permanent way stretcher bar. Two weeks before this incident a signalling technician had identified and replaced a broken stretcher bar bracket. The level of the defects led to the line, which was carrying trains at up to 115 mph (185 km/h), being closed until initial repairs were carried out, after which a 20 mph (32 km/h) temporary speed restriction was imposed. Subsequently, the points were subject to daily examination until major repairs took place in August 2006, but the *fault management system* shows that both signal and track engineers were highlighting stretcher bar problems in October 2006. Network Rail stated that they did not carry out a specific investigation into this incident because the cause was identified as the poor state of the track at the points, and excessively wide gauge.

300 Following the incidents at Treeton and Wood Green, Network Rail carried out a survey to assess the condition of 383 sets of points (paragraph 397). This, in turn, prompted the local track and signal engineers to issue guidance on the maintenance of stretcher bars to the local staff on 17 July 2006. This guidance provided clarification on how the relevant standards should be applied, but did not cover the correct adjustment of the supplementary drive or the acceptable limits of the residual switch opening. The guidance was updated eleven days later to reflect the Shaftholme incident, which had happened in the intervening period. The area signal engineer also referred the problem of stretcher bar failures to Network Rail HQ, giving his view in a covering email that he did not see what Engineering could do about it, as in nearly all cases it was down to poor maintenance.

301 **Preston 671B points, July 2007** – This set of points has a contraflexure configuration with a designed line speed of 80 mph (129 km/h), though it has been subject to a maximum speed restriction of 35 mph (56 km/h) for some three years. As a result of the accident at Grayrigg, it was examined and some fasteners were tightened on 24 June 2007 in accordance with the SIN 99 process, although the points were not, in fact, within its scope due to the temporary speed restriction. As part of this inspection, ten loose[20] fasteners were identified and retightened. The data from the geometric checks indicated that conditions consistent with flange-back contact may have been present at the time the measurements were made and that they had not been corrected; as a consequence Network Rail HQ engineers carried out a further examination of the set of points on 3 and 4 July 2007. This found that nineteen fasteners unwound under the application of a torque of 150 Nm or less, indicating either poor control of the previous re-tightening, or that torque loss had taken place since the fasteners were re-torqued, theoretically to 200 or 250 Nm, nine days before.

302 Subsequent investigations by RAIB also revealed that 671B points had suffered two broken third permanent way stretcher bars in a six-month period (23 Dec 2004 to 13 June 2005). No investigation into the cause of either of these failures was started by Network Rail.

303 **Shrewsbury (Severn Bridge Jcn) 86 Points, 8 May 2008** – This is a trailing set of points with non-adjustable permanent way stretcher bars. The maximum speed over the points is limited to 15 mph (24 km/h). The driver of a train approaching the points observed that they were not properly set, and stopped the train before reaching them. Examination of the points showed that the fasteners between the first permanent way stretcher bar and its bracket had wound loose and fallen free, and that the switches, which were not locked, had moved out of position. The third permanent way stretcher bar appeared to have been missing for some time. As the points were trailing there was a low risk of catastrophic consequences. Network Rail investigated this incident, and concluded that the switches were skewed, and hence the stretcher bars were incorrectly set up, with one never having been installed. This incident took place fourteen months after the derailment at Grayrigg.

[20] 'Loose' in this context means that the nuts could be moved by the application of a short (15 inch) spanner, as defined in Network Rail's SIN 099.

Network Rail's management arrangements

Organisation

304 Network Rail's organisational structure, as it existed immediately before 23 February 2007, is shown in Figure 32. This also shows the lines of communication between out-based engineers in the Areas and Territories, the professional heads and the chief engineer.

305 More detail of the organisation, roles and responsibilities is provided in Appendix K.

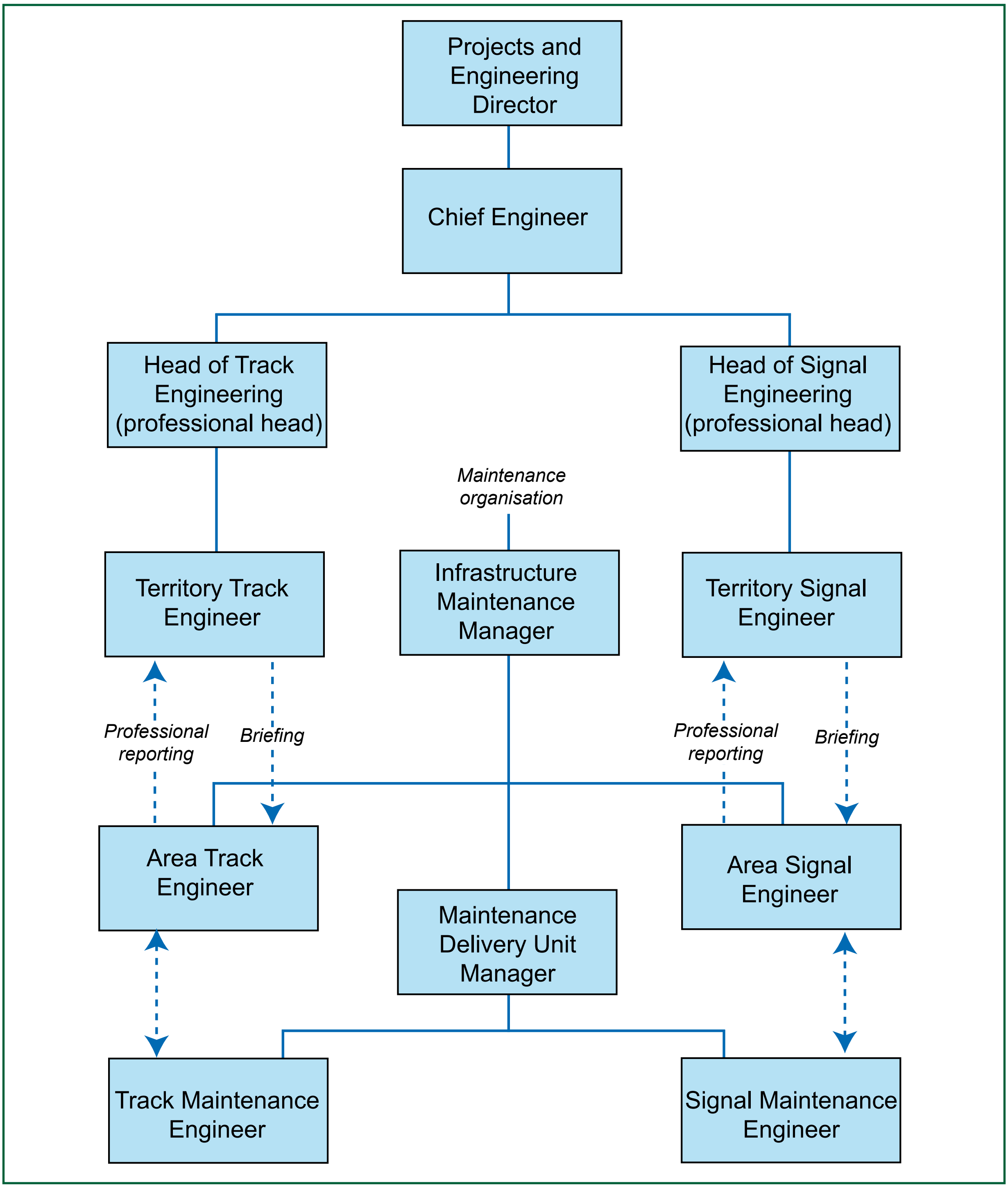


Figure 32: Network Rail's engineering reporting lines as at 23 February 2007

306 The Network Rail professional reporting lines shown in Figure 32 were described within Appendix 4 of its *Safety Case*. RAIB has confirmed that professional and technical communications were taking place between the Areas, Territories and HQ. For example, specific meetings such as the Area Business Review brought together territory and area based staff to discuss maintenance performance and plans for future activities.

307 However, there is evidence that the area-based signal engineer in the Lancashire and Cumbria maintenance area was not always able to perform the professional responsibilities envisaged by Network Rail's management systems (paragraph 274). This resulted in there being limited engineering overview of staff work activities and the end condition of assets.

The allocation of responsibilities for stretcher bars

308 Following the derailment at Potters Bar on 10 May 2002 (paragraph 294), Network Rail clarified the responsibilities for the design, installation, testing and maintenance of points in response to a recommendation from the *Potters Bar Investigation Board* investigation into the accident. The professional heads of signalling and track drew up a responsibility matrix to record the allocation of agreed responsibilities. This matrix indicates that the professional responsibility for S&C lay with the head of track engineering. In the case of stretcher bars the responsibilities are defined as follows:

Design:	track engineer (in consultation with signal engineer)
Installation:	track engineer to provide, signal engineer to adjust
Testing:	signal engineer
Maintenance/inspection:	signal engineer

309 At the time of the accident at Grayrigg, the head of track engineering recognised his responsibilities as including the co-ordination of the activities of the parties involved with stretcher bars and the integration of all system designs relating to points. However, he did not perceive that this meant he had a lead responsibility for the entire design of the S&C.

310 Network Rail standards and instructions reflect the responsibilities described above. Nevertheless, the division of responsibility was not always clearly defined at local level (paragraphs 256 and 257). ORR reports also provided some evidence that there was a lack of local procedures specifying the division of responsibilities between the track and signal engineering departments elsewhere on the network (paragraph 468).

Network Rail's engineering management systems

Inspection of assets

311 Network Rail's arrangements for the inspection of S&C assets are summarised in Table 4.

Asset condition surveys

312 Day to day maintenance was managed by contractors before 2004. During that time Railtrack and later Network Rail had a process for surveillance of the contractors' work. This process, Railtrack company procedure RT/D/P/015, 'Surveillance Checking of Asset Maintenance', required competent people from relevant disciplines, such as signalling, track and electrification & plant, to visit the infrastructure, record the condition of a sample of the assets and undertake a cross-check with records kept by the contractor. The process was designed to ensure the assets themselves were being properly maintained. The standard mandated checks were to take place in accordance with an annual plan which was developed with input from the appropriate professional heads. The annual plan was developed on the basis of the perceived risk that faults and failures within the asset would present to the overall safety of the railway. Such visits were required to be undertaken once for each discipline, every four weeks, in every contract area. This level of surveillance was not intended to cover every asset but was instead intended to provide a representative sample.

313 RT/D/P/015 was withdrawn in December 2004 following Network Rail's decision to undertake maintenance activities in-house. Thereafter, Network Rail removed the requirement for routine checks to be made on the condition of its assets, the quality of workmanship, and/or working practices of inspection and maintenance staff, by personnel independent of those responsible for the maintenance of those assets.

314 At no time did Network Rail's management processes include routine or regular condition surveys of a representative sample of assets to gather additional statistical data on asset performance to enable it to observe trends and to identify issues that existing processes do not recognise.

315 HMRI carried out similar condition surveys for its own purposes following the derailment at Potters Bar in May 2002 and again in 2004/5. In all cases, Network Rail staff accompanied the inspection teams from HMRI and arranged for all defects found to be dealt with expeditiously. Although the surveys were limited in nature, they produced indicative data on the 'health' of the S&C assets, which HMRI used to see trends in the asset, and to inform its future actions. The data collected included the presence of defects associated with non-adjustable stretcher bars. Such defects included loose fastenings and cracked stretcher bars/brackets. A summary of the data obtained is shown below:

Month/Year of survey	Number of points with non-adjustable stretcher bars surveyed	Percentage with defects[21] found
May 2002	62	51
November 2002	87	43
December 2004 - March 2005	134	13

Table 5: Results from HMRI surveys of points with non-adjustable stretcher bars in 2002 and 2004/2005

[21] Any fault found was recorded, including loose or missing components.

316 Information concerning the actual condition of S&C on the network was also obtained during Network Rail's widespread checks carried out following the Grayrigg derailment (see Appendix O).

Management information systems

317 Network Rail recorded infrastructure failures and incidents on its fault management system. This system was intended both to facilitate real time management of failures/incidents and enable analysis of failure data.

318 The fault management system incorporated an existing reporting system, SINCS, which was designed to record and manage signalling and telecommunications safety related failures and incidents.

319 Network Rail standard NR/SP/SIG/10047 covered the classification, investigation and review of safety related signalling faults and incidents. Specific fault modes and consequences were identified in the standard and classified as high risk, low risk or an incident. These were then required to be recorded and analysed within SINCS and classified using a hazard index based on the potential for damage or injury and either the seriousness of the high or low risk failure, or the seriousness of any incident arising from a situation where a malfunction of the signalling equipment could not be ruled out as a contributory factor or cause. While the maintainer was responsible for investigating the failure, the value of the hazard index determined how high within Network Rail's organisation the failure should be escalated for review.

320 Failures with the highest hazard index were reviewed by Network Rail's Signal Engineers' Group at headquarters.

321 Before 30 April 2006, the categories of failure mandated to be entered into SINCS excluded failures of stretcher bars, brackets and fasteners. From 30 April 2006, version 10 of standard NR/SP/SIG/10047 included a new requirement to record both of the following in relation to points:

- broken components reducing safety but unlikely to lead to derailment (for example, single broken or ineffective stretcher bars); and
- broken components reducing safety likely to lead to derailment (for example, multiple broken or ineffective stretcher bars).

322 This revision of the specification therefore acknowledged stretcher bar failure as an issue worthy of recording, but it did not specifically cite loose or missing fasteners as a category of failure.

323 The SINCS system was not configured to identify which component had failed and the nature of the failure unless the person inputting the data chose to record this information as free text. This meant that the system did not readily allow the collation of meaningful management information on all failure modes across the population of points.

324 Network Rail's Ellipse system was used to record and manage maintenance activity. Its value as a source of management data on asset condition was limited because it would only include items that inspection or maintenance teams could not immediately rectify. For example, if a maintenance team found loose nuts on a stretcher bar, they would tighten them as part of their normal work activity. They would not ask for the item to be recorded on Ellipse because there was no outstanding action. In addition, once a defect recorded in Ellipse had been rectified, it would be removed from the database.

Management reporting; key performance indicators

325 Maintenance depots collected a range of data on track performance and safety for reporting up through the areas, territories and thence to HQ. This data formed part of a reporting system known colloquially as AS7. This comprised 40 selected Key Performance Indicators. These included three that specifically related to the condition and maintenance of switches:

- MA117_50 – point ends with NR/SP/TRK/053 (paragraph 254) inspections overdue;
- MA127_50 – *half set*s of switches with NR/SP/TRK/053 repairs overdue; and
- MA106_01 - poor quality track geometry at S&C.

326 The AS7 process did not include any key performance indicators that were specifically related to the condition of stretcher bars, brackets, fasteners or the flangeway clearance. The AS7 reports were reviewed by the track section manager and the track maintenance engineer to provide an input to the short-term planning process for scheduling of outstanding work. The infrastructure maintenance manager also used the AS7 for assurance purposes. Using data extracted from AS7, he compiled a period end report with the area track engineer, which he then reviewed with the territory maintenance director at each period.

327 High level performance data was contained in a four-weekly management report, the 'Infrastructure Condition Report'. This report provided performance data and risk rankings for a wide range of infrastructure failure categories including points failures, track related derailments and wrong side failures.

Monitoring and review

328 Headquarters overview of Network Rail's safety policy and strategy was exercised by a number of management meetings:

- The Safety Health and Environment Committee consisted of the chief executive and four non-executive directors. This committee routinely reviewed safety performance using information provided to it in a monthly report, the Safety and Environmental Assurance Report. This report contained data collected against a range of high level key performance indicators (ie higher than the AS7 indicators). These included the number, and a description, of high risk failures of the infrastructure at system level rather than at component level (eg points rather than stretcher bars).
- The Strategic Safety Group, which consisted of four executive directors and two senior executives, was an executive committee, with the remit of providing leadership and commitment within the business on safety, health and environment. Its terms of reference included review of inquiries into major incidents and monitoring of Network Rail's implementation of those recommendations.
- The Tactical Safety Group consisted of two executive directors and a number of senior executives from headquarters and territories. It was responsible for developing and monitoring plans and risk management activities. This role included establishing processes and procedures designed to deliver effective internal investigation of key incidents and developing, implementing and monitoring of effectiveness of implementation of appropriate action plans for responding to recommendations from incident investigations that had been accepted by the company.

329 The signal engineers group met monthly to review data, wrong-side failure reports and six monthly analysis reports. The signal engineers group was chaired by a representative of the Head of Signal Engineering and attended by:

- territory signal engineers;
- direct reports to the Head of Signal Engineering; and
- engineering representatives from delivery teams working on enhancements.

330 The SINCS data contained within the fault management system (paragraph 319) was routinely analysed by a department within Network Rail HQ Signal Engineering known as the Signalling Performance Group. This department would commission investigations (on request from the signal engineering function at headquarters or territory level) if there were significant numbers of failures in a specific item of equipment or area. This group published the six monthly review of signalling failures for the signal engineers group. This typically included data on the number of point failures. However, extraction of data concerning type of failure required manual analysis of raw data held in the SINCS system.

331 In response to the accident at Grayrigg, the Signalling Performance Group carried out an analysis of point failure categories based on data manually extracted from SINCS and included the results in its report covering the period October 2006 to March 2007. This data included reports of failed stretcher bars that had been entered into SINCS following the revision of standard NR/SP/SIG/10047 in April 2006 (paragraph 321). The analysis was split into two parts. In the 20 day period up to and including 24 February 2007, 36 reports of loose stretcher bar components were recorded. In the three day period from 26 to 28 February 2007 (after the Grayrigg derailment), 78 reports of loose stretcher bar components were recorded[22].

332 The signal engineers group concluded that the increase in the rate of reports of loose stretcher bars could have been indicative of under-reporting before the derailment at Grayrigg, or of a particular focus on this issue in the immediate aftermath of the accident.

Compliance and assurance

333 At the time of the derailment at Grayrigg Network Rail had in place a compliance and assurance regime. The 'compliance' activities included the performance of checks, inspections and surveillance by supervisors and line managers within the maintenance area that encompassed the physical condition of assets and verification of compliance with standards and procedures (some of these checks are reflected in AS7 key performance indicators). Further detail of the checks and inspections that were required to be carried out under Network Rail's compliance regime are given at paragraphs 190 to 194 and 270 to 272.

334 Despite the above process, there is evidence that some of the supervisory and management checks and inspections that were required to take place within the Lancashire & Cumbria Maintenance Area had not been performed as intended (paragraphs 245 and 272 to 274).

335 Network Rail's assurance regime encompassed a process for audit. This was described in Network Rail specification NR/SP/ASR/036 and is summarised in Appendix J, together with a list of relevant audits undertaken in the Lancashire & Cumbria Maintenance Area in the 18 months before the derailment at Grayrigg.

[22] This is in the context of some 13,500 points in running lines with non-adjustable stretcher bars.

336 The selective geographic scope of the audits that were carried out in the Lancashire & Cumbria maintenance area meant that the track maintenance depot at Carnforth and the signal maintenance depot at Carlisle were not always included in the scope of annual audits. Paragraph 209 and Appendix J describe the findings from some of the key audits that did cover these depots. While the audits did identify some minor deficiencies they did not detect the following:

- inconsistencies in patrollers' records (paragraph 213); or
- re-use of PA 11 forms (paragraph 258).

337 None of the protocols for the audits carried out in the Lancashire & Cumbria area in the 18 months before 23 February 2007 involved any checking of the physical condition of the infrastructure or any observation of work activities or any review of documents actually in use by maintenance staff when working on the track.

Risk

The Safety Risk Model

338 An important source of safety risk data used by Network Rail when making business decisions or monitoring safety performance was the *safety risk model*. This model was initially developed by Railtrack but its ownership, and the responsibility for its development, was subsequently transferred to and further developed by the RSSB. The model calculates levels of collective and individual risk associated with the national railway network. It does this using a 'top-down' approach:

- calculating the frequency and predicted outcome of different hazardous events using a combination of historical data (frequency of accidents and incidents and consequences of accidents); and
- specific modelling and workshops involving individuals with expertise in relevant disciplines from RSSB and industry exercising judgement regarding the frequency and consequences of hazardous events.

339 The safety risk model did not therefore derive estimates of the risk arising from component failure from 'bottom-up' analytical techniques such as *Failure Modes and Effects Analysis*.

340 The data sources for the safety risk model include the railway industry's *Safety Management Information System*, which contains reports of incidents and accidents.

341 The version of the safety risk model that was current in 2007 expressed risk contribution in terms of *fatalities and weighted injuries*. This was an overall measure of harm, taking account of injuries and fatalities based on ten major injuries or 200 minor injuries being considered equivalent to one fatality[23]. Using this measure, the safety risk model calculated that S&C faults account for:

- around 23 % of the total risk contribution for those track faults that led to derailment;
- around 9 % of the total risk associated with derailment; and
- around 3.5 % of the total train accident risk (ie risk arising from events such as collisions, derailment and train fires) on Network Rail controlled infrastructure.

342 S&C defects were included within the safety risk model as one precursor to derailment. However, those defects were not disaggregated to component level and for this reason the safety risk model did not provide a means for evaluating the contribution from stretcher bars and stretcher bar fasteners to the overall risk of derailment.

343 The RSSB has developed a linked model, the precursor indicator model, to monitor changes in the risk generated by each of 84 identified 'precursors to accidents' (these are events which do not, by themselves, automatically result in accidents, but could be among the causes). The data sources were identical to those for the safety risk model. However, it was not possible to obtain from the precursor indicator model any further clarification of the risk associated with S&C defects as they were included within a single category that included track faults associated with plain line as well as S&C.

[23] These ratios were based on work undertaken by British Rail and the Department of Transport in the early 1990s. Research recently undertaken on behalf of the RSSB has concluded that there was no 'transparent justification' that could be attributed to the ratios, although they had provided the basis for consistent decision-making since that time. The researchers have proposed an alternative approach to weighting injuries which was adopted by the railway industry in January 2008. Their report can be found at http://www.rssb.co.uk/pdf/reports/research/T440_rpt_final.pdf

Network Rail's perception of the risk arising from existing S&C with non-adjustable stretcher bars

344 Network Rail considered the designs of points equipped with non-adjustable stretcher bars to be performing safely. This was based on the absence of serious train accidents associated with their failure over 50 years (paragraph 291). Network Rail's senior engineers knew that fasteners on stretcher bars were coming loose but believed that the design of the points had sufficient redundancy for this not to be a problem. Network Rail also believed that its standards for patrolling, inspection and maintenance were generally being complied with. One of the factors underpinning this belief was management information produced by the maintenance areas on the level of compliance with maintenance standards (paragraph 325).

345 Network Rail's understanding of the risk associated with existing S&C with non-adjustable stretcher bars was incomplete. Relevant factors were:

- The previous analysis for non-adjustable stretcher bars that was undertaken by Scott Wilson Railways (paragraph 351) did not identify all potential failure modes of non-adjustable stretcher bars. No follow-up research or testing was undertaken, as recommended by Scott Wilson Railways in their report on the findings from the failure modes and effects analysis.
- The range and magnitude of load cases, the different configurations of non-adjustable stretcher bar points, and the loads their components are subjected to were not fully understood by Network Rail (paragraph 142).

346 Despite the general view that the risk was being controlled, Network Rail had recognised that the loss of restraint on one stretcher bar could lead to a progressive degradation of other stretcher bars. This resulted in Network Rail introducing a requirement into standards NR/SP/TRK/001 and SMS PF01 in April 2006 for the imposition of a temporary speed restriction, to remain in place until the fault was rectified, and for a report to the infrastructure fault control if a single stretcher bar was broken or disconnected. This requirement arose from the development of the 'Good Practice Guide' (See Appendix L, theme 2).

Design and maintenance safety analysis

347 Network Rail had processes in place for the review and acceptance of safety justifications supporting the introduction of new technology or new and novel applications of existing technology. However, much of the existing railway equipment was designed and brought into use before the introduction of current safety acceptance processes.

348 Network Rail's Safety Case included the statement that the company would seek to increase its awareness of the condition and performance of its existing assets. It stated that risk would be taken into account in the development of standards. A particular example given in the Safety Case of how this would be done was the adoption of a risk-based maintenance regime for critical signalling equipment. However, the Safety Case did not commit Network Rail to a widespread adoption of a formal risk-based approach to maintenance.

349 In the period before February 2007 Network Rail had adopted two approaches with the intention of allowing it to more accurately determine the suitability of design and the associated maintenance and inspection requirements: design safety analysis and analysis of maintenance requirements.

Design safety analysis

350 In response to Potters Bar recommendations HSE 2.1 and 2.3[24], Network Rail commissioned the consultants Scott Wilson Railways to carry out a design safety analysis of points with adjustable stretcher bars (the design used at Potters Bar). This analysis led to Network Rail deciding to fit '*Hardlock*' nuts to new installations, and to existing installations when adjustable stretcher bars were replaced. No other substantive change to the adjustable stretcher bar design was considered necessary.

351 In early 2004, Network Rail extended Scott Wilson Railways' analysis to include a review of the failure modes of non-adjustable stretcher bars. Scott Wilson Railways did this by collecting and analysing details of stretcher bar failures in one of Network Rail's maintenance areas (Thames Valley).

352 Scott Wilson Railways issued a report containing their analysis to Network Rail in April 2004. This report stated that 47 % of all reported stretcher bar defects in the Thames Valley involved problems with nuts or bolts being either loose or missing.

353 The report also included a preliminary failure modes and effects analysis (FMEA) for points with non-adjustable stretcher bars. Although providing some indication of failure scenarios and their safety criticality, the analysis was not carried out at the level of individual components. Furthermore, the RAIB considers that some assumptions adopted within the analysis were incorrect:

- an assumption that the end result of a broken stretcher bar would be the widening of the flangeway clearance: in fact it would narrow; and
- an assumption that loose nuts are easily detectable through visual inspection: this is not the case because the stretcher bar bracket will normally move with the nut and the gap that opens up behind the bracket is hidden by the rail head.

354 However, the report recognised some of the weaknesses of the failure modes and effects analysis in a conclusion that:

'The FMEA did not identify any of the failure modes as being a cause for concern, on an individual basis. However, this conclusion needs to be considered further in light of failure modes for other parts of the switch and crossing systems and whether the fault profile for the stretcher bar could contribute to a wider failure of a switch, which was catastrophic. Only further examination of other switch and crossing failures and inspections could reveal this.'

355 The report then suggested that further work be undertaken to:

'…determine the critical components within the switch design, which could be changed to reduce failure rates.'

There is no evidence that further work was undertaken in respect of S&C with non-adjustable stretcher bars.

---

[24] For the purpose of this report the Potters Bar recommendations are identified as follows:
- recommendations published in the second HSE interim report (paragraph 373) are identified as HSE 2.n (there were no recommendations in the first interim report)
- recommendations published in the third HSE interim report are identified as HSE 3.n

356 In parallel to the work undertaken by Scott Wilson Railways, Network Rail was developing an analytical process for the design of its critical systems. Some preliminary analysis was undertaken by Network Rail in 2003 with the objective of identifying for each of the component parts of a points system:

- the functional requirements;
- the safety requirements; and
- potential failure modes.

357 Having defined each of the above, Network Rail then intended that a detailed analysis would be performed to demonstrate that the functional and safety requirements would be met by the design. This analysis would also be extended to assess the consequence of failures. The same process would also enable the systematic specification of inspection and maintenance for each system.

358 During 2003, senior engineers in Network Rail's headquarters organisation concluded that its objectives would be best met by adopting a process called '*business critical configuration management*'. The 'business critical configuration management' process was adapted from practice in the nuclear industry.

359 Network Rail established a small team, consisting of one manager and up to two assistants, reporting to the Head of Business Engineering, to manage the development of the 'business critical configuration management' approach.

360 Preliminary work was undertaken by Network Rail to implement 'business critical configuration management'. The first step in the process was to identify safety critical systems (eg points and level crossings). However, by October 2003 the decision had been taken by senior engineers in Network Rail's HQ organisation that the 'business critical configuration management' approach should be piloted using the emerging design of the *NR60/HPSS/Hydrive points*. This decision was driven by a number of factors:

- the desire to ensure that the designs of new and novel assets were validated in line with established good industry practice; and
- problems experienced with the introduction of a new design of *swing nose crossing* installed at Ledburn junction, on the WCML near Leighton Buzzard.

361 Network Rail then intended that this analysis would be extended to include existing designs of points once the process had been completed for the new design. However, since the application of 'business critical configuration management' to NR60/HPSS/Hydrive points was seen as a trial of the process, no programme was established for its wider application at that time.

362 The 'business critical configuration management' activity in relation to the NR60/HPSS/Hydrive points design was completed in December 2006. It included, as inputs to the analysis, performance data from those elements of the design of the points that already existed on Network Rail infrastructure. The final output of the process was a 'design substantiation' or validation of the proposed specification for the new design of points. In the absence of an actual design it did not include any substantive analysis of maintenance or other asset management requirements, which full application of the 'business critical configuration management' process would have provided.

363 Since December 2006, Network Rail has not sought to extend the 'business critical configuration management' process and the resource was deployed to undertake other duties. By February 2007 the chief engineer had become unconvinced of the value of 'business critical configuration management'. He was also doubtful as to whether it was reasonably practicable to extend such a comprehensive design analysis to existing assets, the performance of which he considered to be well understood. However, Network Rail is still using the existing documentation generated by the 'business critical configuration management' process as an input to the development and approval of the NR60/HPSS/Hydrive points design.

Analysis of maintenance requirements

364 In parallel to the 'business critical configuration management' initiative, Network Rail had continued to develop a formal process for the review of signalling maintenance standards using a risk-based approach. This approach was mandated for signalling assets in Network Rail's company standard NR/SP/SIG/10662, 'Process for Introduction of New or Revised Maintenance Regimes for Signalling Assets' (first issued by Railtrack in 2000). The principal steps in the process were:

- identify asset hazards (eg failures) by use of failure modes and effects analysis or similar (validated using historical data);
- determine actions that could mitigate the asset hazards;
- assess the risk (using all available failure data and the findings of site monitoring) and determine an appropriate interval for maintenance activities;
- compile a practical maintenance specification; and
- manage the implementation of the new regimes.

365 Network Rail mandated the adoption of this new approach for maintenance regimes that were being changed or developed for new signalling assets. The process, laid down in standard NR/SP/SIG/10662, was primarily designed to provide the justification for adjusting maintenance intervals and/or activities, rather than for the purpose of safety validation. Network Rail considered that optimum use of the resources available would be achieved by limiting application of the standard to new regimes and assets rather than focusing on existing equipment with 'known performance'. For this reason, the number of maintenance standards that were developed using this approach was limited to eight (these are listed in Network Rail company standard NR/SP/SIG/10661, 'Signalling Maintenance Task Intervals'). The application of the approach did not extend to standards covering the maintenance of non-adjustable stretcher bars and supplementary drives.

366 In October 2006 Network Rail revised standard NR/SP/SIG/10662[25]. The revised standard still required the adoption of a structured risk-based approach to the development of maintenance regimes that were being changed or developed for new assets. However, the approach mandated was now based on the Society of Automotive Engineers Standard JA1011 'Evaluation Criteria for Reliability Centred Maintenance Processes'.

367 Reliability-centred maintenance is an analytical approach focused on identifying and establishing practices to manage the equipment failures that prevent reliable operations and shares many characteristics with the risk-based maintenance approach that applied until October 2006. However, the application of the reliability-centred maintenance process was seen by Network Rail as a more structured and pragmatic approach.

[25] By February 2007 Network Rail had not issued any revised maintenance standards following the revision of the standard NR/SP/SIG/10662.

368 Network Rail has confirmed that its intention had been to apply the reliability-centred maintenance approach to most of its signalling assets over time, although its focus was on those components that were fully within the remit of the signalling engineers, rather than stretcher bars, where the design responsibility sat with the track engineer (paragraph 308). It had prepared a programme which envisaged that the majority of signalling equipment will be subject to this approach by 2010.

369 The manner in which risk had been taken into account when Railtrack and Network Rail developed new or modified maintenance standards for track assets was not comparable with the formal and structured risk-based approach that had been adopted after 2000 by the signalling engineering function.

Standards and briefing to staff

370 Before the accident at Grayrigg, there were a number of deficiencies associated with Network Rail's standards governing the maintenance of S&C. These included:

- the exact wording of the limits for a residual switch opening was only to be found in the installation section of a work instruction, and not in the signalling maintenance specification (paragraph 287 and Appendix I);
- lack of clear definition of the process for investigating loose or missing bolts (paragraphs 277 to 279);
- lack of clarity on the method of tightening bolts and associated torque values (paragraph 281 and Appendix I); and
- the removal of the requirement to use a torque spanner from SMS PF01 (paragraph 262) removed a potential control on the torque in stretcher bar to switch rail fasteners, and hence a possible control on the preload in the associated joint.

371 Network Rail's process for the technical briefing of staff was not always applied effectively within the Lancashire and Cumbria Maintenance Area in the period before the accident at Grayrigg. In particular, technical briefings had not reached the staff on the ground (paragraph 269).

Network Rail's review of previous accidents and incidents and actions taken

Network Rail's process for handling of recommendations arising from investigations into the Potters Bar accident

372 Following the derailment at Potters Bar on 10 May 2002 (paragraph 294), two investigations were launched. One was by the Health and Safety Executive and one by the RSSB, which was the rail industry's formal inquiry. Both investigations resulted in recommendations for Network Rail, although the Health and Safety Executive investigation (undertaken by the Potters Bar Investigation Board, paragraph 474) can only be published when any legal proceedings that may arise from the accident have been completed or ruled out.

373 Between May 2002 and May 2003, the Potters Bar Investigation Board produced three progress reports[26]. The first report, published on 14 May 2002 (within a few days of the accident), contained a brief summary of the early findings from the investigation and no recommendations. The second progress report was published on 4 July 2002. It contained preliminary findings and fourteen recommendations, of which nine were addressed to Network Rail. The third progress report, published on 29 May 2003, contained a further twenty six recommendations, of which eight were addressed to Network Rail alone and six were addressed to Network Rail jointly with one or more other parties.

374 In accordance with Railway Group Standard GO/RT 3473, 'Formal Inquiries, Formal Investigations and Local Investigations', the RSSB commissioned a formal inquiry on behalf of the rail industry. Its formal inquiry report[27] was published to the industry on 18 March 2005[28]and contained 29 recommendations, of which 24 were addressed to Network Rail and one addressed to Network Rail and the RSSB jointly.

375 Although the way in which Network Rail ultimately handled the recommendations from the two Potters Bar investigations was identical, a different process was applied at the outset, reflecting changes in recommendations-handling practice that had occurred between May 2003, when the third Potters Bar Investigation Board progress report was published, and March 2005, when the RSSB's recommendations were published. At the time of the accident, Railtrack (in railway administration) was still the infrastructure manager for the national railway network. Network Rail, which was launched in October 2002, took responsibility for handling all outstanding recommendations from the Health and Safety Executive and RSSB investigations.

376 Railtrack, and then Network Rail, accepted all of the recommendations placed on it by the Potters Bar Investigation Board in the second and third progress reports. Each recommendation was assigned to a senior person in the company to define the nature of the response to the recommendation, develop the implementation plans and define timescales.

377 By the time that the RSSB published its report of the formal inquiry into the accident, Network Rail had revised its approach to considering recommendations from major investigations. It held a recommendations review meeting on 11 May 2005, which a board member and several senior managers attended. At the meeting, each recommendation was evaluated and initial consideration of whether it should be accepted or rejected made.

---

[26] 'Train derailment at Potters Bar, 10 May 2002' and two 'progress reports by the HSE Investigation Board'. HSE, July 2002 and May 2003. Both can be found at http://www.rail-reg.gov.uk by searching on 'Potters Bar'.

[27] Formal Inquiry: Derailment of Train 1T60, 1245 hrs Kings Cross to Kings Lynn at Potters Bar on 10 May 2002. RSSB, 18 March 2005.

[28] A summary of the report can be found at: http://www.rssb.co.uk/pdf/reports/Potters%20Bar%20derailment%20-%20report%20and%20recommendations.pdf.

378 Network Rail appointed a lead manager for each accepted RSSB recommendation, and identified timescales for implementation of them.

379 The process applied by Network Rail to track progress in implementing recommendations from the two Potters Bar investigations comprised regular meetings between the lead manager for each recommendation and a recommendations co-ordinator working within a team led by Network Rail's Head of Recommendations Management. At those meetings progress was discussed and amendments made to proposed activities, and to completion timescales that they considered appropriate.

380 The co-ordinators were project managers rather than specialists in the subject matter of the recommendation, whereas the lead manager was a technical specialist in the relevant field. If the lead manager changed the deadline for completing a recommendation, this was generally accepted by the co-ordinator and the completion date amended on a tracking database. Reasons for changes to deadlines or proposed actions were not subject to approval by senior managers.

381 Railtrack had a senior management forum for discussing specific safety issues known as 'SAFEX', which was replaced in February 2003 by Network Rail's strategic safety group and tactical safety group. Between July 2002 (when the Potters Bar Investigation Board issued their second progress report with recommendations) and February 2007, progress in implementing Potters Bar recommendations was discussed at all three meetings. At the beginning of this period, discussions tended to revolve around a statistical summary of open and closed recommendations. The number of recommendations from major accident investigations that were still open at that time precluded detailed scrutiny of each one. Network Rail's process for reviewing recommendations was refined during 2005 and 2006 and this, in conjunction with the decreasing number of open recommendations from major investigations, resulted in a gradual increase in scrutiny of those that were still open. The tactical safety group in particular began to allocate more time to the consideration of Network Rail's progress in implementing recommendations.

382 Network Rail gave a board director the responsibility for the Potters Bar recommendations and it was this director who gave authority for the closure of individual recommendations. However, he relied on the lead manager for each recommendation to undertake their task in a timely and effective manner and only considered proposals for closing recommendations when they were presented to him, rather than actively seeking closure.

383 By February 2007, Network Rail considered that three recommendations from the second Potters Bar Investigation Board progress report and one recommendation from the third Potters Bar Investigation Board progress report were still open. Those recommendations and their relevance to the Grayrigg derailment are discussed in more detail in the following section and the table provided within Appendix L.

Actions taken by Network Rail in response to Potters Bar Investigation Board and RSSB investigation reports following Potters Bar

384 The RAIB has reviewed the Potters Bar Investigation Board and RSSB recommendations from the various investigation reports. A total of fourteen recommendations, ten from the Potters Bar Investigation Board and four from RSSB, have some relevance to the circumstances of the Grayrigg derailment on 23 February 2007.

385 Although the Potters Bar Investigation Board's second progress report was primarily focused on the safety of S&C with adjustable stretcher bars, the report covered a number of issues relating to the general management of S&C assets. Consequently, six of the recommendations that were made in the report are considered to have some relevance to the accident at Grayrigg. The RAIB considers that these recommendations covered the following four themes:

1. the need for systematic design and safety analysis focused on points with adjustable stretcher bars[29] (recommendations HSE 2.1 and 2.3);
2. the need for a review of standards for installing, setting, adjusting, maintaining, inspecting and testing points, and ensuring that these standards were available, clear and understood by staff (recommendations HSE 2.4, 2.6);
3. the need for a review of the requirements and arrangements for the reporting, recording, reviewing and acting upon deficiencies and safety related events associated with points (recommendation HSE 2.7); and
4. arrangements for independent inspection of points focused on points with adjustable stretcher bars (recommendation HSE 2.8).

386 The Potters Bar Investigation Board's third progress report had a wider scope. It considered many general issues relating to the management of S&C assets. Four of the recommendations are of particular relevance to the investigation into the accident at Grayrigg. The RAIB considers thatthese recommendations covered the following themes:

5. the need to undertake a management review by mapping roles, responsibilities and arrangements against a management model to ensure safety critical components are fit for purpose and to ensure that no gaps remain (recommendation HSE 3.4);
6. the need for the development of a risk-based approach to procurement, installation, inspection and maintenance of points based on an understanding of the design and safety requirements (recommendation HSE 3.5);
7. the need for HMRI and Network Rail to formally agree on applications of good engineering practice to promote a risk-informed preventative maintenance strategy (recommendation HSE 3.10); and
8. the need to review and clearly define the roles and responsibilities of track and signalling maintenance staff to ensure the safety of critical components (recommendation HSE 3.14).

387 The report published by the RSSB following the rail industry's own investigation into the accident at Potters Bar included four recommendations that related to the general management of S&C assets. These recommendations covered the following themes:

9. the requirement for free wheel clearance and supplementary drive settings on points to be checked together at defined intervals as part of maintenance (recommendation RSSB 9); and
10. the need to better manage track inspections to ensure that:
    - they take place as planned (recommendation RSSB 18);
    - they are properly planned and recorded (recommendation RSSB 19);
    - patrollers are competent in respect of points (recommendation RSSB 20).

---

[29] Although this recommendation was focused on S&C with adjustable stretcher bars Network Rail undertook to extend the design analysis to include other types.

388 The table provided within Appendix L provides a summary of the actions taken by Network Rail in response to the actual issues arising from each theme and the areas of concern that are relevant to the Grayrigg investigation. The table also shows the status of each recommendation (as at February 2007) as recorded by Network Rail and by HMRI.

389 At the meeting referred to in paragraph 377 the attendees rejected six of the RSSB's recommendations. Recommendation RSSB 19 was rejected and was one of the four with relevance to Grayrigg. It was concerned with the planning, operating and recording of basic visual inspection procedures, which the RAIB has subsequently found to be deficient at Grayrigg (paragraphs 213 and 234 describe the operation and recording issues, and paragraphs 239 to 245 the track access issues that affected the planning of inspections). Network Rail's stated reason for rejecting recommendation RSSB 19 was that it did not believe it was germane to the Potters Bar accident (nevertheless, it took some actions to improve the process for the planning, operating and recording of the basic visual inspections).

Network Rail's investigation into local incidents

390 In December 2002, Network Rail's Eastern Region issued its report into the displacement of stretcher bar bolts in a set of S&C at Grangetown in August of that year (paragraph 295). The investigation concluded with ten recommendations. Recommendation 4 required a review of the process for installing and replacing (non-adjustable) stretcher bars with a view to implementing procedures based on prescribed dimensions. Recommendation 6 asked Railtrack to consider whether future replacement of stretcher bar bolts should be with a nut containing a nylon insert for locking purposes.

391 Both recommendations were considered by senior members of Network Rail's track and signal engineering teams (Network Rail took over ownership of the infrastructure from Railtrack shortly after the incident). Recommendation 4 was the subject of substantial debate as to whether track or signal engineering was responsible for leading on the issue (this debate was still ongoing in December 2003). No action had been taken by December 2005, when the recommendation was closed on the basis that the work was to be carried out as part of implementing Potters Bar recommendations. In February 2006, Network Rail issued standard NR/SMTH/Part 4/PA02 following its review of the process for installing and replacing stretcher bars as a means of addressing recommendation 4.

392 Recommendation 6 was closed in September 2006 (four years after the incident at Grangetown) on the recommendation of a senior track engineer. This closure was based on his opinion that the incident at Grangetown appeared to have been an isolated incident due to geography and traffic use that did not justify the replacement of stretcher bar bolts with a nut containing a nylon insert.

393 There is evidence that the London North Eastern Territory Recommendations Review Panel had concerns about this statement and referred it back to HQ (through the signal engineers group) for consideration. Despite this the recommendation was not reopened.

394 In July 2006 a local investigation into the circumstances of the incident at Treeton (paragraph 296) concluded that the points had been suffering from repeated broken 4th stretcher bars due to being incorrectly installed. No design issues were identified and the matter was not referred to HQ for attention.

395 In October 2006 the signal engineers group reviewed the incidents at Wood Green (paragraph 297) and Shaftholme (paragraph 299), both of which had involved the failure of multiple non-adjustable stretcher bars.

396 The following issues were common to the incidents at Wood Green and Shaftholme:

- evidence that stretcher bar fasteners were failing in service;
- rapid degradation of the points following a single component failure;
- defective maintenance and inspection; and
- the high dependence on correct track gauge, set up, and on inspections taking place as planned.

397 Subsequent checks carried out by the London North Eastern territory had revealed that of 383 points checked, 111 had at least one loose nut, and 25 % of sites around Wood Green had at least one loose stretcher bar.

398 The signal engineers group considered that the local investigations at Wood Green and Shaftholme had identified serious failures of local maintenance and inspection. Nevertheless, members of the signal engineers group expressed concern that the points were vulnerable to high levels of vibration if flangeway clearance and track gauge were at the limits of set standards. Adjustment of the supplementary drive to increase the dimension of the flangeway was discussed as an option.

399 Towards the end of 2006, these issues were referred by the signal engineers group to track engineering (who had the lead responsibility for the design of points and stretcher bars). The signal engineers group minutes show that the issue had not been closed by February 2007.

Analysis relating to Network Rail's management

Knowledge of asset condition

400 Network Rail did not have any comprehensive data about the condition of stretcher bars, brackets and fasteners across its network at the time of the accident. This lack of data contributed to Network Rail's incomplete understanding of the performance of its S&C assets at component level, and was therefore an underlying factor in the derailment.

401 The reasons for this lack of comprehensive data are summarised below:

- Network Rail's management processes no longer required that independent inspections of asset condition were carried out, as had been the case when maintenance was carried out by contractors (paragraph 313).
- Network Rail neither routinely nor regularly carried out surveys across a representative sample of point components to provide a reliable source of independent data on asset condition (paragraph 314).
- There was no explicit requirement to enter details of stretcher bar failures into SINCS until April 2006. Even after this date it is unclear whether the definition of failure in SINCS included loose or missing fasteners (paragraphs 321 and 322).
- Network Rail's management information systems (SINCS and Ellipse) were not configured, at the time of the Grayrigg accident, to permit efficient analysis of types of failures and identification of trends across a large population of S&C (paragraphs 323 and 324).
- Network Rail's key performance indicators did not include any specific reference to the condition of stretcher bars, brackets, fasteners or flangeway clearance (paragraph 326).
- Until April 2006 there had been no requirement to report loose or missing bolts on stretcher bars. Once this became a requirement there is evidence of significant under-reporting (paragraph 331).
- The Network Rail audit process did not include checks of asset condition or observation of inspection/maintenance activities. Consequently, none of the protocols for the audits carried out in the Lancashire & Cumbria maintenance area in the 18 months before 23 February 2007 involved any checking of the condition of the infrastructure, any observation of work activities or any review of documents actually in use by ground staff (paragraph 337).

Levels of risk arising from existing S&C with non-adjustable stretcher bars

402 Network Rail's approach to the assessment of risk from points defects was based on the RSSB's safety risk model and the linked precursor indicator model (paragraph 339). The level of resolution in these models did not enable the risk impact of individual components to be identified or the input of data derived from 'bottom-up' analytical techniques such as FMEA (paragraphs 339 and 343).

403 The safety risk model is a useful tool that enables the railway industry to quantify the high level risk factors. However, since the safety risk model cannot be readily adapted to incorporate an assessment of the risk impact of individual components or to identify individual failure modes, the RAIB has made no recommendation in this area. The RAIB considers that risk analysis at the level of individual components is best carried out by designers, operators and maintainers of railway equipment. Accordingly recommendations related to understanding the risk of S&C component are targeted at Network Rail.

404 Network Rail standards for the maintenance of signalling assets recognised the value of predicting the hazards associated with failures of both systems and components (and failures to inspect or maintain), by using techniques such as failure modes and effects analysis, *Hazard and Operability Study* and *Task Analysis*. However, significantly, application of the standards was only mandated for changes to maintenance regimes, or for new assets.

405 The high reliance on historical data at the system level, and the limited application of predictive tools, made it less likely that Network Rail would recognise the performance of non-adjustable stretcher bar components as an important risk management issue.

406 For the reasons outlined at paragraphs 344 to 346, Network Rail did not see S&C with non-adjustable stretcher bars to be a significant risk, providing they were properly set up, maintained and inspected. At all levels of the organisation, Network Rail managers considered the tightening of bolts on stretcher bars to be a routine, normal activity that had always been undertaken by maintenance staff.

407 Given the above factors, and the general lack of detailed performance data for S&C components, Network Rail's senior managers had not recognised that at some locations the safe performance of existing S&C with non-adjustable stretcher bars had become over-reliant on routine inspection and maintenance activities.

408 Had Network Rail recognised loose or broken stretcher bar components as a significant risk factor under circumstances such as those that occurred in the accident at Grayrigg, it would probably have taken more steps to understand the causes and to identify suitable mitigation measures. For this reason it is considered that Network Rail's perception of the risk associated with the design of S&C using non-adjustable stretcher bars in some applications was an underlying factor in the accident at Grayrigg.

Network Rail's understanding of the design, inspection and maintenance requirements of S&C

409 Network Rail's understanding of the performance of its existing points with non-adjustable stretcher bars was incomplete. Relevant factors are described at paragraph 345.

410 Network Rail's engineers had commenced systematic design safety analysis of new designs, in particular the emerging design of the NR60 S&C (paragraph 360). However, Network Rail did not place a high priority on such an analysis for existing designs of points because it did not see them as high-risk provided they were inspected and maintained correctly.

411 By the end of 2006, Network Rail had ceased development of the 'business critical configuration management' approach. No alternative system of applying the principles of design safety analysis to existing assets was established (paragraph 363).

412 Network Rail's signalling engineers had established a risk-based approach to inspection and maintenance of signalling assets since 2000 or before. Nevertheless, it was restricted to:

- new designs; and
- proposals for amending inspection and maintenance intervals in order to balance effort expended against benefit derived.

413 The RAIB considers that the application of a systematic and risk-based process for reviewing the performance of existing S&C, and associated maintenance arrangements, based on an understanding of the design and safety functional requirements, would have had resulted in Network Rail having a better understanding of the causes of S&C component failures. This knowledge would then have informed management decisions related to design modification or changes to existing inspection and maintenance arrangements.

414 It is concluded that Network Rail's incomplete understanding of the design and performance of S&C, and its inspection and maintenance requirements, was an underlying factor in the accident at Grayrigg.

Standards and briefing to staff

415 This investigation has identified a number of deficiencies associated with Network Rail's standards governing the maintenance of S&C (paragraph 370). Had these standards been more suitable for use and properly briefed to staff it is possible that the following safe outcomes could have been achieved:

- proper investigation of the joint failure on 7 January 2007 and steps taken to ensure the safety of the line in the interim;
- correct adjustment of the residual switch opening; and
- correct tightening and checking of fasteners in 2B points.

416 The absence of clear, properly briefed, standards in these areas is considered an underlying factor in the accident at Grayrigg. The deficiencies in the contents of Network Rail's standards are associated with a lack of underpinning technical knowledge and analysis of the maintenance requirements.

Extent to which Network Rail's engineering safety management system was aligned with industry good practice

417 The RAIB has compared Network Rail's approach to engineering safety management with the rail industry's own accepted good practice, which is published by RSSB and entitled 'Engineering Safety Management' (the Yellow Book)[30]. The Yellow Book has been developed under the guidance of a steering group of railway professionals drawn from a wide range of organisations including Network Rail.

418 The Yellow Book does not have the status of a mandatory standard. Instead, it is guidance on the application of the safety management principles for people who are changing or maintaining the railway.

419 The Yellow Book was last fully revised in July 2007 and included an abridged version targeted at maintainers. Before this, in November 2005, Yellow Book Application Note 6 was published. This note covered the principles of engineering safety management as applied to the maintenance of railway infrastructure. Accompanying this note was a checklist designed to help maintenance organisations assess the extent of their own compliance with engineering safety management principles.

---

[30] Engineering Safety Management (the Yellow Book), RSSB, 2007. Available at http://www.yellowbook-rail.org.uk.

420 Using this checklist as a guide, the RAIB has assessed Network Rail's activities and management systems for the maintenance of S&C against the Yellow Book 'industry good practice'. This assessment has shown a number of inconsistencies between Network Rail practice and Yellow Book guidance with regard to the management of S&C. These are:

- investigation of failures (paragraphs 277 to 279 and 390 to 399);
- compliance with the requirements for surveillance/supervision of maintenance activities (paragraphs 270 to 274 and 337);
- processes for collecting asset data relevant to the safety and performance of S&C assets (paragraph 326);
- sampling of asset populations (paragraph 314);
- understanding of failure modes, the consequent hazards and risk arising (paragraphs 409 to 413).

421 Network Rail's maintenance of existing S&C with non-adjustable stretcher bars fell short of industry good practice as laid down in the Yellow Book in these areas. This was an underlying factor in the accident at Grayrigg.

Measuring performance

422 In the period before the derailment at Grayrigg, Network Rail had in place a range of key performance indicators. However, these key performance indicators did not include reference to the condition of S&C components, stretcher bars, brackets, fasteners or flangeway clearance. This, combined with the absence of routine S&C condition surveys, resulted in there being insufficient information on the actual performance of S&C assets.

423 A key aspect of an engineering safety management system is the selection of appropriate 'process safety indicators' to give early warning of system failures before catastrophic failure occurs. 'Process safety indicators' are measures of system performance that fall into two distinct categories:

- 'leading indicators' – active monitoring in order to measure the performance of selected risk control systems;
- 'lagging indicators' – reactive monitoring requiring the reporting and investigation of specific incidents and events to discover weaknesses in a system.

424 Current good practice in the area of performance measurement is published in the Health and Safety Executive guidance on developing process safety indicators[31]. This promotes six steps in the development of process safety indicators[32]:

1. the establishment of organisational arrangements to implement ('leading' and 'lagging') process safety indicators;
2. decision on the scope of process safety indicators;
3. definition of the risk control systems and the desired safety outcomes;
4. identification of the critical elements of each risk control system;
5. establishment of a data collection and reporting system; and
6. management review.

[31] HS(G) 254, Developing process safety indicators, HSE Publications, October 2006 (http://www.hse.gov.uk/pubns/books/hsg254.htm).

[32] A 'process safety indicator' can be seen as broadly equivalent to a key performance indicator. However a process safety indicator is focused on measuring those aspects of system performance that affect on the safety of a process.

425 Network Rail's own performance measurement system (ie its key performance indicators), although extensive, had not delivered a clearly defined set of process safety indicators in line with HS(G)254 for S&C. Had Network Rail's performance measurement system been better suited to the management of points assets, it is likely that Network Rail would have been better informed on the actual performance of the design and the adequacy of its inspection and maintenance activities, and been able to identify the defects in stretcher bar assemblies. This is considered to be an underlying factor in the accident at Grayrigg.

426 The RAIB considers that the effective management of engineering safety in the railway industry would benefit from the adoption of a performance measurement model similar to that outlined in the HS (G) 254 guidance. However, the development of suitable process safety indicators is conditional on a thorough understanding of risk and control measures.

Network Rail's process for the management of recommendations

427 The RAIB's investigation has found the following issues in relation to Network Rail's process for handling recommendations from the Potters Bar Investigation Board's second and third interim reports:

- no single person or group in Network Rail was driving recommendations forward to closure;
- no link between the risk that the recommendation was seeking to address and the timeframe for meeting the recommendation was established at the time that Network Rail had considered its response to the recommendations from the *Health and Safety Executive* investigation into the Potters Bar accident;
- the individual recommendations co-ordinators who did monitor progress with implementing recommendations were not technical specialists and were not therefore in a position to challenge the reasons they were given for delays in responding to recommendations (paragraph 380);
- in the period between July 2002 and February 2007, the visibility that the various safety committees such as SAFEX, strategic safety group and tactical safety group had on progress towards closure of recommendations was limited, although changes to process and a reduction in the number of open recommendations from major investigations resulted in a gradual increase in the time available for scrutiny of open recommendations towards the end of this period (paragraph 381); and
- the Board level sign off of closure proposals for recommendations from the Potters Bar investigations reacted to those proposals being presented for closure rather than actively reviewing progress of each one (paragraph 382).

428 Until November 2005, Network Rail supplied HMRI with periodic progress reports on the way it was dealing with Potters Bar recommendations. Network Rail did not receive any feedback from HMRI on its progress in dealing with Potters Bar recommendations or its proposals for closure. After November 2005, HMRI did not seek any further progress reports or closure proposals from Network Rail (paragraph 478).

429 By February 2007, three of the recommendations made to Network Rail that may have had relevance to Grayrigg (Appendix L) were still open (in Network Rail's own assessment) some four years after they had been made.

Network Rail's actions in response to previous incidents

The derailment at Potters Bar (May 2002)

430 The second progress report of the Potters Bar Investigation Board gave close attention to the circumstances that led to the failure of the adjustable stretcher bar, the non-detection of the degradation of the S&C and the consequences of the derailment. Consequently, those recommendations contained in the second progress report concerned with the management of S&C assets were interpreted by Network Rail and HMRI as primarily applying to S&C fitted with adjustable stretcher bars. Nevertheless, the report covered a number of issues that were relevant to the general management of all types of S&C asset.

431 The actions taken by Network Rail in respect of such issues has been assessed by the RAIB (Appendix L). The key findings of this assessment are summarised below:

- Network Rail's 'design safety analysis' performed on adjustable stretcher bars was not extended to include other types, despite a voluntary undertaking to do so (Appendix L) (recommendations HSE 2.1, 2.3);
- Network Rail's review of its maintenance standards and good practice guides had addressed a number of issues, but there was still a lack of clarity in the information available to staff maintaining S&C (recommendations HSE 2.4, 2.6);
- Network Rail's review of its arrangements for the reporting of defects, and associated management data systems, did not fully address the need for the collection of data on the performance of stretcher bar fasteners (recommendation HSE 2.7); and
- Network Rail did not put in place procedures for the independent inspection of points (recommendation HSE 2.8).

432 In the third progress report of the Potters Bar Investigation Board, attention was given to the systems for managing the inspection and maintenance of S&C and other safety critical systems. In relation to maintenance practice the report observed:

'Historic practice would appear to be that loose nuts and bolts would be tightened up during maintenance. Such an approach would have been to check for deficiencies and rectify them only when found, relying on other parts of the points system to ensure safe functioning in the meantime. This does not provide the same level of assurance as an approach based on preventative design and maintenance.'

433 Consequently, the recommendations contained in the third progress report are more general in nature and cannot be reasonably interpreted as applying only to S&C with adjustable stretcher bars.

434 Four of the recommendations are of particular relevance to the investigation into the accident at Grayrigg (recommendations HSE 3.4, 3.5, 3.10 and 3.14). Appendix L contains the RAIB's assessment of the actions taken by Network Rail in respect of each.

435 The RAIB's assessment concluded that Network Rail had made only limited progress with addressing some of the more general safety engineering issues identified in the third progress report. A particular finding is that few substantive actions had been taken to address recommendation HSE 3.5. This recommendation had required the adoption of:

'a risk-based approach to the procurement, installation, inspection, maintenance, etc of railway points, based on an understanding of the design and safety functional requirements'.

436 There is evidence that Network Rail had recognised that implementation of recommendation HSE 3.5 would require an extension of the design and maintenance analyses to include all types of existing S&C. For this reason an analytical technique had been identified ('business critical configuration management') as a means of addressing the need to define 'the design and safety functional requirements' for S&C and other safety critical systems.

437 The RAIB has considered whether the application of recommendation HSE 3.5 to existing types of S&C with non-adjustable stretcher bars could reasonably have led to Network Rail taking actions in sufficient time to avert the accident at Grayrigg in February 2007.

438 Formal techniques such as 'business critical configuration management' are based on a systematic identification of functional and safety requirements and the subsequent gathering and analysis of evidence to demonstrate that each requirement can be met by the design and associated maintenance activities. The full application of such a technique (as promoted by recommendation HSE 3.5) to existing designs of S&C with non-adjustable stretcher bars would have necessitated the acquisition of detailed data on the performance of S&C components, an understanding of the imposed loads and potential failure modes. Had such a technique been fully applied to existing designs of S&C with non-adjustable stretcher bars, Network Rail would have identified that in some applications the joint design was inadequate to withstand the imposed loads and therefore susceptible to rapid degradation and consequent high reliance on basic visual inspection to detect component failure. Such an analysis would also have highlighted the importance of the setting of the residual switch opening and maintenance of the correct flangeway clearance. Provided this analysis been undertaken within one or two years of the issue of the third progress report of the Potters Bar Investigation Board it is probable that steps could have been taken to mitigate the risk of joint failure at high risk locations before February 2007.

439 Network Rail had recognised the value of systematic analysis of design and maintenance requirements. However, Network Rail was convinced that its existing design of S&C was performing well in service (despite the known tendency for the fastenings at some locations to come loose) and did not therefore allocate a high priority to this asset for application of systematic analysis. Network Rail chose to focus its efforts in this area on emerging designs of points and new and modified maintenance standards for signalling equipment. As a consequence, an opportunity was missed to understand more fully the design and asset management requirements for existing S&C with non-adjustable stretcher bars.

440 In summary, the third progress report of the Potters Bar Investigation Board had identified the need for Network Rail to apply a risk-based approach to the management of its S&C assets based on an understanding of the design and safety functional requirements. Network Rail had accepted the value of such an approach but did not consider its application to existing S&C assets with non-adjustable stretcher bars to be a priority. The RAIB has concluded that the limited application of such a risk-based approach is an underlying factor to the accident at Grayrigg.

441 Some of the RAIB recommendations from this investigation into the derailment at Grayrigg address similar issues to those that were identified by the Potters Bar Investigation Board and RSSB following the derailment at Potters Bar. The links between the issues identified following the Potters Bar derailment and the recommendations arising from this investigation into the Grayrigg accident are identified in the last column in the table at Appendix L.

Other previous incidents

442 The serious degradation of points at Grangetown in August 2002 was not directly comparable to the circumstances at Grayrigg. Nevertheless, it revealed that the integrity of stretcher bar fastenings was critically dependent on correct set-up, inspection of the points and maintenance of track gauge. Network Rail's investigation report had therefore identified a need for a review of the suitability of stretcher bar bolts (recommendation 6). Although the solution proposed in this recommendation is unlikely to have addressed the problem of joint integrity, it is possible that effective management action in response to recommendation 6 might have led to other measures that would have improved performance of stretcher bar fastenings.

443 At the time of the accident at Grayrigg, Network Rail was still following-up technical issues arising from its investigation into instances of stretcher bar failures at Wood Green and Shaftholme, in the London North Eastern territory, during July 2006.

444 The incidents at Grangetown (2002), Wood Green (2006) and Shaftholme (2006) gave an indication that stretcher bar fastenings could, under certain circumstances, be subject to rapid degradation if the set-up of the S&C and maintenance of the track gauge is not assured. However, in none of the three incidents was the mode of failure directly comparable to the circumstances that later applied at Grayrigg. In the case of the two incidents that occurred in 2006 it is uncertain that any measures implemented in response to these incidents could have been completed in sufficient time to avoid the circumstances that were later to apply at Grayrigg. For this reason Network Rail's response in respect of these incidents is not considered to be an underlying factor relevant to the catastrophic failure that occurred at Grayrigg. However, the limited nature of Network Rail's responses to some of the issues identified in the investigations provide evidence of a lack of recognition of the need to explore the design and asset management implications of previous failures of stretcher bar joints.

Overall effectiveness of Network Rail organisation and management arrangements

445 A key management interface was the one that occurred between track and signal engineering in relation to stretcher bars. For this reason, following the accident at Potters Bar, Network Rail had set out management responsibilities in respect of the design, installation, testing, maintenance and inspection of S&C. These responsibilities and the interfaces between disciplines were understood at a senior management level and reflected in business processes and standards.

446 Despite there being a process in place for the briefing of staff in the maintenance areas, the clarity over the formal responsibilities in respect of S&C in general, and stretcher bars in particular, had not reached all managers and staff in the Lancashire and Cumbria maintenance area and elsewhere (paragraphs 256 and 468).

447 The placing of the area signalling engineer within the infrastructure maintenance manager's team increased the likelihood of being distracted from engineering duties by other activities (paragraph 307).

448 In the case of proposals for new and novel design, the track engineering function took a lead in driving the development programme forward. However, for existing S&C assets, signal engineering took the lead in reviewing the actual performance of the assets, although this was only occasionally focused on non-adjustable stretcher bars. Track engineering's activity in respect of existing S&C assets was mainly focused on responding to proposals for changes to maintenance practices or providing advice following incidents; there was no consideration of the stretcher bar assembly design.

449 Signal engineering initiatives, such as the roll-out of risk based maintenance, did not extend to consideration of points with non-adjustable stretcher bars. Track engineering management systems did not include any detailed monitoring of stretcher bar assembly performance.

450 Network Rail's monitoring of the reliability of non-adjustable stretcher bar components was incomplete and it did not carry out a detailed assessment of the adequacy of the design and inspection/maintenance arrangements. This is considered to be an underlying factor relevant to the high incidence of failure of non-adjustable stretcher bar joints (Appendix O).

Safety Regulation

Introduction

451 ORR is the safety regulator for Britain's railways; a description of its role is given in Appendix M. HMRI is the part of the ORR that enforces health and safety law on Britain's railways. HMRI also had this role when it was part of the Health & Safety Executive. It transferred to ORR in April 2006. In this section, HMRI's actions in relation to risk from S&C, and its actions following the publication of recommendations following the Potters Bar Investigation Board's investigation into the accident at Potters Bar on 10 May 2002, are reviewed in the context of the derailment at Grayrigg.

The Safety Regulator's actions in relation to S&C

452 From 2002, the planned work of HMRI, which on occasions included inspection of S&C assets, was contained within an annual plan which was initially called an intervention plan and subsequently a delivery plan. The term 'delivery plan' is used in the remainder of this section, irrespective of the year to which it applied. Separate delivery plans were developed for different duty holders, eg Network Rail, train operating companies, and London Underground. Each delivery plan was prepared using a structured process, which was intended to take account of HMRI's perception of risk from different elements of the railway and the way it was operated and maintained, as well as feedback from the implementation of current or previous delivery plans and other topics that HMRI considered needed to be addressed as a result of events during the current year.

453 Delivery plans were broken down into a number of topics (eg track, signalling, operations), and then sub-divided into specific assignments within each topic which contained the detailed activities that HMRI intended to undertake in the forthcoming year. Assignments were generally allocated to regionally-based inspectors. The regional teams were given the opportunity to nominate the assignments that they wished to be involved with, but the senior managers within HMRI responsible for the interface with each duty holder had the final say in allocating regional resources for each assignment. All assignments would be implemented by more than one of HMRI's regional teams. Those teams would plan and undertake the specific activities for each assignment, and the activities varied by regional team.

454 During 2005, individuals within HMRI were tasked with preparing risk topic strategies, using the information contained within RSSB's safety risk model (paragraphs 338 - 343), and the experience and knowledge of HMRI's own inspectors with specialist knowledge in different aspects of railway infrastructure or operations. One of the outputs was a numerate assessment of the risk in discrete areas (eg track, signalling, and level crossings), broken down into sub-areas as appropriate. The intention was that the strategies would inform the contents of the 2006/2007 delivery plan.

455 The risk topic strategy for track was completed in May 2005 and showed that S&C was the highest risk element (score of 92), with the 'remainder' of track scoring 89.

456 When all of the risk topic strategies were reviewed as part of the planning process for the 2006/2007 delivery plan, the five sub-topics with the highest risk scores (in order) were level crossing operation and use, employee safety, S&C, track integrity, and signalling asset integrity.

457 The team managing the development of all delivery plans decided that S&C should continue to be included within the track topic as this would allow train operating company issues to be accommodated (these had been absent from the top five risk topics). They also considered that by examining issues such as Network Rail's compliance with track standards and competence of maintenance staff, any delivery plan items on track would automatically lead to an examination of S&C in these areas.

458 The 2006/2007 delivery plan, when finalised, had five assignments in the track topic (which HMRI considered to include examination of S&C as well):

- management of track asset;
- management of poor track quality sites;
- risk management of engineering change;
- rail defects; and
- renewals.

459 As part of the process of briefing the national and regionally-based teams that would undertake the delivery plan assignments, HMRI prepared briefing sheets for each assignment. Each briefing sheet defined the scope of the assignment, its aims, the questions to be answered during the examination, the key issues, suggested methods of inspection, the outputs and milestones. The briefing sheet was the method by which a general assignment such as 'management of track asset' could be given greater focus. None of the delivery plan briefing sheets for the five track assignments included any specific reference to S&C. All inspectors carrying out the inspections were given a day-long briefing seminar on the contents of the plan and the briefing sheets. Although it does not appear as an agenda item or in the action notes, HMRI states that S&C issues were integral to the discussion.

460 The RAIB has seen nine reports prepared by regional teams who had implemented the five track-related assignments in 2006/2007. Of those reports:

- Four contained detailed references to S&C issues. The report prepared by the HMRI team in Kent investigating asset management made specific reference to a broken component that had been identified within a set of points and the general condition of the S&C in that area. The same team also identified deficiencies in procedures relating to tamping of S&C when undertaking the track renewals assignment. The Western team examining track renewals had visited S&C sites and found issues with regard to the planning of S&C renewals work by contractors and the handover certification when the work had been completed.
- Two contained passing references to S&C issues. The report prepared by the Scotland team on rail defects gave the example of 'ordering of bespoke S&C' as a possible reason for delays in dealing with a defect. The LNW report on the same subject made reference to the frequency with which ultrasonic inspection of S&C was taking place.
- Three of the reports contained no reference to S&C.

461 HMRI produced an overall report which brought together all of the findings from implementation of the 2006/2007 delivery plan. In the section on the management of poor quality track sites, the report referred to satisfactory performance in Western and LNW territories.

462 In the same section, the report also referred to three derailments involving S&C that had occurred in South East Territory during the year (one at Epsom and two at Waterloo); these were events that were relevant to that assignment rather than being a specific finding from the undertaking of the assignment.

463 Overall, between 2002 and 2007, there was a specific assignment on S&C in the delivery plan on two occasions:

- in 2002/2003 an assignment was added to the delivery plan to include inspections of S&C following the accident at Potters Bar; and
- in 2004/2005, there was a follow-up assignment to the 2002/2003 inspections.

464 Table 5 (following paragraph 315) shows the results from the inspections. HMRI discussed its findings with Network Rail. As well as noting that the numbers of faults found had reduced between 2002 and 2004, HMRI sought and received assurances from Network Rail that it would continue to try to reduce the risk from S&C faults.

465 Although HMRI only had two specific assignments on S&C in delivery plans during the period 2002-2007, HMRI's work, undertaken through the delivery plan process, included the analysis of management systems and the identification of failures which are likely to lead to risk.

466 In 2003/2004, under the assignment 'track standards management', the regional HMRI team in Scotland undertook inspections of S&C to assess management of gauge at switches. They found some instances of tight free wheel clearance at the heel of some of the points that were examined. It was only in Scotland that S&C were assessed as part of the track standards management topic and the free wheel clearance issue was not addressed in subsequent delivery plans.

467 In 2004/2005, the regional HMRI team in Scotland undertook inspections under the topic heading 'competence of signalling maintenance staff' which identified some specific issues in relation to:

- the training of staff in maintenance of stretcher bars;
- failures to report the tightening of nuts on stretcher bars; and
- the failure to use torque spanners when tightening nuts.

468 In the same year, the overall report on the outcomes from all the delivery plan topics identified that there was no detailed procedure specifying the responsibilities of the signal and track engineering departments for the various components within adjustable stretcher bars.

469 The 2007/2008 delivery plan included one item on management of S&C within the track topic. This was included partly in response to the S&C derailments that had occurred at Waterloo and Epsom during 2006 (paragraph 462).

470 HMRI collated the findings from all assignments into an overall report (paragraph 461), which described the principal issues emerging and provided an indication of those that HMRI considered to have national significance. A number of meetings were held between HMRI and Network Rail to discuss the outcome from delivery plan assignments:

- at headquarters level, senior managers from HMRI would attend a Network Rail tactical safety group meeting to discuss the outcomes of national significance;
- also at headquarters level, topic specialists from HMRI would discuss the outcomes from specific assignments with the relevant Professional Head within Network Rail; and
- regional inspectors would discuss outcomes from specific assignments with senior managers in the relevant Network Rail territory.

471 HMRI's contact with Railtrack and Network Rail on S&C issues was not limited to the delivery plan process. The meetings between HMRI's topic specialists and the relevant professional heads within Railtrack and Network Rail referred to in paragraph 470 were used to talk about other issues in the relevant discipline. HMRI stated that S&C was discussed during the periodic meetings on track held between HMRI's track specialist and Railtrack/Network Rail's professional head of track engineering.

472 Between 2002 and 2007 HMRI exercised its powers in prosecuting Railtrack/Network Rail and their infrastructure maintenance contractors three times as a result of derailments caused by S&C defects in this period, although none of the prosecutions was in relation to issues that were relevant to the derailment at Grayrigg. HMRI also served a number of improvement notices relating to the management of track in the same period, some of which focused on areas that affected S&C.

473 Following the first round of inspections of S&C undertaken by HMRI after the Potters Bar derailment (paragraph 463), HMRI served an improvement notice on the then infrastructure maintenance contractor and Railtrack at the south end of LNW zone in relation to a need to review and clarify arrangements for inspecting and maintaining shallow-depth switch components including point blade stretcher bar assemblies. It included the requirement to ensure that clear, comprehensive guidance was available on the proper assembly and adjustment of those components and for track and signalling personnel to be briefed appropriately. Compliance with the terms of the notice was recorded as being achieved five weeks later. As the Potters Bar inspections had been undertaken throughout the country, HMRI was able to judge whether this was an issue with national significance.

The Safety Regulator's handling of recommendations addressed to Network Rail and relevant to Grayrigg arising from investigations into the Potters Bar accident

474 After the derailment at Potters Bar on 10 May 2002, the Health and Safety Executive established the Potters Bar Investigation Board to carry out an investigation into the accident. Thirteen of the recommendations produced as a result of this investigation have relevance to the circumstances of the derailment at Grayrigg. These thirteen recommendations were all directed at either Network Rail or HMRI. The relevant recommendations are included in Appendices L and N.

475 The recommendations were made in the second and third interim investigation reports, one group of recommendations in July 2002 and the other group in May 2003. The Potters Bar Investigation Board and Railtrack / Network Rail met on three occasions between August 2002 and February 2004 to discuss the recommendations made to Network Rail. Network Rail and HMRI met on a further three occasions between January 2003 and June 2004 for the same reason. There were no further meetings between Network Rail and HMRI to specifically discuss Potters Bar after June 2004. RAIB has no evidence of any informal discussions after this date.

476 Recommendation HSE 3.26 (Appendix N) required the Health and Safety Executive to periodically review implementation of the recommendations contained in the second and third progress reports prepared by the Potters Bar Investigation Board. The Health and Safety Executive allocated the task to HMRI. When HMRI was transferred into the ORR, it retained its role in monitoring Network Rail's response to the recommendations from the Potters Bar Investigation Board's reports.

477 HMRI conducted its review through a group, initially known as the *Recommendations Action Progress Team*, but re-named in October 2005 as the *RAIB Recommendations Review* Group (known within ORR as R3G). Both groups existed to review responses to all major accident investigations, not just those from the Potters Bar investigation or, more recently, from RAIB investigations.

478 The Recommendations Action Progress Team and R3G were constituted from senior staff within HMRI and the Health and Safety Executive (from 1 April 2006 the ORR). The meetings considered periodic written submissions on progress from Network Rail. After November 2005, HMRI sought no further submissions on the Potters Bar recommendations from Network Rail. However, HMRI considered that in the course of its normal inspection activity, as part of implementing its delivery plan, it would be aware of Network Rail's work to progress the Potters Bar recommendations. The RAIB has found no evidence of formal feedback to R3G from the teams implementing delivery plans, but there is some evidence that individual members of the group received progress reports from inspectors in the field.

479 In 2005, the Health and Safety Executive engaged the services of consultants to conduct a review of actions being taken by all bodies that had recommendations addressed to them as a result of the investigations into the derailments at Hatfield (17 October 2000) and Potters Bar. R3G considered the findings from this review in 2006, using the information to determine whether it needed to continue to monitor Network Rail's actions in responding to the recommendations. The consultants reported that Network Rail had taken substantive actions in respect of many of the recommendations relevant to the design and maintenance of adjustable stretcher bars. They also reported that Network Rail was making progress in respect of recommendations on engineering management issues (eg HSE 3.4 and 3.5), although in some cases, progress was slow.

480 When HMRI decided that there was no longer a need to monitor Network Rail's response to recommendations, it proposed closure of them. Closure of a recommendation did not necessarily mean that the duty holder had completed all the associated actions. In some cases, it meant that HMRI believed that the best way to ensure that the recommendations were implemented was through specific assignments in the delivery plans. Appendix L shows that in February 2007, of the six recommendations relevant to the accident at Grayrigg that were addressed solely to Network Rail, Network Rail reported two as 'open' and four as 'completed' (which meant addressed to Network Rail's satisfaction), whereas ORR reported five as 'open' and one as 'closed'.

481 HMRI indicated that it did not provide written feedback to Network Rail of any concerns from the Recommendations Action Progress Team or R3G on Network Rail's proposed actions or on the progress being made.

482 R3G's decisions to 'close' recommendations of the Potters Bar Investigation Board were reviewed by ORR's *Safety Regulation Committee*, which included non-executive directors with a background in safety. Although the Safety Regulation Committee was not established until three years after the Potters Bar accident, the majority of recommendations arising from the investigation were still open at that stage and so it fell to the Safety Regulation Committee to review 'closure' proposals. This review took place in January 2008, at the time that the last of the recommendations had been 'closed' by R3G. The Safety Regulation Committee cannot direct the decisions of R3G on 'closing' recommendations, but it can endorse or challenge each decision, thereby providing a measure of independent oversight of the work of R3G in this area.

<u>The Safety Regulator's handling of recommendations addressed to HMRI arising from investigations into the Potters Bar accident</u>

483 The Potters Bar Investigation Board's interim reports included recommendations made to the Health and Safety Executive and HMRI. The most important of these recommendations and the actions taken before the date of the accident at Grayrigg are summarised in the table in Appendix N.

484 The process applied by the Health and Safety Executive, and later the ORR, to the consideration of actions taken in response to the recommendations addressed to HMRI was similar to that for recommendations addressed to Network Rail. As described in paragraphs 477 to 482, it involved the Recommendations Action Progress Team and subsequently R3G.

485 Recommendation HSE 3.10 concerned the need for HMRI to agree formally with Network Rail on the application of 'good engineering practice'. HMRI rejected this recommendation on the basis that it was not the role of the safety regulator to reach formal agreements (HMRI considered that it was the role of the safety regulator to ensure that a duty-holder's activities are monitored and improved as necessary). HMRI stated that it was concerned that entering into such an agreement might encourage duty holders to see good engineering practice as a static subject rather than one which would change over time. HMRI stated that its discussions with Network Rail on the development of good engineering practice were part of general dialogue at national technical liaison meetings between the two parties. At the time of the Grayrigg derailment, HMRI's response to recommendation 3.10 had not been presented to R3G for formal scrutiny.

486 Recommendations HSE 3.17 – 3.19 were concerned with the need for HMRI to review its own activities to improve focus on the prevention of catastrophic events. HMRI took actions to improve its structure, processes and strategy. In particular, the HMRI enhanced its formal process for the development of the annual delivery plan.

487 Recommendation HSE 3.21 concerned the need for HMRI to confirm that there were no significant gaps in the rail industry's management arrangements for ensuring that safety critical components or systems are fit for purpose. The ORR stated that in February 2007 it had been minded to close this recommendation on the basis of information provided by Network Rail detailing the progress it was making with the implementation of design safety analysis and risk-based maintenance, and information from its work on the ground. The ORR did not validate Network Rail's claims about progress made against any objective standard such as the Yellow Book.

488 Recommendation HSE 3.25 asked HMRI to agree with Network Rail a strategy and timetable for progressing Potters Bar recommendations. HMRI did not consider it appropriate for the regulator to agree such a timetable. They considered that Network Rail should propose their own timetable and HMRI would apply pressure if they considered it necessary to do so. Overall, HMRI considered that Network Rail was making progress in implementing recommendations. At the time of the Grayrigg derailment, HMRI's response to recommendation HSE 3.25 had not been presented to R3G for formal scrutiny.

489 HMRI's remit to monitor actions taken by Network Rail in response to Potters Bar recommendations came from recommendation HSE 3.26. This recommended that HSE should periodically review progress in the implementation of the recommendations from both of HSE's second and third progress reports, and publish its observations. HMRI decided that, because of the ongoing collection of evidence for potential legal proceedings, it was not appropriate to make the information public at that time.

490 In February 2007, three of the recommendations addressed to HMRI that the RAIB considers to be relevant to the derailment at Grayrigg had been 'closed' and four remained open (these figures include the two recommendations addressed jointly to Network Rail and HMRI – HSE 3.10 and 3.25). All were presented to R3G for closure in November 2007.

491 The decisions made by R3G to close recommendations addressed to HMRI were reviewed by the Safety Regulation Committee. Independent oversight of HMRI's decision not to implement recommendations HSE 3.10 and 3.25 as drafted was exercised as part of the Potters Bar recommendations review undertaken by the Safety Regulation Committee in January 2008.

Analysis – the actions of the Safety Regulator

The safety regulator's actions in relation to switches and crossings

492 In three of the five years leading up to the derailment at Grayrigg, HMRI's delivery plans did not include specific topics on S&C. HMRI said that S&C was implicit in their work on the track topic, and paragraphs 460 and 466 to 468 contain examples to support this statement.

493 Paragraphs 454 - 462 describe the planning, implementation and outcome of the delivery plan process for 2006/2007. HMRI had taken the decision not to include discrete S&C topics in the 2006/2007 delivery plan, believing that S&C would be covered as part of the track topic. Neither the five track assignments selected, nor the detailed guidance provided to those undertaking the assignments included any reference to S&C. Some of the reports on outcomes from track assignments show that the regional teams did include S&C within the scope of the work they undertook, but in only four cases was there a detailed reference to S&C issues. In three regional teams, S&C was not mentioned at all.

494 Although HMRI took action to improve its delivery plan process after the Potters Bar accident and again in 2005 by the introduction of risk topic strategies, there was no specific focus on S&C in the delivery plans for 2003/4, 2005/6 and 2006/7. The RAIB considers that this is explained by the following factors:

- HMRI's view of risk from S&C was influenced by the accidents that had occurred (the specific S&C assignments that did feature in delivery plans were related to the Potters Bar accident and the inclusion of an S&C item in the 2007/2008 delivery plan was in response to three derailments on S&C that had occurred in rapid succession in 2006). HMRI did not identify any major deficiency in the design of existing S&C or maintenance practices, although it had recognised that S&C was the highest risk element in the track system.
- Based on its own inspections carried out in 2002 and 2004, HMRI believed that the condition of points and stretcher bars was improving.
- HMRI believed that engineering management had improved since Network Rail had succeeded Railtrack as infrastructure owner of the national railway network. This belief was based partly on evidence such as the reduction in numbers of points defects found during HMRI's inspections of 2002 and 2004 and more generally on positive contact with Network Rail managers on safety issues during that period including an assessment undertaken by HMRI of the process by which Network Rail had brought maintenance in-house.
- HMRI considered that the primary purpose of inspections arising from implementation of delivery plans was to examine Network Rail's management processes for ensuring the safety of its assets, not to conduct an examination of the assets themselves. HMRI considered that assessing the safety of S&C was an integral part of the delivery plan assignments that were focused on the management of the track asset.

495 It cannot be determined with any certainty whether greater focus on S&C in the delivery plans could have prevented the Grayrigg accident, because:

- there was a range of possible S&C assignments that might have been considered and assignments relevant to the causes of the Grayrigg derailment might not have been selected; and
- the implementation of each delivery plan assignment was not undertaken by all of HMRI's regional teams and the outcome from inspections associated with an assignment that was relevant to the causes of the accident at Grayrigg, may have been dependent on which regional teams undertook the work.

496 However, as an observation, the RAIB considers that HMRI should have made explicit to the teams undertaking relevant delivery plan work in the field the need to include S&C in their work. This would have helped to ensure that S&C was given the level of attention commensurate with the results from the risk ranking process employed by HMRI to inform the contents of their delivery plans.

Actions taken by the safety regulator in response to those Potters Bar recommendations that were directed at Network Rail

497 Between November 2005 and the time of the Grayrigg derailment, HMRI did not actively seek updates from Network Rail on progress being made in implementing Potters Bar recommendations. It considered that it was aware through the delivery plan process of Network Rail's activities in this area. HMRI stated that it did not pursue this issue further as it was of the opinion that this would be difficult to do, because of a pending decision on prosecution arising from the Potters Bar derailment.

498 By the time that the accident occurred at Grayrigg, the ORR had been minded to 'close' the remaining Potters Bar recommendations, whether or not Network Rail had completed all of the associated actions. Having done so, the recommendations would have no longer been subject to monitoring at R3G, but monitored through inspections included in delivery plan assignments.

499 HMRI did not provide any feedback to Network Rail on progress or on the closure proposals it did review. The potential value of doing so would have been to advise Network Rail if there were problems with its proposals or actions, or the speed with which they were being taken. ORR is now required to provide feedback to the RAIB on the action taken in responding to recommendations contained within RAIB reports. In order to discharge that responsibility, ORR has developed a process of regular meetings with duty holders to discuss progress in implementing recommendations, at which the opportunity exists for ORR to provide feedback to duty holders on their intended actions and progress in implementing recommendations.

500 The RAIB has considered whether the accident at Grayrigg might have been avoided if HMRI had taken more vigorous action in scrutinising Network Rail's response to Potters Bar recommendations. HMRI's belief that the performance of S&C was improving (paragraph 495) meant that its perception of risk in this area was no different from that of Network Rail. It had no particular reason to insist that Network Rail made faster progress with implementing recommendation HSE 3.5.

501 Given HMRI's perception of risk in this area, the following steps would have been necessary to effect a change which could have resulted in pressure being brought to bear on Network Rail to expedite its response to recommendation HSE 3.5:

- HMRI would have needed to be aware of precursor data that indicated failures in non-adjustable stretcher bars, or, in the absence of such data, evaluated the risk from failures of non-adjustable stretcher bars;
- HMRI would have needed to ensure Network Rail prioritised and suitably resourced its response to addressing the risk from non-adjustable stretcher bars; and
- the action taken to address the risk would need to have been completed at Lambrigg by 23 February 2007.

502 Given HMRI's and Network Rail's belief about the risk from non-adjustable stretcher bars and the absence of precursor data to provide evidence of a contrary view, it is unlikely that all these steps could have been taken by 23 February 2007. For that reason, the RAIB considers that HMRI's actions in regard to the Potters Bar recommendations directed to Network Rail are not a factor in the accident at Grayrigg.

Actions taken by the safety regulator in response to those Potters Bar recommendations that were directed at HMRI

503 The recommendations from the Potters Bar Investigation Board's second and third interim reports directed at HSE (and subsequently delegated to HMRI) were primarily concerned with changing HMRI's own processes to allow a focus on catastrophic events, the monitoring of progress being made in implementing Potters Bar recommendations and the promotion of good engineering practice within Network Rail.

504 HMRI had modified its processes and increasingly used risk as one of the factors to be considered in planning its work for the following year. The introduction of risk topic strategies in 2005 and their use in informing the 2006/2007 delivery plan was a significant change in order to achieve this, although the RAIB has reservations about how the topics were briefed to inspectors undertaking the associated assignments (paragraph 496).

505 HMRI did not implement recommendation HSE 3.10 because it did not think it appropriate to enter into agreements with duty holders.

506 Similarly, the two recommendations associated with monitoring progress (HSE 3.25 and 3.26) were not implemented by HMRI. HMRI did not see it as appropriate to agree a strategy with Network Rail for addressing Potters Bar recommendations and did not publish the results from its scrutiny of progress reports and closure proposals. Publication of periodic progress reports could have provided reassurance to the public that suitable steps had been taken by a duty holder to prevent recurrence. However, HMRI considered that possible pending legal action was a reason for not publishing progress reports.

507 HMRI had, in effect, rejected recommendations HSE 3.10, 3.25 and 3.26. The RAIB has considered how the decision to reject those recommendations was scrutinised by the safety regulator.

508 The process employed for monitoring and closing Potters Bar recommendations addressed to HMRI was affected by those recommendations having been made before HMRI was transferred to ORR. The process that has applied since HMRI was transferred to ORR involves an initial evaluation of the nature and importance of the recommendation and associated actions. This determines whether scrutiny of the proposed method for addressing the recommendation, progress in implementing its provisions and oversight of the proposal to close the recommendation is undertaken by the Safety Regulation Committee, the ORR Directors Group, the ORR Board or some combination of these three bodies.

509 As Potters Bar recommendations were not subject to this initial evaluation, they were dealt with in a different manner. R3G did occasionally consider status reports on open recommendations, but HMRI's decision not to implement recommendations HSE 3.10 and 3.25 as drafted were not formalised through a closure proposal until November 2007, and were not subject to independent scrutiny until January 2008 (over four years after the recommendation had been made). The process currently employed by ORR is designed to ensure more effective scrutiny of actions associated with such recommendations in the future.

510 The RAIB has considered whether a different response to recommendations made to HMRI could have prevented the accident at Grayrigg. The purpose of these recommendations was to improve HMRI's own processes, ensure that Network Rail's management arrangements were robust and ensure that Potters Bar recommendations were properly addressed and progressed. Their focus was general in nature rather than specific to S&C. The RAIB considers that it is unlikely that a different response would have had any direct effect on the causes of the Grayrigg accident. For this reason, the safety regulator's response to Potters Bar recommendations addressed to HMRI is not considered to be a factor in the accident at Grayrigg.

Timeline of events

511 Table 6 below indicates the key dates in the deterioration of 2B points, taken from all the preceding sections, with the physical evidence in the left-hand column, and the intervention by operational staff in the right-hand column.

State of 2B points	Date	Intervention/activity on 2B points
Residual switch opening of between 4 and 8 mm.	April 2004	
Loose check rail bolts identified on crossing of 2B points	1 December 2006	Permanent Way Supervisor's inspection
	2 December 2006	Tamping to restore track alignment
Unclear what activities undertaken and hence point's condition. JPT stated that records do not show this and hence points condition is unclear	17 December 2006	Joint Points Team 3 monthly maintenance visit and patrol – Permanent Way part of the team not present
	24 December 2006	Routine basic visual inspection – nothing reported
	31 December 2006	Routine basic visual inspection – nothing reported
	6/7 January 2007	Overnight rectification of defects identified on 1 December 2006
3rd Permanent Way stretcher bar right-hand bracket joint had failed and was found fully loose	7 January 2007	Basic visual inspection identifies 3rd Permanent Way stretcher bar right-hand bracket joint fasteners failed – they are renewed
3rd Permanent Way stretcher bar right-hand bracket joint failed again	After 7 January 2007 and on or before 12 February 2007	
	by 10 January 2007	Six foot scanner from the New Measurement Train on 10 January 2007 showed relative position of rails
	14 January 2007	Routine patrol – nothing reported
	21 January 2007	Routine patrol – nothing reported
Inspection identified alignment defects with rectification within 6 months	25 January 2007	Permanent Way Supervisor's inspection

State of 2B points	Date	Intervention/activity on 2B points
	28 January 2007	Routine basic visual inspection – nothing reported
	4 February 2007	Routine basic visual inspection – nothing reported
	11 February 2007	Routine basic visual inspection – nothing reported
3rd Permanent Way stretcher bar right-hand bracket joint has failed and stretcher bar is fractured – dimensions recorded indicate flange back contact happening	by 12 February 2007	Structure Gauging Train ran on 12 February 2007 – scan data showed position of stock rail relative to switch rail
	18 February 2007	Missed basic visual inspection – nothing reported
2nd Permanent Way stretcher bar joints had failed and was missing – high forces from severe flange back contact	by 21 February 2007	Images from New Measurement Train on 21 February 2007 showed position/state of some components
Failure of 1st Permanent Way stretcher bar and lock stretcher bar	between 21 February 2007 and 23 February 2007	
Derailment	23 February 2007	

Table 6: Accident timeline

The Cause of the Derailment

This section describes RAIB's conclusions as to the causal, contributory and underlying factors that led to the derailment, and also its observations on infrastructure issues.

The cause of the derailment

<u>Immediate cause</u>

512 The immediate cause of the derailment was the interaction of the train with 2B points, which were in an unsafe state and forced some of the wheelsets from the first vehicle into the reducing gauge between both switch rails. All the other vehicles of train 1S83 derailed as a consequence.

Reference paragraphs 80 and 538.

Causal factors[33]

513 Lambrigg 2B points were in an unsafe condition on 23 February 2007 because all restraint on the left-hand switch rail had been lost. This was caused by successive failures of all three permanent way stretcher bar assemblies and the lock stretcher bar assembly. This combination of failures allowed the left-hand switch rail to move, un-commanded by the signalling system, to a position close to the stock rail without losing signalling detection.

Reference paragraph 174.

Fastener loading and design

514 The first failure in the degradation of the points was the undetected failure of the third permanent way stretcher bar right-hand bracket to switch rail joint, caused by the clamping force in the joint being less than the normal forces of traffic. The failure of the joint was a causal factor of the accident.

Reference paragraphs 139 and 182.

Recommendations 1, 2, 3, 4, 5 and 12.

Excessive residual switch opening

515 The setting of the escapement joint to give a residual switch opening of between 7 and 10 mm (this was greater than the nominally specified value of 1.5 mm), allowed the flange-back contact by most wheelsets[9] on the left-hand switch rail to occur once the third permanent way stretcher bar right-hand bracket to switch rail joint had failed, increasing the forces seen by the remaining stretcher bars and causing the subsequent collapse of the points system. The excessive residual switch opening was a causal factor of the accident.

Reference paragraphs 154, 182 and 284.

Recommendations 1 and 8.

Missed inspection

516 The deterioration in the condition of the third permanent way stretcher bar and its joint, and possibly some aspects of the deterioration of the second permanent way stretcher bar, should have been visible to a basic visual inspection on 18 February 2007, had it passed 2B points. The omission of the basic visual inspection of 2B points on 18 February 2007 was a causal factor.

Reference paragraphs 230 and 247.

Recommendations 10, 11 and 12.

[33] A causal factor is any condition, event or behaviour that was necessary for the occurrence. Avoiding or eliminating any one of these factors would have prevented the occurrence from happening.

Contributory factors[34]

Access for inspection and maintenance and resource availability

517 The constraints from access problems were a contributory factor in the the track section manager's decision to combine his supervisory inspection with a basic visual inspection on 18 February 2007, which ultimately led to 2B points not being inspected on that date.

Reference paragraphs 239 to 246 and Appendix H.

Recommendations 16 17 and 19.

518 The omission of the basic visual inspection at 2B points was not identified at the plan-do-review meeting on 19 February 2007. The depot records were incorrectly updated to record that inspection H was completed and this made it less likely that the omission of part of that inspection would be identified, or that corrective action would be taken. The weak process and inaccurate input was a contributory factor.

Reference paragraphs 231 and 251.

Recommendations 11 and 14.

[34] A contributory factor is any condition, event or behaviour that affected or sustained the occurrence, or exacerbated the outcome. Eliminating one or more of these factors would not have prevented the occurrence but their presence made it more likely, or changed the outcome.

Underlying factors[35]

519 The following points were underlying factors to the derailment:

- Network Rail's incomplete technical knowledge and analysis of the maintenance requirements of S&C with non-adjustable stretcher bars resulted in:
  - an absence of clear, properly briefed, standards for setting up, periodically checking and adjusting the supplementary drive and the residual switch opening;
  - little or no investigation of loose or missing fasteners; and
  - the maintenance instructions not specifying how stretcher bar fasteners found in need of tightening should be tightened.

Reference paragraph 416.

Recommendations 1, 7, 8, 9 and 12.

- The absence of awareness throughout Network Rail of the importance of the residual switch opening, its relationship with flange-back contact, and the need to check and rectify it.

Reference paragraph 290.

Recommendations 1, 2, 3, 4, 5, 6, 8 and 12.

- Network Rail's limited application of a systematic risk-based process for the analysis of design and maintenance requirements resulted in an incomplete understanding of the design, maintenance and inspection of non-adjustable stretcher bar S&C.

Reference paragraph 440.

Recommendation 1.

- Network Rail's perception that the risk associated with the existing design of S&C with non-adjustable stretcher bars in some applications was low adversely affected its regime for inspection, reporting of faults and maintenance of S&C of this design.

Reference paragraph 408.

Recommendation 2.

- Incomplete management information within Network Rail regarding the performance of safety-related components in S&C.

Reference paragraph 400.

Recommendations 2, 14 and 15.

- Within Network Rail's organisation there was an incomplete understanding of the performance of S&C, and no detailed assessment of the adequacy of the design or the inspection and maintenance arrangements.

Reference paragraph 414 and 450.

Recommendation 18.

[35] An underlying factor is any factor associated with the overall management systems, organisational arrangements or the regulatory structure.

- Network Rail's processes for performance measurement of S&C were not based on a thorough understanding of risk and control measures.

Reference paragraph 425.

Recommendations 2 and 14.

- Network Rail's maintenance of S&C assets fell short of industry good practice as laid down in the Yellow Book.

Reference paragraph 421.

Recommendation 20.

Observations[36]

520 The process used for detecting and recording defects found by the basic visual inspections at Carnforth varied considerably between individuals. As there is no physical evidence that the joint was deteriorating until after the inspection of 11 February 2007, it is not possible to definitely link this process to the derailment.

Reference paragraph 213 and 234.

Recommendations 1, 10 and 13.

521 The track section manager worked extended hours in the weeks before the accident. The RAIB has no clear evidence whether this contributed to the omission of the basic visual inspection but is aware of other work which suggests that there may be a link between long hours and performance. The RAIB recommends further study in this area as it is aware that supervisory managers often work extended hours.

Reference paragraph 229.

Recommendation 29.

522 In the course of this investigation, the RAIB found considerable evidence of issues relating to staff competence, indicating that there were deficiencies in the competence management system. However, the only competency issue that can be positively linked to the derailment was the lack of knowledge about residual switch opening issues, which has already been identified as an underlying factor. The other deficiencies in the competence management system, although unsatisfactory, cannot otherwise be directly linked to the causation of the accident. Accordingly, several recommendations include issues regarding competency of staff.

Reference paragraphs 208, 213 and 264.

Recommendation 12.

523 There were deficiencies in the audit system, primarily because it did not include any examination of the asset. The audits that were performed did not detect the inconsistencies in the documented maintenance regime and its practice.

Reference paragraphs 336 and 337.

Recommendation 15.

524 Network Rail's investigations into non-adjustable stretcher bar fastener failures at Grangetown, Wood Green and Shaftholme before the Grayrigg accident reviewed the performance of inspection and maintenance, but did not carry out a detailed investigation into what caused the fasteners to come undone.

Reference paragraph 444.

Recommendation 5.

525 The placing of the area signalling engineer within the infrastructure maintenance manager's team increased the likelihood of being distracted from engineering duties by other activities.

Reference paragraph 447.

Reference actions taken, paragraph 681.

---

[36] An *observation* is an element discovered as part of the investigation that did not have a direct or indirect effect on the outcome of the accident but, in the opinion of the RAIB, does deserve scrutiny.

526 HMRI identified that S&C was the third highest risk element on Network Rail in preparing risk topic strategies as input to their 2006/7 delivery plan, but decided not to include S&C as part of the track topic. HMRI did not reflect the significance of S&C risk in the briefing of the track assignments chosen for the 2006/2007 delivery plan to ensure that an appropriate focus on S&C risk was made by its regional teams charged with undertaking the assignments.

Reference paragraph 493.

Recommendation 21.

527 The detection of the position of the open switch rail relied upon the integrity of the connection of the detection equipment to the switch rail. Alternative options that might detect open switch movement include the provision of independent open switch rail detection, or trying to link the detection rod and the switch separately from the connection to the lock stretcher bar. On the basis of one accident, where the lack of this detection may not have made any difference to the outcome, the RAIB considers that making these changes is not likely to be reasonably practicable in relation to the risks identified. This is particularly the case if the RAIB's other recommendations are implemented, and the risk of a similar failure occurring is thus reduced.

Reference paragraph 171.

The Derailed Train: Evidence, Analysis and Conclusions

This section describes the evidence, analysis and conclusions relating to the performance of the vehicles of the train during the accident, under the following headings:

- the train before the derailment;
- the derailment sequence;
- damage to the train;
- egress routes from the train;
- analysis of causes of injury;
- crashworthiness performance of the train; and
- conclusions.

Evidence, Analysis and Conclusions: The Derailed Train

Introduction

528 The RAIB examined the derailed train, its associated records, and the evidence collected on site to determine:

- the pre-derailment condition and operation of the train and whether there were any faults which may have contributed to the derailment;
- the post derailment paths of the vehicles, the sequence of events from the initial derailment at 2B points until the vehicles came to rest, the resulting damage to the train and the accelerations experienced by the vehicles;
- how passengers and crew evacuated the train;
- how passengers and train crew became injured; and
- the crashworthiness performance of the train and its on-board emergency lighting system.

Pre-derailment condition of the train

Maintenance condition

529 The train's maintenance records from 1 September 2006 to the day of the accident were continuous and showed that maintenance examinations had been carried out to the schedules laid down by the train's manufacturer, Alstom Transport Ltd, and that none were overdue.

530 The records also showed the defect history for the train over this period and the subsequent maintenance activities undertaken to correct those defects. There was no indication of any ongoing major failures and the types of defect recorded were either minor failures or planned equipment changes.

531 There were 41 maintenance work orders open at the time of the accident which covered defects, monitoring of equipment, examination and capturing of information. There were also four safety bulletins for the class 390 trains, issued by the manufacturer, in force at the time of the accident. None of the outstanding work covered in the open work orders and the safety bulletins could have contributed to, or altered, the cause or consequences of the accident.

532 The *wheel profiles* on the leading five bogies were within the allowable tolerances specified in Railway Group Standard GM/RT2466, 'Railway Wheelsets'. Data from the *wheelchex* (wheel impact monitoring) sites at Cheddington (Hertfordshire) and Dallam (Warrington) over which train 1S83 ran on its journey on 23 Feb 2007, showed no abnormal wheel forces due to defective wheel geometry.

Operation of the train and its systems on the approach to Lambrigg

533 The running status of a class 390 train is monitored by several different onboard systems including OTDR equipment, the Train Management System, the tilt system and the Traction Electronics Control System. Data from these sources was used to determine the status of the train before the accident and also to provide information on the derailment sequence.

534 The tilt system was recorded as 'available' (ie the train was permitted to tilt). There was no *wheel slide protection* activity and all safety systems monitored were in the status expected of the train in normal operation. There were no fault messages reported in the Train Management System, and the tilt system was functioning correctly.

535 The OTDR showed that the train left Preston Station at 19:43:45 hrs bound for Carlisle. Shortly afterwards, the tilt system was correctly enabled and the train was running under the supervision of the *tilt authorisation speed supervision system*. After passing through Oxenholme, the driver engaged the Speed Set system and demanded 95 mph (153 km/h), the correct EPS for this section of the line. The train subsequently maintained a speed of between 94 and 95 mph on the approach to Lambrigg.

536 At 20:11:37 hrs, the OTDR on the train recorded its last event before reaching 2B points. This was a change in traction demand made by the Speed Set system, and occurred 492 yards (450 metres) before 2B points. At 20:11:49 hrs, when the front of the train was approximately 48 yards (44 metres) beyond the toes of 2B points, the OTDR data shows that the relays which control the application of emergency braking de-energised briefly and then re-energised and that a very short *emergency brake application* demand was made. This abnormal event, after passing 2B points, was the first indication of the derailment on the OTDR. None of the messages recorded by the train systems up to this point indicated the train had any fault which could have caused or contributed to the derailment.

The derailment sequence

537 The likely sequence of events, from initial derailment to the time the vehicles came to rest, was constructed using information from:

- marks and damage at the switches of 2B points and on the track and infrastructure along the derailment path;
- marks and damage to the train;
- data recorded by systems on board the train;
- accounts of passengers and train crew; and
- simulation studies of post-derailment behaviour.

In the following paragraphs, vehicles and bogies are referred to in running order; ie bogies 1 and 2 belong to vehicle one; bogies 3 and 4 belong to vehicle two and so on.

538 Vehicle one was the first to derail, either by bogie 1 or 2. It is unclear from the derailment marks exactly which of these bogies derailed first but the outcome, in terms of subsequent vehicle paths, would have been similar. It is clear that bogie 1 was derailed by the time it reached the crossing of 3A points. The time between it reaching 2B points and reaching 3A points would have been 3.2 seconds. Marks on the components of 2B points made by the wheels of the train showed that at least four wheelsets derailed at the switch rails of 2B points.

539 The mechanism of derailment (of either bogie 1 or 2) was flange climb of the wheelsets as they were constricted between the converging left and right-hand switch rails of 2B points, as explained in paragraph 161. The movement of the left-hand switch, which initiated the gauge narrowing, occurred either under the preceding train or under the leading bogie of the train without derailment.

540 Track damage showed that a number of wheelsets had crossed over and run close to, or in, the up line. These included wheels from bogie 2 and bogie 3. Whether or not bogie 1 derailed first, it stayed close to the down line and with bogies 2 and 3 running close to the up line, a misalignment formed between vehicles one, two and three, as shown in Figure 33.

Figure 33: Diagram of the misalignment which developed between vehicles one, two and three after passing 2B points

541 After the initial constriction of the wheelsets between the switch rails, the left-hand switch toe gap widened. This was probably initiated by the dynamic effects of the derailed wheels from the leading bogies on the switch rail causing the slight movement that was necessary for the first of the following wheels to pass to the left of the switch rail. After these wheels passed through the newly widened switch toe gap, they were derailed almost immediately by the effect of the preceding bogies, running derailed and deforming the track. The deformation worsened as more bogies derailed, and widened the switch toe gap further, so that all remaining wheels ran to the left of the switch rail before derailing on the distorted track.

542 By the time bogie 1 reached the 3B-to-3A crossover, it was running derailed to the down cess, either because it had derailed at 2B points or subsequently due to the *yaw* attitude of vehicle one resulting from the misalignment with vehicle two. The front of vehicle one then demolished a row of light-weight signalling location cabinets positioned alongside the track and struck an eight-metre length of scrap rail by the line-side, but these did not significantly affect its trajectory. Bogies 2 and 3 continued to run close to the up line, while the following bogies remained closer to the down line.

543 The misalignment between vehicles one and two developed into a jack-knife condition as the rear of vehicle two was being pushed by the trailing vehicles. The yaw angle of vehicle one relative to the track (when viewed from above) increased anticlockwise and as it experienced increasing lateral drag on its bogies, resulting in overturning forces, it rolled progressively over onto its right-hand side. It struck an overhead line equipment mast (M1) on the left-hand side of the track while partially rolled over as shown in Figure 34, leaving impact marks on the vehicle's *cantrail* and roof. The *coupler* between vehicles one and two, which was overloaded by the jack-knifing action, probably fractured and separated at this time, causing the emergency brake to be applied automatically as the *train continuity circuit* was interrupted.

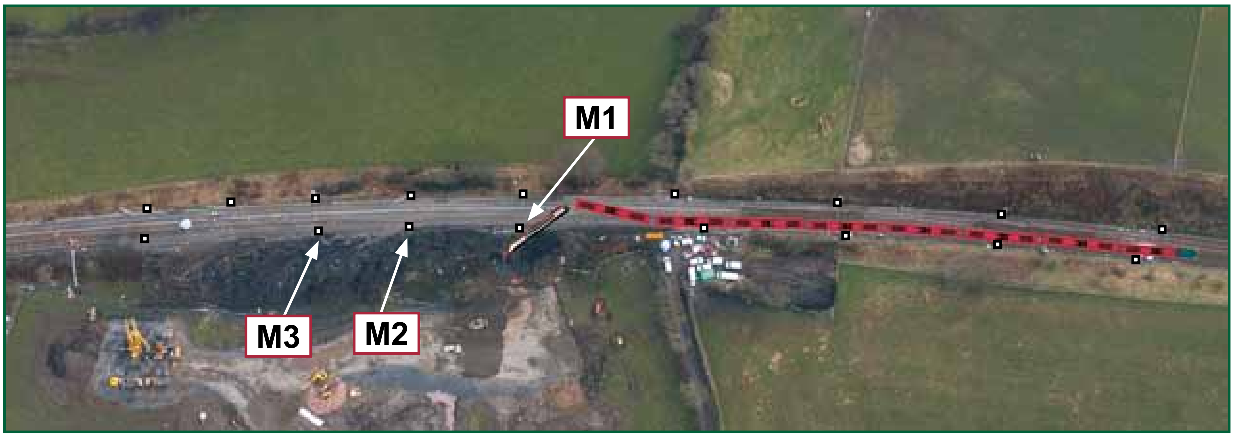


Figure 34: Diagram of vehicle one, partially rolled over and striking overhead line equipment mast M1

544 Vehicle one continued to yaw in an anticlockwise sense as it was pushed by the remainder of the train. When it was approximately perpendicular to the track and rolled over about 70 degrees onto its right-hand side, its trailing end struck mast M2 (Figure 34). More pushing from the vehicles behind it caused vehicle one to yaw even further until it lost contact with vehicle two and began to slide down the embankment slope. As it descended the embankment, it rolled over onto its side and continued to yaw. It came to rest at the foot of the slope, approximately 9 – 10 seconds after it first derailed, and having rotated through approximately 190 degrees to face backwards.

545 Vehicle two, after becoming detached from the leading vehicle, continued to run misaligned and was pushed into yawing in a clockwise sense by the following vehicles. The trailing end of vehicle two struck overhead line equipment mast M3 as shown in Figure 35. Thereafter, it began to roll on to its left-hand side as the overturning forces resulting from the drag on its bogies increased. Its leading end then struck two overhead line equipment masts on the up line (M4 and M5 in Figure 35) and its centre section struck mast M6 on the down line. As it approached an orientation approximately perpendicular to the track, it was skidding on its left-hand side, perched on the crest of the embankment by the down line. Vehicle two came to rest shortly after with its trailing end at the foot of the embankment and its leading end overhanging the up line.

Figure 35: Reconstruction of vehicle two first striking overhead line equipment mast M3

546 Vehicles three to five followed the trailing end of vehicle two down the embankment, rolling onto their left-hand sides just before coming to rest. Vehicle five struck the concrete foundation block from overhead line equipment mast M2 as it ran down the embankment. The couplers between vehicles two and three, and vehicles three and four parted but the interconnecting electrical cables remained intact, indicating that separation most likely occurred at, or near, the end of their travel.

547 Vehicles six to nine remained coupled and followed the preceding vehicles, coming to rest variously orientated on the embankment slope and in the down cess, with the cab of vehicle nine just past the toes of 3A points. The leading bogie of vehicle six was found on top of the concrete block first struck by vehicle five and, which formed the foundation for mast M2. Figure 36 shows the final location of the vehicles. The time from the moment of the derailment until all the vehicles came to rest was approximately 13 seconds.

Figure 36: Final location of the vehicles from train 1S83 after the derailment

Damage to train structures

548 As a consequence of the derailment, vehicle one suffered damage to the leading and trailing ends and the right-hand body side, which was buckled and severely scored (Figure 37). The floor was distorted and underframe-mounted equipment was severely damaged. There were concentrated impact damage marks at the two positions along the right-hand cantrail where it had struck overhead line equipment masts (paragraphs 543 and 544) but there was no loss of survival space or penetration through the body structure. Damage to the left-hand side was confined to the leading door and underframe equipment.

Figure 37: Damage to the right-hand bodyside of vehicle one and obstacle deflector

549 The *obstacle deflector* at the leading end of vehicle one (Figure 37) had been pierced by a length of rail at its lower left-hand corner (paragraph 542). The leading bogie of vehicle one was damaged but remained attached to the body. The trailing bogie had become detached from vehicle one at the end of its trajectory and was found near it. The coupler connecting vehicles one and two was bent and fractured, consistent with an overload in bending.

550 Vehicle two sustained damage to both leading and trailing ends, particularly at the left-hand corner of the trailing end which had been pushed in by approximately 320 mm. This localised damage probably occurred when it slid down the embankment on its side, at the end of its travel, and hit the ground before it came to rest. The left-hand side was severely scored by sliding on ballast and had been pushed in by approximately 160 mm at the central section (Figure 38). The right-hand body side was scarcely damaged. Three of the four external doors were jammed in the closed position but this did not hamper evacuation as explained at paragraph 565. Both bogies were damaged but remained attached to the body. The coupler attaching vehicle two to vehicle three had parted at its central connection.

Figure 38: Damaged central section of the left-hand bodyside of vehicle two

551 Vehicle three suffered damage to both leading and trailing ends, particularly the leading left-hand corner which had been pushed back approximately 350 mm and inward by approximately 250 mm, resulting in a minor loss of survival space in this area. Both external doors on the left-hand side were jammed closed. The form of the localised damage and the mud stuck to it was consistent with an impact with the ground during the final stages of its movement. There was no loss of survival space in the passenger compartment. The left-hand bodyside, onto which the vehicle had rolled at the bottom of the embankment, suffered superficial damage. The right-hand bodyside was undamaged. Both bogies were damaged but remained attached to the body. The coupler connection between vehicles three and four fractured, consistent with an overload failure.

552 Vehicles four to nine suffered minor damage to their bodyshells: typically scrape marks, minor dents and bruises and tearing or crushing of the glass reinforced plastic mouldings at the body ends. All the bogies on these vehicles, with the exception of those from vehicle five, ran derailed but remained attached to their vehicles. The trailing bogie of vehicle five became completely detached and its leading bogie was almost detached following impact with the concrete block foundation of mast M2. Subsequently it became detached during recovery.

Damage to train interiors and windows

Interiors

553 The interior of the passenger compartment in vehicle one remained largely intact except for the detachment of all six reading light panels from their mountings. The retaining locks, which secure the outboard edges of the panels to the interior of the bodyside, had distorted and allowed the panels to swing down on hinges mounted on the luggage racks. Five panels detached completely (Figure 39); the sixth remained attached by its hinges.

Figure 39: Detached reading light panels in the leading right-hand side of vehicle one

554 At the leading end of vehicle one, the door to the driver's cab could not be opened because a ceiling panel in the cab access corridor had become partially detached and displaced enough to interfere with the door. A similar detachment occurred in a derailment on 26 November 2005 at Moy, Inverness-shire, involving a Class 170 unit[37]. The *emergency coupler*, located in the compartment between the passenger saloon and cab, also broke free of its mount, but did not obstruct the cab door.

555 The interior of vehicle two suffered damage as a direct result of the left-hand bodyside deforming inwards (paragraph 550). Five pairs of seats in the centre section of the left-hand side, each having two pedestals mounted to the floor, became detached (Figure 40) as the bodyside pushed against them, either because the seat pedestals fractured or because the mounting bolts pulled out of the floor fixings. There were equal numbers of each type of failure; two pedestals also exhibited both types of failure.

[37] "Derailment at Moy, Inverness-shire on 26 November 2005", RAIB report No. 22/2006, available at www.raib.gov.uk.

Figure 40: Detached seating on the left-hand side of vehicle two

556 The interiors of vehicles three to nine remained largely intact. However, a number of catering trolleys broke free during the derailment. At the trailing end galley in vehicle nine, several trolleys, which were stowed and locked away, broke free. This area is not normally accessible to passengers and there were no staff in this area at the time. In vehicle three and vehicle eight, trolleys also broke free and ran down the aisle. In the case of the latter, the trolley came free from a member of the train crew who was pushing it, then it toppled onto its end, and slid down the length of the aisle at speed. The trolley brakes had been applied by the crew.

Windows

557 All the standard bodyside windows on the train are laminated double glazed units comprising a toughened outer pane, an air gap, and a laminated inner pane. One window on each side is designated an 'egress window' and has a different type of laminated inner pane from the standard window so that it can be broken more easily for escape.

558 In vehicle one, all the standard windows on the right-hand side shattered (ie with the inner and/or outer panes fractured). However, none of these windows had disintegrated to the extent that there was a hole in the bodyside which might not have constrained passengers within the train. Only the egress window on this side was completely broken through, leaving an exposed hole. On the left-hand side, all but one of the windows had shattered inner and outer panes but none was completely broken through. One passenger was partially ejected from this vehicle through an egress window (paragraph 567).

559 In vehicle two, five of the eight windows on the left-hand side had shattered inner and outer panes and of these, three in the centre section were completely broken through, including one egress window. Three other windows had shattered outer panes only. Approximately half a tonne of ballast and soil had entered the interior through these windows. All the windows on the right-hand side remained intact. One passenger was ejected through an egress window in this vehicle (paragraph 567).

560 In vehicle three, eight of the nine windows on the right-hand side had shattered outer panes, but only one of these, an egress window, was completely broken through. On the left-hand side five of the eight windows had shattered outer panes but none was completely broken through.

561 In vehicles four to nine, 15 of the total number of 92 windows on these vehicles were shattered, but only one egress window, located on the right-hand side of vehicle four, was broken through completely.

Egress routes from the train

562 The train had 52 egress routes through doors and gangways and 18 exits through emergency egress windows. None of the doors had been locked out of use before the derailment but many became blocked either because of damage or the attitude of the vehicles at rest. The status of non-window egress routes, whether blocked, hazardous or available, and the routes used by passengers and crew to evacuate the train, assisted by the rescue services in some cases, are summarised in Figure 52 of Appendix Q. This information is based on photographic and witness evidence and results of door tests undertaken on the recovered vehicles when upright.

563 In vehicles one to five, 12 of the 29 non-window egress routes were completely blocked, either because the bodyside doors were on the low side and against the ground (ten cases) or on the high side and jammed closed (two cases). Eight other routes through bodyside doors on the high side remained available but they would have been difficult to use without some form of steps or assistance. A further three routes through gangway connections on vehicles one and two were passable but hazardous for various reasons: eg the presence of broken toilet doors, a jump down onto the track, or the steep embankment slope. The remaining six routes through the gangway connections in vehicles three to five appear to have been passable with care. The two crew egress routes in the leading cab were not used.

564 In vehicles six to nine, four of the 23 non-window egress routes were completely blocked, because either the doors were jammed closed (one door on each of vehicles six and nine) or the interior door to the galley to access them (vehicle nine) was jammed closed. The remaining routes were useable, but the down-the-slope egress routes were not used because they were more hazardous than the up-the-slope routes.

565 Egress windows were used in vehicles two and three as shown in Appendix Q. In vehicle two, most passengers exited through the three broken windows on the left-hand side, either by jumping down onto the embankment or by means of a ladder obtained from the nearby farm. In vehicle three, passengers broke the right-hand side egress window, having tried unsuccessfully to open the trailing right-hand door, and climbed out onto the high side. They then used ladders to descend to ground level. There were two abortive attempts to break out of egress windows. In vehicle one a passenger abandoned his attempt to break out when glass showered down on injured passengers below the window. In vehicle four, passengers broke through the egress window on the high side but then most of them opted to use the trailing right-hand door when it was found to be available.

Analysis of causes of injury

566 The RAIB has considered the severity of the physical injuries sustained in each vehicle and how those injuries were caused. The location of each passenger and crew member on the train was identified using witness accounts and on-board CCTV recordings. Injuries were analysed using information from:

- passenger and crew accounts;
- surveys of the vehicles' interiors; and
- vehicle movements during the derailment (paragraphs 537 to 547).

The analysis has not attempted to capture or quantify the level of any psychological trauma suffered by passengers and crew.

567 The distribution of fatal, serious and minor injuries for passengers and train crew in each vehicle is given in Table 7. The principal cause of injuries at Grayrigg was *secondary impact*, which occurs when vehicles are subjected to high accelerations and occupants are forced into impacts with the interior or other passengers. Very few occupants were injured by other causes; among the exceptions was a passenger who was ejected through an egress window in the centre section of vehicle two as it came to rest on the embankment, sustaining serious injuries as a result. Another passenger, who also suffered serious injuries, was found with her lower body protruding out of the broken egress window on the right-hand side of vehicle one. It is not clear in this case how much injury, if any, was caused by the partial ejection. Some passengers also suffered minor grazes to hands and face caused by broken glass during egress through broken windows.

Vehicle	Passengers + [Crew]				
	No Injury	**Minor**	**Serious***	**Fatality**	**Totals**
1	0	2	9 + [1]	1	**12 +[1]**
2	1	11	6	0	**18**
3	4	13	2 + [1]	0	**19 + [1]**
4	2	15	6	0	**23**
5	4	10	5	0	**19**
6	1	1	0	0	**2**
7	3	0	0	0	**3**
8	3 + [1]	6	0	0	**9 + [1]**
9	0 + [1]	0	0	0	**0 + [1]**
Totals	**18 + [2]**	**58**	**28 + [2]**	**1**	**105 + [4]**

[* Serious Injury as defined in the Railways (Accident Investigation and Reporting) Regulations 2005]

Table 7: Distribution of injuries by vehicle

568 Vehicle one was subjected to the most extreme movements of any of the vehicles (paragraphs 543 and 544). The yaw rotation during the latter stages of its movement generated longitudinal accelerations which added to the general deceleration of the vehicle. This was compounded by other accelerations in the vertical and lateral directions, also resulting from the motion of this vehicle, the combined effect of which was that passengers were thrown out of their seats and around the vehicle interior.

569 Mrs Masson, who lost her life in the accident (paragraph 92), was seated at the trailing right-hand corner of vehicle one and suffered multiple injuries, principally to the chest and the head.

570 The driver of the train suffered serious injuries when he was propelled into the ceiling of the cab and then over the console into the windscreen, most probably during the earlier stages of the derailment but not at the switches of 2B points.

571 All 28 passengers who sustained serious injuries were located in the first five vehicles which rolled over onto their sides. All the occupants of vehicle one were thrown out of their seats and all sustained serious injuries. The percentage of those thrown from their seats in each of vehicles two to five, varied between 30 % and 60 % and approximately half of these people suffered serious injury. Generally, those passengers who were seated on the high side during the roll-over sustained more severe injuries than passengers on the low side. However, some passengers seated in the low side also suffered serious injuries in vehicles one to five and reported being struck by other passengers.

572 Some passengers in vehicle one reported striking or being struck by the reading light panels which became detached (paragraph 553). These panels probably caused some of the head injuries reported in that vehicle. Some passengers also reported being trapped by the same panels and found it difficult to move once the vehicle had come to rest. Other head injuries in vehicle one and other vehicles that rolled over appear to have been caused by impacts with the underside of the luggage racks.

Analysis of crashworthiness performance of the train

Standards

573 The train was designed to be compliant with the following standards aimed at improving survivability in train accidents:

- Railway Group Standard GM/RT2100, 'Structural Requirements for Railway Vehicles', Issue 2, April 1997, which defines the static and fatigue strength requirements and *collapse characteristics* for the vehicle's bodyshell and other major parts. This was and remains a mandated standard.
- Railway Group Standard GM/TT0122, 'Structural Requirements for Windscreens and Windows on Railway Vehicles', June 1993, which mandated the use of laminated glass for all non-egress windows, a requirement which remains current.
- British Rail codes of practice GM/RC2502, 'Code of practice for structural aspects of railway vehicle interiors', Issue 1, November 1994, and BR/BCT609, 'Railway Vehicle Interior Crashworthiness', Issue 1, July 1996; which define the static strength and collapse characteristics for interior furniture such as seats and tables. These standards were issued for guidance and represented best practice at the time the Pendolino was designed; they were not mandatory.
- Additional safety features (beyond those mandated by Railway Group Standards) which were required by HMRI for new trains operating above 100 mph (161 km/h) with passengers in the leading vehicles. These additional safety features, introduced by the train designers, comprised enhanced energy absorption capacity in the *crumple zone* of the driving cabs, passenger free spaces behind the cabs, stronger vehicle sides and a majority of rearward facing seats in the leading vehicle. These safety enhancements were accepted by HMRI in 2002.

Vehicle structures

574 Some of the structural crashworthiness features built into the Pendolino, such as crumple zones and *anti-climbers* were designed to mitigate the effects of collisions between trains and, therefore, these features were not exercised in this derailment. Features of the design which were of particular relevance to passenger safety in this derailment were the structural partitions and double skinned aluminium extrusion construction of the bodyshell, strength of the couplers, retention of the bogies and laminated bodyside windows as described in the following paragraphs. All but the first two features are specified in Railway Group Standard GM/RT2100.

575 There was no significant loss of survival space in those vehicles which rolled over onto their sides. Although the left-hand bodyside of vehicle two bowed inwards as it slid along the ballast, it was supported by the internal structural partitions located at the one-third and two-thirds positions. These were fitted to stiffen the bodyshell to minimise vibration and improve passenger comfort; however, their strength also helped to minimise the deformation and intrusion into the passenger compartment.

576 The bodyshells of the leading two vehicles resisted penetration by the overhead line equipment masts into the passenger compartments, probably assisted by the double-skin construction of the bodyshell (used primarily to provide sufficient bending stiffness of the aluminium bodyshell and simplify manufacture). The relatively low bending strength of the overhead line equipment masts, in relation to the vehicle's strength, also helped to ensure the masts collapsed first.

577 The rigid couplers generally kept vehicles attached to each other and in line, almost until they came to rest, thereby minimising vehicle scatter and reducing the risk of impacts between vehicles. The only exception was the coupler between vehicles one and two which separated under severe bending as these vehicles jack-knifed on the embankment. The fracture of the couplers between vehicles two and three and between three and four occurred towards the end of the derailment trajectory, by which time the speed of the vehicles was low and the risk of further scatter was much reduced.

578 Only two of the eighteen bogies on the train detached completely and then only once the vehicles had almost come to rest. The attached bogies ran derailed through ballast, trackwork and soil, helping to decelerate the train in such a way that the passenger compartments were largely preserved. Additionally, the retention of the bogies also minimised the risk of them becoming projectiles or obstacles embedded in the ground which could then collide with and compromise passenger spaces, events which occurred in the derailment at Ufton Nervet level crossing on 6 November 2004[38].

579 Although most bogies were successfully retained to the vehicle bodies, in nearly all cases the four retaining straps on each bogie were broken by the forces generated by the post derailment movement of the vehicles. However, the Pendolino bogies also feature anti-roll bar links, four of which connect each bogie to the vehicle body. Although these links were not designed to provide bogie retention, they did provide effective secondary retention. The risks from bogies becoming detached in accidents has been evidenced in previous accidents with older rolling stock. Further knowledge is required to understand the forces acting on bogies in derailments, and to determine if it is practicable to improve current design standards for the strength of bogie retention systems on future vehicles.

580 Generally, as outlined in the above paragraphs, the Pendolino avoided, almost completely, a number of hazards seen in previous major accidents and which have been known to cause fatal and serious injuries. Specific comparisons with previous derailments cannot be made since the forces to which the vehicles at Grayrigg were subjected will be different from those in other derailments.

581 In spite of the above points about the Pendolino's crashworthiness performance at Grayrigg, generally, the structural design requirements in Railway Group Standard GM/RT2100 are primarily based on mitigating the effects of train collisions, as opposed to derailments. This is because, at the time rail vehicle crashworthiness standards were introduced in the UK in the late 1980s and early 1990s, collisions posed a greater risk to train occupants than derailments. Since the implementation of the *Train Protection and Warning System* on the national network in 2003, the risk of train collisions has been reduced significantly, thereby reducing the absolute risk to passengers in train accidents generally. The risk from derailments now forms a higher proportion of the overall reduced residual risk to passengers[39]. However, the behaviour of rail vehicles in derailments, and in particular the forces acting on key components such as bodyshells, bogies and couplers is not well understood. Bodyshell roll-over strength and resistance to penetration by external structures, both of which were important in this accident, are not currently covered by Railway Group Standards. Further research is required to determine the key factors in mitigating the consequences of derailments and improvements to design standards.

---

[38] 'Ufton Nervet Level crossing: Passenger train collision with a road vehicle and subsequent derailment on 6 November 2004', published by RSSB, 21 June 2005.

[39] Annual Safety Performance Report, 2007, Rail Safety and Standards Board, http://www.rssb.co.uk/pdf/reports/ASPR_2007.pdf.

Vehicle interiors

582 Of the 135 laminated bodyside windows on the train, only six were completely broken during the derailment. Four of these were egress windows (paragraph 557), including two which were broken by passengers, and two were standard windows. The remainder survived the effects of overturning, contact with trees and impact with sprayed ballast without complete failure. In both cases where ejections happened (paragraph 567), they occurred at the end of the vehicle's travel and the injuries sustained were not fatal. In previous accidents involving the roll-over of vehicles fitted with toughened glass, such as at Ufton Nervet level crossing, there were multiple fatalities caused by the windows not containing the passengers.

583 The detachment of the reading light panels in vehicle one (paragraph 553) occurred because the retaining locks were not strong enough to withstand the accelerations in that vehicle, and failed mechanically. Estimates of the accelerations experienced by vehicle one were obtained by mathematical modelling and indicate that peak values could have reached or even exceeded (by approximately 20 %) the levels prescribed in the load cases of GM/RT2100, the design standard.

584 The detachment of the five rows of double seats in vehicle two (paragraph 555), was initiated by the deformation of the bodyside. This caused the seat pedestals, which are made from cast aluminium, to fracture in six cases and the mountings bolts to pull out of the seat rails on the floor in six cases. The manner of these pedestal overload failures was not ductile as required by BR/BCT609, the voluntary code of practice adopted during the class 390 Pendolino design. This has now been superseded by the ATOC vehicles standard AV/ST/9001, Vehicle Interior Crashworthiness, and is currently being incorporated into a Railway Group Standard. One passenger was trapped under some of the detached seats. Although there was no evidence in the witness accounts that the detached seats had struck and injured passengers, it is possible that they could have and there was potential for an even greater hazard, had the seats become airborne.

585 Various other detachments also occurred; in vehicle one a ceiling panel in the cab access corridor and the emergency coupler in the same area (paragraph 554) became detached. In vehicle nine, stowed catering trolleys broke free from their locks (paragraph 556). However, the harm in these cases was not significant since the trolleys were in unoccupied parts of the train, and could only travel a short distance as they were stowed across the vehicles rather than along them.

586 The following features limited the extent of passenger injury:

- furniture generally stayed attached except for those items mentioned in preceding paragraphs;
- the lower surfaces of the luggage racks, which were manufactured from thin gauge perforated aluminium sheet and which were struck by the heads of passengers in the leading five vehicles (paragraph 572), deformed significantly, thereby reducing the severity of the impacts and the consequent head and neck injury levels; and
- edges and corners of furniture were designed with generous radii and these also probably minimised secondary impact injuries.

587 The principal cause of serious injuries at Grayrigg, in the leading five vehicles which rolled over, was secondary impact. The high speed of the derailment, the occurrence of jack-knifing, roll-over, and the presence of the embankment, all contributed to the wide deviations of vehicle one's trajectory from the remainder of the train. Mathematical modelling of the accelerations in vehicle one indicated that the vertical and lateral accelerations combined with those in the longitudinal direction so that the magnitudes of the acceleration were sufficient to propel occupants from their seats into contact with the luggage rack and other parts of the vehicle interior and along the vehicle. Injury mechanisms in conditions where there are multi-axial accelerations have not been previously investigated in the rail industry. Further research is needed in this area to determine whether there are further improvements that can be made to interior crashworthiness in derailment accidents involving roll-over.

588 The Grayrigg accident raises the question of whether injury levels would have been lower had occupants been wearing seat belts. Currently, there are no railway standards in the UK or overseas which mandate their fitment. The RSSB has undertaken research into the performance of seat belts on trains. This work, which examined the experiences of passengers in seven major accidents, some of which involved roll-over, concluded there was a definite safety disbenefit in using two-point seat belts, although there may be some benefit with three-point seat belts in certain circumstances. However, this benefit was substantially outweighed by the potential disbenefit in accidents where there was loss of survival space. Additionally, a preliminary assessment by the RSSB suggests that the cost of fitting seat belts is likely to be grossly disproportionate to the benefits, even if seat belts were always worn by passengers.

589 However, the RSSB conclusions are not directly relevant to the circumstances of this derailment, since there was no loss of survival space. No conclusion can be drawn from the research as to whether or not seat belts would have been a benefit at Grayrigg. Therefore, the technical findings from RSSB's research should be reviewed and the preliminary cost benefit analysis recalculated in the light of the Grayrigg derailment.

Emergency lighting

590 The Pendolino lighting system was designed to comply with the requirements of Railway Group Standard GM/RT2176 Issue 1 'Air Quality and Lighting Environment for Traincrew Inside Railway Vehicles', which requires that in the event of a power loss either due to failure of the overhead line supply or a train defect, the train batteries should provide 90 minutes of emergency lighting. However, there is no specific requirement for the lighting to remain functional following a train accident.

591 Each vehicle of the Pendolino is equipped with its own batteries and charger. All the batteries are connected to a *busline* so that current can be supplied by any vehicle's battery set. The busline system is set up such that either vehicles three or seven can command contactors on other vehicles to close and provide power to the busline. Hence, if the batteries in one vehicle fail, power can be drawn from other vehicles, provided the busline and its associated controls remain intact.

592 The lighting in vehicles one, two, three and five failed during the derailment, leaving them in complete darkness. Passengers used light from their mobile phones to aid egress, although two light sticks are provided in each vehicle. While there was no evidence in witness accounts that the lack of vehicle lighting had directly caused or contributed to injuries (eg from slips, trips and falls), there was potential for this. Additionally, research by the RSSB[40] has shown that the absence of onboard lighting deters passengers from remaining on board the vehicle, where they are usually safer than trying to evacuate the train[41], unless there is a compelling reason to do so.

593 The lighting failures were caused by damage to the busline system, either because vehicles separated (vehicles one and two) or because vehicle ends were damaged. On vehicles four and six the lighting switched off momentarily during the derailment (probably because the train's DC supply dropped below preset thresholds as damage occurred) and returned by the time these vehicles came to rest. The lighting in vehicles seven, eight and nine, which did not suffer significant damage to their vehicle ends, remained on throughout the derailment.

594 A new Railway Group Standard, GM/RT2130 'Vehicle fire, safety and evacuation' and its associated code of practice GM/RC2531 'Recommendations for rail vehicle emergency lighting', both issued in June 2008, specify the requirements for emergency lighting systems on new vehicles. These must be both independent of the train power supplies (other than for charging) and able to survive the rigours of an accident. GM/RC2531 also recommends specifications for emergency lighting systems to be fitted to existing trains undergoing refurbishment and those approaching the end of their life, although such retrospective fitment is not mandatory.

---

[40] RSSB project T314 Phase 2– Validation of Emergency Lighting Specification, October 2007.

[41] RSSB project T066a, Train Evacuation Risk Model 'Stay or Go', June 2002.

Conclusions – the train

The pre-derailment condition of the train

595 There was no fault or malfunction of the train which could have caused or contributed to the derailment; the maintenance condition of the train and its running gear was satisfactory and relevant train systems, such as the tilting and braking systems, were functioning correctly.

The operation of the train

596 The train was being correctly driven at 95 mph (153 km/h), the EPS applicable to the class 390 Pendolino for the normal route over the Lambrigg points, when the derailment occurred. The subsequent motion of the derailed leading vehicle propelled the driver out of his seat and he was unable to apply the emergency brake. However, the emergency brake applied automatically four seconds later when vehicle one separated from vehicle two.

The derailment sequence

597 Vehicle one derailed first, either by its leading or trailing bogie (it remains unclear which bogie derailed first). The wheelsets of the first bogie to derail were squeezed between the converging left and right-hand switch rails of 2B points in their degraded state, until their flanges climbed over the rails.

598 A key stage in the sequence of events was the misalignment which formed between vehicles one and two between 2B and 3A points. Bogies 2 and 3 deviated towards the up line while bogies 1 and 4 remained closer to the down line. This misalignment developed further into a full jack-knife condition within 200 metres of 2B points as the compression forces on the train formation increased due to the orientation of the leading two vehicles. The paths taken by the vehicles until they came to rest were largely determined by these initial motions and the effect of the embankment.

599 The impact between vehicle one and a length of rail in the down cess near 3A points did not significantly affect the vehicle's subsequent trajectory.

Egress from the train

600 There were no significant egress issues at Grayrigg. In vehicles one to five, the majority of non-window egress routes were either blocked (40 %) or difficult to get through without help (40 %), either due to damage or the attitude of the vehicles. The remainder were available. Despite the difficulties of evacuating from these rolled-over vehicles in darkness, passengers and crew managed to evacuate successfully. Those whose injuries prevented self-evacuation were successfully rescued by the emergency services, although access to the driver's cab was initially blocked by a detached ceiling panel (paragraph 520). The evacuation at Grayrigg was made easier by the relatively low number of passengers on the train. In vehicles six to nine, which remained upright, most of the non-window egress routes remained available; the remainder (17 %) were blocked. Egress windows were used by passengers in vehicles two and three.

Causes of injury

601 The principal cause of the fatal injuries to Mrs Masson, who was travelling in vehicle one, and the injuries to other passengers and train crew was secondary impact, resulting from people and objects being thrown around the interior of the carriage. This resulted directly from the motions of the individual vehicles of the train following derailment. Amongst the exceptions were one passenger who was ejected from vehicle two, another who was found with part of her body protruding out of a broken window in vehicle one and other passengers who received minor grazes caused by broken glass during egress through broken windows.

602 The fatal and serious injuries occurred in the leading five vehicles of the train which rolled over onto their sides. All the occupants in vehicle one, whose post derailment motion was particularly severe, and 30 - 60 % of occupants in vehicle two to five were thrown out of their seats.

603 Some head injuries in vehicle one were probably caused by the reading light panels which became detached and fell down. Passengers also reported being trapped by the fallen panels.

604 No serious injuries were caused by penetration of vehicles by infrastructure, foreign objects, or detached train parts. Some cuts and bruises were caused by ballast that entered the leading end, left-hand side of the second vehicle towards the end of its trajectory through three broken windows.

The crashworthiness performance of the train

605 Overall, the crashworthiness performance of the class 390 Pendolino avoided, almost completely, a number of hazards such as multiple cases of passengers not being contained by the windows, loss of survival space and penetration of the passenger compartment by external structures, all of which have been known to cause fatal and serious injuries in past accidents.

606 Features of the train's structure of particular note were:

- laminated windows which largely contained passengers within the vehicles (paragraphs 557 to 561);
- the design of the couplers which generally kept the vehicles together (paragraph 577);
- the anti-roll bar links which ensured that most of the bogies remaining attached to the train (paragraph 578);
- the resistance to penetration of the bodyshell (paragraph 576); and
- the roll-over strength of the bodyshell (paragraph 575).

607 There has been a lack of knowledge in the industry about the behaviour of rail vehicles and forces in derailments and currently there are no specifications for roll-over strength and penetration resistance. The RSSB has been undertaking research to investigate bogie retention, coupler strengths and obstacle deflectors in order to mitigate risk consequent to derailment.

Recommendations 25a and 25b.

608 The performance of the train's interior was assisted by interior furniture generally staying attached and having compliant and rounded contact surfaces and edges (paragraph 586).

609 Notable exceptions were:

- The reading light panels in vehicle one became detached because the retaining locks failed mechanically, and the panels then became detached from their hinges.

Reference paragraph 583.

Recommendations 23 and 24.

- Some of the seats on the left-hand side of vehicle two became detached as a result of the deformation of the adjacent vehicle bodyside, increasing the potential for injury.

Reference paragraph 584.

Recommendation 22.

610 Injuries were exacerbated by the presence of multi-axial accelerations arising from the motions of individual vehicles.

611 Research is required to identify if there are further measures that can be taken to mitigate injuries in such cases.

Reference paragraph 587.

Recommendation 25c.

612 The effect of wearing seat belts on the severity of injuries at Grayrigg, where severe vehicle movements and multiple vehicle roll-over caused the majority of injuries, is not known. RSSB's research on the technical performance of seat belts and its related preliminary cost benefit analysis are not directly relevant to the conditions at Grayrigg, and the RAIB recommends reviewing the previous technical research in the light of the Grayrigg derailment and then confirming and publishing the cost benefit analysis.

Reference paragraph 589.

Recommendations 25d and 25e.

Emergency lighting

613 The failures in the train's lighting system resulted from the system not being designed to be crash proof. The new Railway Group Standard issued in June 2008 specifies mandatory crash proof emergency lighting requirements for new trains and less stringent non-mandatory requirements for retrofit to existing trains. Accordingly there is no recommendation in this area.

Reference paragraphs 593 and 594.

Rescue and First Aid: Evidence, Analysis and Conclusions

This section describes the evidence, analysis and conclusions relating to the rescue of the passengers and crew from the train after the accident, and reviews the performance of:

- the railway staff;
- the passengers and local residents;
- the emergency services; and
- other rescue bodies.

Rescue and First Aid: Evidence, Analysis and Conclusions

Evidence regarding rescue and first aid

Actions of the railway personnel and employees

614 The motion of the derailed train propelled the driver out of his seat, up against the windscreen and eventually onto the right-hand bodyside which had then become the 'floor', and at some stage rendered him unconscious. Upon regaining consciousness, the driver, who had been seriously injured, was unable to reach the driving controls or train communication system, and used the only communication equipment he could reach, his personal mobile phone. He called an off-duty employee of Virgin Trains (whose number was programmed into his phone) to relay a message to Virgin Trains operations control to arrange for trains to be stopped on the up line.

615 The train manager was alone in the rear vehicle of the train (nine) at the time of the accident and unable to communicate with colleagues on the train. He could not make public address announcements because he was unable to gain access to the PA equipment located in the galley, due to internal doors being tilted and too heavy to open. He was unable to move forward to vehicle eight and the rest of the train because the interior gangway doors were jammed shut. He contacted Virgin Trains control office by mobile phone and advised them of the accident, but could not inform them of the exact location, nor of the extent of the damage or injuries.

616 The customer services manager was walking through vehicle eight with a catering trolley at the time of the accident, as described in paragraph 556. He made contact with the train manager in vehicle nine by shouting through the jammed gangway doors. He managed to move forward through to vehicle six, but was unable to get any further. En-route, he reassured passengers and requested that they remained within the train and waited for the emergency services to arrive. Later, when evacuating passengers, he helped them bridge the gap in vehicle eight across the open door space of the disabled toilet as the angle of that carriage made it difficult to get past it.

617 The customer service assistant was in the vicinity of the shop in vehicle three and was seriously injured during the accident. She called the emergency services, using her personal mobile phone. Passengers were starting to break out of the vehicle at this time, and she assisted them and made her way out of the carriage via a broken window and down a ladder that had been supplied by a local resident.

618 An off-duty member of Network Rail staff who was travelling in vehicle six realised the danger posed to other rail traffic by train 1S83. He was unable to get a connection on his mobile phone, so he detrained to apply safety procedures to prevent a southbound train from hitting the wreckage. Upon seeing the damage caused to the track and overhead line equipment he was reassured that the protecting signals would have been placed to red automatically, and rejoined the train.

619 The Network Rail signaller at Carlisle, and staff in the electrical control room (ECR) at Crewe were immediately aware of problems in the Lambrigg area from fault indications on their display panels, but they were unable to determine what was wrong. Alarms indicated signalling remote control and power supply failures. The signalling and ECR staff implemented procedures to secure the safety of the area by setting all signals in the area to danger and isolating the overhead line supply. The ECR operator was aware that electrical circuit breakers had tripped and thus the up and down lines between Natland (south of Oxenholme) and Tebay were de-energised. He was initially unable to contact the signaller at Carlisle as the direct lines were disrupted. He followed procedures and attempted a single reset of the up and down lines, but these tripped immediately and he took an emergency isolation in conjunction with the signaller at Carlisle once the cause of the tripping had been established.

620 A southbound passenger train, reporting number 1M99, was slowed by a normal signal sequence on the approach to the Grayrigg area, coming to a stand at controlled signal CE75 (approximately 350 metres from the site of the derailment) nine minutes after the derailment. The driver of train 1M99 was initially unaware of the derailed train ahead, and attempted to contact the signaller at Carlisle to ascertain the reason for the delay. He was unable to connect via the signal post telephones at CE75 and CE76 (opposite) as these were no longer operational due to the damage incurred by the derailment. Communication was subsequently achieved using a mobile phone.

621 Northbound passenger train 1S86 was following several minutes behind train 1S83 and was stopped by a normal signal sequence at signal CE66, nearly three miles south of the derailment site.

622 Network Rail was able to confirm at 20:34 hrs to the Cumbria Fire and Rescue Service that rail traffic was stopped and that the overhead power lines were safe to approach but not to touch. Localised earthing to make the overhead line equipment completely safe was achieved at 22:35 hrs, after staff had arrived from Carnforth by road to carry it out. Their arrival was significantly delayed by the number of vehicles in the area by that time.

The initial response of the passengers and local residents

623 A number of passengers on the train notified the emergency services of the accident, using their mobile phones, from 20:08:35 hrs[42] onwards. Many of the passengers left the train and made their way, in the dark and across wet fields, to Bracken Hall Cottage and to Cross Houses, where the residents offered assistance.

624 At least two local residents who had heard a loud noise also called the emergency services. The phone call from one of them, containing an address and postcode, was logged by Cumbria Police at 20:17 hrs.

625 Some local residents also assisted passengers to escape from the train by shining vehicle headlights to illuminate the scene and providing ladders, and opened up their homes to provide shelter.

[42] The times recorded by Cumbria Fire and Rescue Service and Cumbria Police do not accord with those recorded by the railway by some three minutes, as railway data sources indicate that the accident occurred at 20:11 hrs. The RAIB has not attempted to reconcile this time difference, which has no relevance to either the accident or the rescue operation.

The initial response of the emergency services

626 Upon receiving the first emergency calls Cumbria Police and Cumbria Fire and Rescue Service contacted the Network Rail operations control room at Manchester, but at that point Network Rail was unable to confirm the actual location of train 1S83 as all signalling indications had been lost between Oxenholme and Tebay.

627 Cumbria Police and Cumbria Fire and Rescue Service and the North West Ambulance Service NHS Trust were the first elements of the emergency services to respond, followed shortly by the BTP. Fire, police and ambulance crews were mobilised by their respective controls to the vicinity of Grayrigg Cottage, although the controls could not, at that time, provide a precise location. The nearest BTP officers were at Preston at the time of the accident.

628 Because of the high volume of emergency communications taking place, all the emergency services had difficulty in locating the accident site. Cumbria Police overlooked the significance of the call made to them at 20:17 hrs when the caller gave his address and postcode.

629 An uncoordinated search of the line from roads between Oxenholme and Tebay commenced with emergency service vehicles driving up and down roads that ran near to the railway. One fire crew found the southbound train 1M99, which was standing 350 metres north of the crash site and out of sight of it due to curvature of the line. The train driver told the crew that his train was not involved, and that the site was likely to be forward of him towards Oxenholme.

630 At 20:46 hrs the first ambulance and fire crew from Kendal located train 1S83. Once the location was radioed back other appliances and services congregated at Cross Houses, immediately to the east of the accident site.

Major incident arrangements

631 The above three services quickly increased their resources as the number of calls received from passengers and members of the public indicated the magnitude of the accident. At 20:50 hrs, after the first situation report was received from personnel at the scene, Cumbria Fire and Rescue Service declared a major incident.

632 Cumbria Police established a *Rendezvous Point* at Bracken Hall, about 100 metres from the leading vehicles.

633 In total the following emergency services attended the scene of the accident to perform the immediate rescue and first aid duties:

- Cumbria Police;
- Cumbria, Lancashire and Greater Manchester Fire & Rescue Services;
- North West Ambulance Service NHS Trust;
- British Transport Police (BTP);
- Cumbria and RAF Leeming Mountain Rescue teams;
- The *British Association for Immediate Care* (BASICS) emergency response doctors;
- RAF *Search and Rescue* helicopters; and
- Merseyside Police Service helicopter.

634 Cumbria Police instigated a *Gold/Silver/Bronze command* system, and this was echoed by North West Ambulance Service, Cumbria Fire and Rescue Service, the BTP, and the railway industry.

635 Cumbria Police established a *Casualty Bureau* at its HQ at Penrith to deal with callers seeking information on persons thought to have been on train 1S83. The BTP set up a family liaison point in an hotel near Glasgow Central station to cater for relatives and friends who were expecting to meet passengers off train 1S83.

636 As the derailed vehicles were lying nearly half a mile across fields from the A685 Kendal to Tebay road Cumbria Police called for extra assistance from Cumbria's mountain rescue teams. The teams from Kendal, Ambleside, Keswick, Langdale, Penrith and Cockermouth were mobilised. In addition, an RAF mountain rescue team that was on an exercise in the Lake District assisted. Cumbria mountain rescue team also mobilised the cave rescue team from Clapham, North Yorkshire. The International Rescue Corps self-mobilised a team to Kendal to assist.

637 A BASICS emergency trauma doctor from Kendal was called in by North West Ambulance Service, and further BASICS assistance was mobilised from Cumbria, Lancashire, West Yorkshire and Merseyside.

638 At 20:34 hrs Cumbria Police contacted the RAF Search and Rescue control and requested assistance. Search and rescue scrambled four helicopters, two from RAF Valley and one each from RAFs Boulmer and Leconfield. The first of these arrived on the scene at 21:48 hrs. Merseyside Police offered their force helicopter, and this was deployed at 21:12 hrs and arrived at 21:44 hrs. This performed an aerial support unit platform role co-ordinating the aerial activities.

639 Military search and rescue helicopters are not equipped to communicate directly with civil emergency ground units. This can cause communication difficulties as messages need to be relayed. In this instance the aerial support unit helicopter was initially used as a communications link between the military craft and the ground units, with police staff relaying messages. The RAF is aware of this limitation and deployed a *Search and Rescue Liaison Officer* on board the helicopter from RAF Boulmer arriving at Grayrigg at 22:30 hrs. He took over local control of the RAF helicopters.

640 Network Rail mobilised a Rail Incident Officer to the Grayrigg site and he took the immediate role of representing the rail industry and liaising with the emergency services. He arrived from Carnforth at 21:10 hrs and his first duties were to ensure that the railway site was protected from further railway hazards. He confirmed that all traffic was stopped and that the electrification team had been summoned to earth the overhead line equipment. The rail incident officer attended the initial silver level meeting.

641 The first fire crews to attend undertook a dynamic risk assessment and noted that vehicle two (the one that was easternmost on the site) was in contact with damaged overhead line equipment. Some passengers reported that the overhead line equipment had been 'sparking and flashing' for a 'few minutes' in the early stages after the accident which had compelled them to leave some of the vehicles. The other vehicles were judged to be safe enough for rescue work to continue without further measures as they were sufficiently stabilised by being either at the bottom of the embankment, or supported by the earthworks, vegetation and debris on the embankment. The couplers remaining intact between vehicles four to nine also helped the vehicles support and restrain each other, especially those that were on the full slope of the embankment.

642 There is a protocol in place between the emergency services and Network Rail which should be enacted when emergency services need to access the railway lines. Network Rail's operations control in Manchester was called by Cumbria Fire and Rescue Service and also by Cumbria Police. Network Rail confirmed to both at 20:34 hrs and 20:54 hrs respectively that all trains had been stopped and that the overhead line equipment was isolated – 'safe to approach but not to touch'. There was no record of any request from the North West Ambulance Service. North West Ambulance Service response staff went onto the railway without having been advised of the status of the lines.

643 Upon the arrival of senior support officers from Cumbria Fire and Rescue Service, vehicle two was placed out of bounds. This follows normal Fire and Rescue Service practice when it is adjudged that all immediate life risks in a 'sector' have been saved and there are hazards present that may endanger rescuers. The Fire and Rescue Service was uncertain as to when the overhead line equipment had been isolated and earthed, until this was confirmed by Network Rail's rail incident officer at 22:40 hrs.

644 The North West Ambulance Service set up a *field triage* and immediate first aid treatment point at about 21:30 hrs as soon as their resources permitted. All passengers and crew were assessed there or on board the train by medical staff. People assessed by the field triage or identified as needing medical treatment while trapped on the train were taken by fire, ambulance or mountain rescue personnel to ambulances or to the RAF search and rescue helicopters. The ambulances and helicopters were used to ferry the injured directly to receiving hospitals at Kendal, Barrow-in-Furness, Carlisle, Lancaster and Preston. These hospitals activated their major incident emergency procedures.

645 In total 54 passengers and two train crew were taken to hospital. Eighteen of these were transferred by air, the remaining 38 by road ambulance. Thirty five passengers and two crew members were treated by medical staff at the field triage and released. The remaining passengers did not require medical attention.

646 When all passengers and crew were thought to be clear of the train, a search was undertaken by specialist Urban Search & Rescue teams and trained 'CANIS' sniffer dogs from Greater Manchester Fire and Rescue Service to confirm nobody was trapped. The search also extended across the surrounding fields in case anyone had become lost. A search and rescue helicopter using infra-red equipment gave aerial support to the mountain rescue teams, who carried out the ground search.

Response by the local community

647 Residents of Grayrigg opened the village school hall. This was used as a reception centre where passengers were brought by police services and the North West Ambulance Service. Cumbria Council's emergency planning staff arranged manning.

648 Voluntary services worked with Virgin Trains' staff in providing care for the uninjured passengers at the school hall and arranging onward transport or overnight accommodation.

649 One problem that quickly manifested was traffic management. Roads in the Grayrigg area consist of the A685 and a network of narrow lanes. The emergency services, other rail industry support and many press or private vehicles approached the site from all directions. Vehicles were parked haphazardly and blocked further traffic. This made the passage of further emergency or priority vehicles, particularly North West Ambulance Service ambulances very difficult. Cumbria Police started setting up road access points from 22:00 hrs. At the first silver level meeting Cumbria Police tasked officers at 22:55 hrs to provide a bronze level traffic control.

Air traffic issues

650 From the outset there was intense press interest. A press helicopter was above the scene before any of the emergency service helicopters arrived and as the rescue craft arrived it was asked to vacate the area. The National Air Traffic Services Control at Swanwick implemented a '*Temporary Danger Area*' of four miles radius from the derailment and to an altitude of 3000 feet.

Analysis and conclusions regarding rescue and first aid

Response by the on-train staff

651 The train manager and customer services manager as permanent employees of Virgin Trains had undergone initial safety training and periodic refreshers. In this training, crew are taught that it is safer to remain on board the train as the environment outside is generally more hazardous. Only if there is perceived danger in remaining in the train should evacuation take place. Their conscious decisions to remain on board and keep the passengers contained were therefore correct.

652 The customer service assistant, a member of agency staff on contract to Virgin Trains, was in vehicle three and had been seriously injured. She made her way out alongside passengers from that vehicle. As part of her induction the customer service assistant had been given half a day's emergency procedure training, which had included the "stay on board unless in danger" message (paragraph 651). She chose to leave the train as the passengers were doing so. She had also worked as an air stewardess, where she was trained to encourage early evacuation, and this may have influenced her actions.

The rescue and first aid phase – response by the passengers

653 Some passengers decided to try and self-evacuate from vehicles one to five. There were no train crew announcements (paragraph 615) to dissuade them. Exit attempts are described in paragraphs 562 to 565. Passengers leaving from windows broken in the saloons would not have seen the notices in the vehicle vestibules advising passengers to stay on board the train in an emergency unless the situation was life threatening.

654 In the carriages where the emergency lighting had failed passengers reported using mobile phones for illumination to assist their escape. There were also emergency lighting snap-sticks – in a small holder with luminescent print – provided at one end of each saloon, but none of these were used. It is therefore possible that the luminescence was insufficient to attract the passengers' attention to the snap-sticks, but more likely that passengers preferred to use their mobile phones, as they were more convenient.

The rescue and first aid phase – response by the emergency services and others

655 In general the actions of the emergency services were swift, proportionate and well co-ordinated in potentially very chaotic circumstances. However, there are issues that the RAIB considers could usefully be reviewed to improve any future emergency response.

656 Cumbria Police, Fire & Rescue and North West Ambulance Service lost some response time because of the lack of awareness of where the train was. Nobody on the train knew where they were (apart from the driver, who was incapacitated); and the loss of the signalling system prevented Network Rail determining its exact location. The RAIB estimates that the first response units could have arrived on site twelve minutes earlier if the significance of the call from local residents with the correct accident location had been realised. Medical opinion obtained by the RAIB is that this delay did not contribute to Mrs Masson's death.

Reference paragraph 624.

Recommendation 26.

657 The RAF search and rescue helicopters were unable to communicate directly with the ground emergency services (paragraph 639) and needed the police helicopter to relay messages until the search and rescue liaison officer arrived. While not adding undue delay to the communications process, the lack of direct communications introduced an inconvenience in co-ordinating the helicopter activity. New radio technology, known as 'Airwave', is being introduced to the civil emergency services and this will allow a direct speech facility between each service. The Ministry of Defence's search and rescue helicopters (RAF and Royal Navy) could also be fitted with this technology at some point in the future and if this occurred, it would permit direct communication, saving time and reducing the potential for error.

Recommendation 28.

658 Network Rail has produced, in conjunction with the emergency services, specific awareness and training material for emergency access onto the railway (a booklet issued in 2001 and a DVD in 2004). This includes a specific communications protocol for emergency personnel requiring access to the railway. Network Rail stated that it had sent all this material to the emergency services, but North West Ambulance Service were not aware of its existence. The earliest ambulance crews who attended the derailment had no training in railway safety or knowledge of these protocols. This resulted in them being on a railway line, in the dark without any assurance that trains had been stopped, and while the overhead line equipment had still to be earthed and could have held some residual potential. The first ambulance crews to arrive saw that passengers had left the train from carriages one to five, which may have prompted them to cross the line from the Cross Houses side to render assistance without seeking assurance from their control or from the Fire and Rescue Service. However, evidence from three different Ambulance NHS Trusts about rail safety protocols showed they too had no knowledge or training on basic rail safety, apart from the comments that railways were hazardous places. Another example of lack of awareness of railway operation (with air ambulances) can be found in paragraphs 171 and 173 of the RAIB report 04/2008 on the track worker fatality at Ruscombe Junction on 29 April 2007 (published on RAIB's website www.raib.gov.uk). There are further examples in the 2008 report by the National Audit Office 'Reducing passenger rail delays by better management of incidents' (published on the NAO's website www.nao.org.uk).

659 There is no formal operational safety body within the English Ambulance Service Trusts. The RAIB considers that the Trusts (and their Scottish and Welsh equivalents) should promote the training of front line and control room staff on railway safety awareness. The protocols established with Railtrack plc in 2001 work well with the other emergency services.

Recommendation 27.

660 Persons essential for the management of scene safety such as the overhead line equipment team were unable to reach the site. Where life is at risk, in addition to being used to evacuate personnel and casualties from the scene, MOD search and rescue helicopters could be used to ferry priority rescuers (such as the overhead line equipment team) and specialist equipment to the scene. This is an existing arrangement under the Military Aid to Civil Authorities The RAIB has advised Network Rail, which will incorporate this into its emergency planning arrangements.

Observations regarding rescue and first aid

661 The Network Rail rail incident officer had conducted a railway safety check of the site, and confirmed that there was no possibility of further trains running in, and that the overhead line equipment was at first isolated and then later earthed. He did not identify the possibility of the 650 V signalling circuit cables still being live, and the damage was such that these were exposed and encountered during the recovery phase. The rail incident officer's log-book (a pre-printed booklet issued by Network Rail to all rail incident officers) prompts rail incident officers to check for site hazards, and while specifically mentioning traction power systems, it does not mention signalling system power supplies. The rail incident officer was trained and qualified by Network Rail as competent to act in that role and had undergone the standard (at that time) rail incident officer training course, comprising three days tuition and an examination. The course contents included site safety and risk assessments, but did not specifically include the 650 V signalling circuit cables. The RAIB has written to Network Rail to make them aware of this omission and Network Rail has agreed to highlight other significant hazards, in addition to traction power, in the rail incident officer training package and log-book.

662 The effectiveness of the emergency services and railway response staff operating at the scene would have been higher if Cumbria Police had been able to introduce a controlled traffic and parking strategy from the outset. In particular this would have permitted ambulances to approach and depart from the field triage without undue delays. Cumbria Police should review how it might introduce early traffic management if ever faced with a similar event.

663 Overall, the response by the emergency services, volunteer organisations, and local residents, especially those at Bracken Hall Farm, Bracken Hall Cottage and Cross Houses, dealt efficiently with those who were travelling on the train. This well co-ordinated combined effort prevented further avoidable injury and trauma to those who were involved in the accident.

Action Reported as Already Taken or in Progress

Actions reported as already taken or in progress

Action reported as undertaken by the RAIB and ORR

664 In the course of its investigation the RAIB has issued two separate urgent safety advice documents detailing concerns arising from its emerging findings. Both of these were issued to Network Rail, Nexus (Tyne and Wear Metro), Northern Ireland Railways and London Underground Limited. All of these infrastructure owners and maintainers use switches of a similar design (spring-steel non-adjustable stretcher bars). The urgent safety advices are given in full in Appendix P.

665 The first urgent safety advice was issued on 6 June 2007 because of a concern over the effect of an excessive residual switch opening on the integrity of a stretcher bar and the likely rate of degradation of 2B points following the failure of the third stretcher bar. It drew attention to:

- the risk of progression to failure of this design of S&C resulting from an opening between the switch and stock rail on the through (normal) route in the vicinity of the third stretcher bar;
- the speed with which the switch's remaining stretcher bars degraded;
- the need to review the method and frequency of inspection and maintenance tasks performed to prevent the loss of integrity of stretcher bar fasteners and fractured stretcher bars, particularly in facing points where the consequences of such failure are assessed to be more serious; and
- the potential inadequacy of current inspection techniques in identifying *fatigue failure*s in permanent way stretcher bars and their associated brackets.

666 On 26 November 2007, the RAIB issued a second urgent safety advice, identifying concerns with the integrity of the permanent way stretcher bar bracket's joint to the switch rail. Analysis of the joint and the integrity of its fasteners indicated that it could not withstand the loads imposed on it by traffic with an adequate safety margin under some circumstances. The loads were established by measurements on 2B points in the laboratory and by measurements on points in traffic on the network.

667 The ORR has issued two nation-wide improvement notices to Network Rail:

- the first improvement notice, issued on 12 December 2007, related to track patrolling not being conducted in accordance Network Rail's current standards; and
- the second improvement notice, issued on 9 June 2008, related to the joint between non-adjustable stretcher bar brackets and switch rails and arose from the RAIB's second urgent safety advice. At the time of publication, this notice is subject to an appeal at an Employment Tribunal.

668 ORR has developed a process of regular meetings with duty holders to discuss progress in implementing recommendations, at which the opportunity exists for ORR to provide feedback to duty holders on their intended actions and progress in implementing recommendations.

Industry investigation

669 Network Rail and Virgin Trains held a joint investigation into the accident and published their report on 4 September 2007. The recommendations from this have informed many of the actions undertaken by Network Rail subsequently, and these are included in the following paragraphs.

Actions reported as undertaken by Network Rail

670 Following the accident, discussions with the RAIB and the ORR, and with the ORR's agreement, Network Rail issued a Special Inspection Notice, NR/SIN/097, which led to the examination of 1437 sets of points. The examinations focused on stretcher bars, stretcher bar fasteners, free wheel clearance and track gauge. No points were found to be in a similar state of degradation to 2B points. However in some cases there were indications of precursor failures. Appendix O gives details of the criteria for selection of points and the results obtained from this, and later inspections. All identified precursor failures were rectified.

671 After the accident, Network Rail reviewed traffic patterns on the WCML and decided that the railway could be operated satisfactorily without the Lambrigg crossovers. They have subsequently removed the remaining points from Lambrigg.

672 After issue of RAIB's first urgent safety advice, dated 6 June 2007, Network Rail undertook a further examination of all points which had the same configuration as 2B points (contraflexure) and where the line speed was 80 mph (128 km/h) or greater, a total of 115 sets of points. The instructions for this examination, within NR/SIN/099 Issue 1, included measurement of residual switch opening, free wheel clearance and the escapement device setting as well as issues identified in NR/SIN/097. All identified defects have now been rectified. The results from these inspections are presented in Appendix O.

673 As a result of these inspections Network Rail issued a revised NR/SIN/099 (Issue 2) in July 2007, to correct the deficient free wheel clearances identified while carrying out the inspections from Issue 1. Additionally, Network Rail replaced all the stretcher bars and implemented an alternative fastener arrangement on these points. Subsequent checks after between two and five months found that 12 % of the fasteners in the new arrangements had become loose in accordance with Network Rail's definition of this (Appendix O).

674 In October 2007 Network Rail revised NR/SIN/099 to Issue 3. This focused on points identified by their fault management system as having four or more recorded stretcher bar faults since January 2005. 112 sets of points were identified. The findings from these inspections are presented in Appendix O.

675 In December 2007, Network Rail undertook a general update of selected parts of its signalling maintenance specifications, reissued it, and re-designated it NR/L3/SIG/10663. This included parts of the signalling maintenance specifications PA11 (Point Inspection), PC41 and PF01. The changes to SMS PF01 include:

- a new requirement that where any corrective action is taken as part of maintenance, such as the adjustment or tightening of nuts, lock nuts, bracket fasteners or replacement of units, a report must be made to the Integrated Control Centre or the infrastructure fault control; and
- only when first fitted are fasteners to be tightened with torque spanners to 250 Nm; thereafter, they should be checked for tightness using a short spanner.

676 In February 2008 Network Rail issued NR/SIN/101 to measure and analyse the residual switch opening and free wheel passage on running lines fitted with non-adjustable stretcher bars. This work is on-going and the findings to date are given in Appendix O.

677 In June 2008, Network Rail commissioned testing on fastener performance under vibration when a joint is subjected to a tensile axial load. This includes the practical evaluation of different nut locking methods to inform decisions on their future application.

678 Following the stretcher bar force measurements described in paragraph 142, Network Rail has, from June 2008, carried out measurements on a further 12 sets of points with non-adjustable stretcher bars across the network to identify the service forces present in the stretcher bars and their fasteners. Findings to date indicate permanent way stretcher bar forces in the order of 4 kN for points set in a condition compliant to standards, and up to 20 kN where flange-back contact is present.

679 Network Rail is continuing to work on actions arising from the RAIB's second urgent safety advice of 26 November 2007. At the time of writing this report, it has a design proposal for a revised stretcher bar assembly including its fasteners, using the findings from the measurements and tests above as guidance.

680 Network Rail updated standard NR/L2/SIG/10047 'Management of Safety Related Reports for Signalling Failures' and implemented it in August 2008. The update takes into account the reporting issues learned from Grayrigg and the subsequent special inspection notice results. The revision includes the capture of single loose, broken, missing, cracked, insecure or defective point components and requires such incidents to be reviewed nationally on at least an annual basis.

681 Network Rail has also:

- Refined and developed its process for recommendations handling. Tactical Safety Group reviews all open recommendations on a periodic basis and recommendations associated with significant incidents are now required to be signed off by the relevant professional head, his or her line manager and a board director.
- Issued a Letter of Instruction (LOI 073) to ensure that branding is removed from the length of all new switch rails where stretcher bars or other equipment may be fitted to the rail web.
- Issued a Letter of Instruction (LOI 076) that has introduced a standard format for patrolling diagrams across the whole system, and developed an enhanced procedure for management of patrolling which will be introduced from September 2008.
- Reviewed its engineering management organisation, and from early September 2008 the area track engineer and area signal engineer posts have been removed from the infrastructure maintenance management organisation. Nationally managed engineers, who are part of Network Rail's Engineering organisation, now provide professional support to the local engineers within the new infrastructure maintenance delivery manager organisations. The new organisation is remitted to carry out compliance checks at asset level independent of the maintenance function. The RAIB had considered making a recommendation in this area, but the ORR has confirmed that this new organisation has addressed the RAIB's concerns in this area.

682 In addition Network Rail has stated that it has:

- Undertaken a cross-functional programme of work to review and map the existing safety assurance processes at all levels of the organisation. This identified a number of improvements, which are being implemented to provide assurance that the safety, health and environment committee, strategic safety group, and tactical safety group all receive the necessary information on current safety performance.
- Carried out human factor studies into the role of the patroller, and into depot management, and is using the outcome from these studies to improve working practices, briefing and competence management.
- Reviewed company standard NR/SP/OPS/031, Timetable Risk Assessment, with a view to introducing a revised version in December 2008 to address the access issues identified at Grayrigg.

683 Network Rail is to introduce an 'S&C consolidation document' in November 2008. This will be a single source of information for front line staff involved in the management of S&C with non-adjustable stretcher bar assemblies.

Action reported as undertaken by RSSB

684 RSSB issued a new Railway Group Standard in June 2008 (paragraph 613) which specifies mandatory crash proof emergency lighting requirements for new trains and less stringent non-mandatory requirements for retrofit to existing trains.

685 RSSB are currently consulting with industry about a new issue of GM/RT2100 which includes proposals to enhance crashworthiness performance of seats and interior panels along the lines of Recommendation 22.

Action reported as undertaken by the ambulance services and Network Rail

686 The North West Ambulance Service NHS Trust established an interim protocol with Network Rail following an internal debrief in 2007. Further high level dialogue is underway between the NHS National Emergency Preparedness Board and Network Rail as how to achieve consistent application of the protocols.

Recommendations

Recommendations

Introduction

687 There are twenty nine safety recommendations[43] made in this report:

Recommendations arising from causal and contributory factors

- Recommendation one is targeted at Network Rail and concerns a review of the design, inspection and maintenance of non-adjustable stretcher bars in S&C.
- Recommendations two to five are targeted at Network Rail and concern long term design, inspection and maintenance issues on all types of S&C.
- Recommendations six to twelve are targeted at Network Rail and concern actions that can be taken in the short and medium term to mitigate risk from S&C in advance of the implementation of the longer term recommendations.
- Recommendations thirteen to twenty are targeted at Network Rail and concern underpinning engineering and risk management issues.

Recommendations arising from other factors

- Recommendation twenty-one arises from an observation, and is addressed to the Safety Authority regarding the briefing of their annual delivery plan.
- Recommendations twenty-two to twenty-five are targeted at the RSSB, or Virgin Trains and Angel Trains. They concern issues associated with the behaviour of the train as a consequence of the derailment.
- Recommendations twenty-six to twenty-eight are addressed to organisations involved in the rescue after the accident. They concern the rescue operation.
- Recommendation twenty-nine arises from an observation, and is targeted at Network Rail. It concerns research into any link between long work-hours and human error.

[43] Duty holders, 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, recommendations 1 to 25, and 29 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.

Recommendation 26 is addressed to Cumbria Police in accordance with Regulation 12 (1) (b).

Recommendation 27 is addressed to various Ambulance organisations in accordance with Regulation 12 (1) (b).

Recommendation 28 is addressed to the Ministry of Defence in accordance with Regulation 12 (1) (b).

Copies of both the Regulations and the accompanying guidance notes (paragraphs 167 to 171) can be found on RAIB's web site at www.raib.gov.uk

Recommendations to address causal, contributory, and underlying factors

Primary Technical recommendation concerning non-adjustable stretcher bar assemblies in S&C

1. The intention of this recommendation is that Network Rail should modify the design of the non-adjustable stretcher bar assembly, including its joints, so that it can withstand normal operational loads (and credible faults) with a safety margin and without excessive reliance on human intervention.

   Network Rail should review its S&C non-adjustable stretcher bar assembly design, so as to understand the relationships between the design, loading, usage, and the inspection and maintenance regimes, and implement any appropriate modifications to the design or the regimes.

   The following elements (A to F) should be considered to achieve this:

   A. Define the system level functional and safety requirements for S&C with non-adjustable stretcher bars.

   B. Determine all of the functions that the non-adjustable stretcher bar assembly is required to deliver for the functional and safety performance of the S&C system, including from traffic, fastenings and operating/ motor forces.

   C. Determine a set of load cases for the non-adjustable stretcher bar assembly, including its rail fastening arrangement. This should include forces which it experiences during both normal and reasonably foreseeable fault conditions. All foreseeable combinations of normal and fault conditions that could exist within the stretcher bar assembly itself, other components and the S&C system, should be considered. This should include, but not be limited to:

      a. configurations of S&C on which it is fitted;

      b. traffic usage patterns and track geometries;

      c. manufacturing and installation variations.

      The load cases should be established and validated by field measurements, supported by appropriate other testing, modelling and/or calculation.

   D. Assess the performance of the current non-adjustable stretcher bar assembly against the forces that arise from the load cases.

   E. If justified by the outcomes of the previous work, modify the current design of the non-adjustable stretcher bar assembly to include an appropriate factor of safety. The revised design should be risk assessed, taking into account the quality and reliability of human intervention in inspection and maintenance (refer also to Recommendation 13).

      Should measures such as component redundancy or other defence barriers be necessary to achieve the required integrity, the reliability of each redundant element and defence barrier should itself be assessed using the above process.

F. Modify the current installation, inspection and maintenance regimes against the requirements determined in E so that they are appropriately risk based for the new design (refer also to recommendation 13).

G. Introduce processes to implement the modified design and modified inspection and maintenance regimes and any associated mitigation measures where justified.

This recommendation arises from paragraphs 514, 515, 519 and 520. Actions already reported as taken by Network Rail can be found in paragraphs 677, 678 and 681.

Recommendations for all S&C

2. The intention of this recommendation is that Network Rail should implement processes to gather and analyse data, both in the short term and thereafter, that will enable it to identify and monitor accident precursor events in its S&C. This information can then be used to identify potential problems before they can lead to catastrophic failure, and also to inform the development of process safety indicators (see Recommendation 14).

   Network Rail should implement processes to:

   a. **capture, and record on a single national database, data about component failures, and interventions made during maintenance and inspection activities, for each set of S&C;**

   b. **use the data from a) above to monitor failure and intervention rates locally and nationally in the behaviour of S&C components;**

   c. **identify precursor faults that might lead to more serious failures; and**

   d**. identify those precursor faults where the failure and intervention rates indicate a need to reduce the risk of catastrophic failure**

   This recommendation arises from paragraphs 514 and 519.
   Actions already reported as taken by Network Rail can be found in paragraph 679.

3 The intention of this recommendation is that Network Rail should implement the measures it identifies from Recommendations 2.

   Network Rail should introduce processes to implement any design modifications arising from Recommendation 2 using the principles outlined in Recommendation 1.

   This recommendation arises from paragraphs 514, and 519.

4 The intention of this recommendation is that Network Rail should move to a risk-based regime for the maintenance and inspection of S&C.

   Network Rail should introduce processes that require the adoption of a structured risk based approach when reviewing and enhancing its standards for the inspection and maintenance of all existing types of S&C.

   This recommendation arises from paragraphs 514 and 519.

5 The intention of this recommendation is that Network Rail should, as soon as possible, provide its front line staff with clear guidance on when a defect, fault or failure requires investigating, and the scope of investigation required.

Network Rail should include in maintenance standards and instructions:

- **the circumstances under which an investigation of a defect, fault or failure to S&C systems as a whole or its sub-components is required; and**
- **definition of the scope of the investigation and other immediate actions to be taken (eg temporary speed restrictions, special monitoring) for each situation.**

This recommendation arises from paragraphs 514, 519, and 524.

Short and medium-term actions with respect to set-up, inspection, and maintenance

6 The intention of this recommendation is that Network Rail should be able to systematically identify, and rectify, any potential or actual incidence of flange-back contact.

Network Rail should review its processes for S&C examination so that the following are included:

a. examination for, and reporting of, signs of flange-back contact; and

b. measuring, recording and reporting gauge, free wheel clearance and residual switch opening dimensions,at frequencies commensurate with adequate risk control.

This recommendation arises from paragraph 519.

7 The intention of this recommendation is that Network Rail should provide its front line staff with adequate information on the correct installation, inspection and maintenance of fasteners associated with non-adjustable stretcher bars.

Network Rail should modify its maintenance instructions to define:

- **how staff should initially fit and tighten non-adjustable stretcher bar fasteners;**
- **how staff should inspect and maintain the fasteners if necessary during subsequent visits, including practical instructions to achieve any required torque;**
- **when a fastener is considered to be loose taking into account the nut rotation required to achieve the required preload;**
- **how staff should act in the event of a fastener being identified as loose;**
- **how staff should record actions taken; and**
- **how staff should carry out any other actions identified from Recommendation 4.**

This recommendation arises from paragraph 519.
Actions already reported as taken by Network Rail can be found in paragraphs 675 and 680.

8 The intention of this recommendation is that Network Rail should provide its front line staff with clear information on permitted residual switch opening dimensions.

Network Rail should revise its maintenance instructions to clearly specify the value (or range of values) required for residual switch openings, particularly with reference to the maximum permissible value (or range of values) and the frequency at which it must be checked.

This recommendation arises from paragraphs 515 and 519.

9 The intention of this recommendation is that Network Rail should provide its front line signalling maintenance staff with all the information that they need to carry out their work, including secondary documents referred from principal documents, and that its systems provide for checking and recording the actions taken. The information from this system should be readily accessible and usable on or off site.

Network Rail should review management systems and associated documentation covering the maintenance of S&C systems so that signalling maintenance staff:

a. have ready access to all relevant documentation on and off site;

b. are reminded on site of all the required maintenance actions;

c. positively record that each required maintenance action has been carried out; and

d. are subject to regular supervisory checks to verify that actions that are required to be taken have been carried out to the required quality.

This recommendation arises from paragraph 519.
Actions already reported as taken by Network Rail can be found in paragraph 683.

10 The intention of this recommendation is that Network Rail should improve the quality of the existing basic visual inspections. Longer term issues concerning track inspection are dealt with under Recommendation 19.

Network Rail should review and amend its processes for basic visual track inspection so that the issues identified in this report are addressed.

To achieve this Network Rail should consider issuing modified instructions to define:

a. the contents of task instructions issued to staff undertaking basic visual inspections;

b. the nature of defects that can occur and how to detect those that are difficult to readily observe;

c. job cards to advise the start and finish locations and the direction of the inspection for every occasion;

d. the information supplied to a patroller before an inspection in terms of clearly-presented intelligence on previously-reported defects;

e. the scope of information that is to be recorded during an inspection (including definition of the need to record or comment on previously-reported defects);

f. **the requirement to make positive statements about areas of the inspection where no defects have been found;**

g. **the checks for completeness that should be made within the track section manager's office, including verification that every inspection has been carried out;**

h. **the analysis and supervision that should be undertaken to confirm that inspections are being conscientiously completed; and**

i. **a suitable level of continuity that can be achieved by identifying individual patrollers with individual sections.**

This recommendation arises from paragraphs 516 and 520.
Actions already reported as taken by Network Rail can be found in paragraph 681.

11 The intention of this recommendation is to ensure that when a supervisory and a basic visual inspection are combined, both are fully and correctly delivered, and recorded.

Network Rail should modify its processes to specify the following safeguards when a supervisor's visual track inspection is combined with a basic visual inspection:

a. **all the paperwork relevant to the basic visual inspection (see Recommendation 10) is supplied to the supervisor; and**

b. **an assurance check is carried out by a person other than the relevant supervisor to confirm that both inspections have been completed and recorded appropriately.**

This recommendation arises from paragraphs 516 and 518.
Actions already reported as taken by Network Rail can be found in paragraph 682.

12 The intention of this recommendation is that Network Rail should address the competence and management issues relating to the inspection and maintenance of S&C that have been demonstrated in this report.

Network Rail should review its processes for practical training, assessment competence assurance for those undertaking S&C inspection and maintenance against current UK rail industry best practice (eg ORR's publication 'Developing and Maintaining Staff Competence'), and make relevant changes so that the requirements arising from Recommendations 6, 7, 8, 9, 10 and 11, as appropriate, and those from the more general observation about competence in this report, can be delivered.

This recommendation arises from paragraphs 514, 51, 519 and 522.

Underpinning engineering and risk management

13 The intention of this recommendation is that Network Rail should establish whether it is practicable, in human factors terms, for the inspection and maintenance processes to identify and rectify all defects to an adequate and consistent standard, and revise the design of S&C to allow for any identified impracticability or variability in those activities.

Network Rail should conduct a review, focused on human factors, to develop an accurate understanding of the practicability of, and variability in, the performance and outcome of inspection and maintenance so that any issues identified can be taken into account in the design of S&C systems and the associated inspection and maintenance specification. This activity is integral to Recommendations 1 and 10, and a precursor to Recommendation 19.

This recommendation arises from paragraph 520.

Actions already reported as taken by Network Rail can be found in paragraph 682.

14 The intention of this recommendation is that Network Rail should have adequate monitoring of S&C failure precursors.

Network Rail should review and improve its management arrangements for monitoring performance in relation to the inspection and maintenance of S&C assets, taking account of the guidance contained in HS(G) 254, 'Developing process safety indicators' by introducing an suitable 'leading' and 'lagging' performance indicators. The indicators should encompass measures of the reliability of both maintenance and inspection activities and the performance and condition of key components;

This recommendation arises from paragraphs 518 and 519.

15 The intention of this recommendation is that Network Rail's compliance and assurance systems should mandate site checks of its S&C asset so that it is independently aware of the actual state of its assets on the ground, any developing trends in its asset performance (see Recommendation 2), and their relationship to its records from inspections.

Network Rail should extend its compliance and assurance processes to include independent end product checks on a sample of its S&C asset to:

- **confirm that its inspections and work database reflect the physical state of its assets;**
- **confirm that the asset is compliant with appropriate standards;**
- **confirm that the actions identified in Recommendations 1 to 3 are, in fact, delivering an improvement in the performance of S&C assets;**
- **observe for defects or problems that, although the asset and systems may comply with the appropriate standards, may effect the safety of the line.**

Action already reported as taken by Network Rail can be found in paragraph 681.

This recommendation arises from paragraphs 519 and 523.

16 The intention of this recommendation is that Network Rail should specify adequate opportunities for inspection (and also for maintenance, although recognising that lack of maintenance opportunities was not an issue in the Grayrigg derailment) activities when developing infrastructure enhancement projects.

Network Rail should include within its infrastructure enhancement project processes an assessment of the impact of any project on the inspection and maintenance of the assets at a stage of the project which allows identification and implementation of suitable measures before commissioning.

This recommendation arises from paragraph 517.

17 The intention of this recommendation is that Network Rail should review whether there is currently adequate access for inspection on its main-line routes.

Network Rail should review and, if necessary, revise its access arrangements and plans (including Rules of the Route) for its main-line routes. This should be done to provide for the needs of maintenance and inspection of existing infrastructure, given current and planned traffic levels.

This recommendation arises from paragraph 517.
Actions already reported as taken by Network Rail can be found in paragraph 682.

18 The intention of this recommendation is that Network Rail should review the interfaces in its headquarters' engineering department concerning S&C, with particular reference to track and signalling engineering.

Network Rail should review and, if necessary, revise its management organisation to provide effective stewardship of S&C assets. The review should include consideration of the creation of a single professional department (design authority) responsible to the chief engineer for all aspects of S&C, including specifying design, procurement, installation, set-up, commissioning, inspection, maintenance and performance.

This recommendation arises from paragraph 519.
Actions already reported as taken by Network Rail can be found in paragraph 682.

19 The intention of this recommendation is that Network Rail should review its track inspection requirements so that best use is made of new technology for plain line and S&C inspections[44].

Network Rail should re-assess the differing requirements of plain line and S&C track inspections with regard to:

- **the amount that is appropriate to be done by human intervention, and the amount by automated data capture, for both types of track;**
- **the different relative frequencies that may be appropriate for both types of track; and**
- **what protection arrangements should be provided.**

Consideration should be given to separate processes for plain line and S&C inspections to recognise the different requirements of each.

This recommendation arises from paragraph 517.

20 The intention of this recommendation is that Network Rail should carry out its S&C engineering safety management in line with UK railway industry documented best practice.

Network Rail should review its S&C engineering safety management arrangements with reference to current UK rail industry best practice (eg the 'Yellow Book') and address any deficiencies identified.

This recommendation arises from paragraph 519.

[44] This recommendation is associated with a recommendation from the RAIB's investigation into a staff accident at Leatherhead, where staff safety issues have produced a similar conclusion (RAIB report 19/2008, recommendation 2)

Recommendations to address other matters observed during the investigation

Safety Authority delivery plans

21 The intention of this recommendation is to ensure that, in the short term, ORR explicitly includes S&C in its delivery plan assignments for as long as it remains an identified high risk in the ORR's assessment. In the longer term the intention is to ensure that the ORR includes assignments for all the higher risk items within its delivery plan, irrespective of the topic in which it is grouped.

The ORR should amend its process for planning and briefing the annual delivery plan to make explicit when an area of high risk is to be included within an individual assignment.

This recommendation arises from paragraph 526.

Recommendations relating to the injuries to passengers, vehicle design and safety

22 The intention of this recommendation is to minimise the risk of injury from detachment of seats in the event of an accident, by enhancing the requirement in the current design standard, for seats to deform in a ductile manner when overloaded, particularly in the lateral direction.

RSSB should make a proposal in accordance with the Railway Group Standards code to introduce a specific requirement in the relevant interiors design standard, that future seats designs, including those that may be fitted at refurbishment, should demonstrate a ductile deformation characteristic, when overloaded in the vertical, lateral or longitudinal directions, in order to minimise the risk of complete detachment in accidents.

This recommendation arises from paragraph 609.
Actions already reported as taken by RSSB can be found in paragraph 685

23 The intention of this recommendation is to minimise the risk of injury arising from the detachment of heavy internal panels in the event of an accident.

RSSB should consider, and where appropriate, make a proposal in accordance with the Railway Group Standards code to implement a requirement in the relevant design standard to provide sufficient means of retention for internal panels assessed as capable of causing serious injury in the event of complete detachment.

This recommendation arises from paragraph 609.
Actions already reported as taken by RSSB can be found in paragraph 685.

24 The intention of this recommendation is to minimise the risk of the reading light panels in a Pendolino train becoming detached in the event of an accident.

Virgin Trains and Angel Trains should review the mounting of the reading light panels on the Class 390 Pendolinos and take steps to minimise occupant injury from failure of the panel retention system.

This recommendation arises from paragraph 609.

25 The intention of this recommendation is that general safety lessons regarding rail vehicle crashworthiness emerging from the Grayrigg accident are considered and, where appropriate, research is undertaken to assess the practicability of making improvements. If suitable improvements are found, proposals should be made for changes to crashworthiness standards.

RSSB should:

a. Identify any gaps in industry knowledge about vehicle dynamic behaviour in derailments (for example the forces acting on inter-vehicle couplers and bogie retention systems) and where appropriate, undertake research to investigate improvements in vehicle performance. Where appropriate, RSSB should make a proposal in accordance with Railway Group Standards code to change relevant design standards.

b. Investigate and, where practicable, make a proposal in accordance with Railway Group Standards code to introduce specifications for roll-over strength and penetration resistance of rail vehicle bodyshells in design standards to ensure consistency of performance in accidents across all future fleets;

c. Undertake research into the injury mechanisms at Grayrigg to identify means of improving occupant survivability in future rail vehicle designs. Where appropriate, RSSB should make a proposal in accordance with Railway Group Standards code to change relevant design standards;

d. Review and revise, if necessary, its past research into seat belts in rail vehicles in the light of the findings from the Grayrigg derailment, taking into account foreseeable changes to vehicle behaviour in future accidents, in order to check whether the conclusions reached therein remain valid; and

e. Confirm and publish the results of its cost benefit analysis as to the reasonable practicability of fitting seat belts to passenger trains. If the analysis shows that fitting seat belts is other than grossly disproportionate to the risks involved, further investigate how to take the issue forward.

This recommendation arises from paragraph 607, 610 and 612.

Recommendations relating to the Emergency Services' response to the accident

26 The intention of this recommendation is to assist the emergency services to optimise their response to an accident.

Cumbria Police should carry out a review of, and change as appropriate, its management, procedures and training relating to the rapid and accurate location of an accident from information received in emergency calls in the control room so that received information is filtered effectively and without loss of significant data.

This recommendation arises from paragraph 656.

27 The intention of this recommendation is to promote the safety of Ambulance Service personnel who are called upon to carry out rescue work after a railway accident.

The Department of Health's eleven mainland Ambulance Service NHS Trusts, the Welsh Ambulance Services NHS Trust and the Scottish Ambulance Service should:

- **agree and implement suitable processes so that their staff are suitably trained for work on the railway; and**
- **agree a protocol with Network Rail to cover the necessary steps for the ambulance services to enter Network Rail property safely in an emergency.**

This recommendation arises from paragraph 659.

28 The intention of this recommendation is to improve communications between rescue organisations after an accident.

The Ministry of Defence should equip the Royal Air Force and Royal Navy search and rescue fleet of helicopters with radio communication equipment that allows direct contact with civil emergency services.

This recommendation arises from paragraph 657.

Recommendation relating to work hours and number and distribution of rest days for workers with safety critical tasks

29 The intention of this recommendation is to identify possible links between working hours and performance, and to implement steps that can be taken to reduce any resultant risk.

a. **Network Rail should carry out research to establish if there is a link between working long hours over extended periods, including the number and distribution of rest days, and the propensity for human errors during safety critical tasks. The study should include, but not be limited to, those staff who have ordinary office-based duties interspersed with safety critical tasks, such as inspections. The output of the research should be a set of threshold levels of hours for differing roles.**

b. **Using the output of the research, Network Rail should establish procedures to deliver compliance with the thresholds identified.**

This recommendation arises from paragraph 521.

This page is left intentionally blank

Appendices

Appendices

Appendix A - Glossary of abbreviations and acronyms

BASICS	British Association for Immediate Care
BTP	British Transport Police
CCTV	Closed Circuit Television
EPS	Enhanced Permissible Speed
FMEA	Failure Modes and Effects Analysis
HMRI	Her Majesty's Railway Inspectorate
ORR	Office of Rail Regulation
OTDR	On Train Data Recorder
PICOP	Person In Charge Of Possession
RAIB	Rail Accident Investigation Branch
RSSB	Rail Safety and Standards Board
S&C	Switches & Crossings
SIN	Special Inspection Notice
SINCS	Signalling Incident System
WCML	West Coast Main Line
WCRM	West Coast Route Modernisation

Appendix B - Glossary of terms

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

Absolute track geometry	Track geometry that has a current approved design, normally based on co-ordinate geometry.*
Anti-climber	Device fitted to the ends of a passenger vehicle to help interlock it with other vehicles in a collision and prevent the vehicles overriding each other.*
Assessment in the line	Part of Network Rail's competence management system involving an assessment of competence carried out under the supervision of an employee's line management.
Authority to work	A document issued to staff by their line manager authorising them to work following a review of their competence each year.
Back drive	See 'Supplementary drive'.
Ballast	Crushed stone, nominally 48 mm in size and of a prescribed angularity, used to support sleepers, timbers or bearers both vertically and laterally.*
Baseplate	A cast or rolled steel support for flat bottom rails.*
Bearer	A term used to describe a wooden or concrete beam used to support the track. The term generally applies to long switches and crossings.*
Bogie	A metal frame equipped with two or three wheelsets and able to rotate freely in plan, used in pairs under rail vehicles to improve ride quality and better distribute forces to the track.*
Bolt retaining plate	A plate located under the head of a bolt which prevents it rotating when being tightened (similar to a tab washer).
Branding	See 'Rail branding'.
British Association for Immediate Care	An association of highly trained immediate care practitioners who provide their services in support of the ambulance service.
British Transport Police	The national police force for the railways, including the London Underground network.
Brittle overload	Component failure where there is little or no deformation of the material prior to its breakage.
Bronze command	See 'Gold / Silver / Bronze command'.
Business Critical Configuration Management	A process that Network Rail decided to adopt in 2003 with the objective of identifying the functional requirements, the safety requirements and the potential failure modes for each of the component parts of safety critical assets as a precursor to analysis that would demonstrate that the functional and safety requirements are met by the design and management arrangements.

Busline	The electrical interface which distributes power to the separate components of the system.
Cant	The design amount by which one rail of a track is raised above the other rail, measured over the rail centres* (see also Appendix G).
Cant deficiency	The permissible shortfall in cant or superelevation of the track* (see also Appendix G).
Cantrail	The point on a rail vehicle at which the side of the vehicle body meets the roof profile.*
Casualty Bureau	A contact centre established in the event of a major incident for relatives and friends to register persons thought to be involved.
Causal factor	Any condition, event or behaviour that was necessary for the occurrence. Avoiding or eliminating any one of these factors would have prevented the occurrence from happening.
Cess	The part of the track bed outside the ballast shoulder that is deliberately maintained lower than the sleeper bottom.*
Chain(s)	A unit of length, being 66 feet or 22 yards (approximately 20.117 metres). There are 80 chains in one standard mile.*
Check rail	A rail or other special section provided alongside a running rail to give guidance to flanged wheels by restricting lateral movement.*
Clamping force	The tensile force in bolts.
Coefficient of friction	A value which represents the friction between two contacting surfaces.
Collapse characteristics	The behaviour of a structure in terms of its axial displacement, bending behaviour and energy absorption when subject to forces which causes it to collapse.
Common crossing	A switch and crossing unit comprising a point rail and a splice rail and two wing rails.*
Contraflexure	A curve of opposite hand to another related curve.*
Contributory factors	Any condition, event or behaviour that affected or sustained the occurrence, or exacerbated the outcome. Eliminating one or more of these factors would not have prevented the occurrence but their presence made it more likely, or changed the outcome.
Coupler	A device used to connect rail vehicles together.
Crashworthiness	The capacity of a vehicle to protect its occupants during an impact.
Crossing vee (may also be referred to as a common crossing vee)	The assembly formed by fixing together a common crossing point rail and a common crossing splice rail. The term is also used to describe any similar assembly.*
Crossover	Two turnouts connected to permit movements between parallel tracks.*

Crumple zone	Areas located at each end of a rail vehicle which are designed to deform in a controlled manner and absorb energy during a collision, in order to protect passengers from a loss of survival space and excessive accelerations.
Customer Service Assistant	Member of train crew who assists the customer services manager with on-board catering and retailing activities.
Customer Services Manager	Member of train crew with responsibility for the management of on-board catering and retailing activities. Assists the train manager with the care of passengers following an accident.
Cutting	An area excavated to permit a railway to maintain its level and gradient through high ground without excessive deviation from a straight course.*
Cybernetix IVOIRE III	The Cybernétix IVOIRE high resolution linescan camera system. This system has cameras looking at the rails in close up and giving both rails on one picture, as well as a camera on each side looking at a wider view to include the rail fasteners. IVOIRE III is a trademark of Cybernétix SA, France.
Danger	Universal term for a red signal aspect.*
Detection	A mechanism intended to prove that a set of switches (set of points) are correctly set.*
Detection equipment	The equipment within the set of switches (set of points) that provides the detection function.
Detector rod	A straight bar that connects the detection equipment to the toe of the switch so that the position of the toe can be detected.
Down (line)	In a direction away from London or towards the highest mileage.*
Electric Multiple Unit	An electrically powered train comprising two or more cars that can be driven and controlled as a single unit from the leading driving cab.
Electrical Control Room (ECR) Operator	The person having control over supply to, switching of and isolation of an electrification system in a geographical area.*
Electrical release	The removal of locking on a function using an electrical signal, for example, the unlocking of a function such as a ground frame.
ELLIPSE	A computer based asset management system used by Network Rail to record and prioritise what maintenance is work required to be done and when it needs to be done by.
Embankment	A filled area to permit a railway to maintain its level and gradient across low ground without excessive deviation from a straight course.*

Emergency brake application	A demanded brake application that uses a more direct and separate control system than that used for normal service braking applications. This may result in quicker application of braking. On certain vehicles, the retardation rate may be specified to be higher than that of the full service braking application; this is described as 'enhanced emergency braking'.
Emergency coupler	Typically carried by multiple unit trains, this is an adapter which allows a locomotive (fitted with a hook type coupler) to draw a train fitted with an automatic coupler. These devices are generally intended for a limited number of emergency uses.*
Emergency crossover	A crossover provided to allow trains to cross between running lines during times of degraded operation or single line working. See also 'Emergency Ground Frame'.*
Emergency ground frame	A ground frame controlling one or more crossovers used only in times of emergency or possession.*
Emergency isolation	An interruption to the traction electricity being supplied to a particular part of the overhead line equipment (OLE), undertaken in an emergency. Once an emergency isolation has been carried out the OLE becomes safe to approach but not to touch, as it may still contain a small residual potential. This can be discharged by an additional process known as earthing.
Engineering acceptance	The process whereby conformance of railway vehicles to the mandatory requirements of Railway Group Standards is scrutinised and certificated.
Engineering train	A train used in connection with engineering works, including On Track Machines.*
Enhanced Permissible Speed (EPS)	The Tilt Authorisation and Speed Supervision system authorises a train to undertake tilting operations. It also provides speed supervision of the train on certain sections of the line in which tilting trains are authorised to proceed at a higher speed than non-tilting trains. This higher speed is known as an Enhanced Permissible Speed.
Escapement joint	A joint which reduces the movement of one part relative to the other. Also known as a 'lost motion' joint.
Facing point lock	A device fitted to a set of facing switches at the front stretcher bar position which positively locks the switches in one setting or the other, totally independently of any other switch operating mechanism.*
Facing point lock test	A test to ensure the switch blade on the closed side is in its correct position and locked in order for the signalling system to obtain detection. Facing point lock tests require the use of a 3.5 mm and a 1.5 mm thick gauge. With the 3.5 mm gauge inserted, the lock should not be able to enter the lock slide in the point machine so preventing the signalling system obtaining detection, whereas with the 1.5 mm gauge inserted, the points should be able to lock and the signalling system obtain detection.

Facing points	A set of points or set of switches installed so that traffic travels from switch toe to switch heel in the normal direction of traffic.*
Fault Management System	The computer system used for logging failures occurring in signalling equipment.
Fasteners	Collective name for the bolts, washers and lock nuts used to secure the stretcher bar components.
Failure Mode Effects Analysis (FMEA)	An analysis which examines the ways in which a component might fail and considers the effect of each failure on the functioning of the system of which the component is a part.
Fatigue (failure)	The failure of an item by fracture under repeated loads which are of a magnitude which would not normally have caused the item to fail by overloading.
Fatalities and Weighted Injuries	Within the rail industry, fatality and injury levels are used in order to assess both safety risk and the impact of proposed changes. These are measured by using units of Fatalities and Weighted Injuries (FWI), whereby 1 FWI is equal to 1 Fatality or 10 serious injuries or 200 minor injuries. (Note: these values were correct at the time of the Grayrigg accident; they have since been adjusted).
Field side	Describing the side of a line or track nearest the cess*.
Field triage	A process for sorting injured people into groups based on their need for or likely benefit from immediate medical treatment at the scene of an accident.
Flange back	The inner back face or gauge side of the wheel flange.
Flange back contact	Contact between the flange back of a train wheel and a rail.
Four-aspect colour light signalling	A colour light signal capable of displaying four aspects: 1. Green (G) – proceed aspect, the next signal may be displaying green or double yellow. 2. Double Yellow (YY) – first caution (preliminary caution), two signal intervals to the stop signal. The next signal may be displaying a single yellow. 3. Single Yellow (Y) – caution aspect, the next signal may be displaying a red. 4. Red (R) – danger (stop) aspect.*
Four-foot	The area between the two running rails of a standard gauge railway.*
Free wheel clearance	The dimension between the stock rail and the switch rail on the open switch side. This must be sufficient to allow the wheel on the open switch rail side to pass without contact.
Gauge	The distance between the running edges of related running rails, measured between two points each 14 mm below the crown of the rail.*

Gauge side	The side of a running rail nearest the other related running rail.*
Gold/Silver/Bronze command	The standard management framework employed at complex or major incidents, mandated by the Civil Contingencies Act (2004).
Green Zone	A site of work on or near the line within which there are no train movements (except for possibly engineering trains or on-track plant moving at no faster than walking pace). Green zone working is the preferred method of working on or near the line.
Ground frame	A small group of signal and points levers or a switch panel located close to a facility such as a crossover. These levers or switches are locked by the controlling signal box, and are only released for operation when required.
Half set	One switch rail and one stock rail together make a switch half set.
Hardlock	A branded two-piece lock nut.
Hazard and Operability Study	A structured and systematic study of a design or process, undertaken by a multi-disciplinary team. This analysis seeks to identify and evaluate any potential risks to safety and/or operational efficiency presented by the design or process under consideration.
Hazard Directory	A database maintained by Network Rail which contains details of the health, safety and environmental hazards known to exist at certain locations on Network Rail controlled infrastructure.
Health and Safety Executive (HSE)	The government body responsible for protecting people against risks to health and safety arising out of work activities in Great Britain. Prior to April 2008, this body worked in support of the Health & Safety Commission (HSC) which was responsible for health and safety regulation in Great Britain. In April 2008, the HSE and HSC merged to form a single body, which retained the name of the Health and Safety Executive and the former statutory functions of both organisations. The scope of the HSE's activities included the regulation of health and safety in the railway sector until this was transferred to the Office of Rail Regulation in April 2006.
Heel block	Metal block fitted between the switch rail and stock rail at the switch heel to maintain the correct geometry and prevent longitudinal movement of the switch rail.*
Her Majesty's Railway Inspectorate (HMRI)	Part of the Office of Rail Regulation (ORR), which is the independent health and safety regulator for the railway industry in Great Britain (see Appendix M). HMRI was part of the Health and Safety Executive from 1990 until April 2006, when the regulation of health and safety in the railway sector was transferred to the Office of Rail Regulation.

Hogging	Hogging is a condition where the forces acting on an item cause the centre to rise in relation to the ends, thus causing the item to bend upwards. The opposite condition is known as sagging.
Improvement Notice	Where an HMRI Inspector is of the opinion that a railway undertaking is contravening or has contravened and is likely to continue to contravene a relevant statutory provision, then they may issue an improvement notice to them under Section 21 of the Health and Safety at Work Act 1974. An improvement notice will detail the nature of the contravention and the date by which it must be remedied. An improvement notice may or may not require specific remedial measures to be undertaken. Appeals against improvement notices may be made to an Employment Tribunal within 21 days of them being served. The entering of an appeal suspends an improvement notice until the appeal has been determined, but does not automatically alter the date by which the contravention must be remedied.
Infrastructure Fault Control	A Network Rail control office to which Infrastructure defects are reported, which controls the fault teams that rectify the defects, and which records defects and their rectification into the fault management system.
Infrastructure Maintenance Contractor	A contractor who was responsible for carrying out infrastructure maintenance within a defined geographical area. The function has since been brought within Network Rail's direct control.
Infrastructure Maintenance Manager	At the time of the incident, this was the Network Rail senior manager responsible for the delivery of infrastructure maintenance, and the line management of the Maintenance Delivery Unit Managers, within a broad geographic area.
Joint length	The length of a bolt in a joint that is under tension.
Joint Points Team	A team consisting of staff from the signal and track engineering functions responsible for the maintenance of switches and crossings within a defined area.
Left-hand curve	A curve which diverges to the left when viewed facing in the same direction as rail traffic.
Ligaments	The curved part of the stretcher bar bracket where it bends to connect to the stretcher bar assembly.
Load case	The specification of the duty under which a product must perform. Can be derived from calculation, analysis and or testing. Commonly the product is validated against the load case to ensure that it is fit for its intended purpose.
Lock stretcher bar	A bar located at the toes of the switches which hold them locked in the position to which they have been commanded.
Lookout	A person who has been assessed as competent to watch for and to give an appropriate warning of approaching trains.*

Loss of survival space	Loss of spaces on a train normally occupied by passengers or crew caused by severe structural and often resulting in serious or fatal injury if the affected spaces were occupied at the time of the accident.
Maintenance Delivery Unit Manager	At the time of the incident this was the Network Rail manager responsible for the delivery of infrastructure maintenance, and the line management of the Track Maintenance Engineers, within a defined area.
Major incident	A major incident is any emergency that requires the implementation of special arrangements by one or more of the emergency services.
Minor injuries	Any physical injuries that are not listed in Regulation 2(4) of the Railways (Accident Investigation and Reporting) Regulations 2005.
New Measurement Train	A geometry and condition recording train that measures various parameters relating to the track and infrastructure at speeds up to 125 mph (201 km/h). The train also carries a number of track and line-side video cameras and other sensors (see Appendix F).
Non-adjustable stretcher bar	A permanent way stretcher bar of a design where the dimension between the two switch rails cannot be altered after initial installation. (An adjustable stretcher bar has a threaded length that allows this dimension to be adjusted during maintenance).
Normal	For a set of points or set of switches, this is the default position, decided generally as being the position which permits the passage of trains on the most used route. The opposite position is known as reverse.*
NR60/HPSS/Hydrive points	Designs of S&C introduced by Railtrack and Network Rail that do not use non-adjustable stretcher bars.
Observations	An element discovered as part of the investigation that did not have a direct or indirect effect on the outcome of the accident but, in the opinion of the RAIB, does deserve scrutiny.
Obstacle deflector	A device mounted to the body of the leading vehicle of a train which is intended to reduce the risk of a derailment in the event of a collision between the train and a large obstacle on the track.
Office of Rail Regulation (ORR)	The economic and safety regulator for the railway industry in Great Britain (see also 'Her Majesty's Railway Inspectorate').
Omnicom	Omnicom Engineering Ltd., the company that owns the 'OmniSurveyor3D' system.
OmniSurveyor3D	A system which includes seven calibrated cameras mounted on a rail vehicle to record the view from front, rails and sides. The system is calibrated so that measurements can be taken from the video. OmniSurveyor3D is a trademark of Omnicom Engineering Ltd (see Appendix F).

On Train Data Recorder (OTDR)	Equipment fitted on-board the train which records the train's speed and the status of various controls and systems relating to its operation. This data is recorded to a crash-proof memory and is used to analyse driver performance and train behaviour during normal operations or following an incident or accident. This equipment may also be known as an OTMR, Black Box or Incident Recorder.
Overhead Line Equipment	An assembly of metal conductor wires, insulating devices and support structures used to bring a traction supply current to suitably equipped traction units. The conducting wires are normally strung between masts or poles in some form of catenary arrangement.*
Pendolino	The brand name of the Class 390 tilting train.*
Permanent way	The track, complete with ancillary installations such as rails, sleepers, ballast, formation and track drains, as well as lineside fencing and lineside signs.*
Permanent way stretcher bar	A bar which maintains the distance between the switch rails.
Person In Charge Of Possession	A certificated member of railway staff responsible for implementing and then managing a possession of the line.
Plain line	Track without switches and crossings.*
'Plan-Do-Review'	In Network Rail. a meeting held to review work that has been carried out to identify any required arising actions.
Plastic deformation	The change seen in an object's dimensions when a stress is applied which leaves a permanent deformation once this stress is removed.
Points machine	A generic term for any powered device that operates a set of points. Also known as Points Motor.*
Points	An assembly of two movable rails, the switch rails, and two fixed rails, the stock rails. Also known as a set of switches. Used to divert vehicles from one track to another.
Possession	A period of time during which one or more tracks are blocked to normal service trains to permit work to be safely carried out on or near the line.*
Potters Bar Investigation Board	A body appointed by the Health and Safety Commission after the Potters Bar derailment in 2002 to oversee the Health & Safety Executive's (HSE) investigation into the accident and produce a report and recommendations. Its membership included representatives from the HSE and three individuals with relevant expertise who were independent of HSE and HMRI.
Power Signal Box	A signal box which controls the points and signals over an area by electrical means.*

Preload	Tightening a threaded fastener once the joint surfaces are in contact results in the bolt extending. The resultant longitudinal force in the bolt is known as the preload.
Prevailing torque	The resistance of a nut against it rotating before any clamping force is applied by the fastener.
RAIB Recommendations Review Group (R3G)	The group within ORR responsible for reviewing responses to RAIB recommendations and those arising from major investigations (such as that into the Potters Bar derailment) which were still open at the time that the group was set up.
Rail branding	Raised markings on a rail web that identifies rail type, material grade and date of manufacture.
Rail Incident Officer	A nominated and certificated member of railway staff, charged with the on-site command and control of railway organisations at an incident.
Rail Safety and Standards Board (RSSB)	An independent rail industry body which manages the creation and revision of certain mandatory and technical standards (including Railway Group Standards) as well as leading a programme of research and development on behalf of government and the railway industry.
Railway Group Standard	A document mandating the technical or operating standards required of a particular system, process or procedure to ensure that it interfaces correctly with other systems, processes and procedures.*
Recommendations Action Progress Team	A body, formed by the HSE and including members of HMRI staff, which was established to monitor the implementation of recommendations from a range of inquiries and investigations, including the Potters Bar derailment.
Red zone	A site of work on or near the line where trains are running normally and where protection may be provided by a number of means, including lookout(s). Red zone working is the least preferred method of working on or near the line and is prohibited at some locations.
Reliability Centred Maintenance	A structured technique which indentifies how operational practice, maintenance management and investment policies could be managed most effectively in order to reduce the risks of equipment failure. This approach was developed in the United States commercial airline industry and is now widely seen as a benchmark standard. As a discipline it requires users of technical systems to establish formal processes for monitoring, assessing, predicting and understanding the working of their physical asset.
Rendezvous point	A prearranged meeting place for vehicles and resources attending an incident.
Residual potential	The voltage left in electrification equipment that has been isolated but not earthed.
Residual Switch Opening	The gap between the rail heads of adjacent switch and stock rails on the closed side of points.

Rest day	A day within a work roster when an employee is designated as free from duty.
Reverse	For a set of points or lever this is the 'wrong' position, either permitting the passage of trains on the least used route or pulled fully forward in the lever frame respectively. The opposite is 'Normal'.
Rolling Stock Acceptance Board	The body established by Railtrack to manage the acceptance process for new or modified vehicles designed to operate over its infrastructure. This body was subsequently replaced by the Network Rail Acceptance Panel.
Rule book	Railway Group Standard GE/RT8000, which incorporates most of the rules to be observed by railway staff for the safe operation of the network.
Rules of the Route	A document agreed between the Network Rail and the freight and train operating companies which sets down the planning rules for those who require access to the rail network for engineering purposes such as maintenance, renewal and enhancement work. It will also contain route-specific details of any restrictions in the use of the network arising from such work.
Safety Case	A document submitted in support of a system or process, providing evidence that the system complies with relevant safety objectives.* Following the introduction of the Railway and Other Guided Transport Systems (Safety) Regulations 2006 (ROGS) Network Rail's safety case has now been replaced by a safety management system which is the subject of authorisation by the safety authority (in this case the Office of Rail Regulation).
Safety Management Information System (SMIS)	A system used by members of the Railway Group to record all safety-related events that occur on Network Rail controlled infrastructure.
Safety Regulation Committee	An Office of Rail Regulation body including executive and non-executive directors which, amongst other matters, considers decisions made by R3G on closure of recommendations from major accidents and may endorse or challenge those decisions.
Safety Risk Model	A computerised model managed by the RSSB which is a quantitative representation of the potential accidents resulting from the operation and maintenance of Britain's rail network.
Scotches	A large wooden wedge that can be placed either in an open switch of a set of points to prevent movement or between the wheel of a rail vehicle and the rail head to stop the rail vehicle moving.
Search and Rescue	Rescue helicopters provided by the national Search and Rescue Service, which is made up of teams from the RAF, Royal Navy and H.M. Coastguard.
Search and Rescue Liaison Officer	A liaison officer from the RAF or Royal Navy deployed on the ground at the scene of an accident or incident in order to facilitate communications with search and rescue helicopters.

Secondary impact	Impact between occupants and the vehicle interior or other occupants, caused by the passenger compartment being subject to severe accelerations arising from a primary impact event such as collisions with other vehicles or infrastructure or derailments in which vehicles undergo rapid and extreme movements, including roll-over.
Serious injuries	Physical injuries that are listed in Regulation 2(4) of the Railways (Accident Investigation and Reporting) Regulations 2005.
Sidewear	A progressive removal of rail metal generally afflicting the high rail of curves, due to the high lateral forces produced when a train negotiates a curve with insufficient cant or high cant deficiency.*
Signaller	A person engaged in operating a signal box.*
Signalling Maintenance Assistant	The local manager directly responsible for managing teams of signal engineering staff.
Signalling Maintenance Specification	Documents instructing what maintenance should be carried out to signalling equipment.
Silver Command	See ‘Gold / Silver / Bronze command’.
Single line working	The temporary use of one track for working in both directions.*
Six foot	The term for the space between two adjacent tracks, irrespective of the distance involved.*
Sleeper	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.*
Slide chair	A chair with a single jaw designed to support both the stock rail and the switch rail in a switch, the stock rail being bolted to the jaw and the switch rail sliding on a flat base adjacent to this.
Slip	When the clamping force in a bolt is low enough to allow the contacting surfaces within the joint to separate or move relative to each other under an applied force.
Speed restriction	Any imposed reduction of permissible speed or enhanced permissible speed.*
Speed Set	A system which can be engaged by the train driver once a certain speed is reached and which will maintain that speed automatically by varying the traction power applied. It is analogous to ‘cruise control’ in a car.
Spring washer	A general name given to a type of washer that can be used to act as a spring take-up with a bolt to restrict movement between parts.
Stock rail	The fixed rail in a switch half set.*

Stretcher bar	A bar that links the two switch rails in a set of switches (set of points) and maintains their correct relationship, eg one is open when the other is closed.*
Stretcher bar assembly	The total of the stretcher bar, brackets (ligaments), swan neck insulation and associated fasteners.
Structure Gauging Train	A vehicle based gauging system using white light. The train also includes front facing video and runs at night relying on floodlights for illumination (see Appendix F).
Supplementary detector	A second set of detection equipment fitted to a long set of switches, generally at the locations of the supplementary drives.*
Supplementary drive (also known as a back drive)	An arrangement of rodding and cranks, hydraulics or torsion drives that transfers some of the motion of the switch toes to one or more points further down the switch, nearer the switch heel. This system compensates for the flexibility of long switch blades.*
Survival space	See 'Loss of survival space'.
Swan neck	The joint in the stretcher where the long and short sections meet.
Swan neck insulation	A piece of non-conducting material fitted between the two sections of the stretcher bar assembly to provide electrical isolation between the two switch rails.
Swing nose crossing	A common crossing in which the crossing vee can be moved laterally to close up to each wing rail.*
Switch (may also be referred to as a set of switches or points)	An assembly of two movable rails (the switch rails) and two fixed rails (the stock rails) and other components (baseplates, bolts, soleplates, stress transfer blocks and stretcher bars) used to divert vehicles from one track to another.
Switch rail	The thinner movable machined rail section that registers with the stock rail and forms part of a switch assembly.*
Switch rail extension piece	Bracket fitted to the switch toe giving a means of connection for the point machine detection rods.
Switches and Crossings (S&C)	Track consisting of switches and crossings forming connections between lines.* Points are a specific type of switch and crossing, albeit the overwhelming majority installed in the Network Rail system.
Tamping	The operation of lifting the track and simultaneously compacting the ballast beneath the sleepers.*
Task Analysis	A structured study into how a specific task is undertaken. It will examine the physical and mental elements of a particular task and the possible outcomes of each step involved. It will also consider the duration, frequency and complexity of the task, the environment in which it is performed and any requirements for team working, training and equipment.

Temporary Danger Area	An area of temporary flying restriction imposed by the UK's National Air Traffic Service.
Through timbers	Wooden switch and crossing bearers that support the rails of more than one track.*
Tilt Authorisation Speed Supervision System	A system which authorises tilting trains to undertake tilting operations. The system will restrict such operations to those areas which have been pre-defined as safe for tilting to take place. It also provides speed supervision of the train for sections of the line in which tilting trains are authorised to proceed at a higher speed (known as an 'enhanced permissible speed' or EPS) than non-tilting trains, as well as sections of the line fitted with the system where tilting trains must maintain the same speed as other non-tilting trains.
Toe	The movable end of a switch rail.*
Torque	The tendency of a force to rotate an object about an axis, equal to the force multiplied by its distance from the axis.
Track Maintenance Engineer	The Network Rail manager responsible for the delivery of track maintenance, and the line management of the Track Section Managers, within a defined area.
Track Section Manager	The local Network Rail manager directly responsible for managing teams of track maintenance staff.
Train continuity circuit	An electrical circuit which is energised only once certain conditions relating to the safety of the train and its systems are satisfied. Should this circuit be interrupted by a change in the status of one of these systems then this circuit will de-energise and an emergency brake application will result.
Train Management System	An on-board computer system which monitors equipment performance and provides information to the driver.*
Train Manager	Member of train crew with the overall responsibility for the management of the on-board staff, revenue protection and passenger liaison. Undertakes the duties of the guard following an accident, including the care of passengers and, if necessary, the protection of the line.
Train Protection and Warning System	A system fitted to certain signals which will automatically apply a train's brakes if it approaches the signal at too high a speed, or fails to stop at it, when it is set at danger. It will also automatically apply a train's brakes if it is travelling too fast on the approach to certain speed restrictions and buffer stops.
Transition curve	A composite curve with a continuously varying radius from straight to the circular part of a curve, vice versa, or between curves of different radii.
Turnout	A junction that comprises a switch, an acute common crossing and appropriate closure rails. May also be known as a single lead.*

Underlying factors	Any factors associated with the overall management systems, organisational arrangements or the regulatory structure.*
Up (line)	Moving in a direction towards London.*
Unassisted lookout protection	A lookout system for warning of approaching trains based only on the line of sight of those undertaking lookout duties (ie without assistance provided by a supplementary warning system).
Urgent Safety Advice (USA)	Guidance issued by the RAIB to the industry and the safety authority which alerts relevant parties to matters of immediate safety.
Vehicle Acceptance Body	A body given authority by RSSB to undertake engineering acceptance for rail vehicles.
West Coast Main Line (WCML)	The route from London Euston to Glasgow via Rugby, Crewe and Carlisle, running up the west side of Britain. The main branches to Birmingham, Liverpool and Manchester are also included.*
West Coast Route Modernisation	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 Slide Protection (WSP)	A vehicle system which identifies when train wheels have started to slide and then releases and re-applies the brakes in order to optimise braking and prevent damage to the wheels.
Wheelchex	A track-mounted monitoring system designed to measure the vertical wheel loads of passing trains and identify those with the potential to cause excessive damage to the infrastructure.
Wheel profile	The shape of a section of a rail wheel taken through the axis of rotation. Typically this is a conical section with a flange on the side of the greatest diameter.*
Whitworth bolts	A fastener of the British Standard Whitworth (BSW) type which, at the time of the accident, had thread forms, sizes and tolerances which were in accordance with the requirements of standards BS84:1956 (this standard was superseded by BS 84:2007 in November 2007).
Wing rail	Short lengths of angled rail fastened one to each side of the crossing vee in a common crossing assembly, extending in front and flared to the rear of the crossing nose.*
Worksite	The area within a possession that is managed by an Engineering Supervisor.*
Yaw	The rotation of a body (for example a car body or bogie) about a vertical axis.

Appendix C - Key standards current at the time

British Railways Board Safety Directorate Code of Practice BR/BCT609, Issue 1, July 1996	Railway Vehicle Interior Crashworthiness
British Standard BS3692:2001	ISO Metric Precision Hexagon Bolts, Screws & Nuts
Engineering Safety Management (the 'Yellow Book'), Issue 1.0, November 2005	Checklist for Application Notes - Maintenance
Health and Safety Executive - Health and Safety Guidance HS(G) 254	Developing Safety Process Indicators
Network Rail Standard NR/C&TM/TR/9 Issue 1 April 2006	Supervisor's Visual Track Inspection course
Network Rail Standard NR/GN/SIG/11772, Issue 1, April 2001	Guidance Note: 'Supplementary Point Drives and Detection'
Network Rail Standard NR/GN/TRK/7001 Issue 1 Feb 2007	Index of Trackwork Information Sheets
Network Rail Standard NR/L3/SIG/10663-SMS PA00, Issue 02, April 2006	Network Rail Signalling Maintenance Specifications: 'Point Equipment: General'
Network Rail Standard NR/SP/SIG/10660, Issue 5, Oct 2006	Implementation of Signalling Maintenance Specifications (SMS)
Network Rail Standard NR/SP/SIG/10661, Issue 7, Oct 2006	Signalling Maintenance Task Intervals
Network Rail Standard NR/SP/SIG/10662, Issue 3, Oct 2006	Process for the Inspection of new or Revised Maintenance Regimes for Signalling Assets
Network Rail Standard NR/PRC/MTC/TK0075, Issue 02, October 2006 (compliance date: 1 April 2007)	Management of Permanent Way Inspections
Network Rail Standard NR/SP/ASR/036, Issue 3, April 2005	Network Rail Audit Manual
Network Rail Standard NR/SP/SIG/10028, Issue E3, April 2004	Inspection and Surveillance of Signal Engineering Activities
Network Rail Standard NR/SP/SIG/10047, Issue 10, Feb 2006	Management of Safety Related Reports for Signalling Failures
Network Rail Standard NR/SP/SIG/10160, Issue 1, Feb 2005	Signal Engineering: Implementation of IRSE Licensing Scheme – The Route to Competence
Network Rail Standard NR/SP/SIG/10660, Issue 5, Oct 2006	Implementation of Signalling Maintenance Specifications (SMS)

Network Rail Standard NR/L3/SIG/10663-SMS PA11, Issue 05, Dec 2007	Network Rail Signalling Maintenance Specifications: ‘Point Inspection’
Network Rail Standard NR/SP/SIG/10660-SMS/ Part /Z02	Network Rail Signalling Maintenance Specifications: ‘Point Reference Values’
Network Rail Standard NR/L3SP/SIG/1066310660-SMS PF01, Issue 0504, Dec 2007April 2006	Network Rail Signalling Maintenance Specifications: ‘Point Fittings’
Network Rail Standard NR/L3/SIG/10663-SMS PF02, Issue 05, Dec 2002	Network Rail Signalling Maintenance Specifications: ‘Mechanical Supplementary Drives’
Network Rail Standard NR/SP/SIG/10660, Issue 5, October 2007 (also known as RT/E/S/10660)	Implementation of Signalling Maintenance Specifications
Network Rail Standard NR/SP/SIG/10661, Issue 7, Oct 2006	Signalling Maintenance Task Intervals
Network Rail Standard NR/SP/SIG/10662, Issue 3, Oct 2006	Process for the Inspection of new or Revised Maintenance Regimes for Signalling Assets
Network Rail Standard NR/SP/SIG/19811, Issue 1, Apr 2007	FMS Data Entry
Network Rail Standard NR/SP/TRK/001, Issue 02, Oct 2005	Inspection and Maintenance of Permanent Way
Network Rail Standard NR/SP/TRK/053, Issue 03, Oct 2002	Inspection and repair Procedures to Reduce the Risk of Derailment at Switches
Network Rail Standard NR/WI/SIG/00111, Issue 02, Apr 06	Company Work Instruction: ‘Points General – Supplementary Drives – Mechanical’
Network Rail Standard NR/WI/SIG/10179, Issue 2, April 2006 (Compliance date: July 2007) (also known as RT/E/C/10179)	The Set up and Maintenance of Adjustable Stretcher Bars
Network Rail Standard NR/WI/TRK/001, Issue 01, Oct 05	Track Inspection Handbook
Railway Group Standard GE/RT8000,	Rule Book
Railway Group Standard GI/RT7004 1 December 2000	Requirements for the design, operation and Issue maintenance of points
Railway Group Standard GM/RC2502, Issue 1, Nov 1994	Code of practice for structural aspects of railway vehicle interiors
Railway Group Standard GM/RT2100, Issue 2, Apr 1997	Structural Requirements for Railway Vehicles

Railway Group Standard GM/RT2176, Issue 1, Dec 1995	Air Quality and Lighting Environment for Traincrew Inside Railway Vehicles
Railway Group Standard GM/RT2466, Issue 1, June 2003	Railway Wheelsets
Railway Group Standard GM/TT0088, Issue 1, December 1993	Permissible Track Forces for Railway Vehicles
Railway Group Standard GM/TT0122, Issue 1, Rev A, June 1993	Structural Requirements for Windscreens and Windows on Railway Vehicles
RT/CM/SO/P/305, July 2001	Rail Incident Protocol
Society of Automotive Engineers Standard SAE JA1011, August 1999	Evaluation Criteria for Reliability-Centred Maintenance (RCM) Processes
Statutory Instrument 1994 No. 157	Railways and Other Transport Systems (Approval of Works, Plant and Equipment) Regulations 1994
Statutory Instrument 2002 No. 1166	Railways (Interoperability) (High Speed) Regulations 2002
Statutory Instrument 2006 No. 557	Health and Safety (Enforcing Authority for Railways and Other Guided Transport Systems) Regulations 2006

Appendix D - An overview of points operation and terms

1 Points allow trains to be diverted from one route to another. The diversion is carried out by having two rails that move from one side of the track to the other, to set the route as required by the signalling system. These movable rails are known as the switch rails and are designed to abut against static rails known as stock rails (Figure 41).

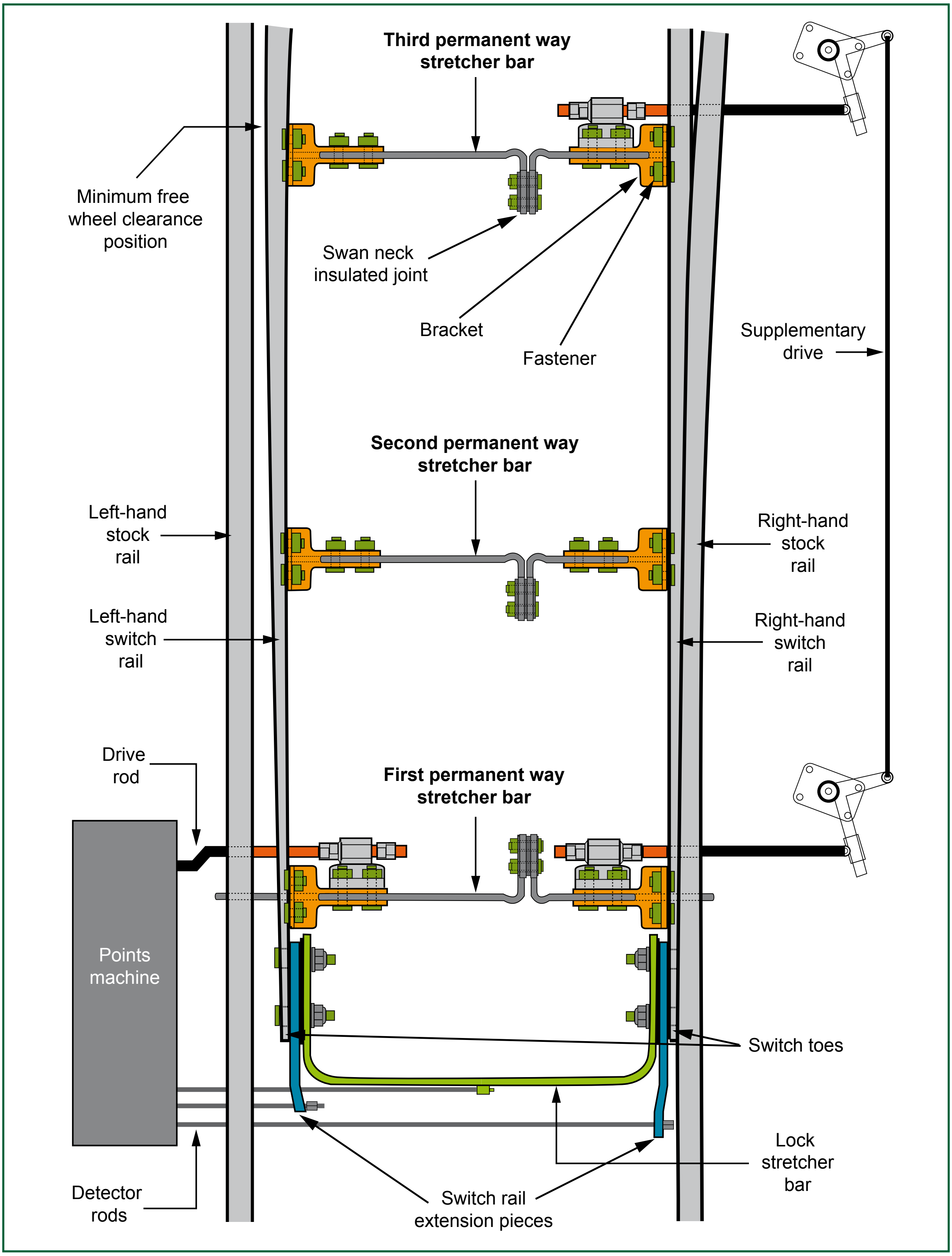


Figure 41: Layout of points showing switch and stock rails and stretcher bars

2 In the UK the two switch rails are maintained a set distance apart and are made to move together by a series of stretcher bars. The bar at the toes, ie the movable end of the points, is known as the lock stretcher bar, and along with detector rods (attached to the switch rails via switch rail extension pieces), indicate to the signalling system that the switches are correctly positioned. The other stretcher bars are known as permanent way stretcher bars.

3 Facing points are used where two routes diverge in the direction of travel, and trailing points where two routes converge. Lambrigg 2B points were facing points (Figure 42).

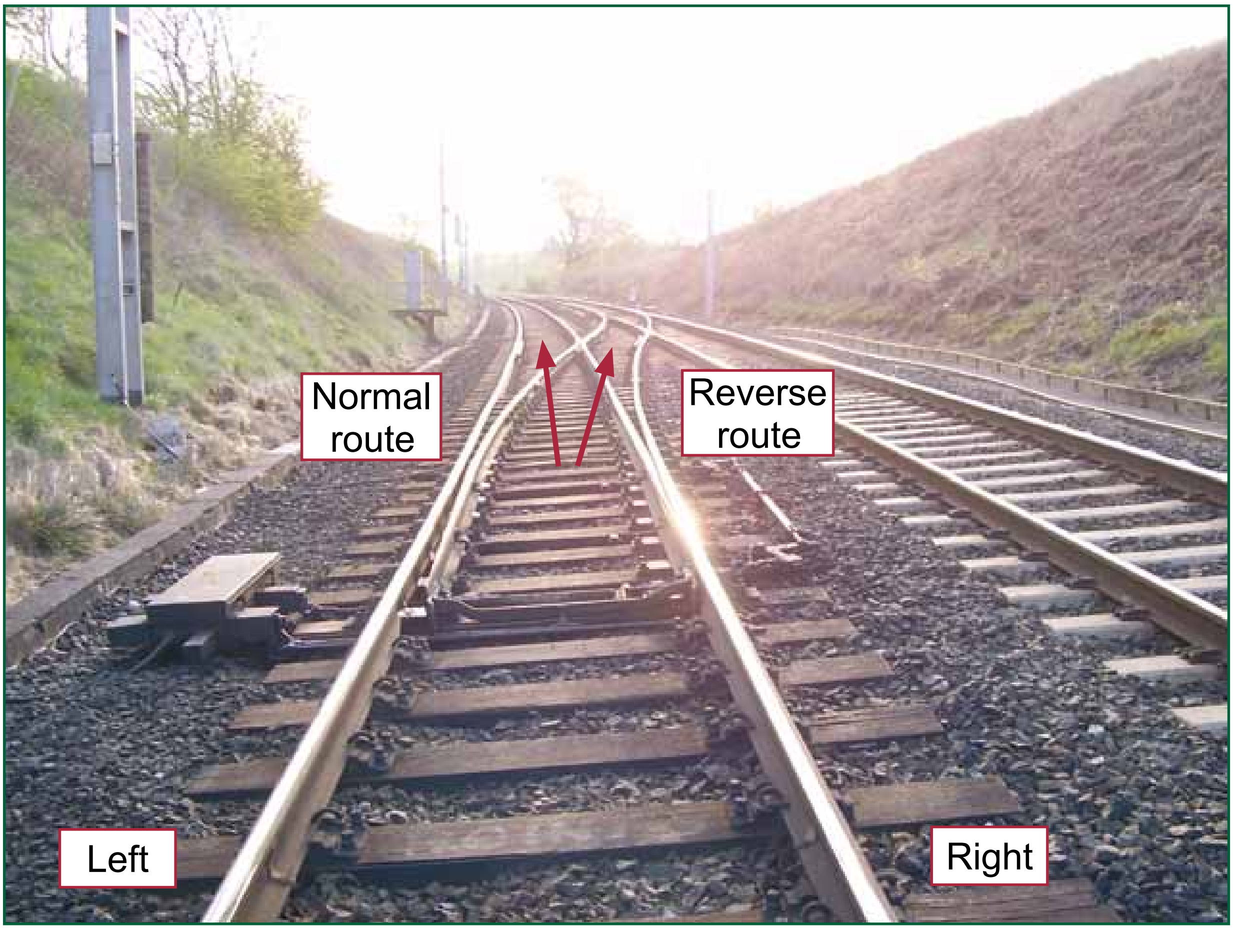


Figure 42: Lambrigg 2B points in May 2006 (courtesy of Network Rail)

4 The 'normal' status for points is usually when they are set for their main route, and the 'reverse' status when set for the diversionary route. The operation of 2B points was that with the points set to 'normal', the left-hand switch rail was open and the right-hand switch rail was close to its adjacent stock rail. This is the position shown in Figures 41 and 42.

5 The points at Lambrigg were made of BS 113A FB section rail, installed with the rails in a vertical plane. The design uses stretcher bars made from a flat spring-steel. These are non-adjustable in length once they are installed; this is achieved by measuring the required length, drilling two holes and bolting together between the bar and the bracket. Network Rail estimate that there are currently some 13,500 units of S&C with non-adjustable stretcher bars on their signalled routes.

6 To allow for the operation of track circuits, non-adjustable stretcher bars are divided into two parts, connected by a bolted insulated joint, commonly known as a swan neck (Figure 43). The two sections of the stretcher bar are of unequal length.

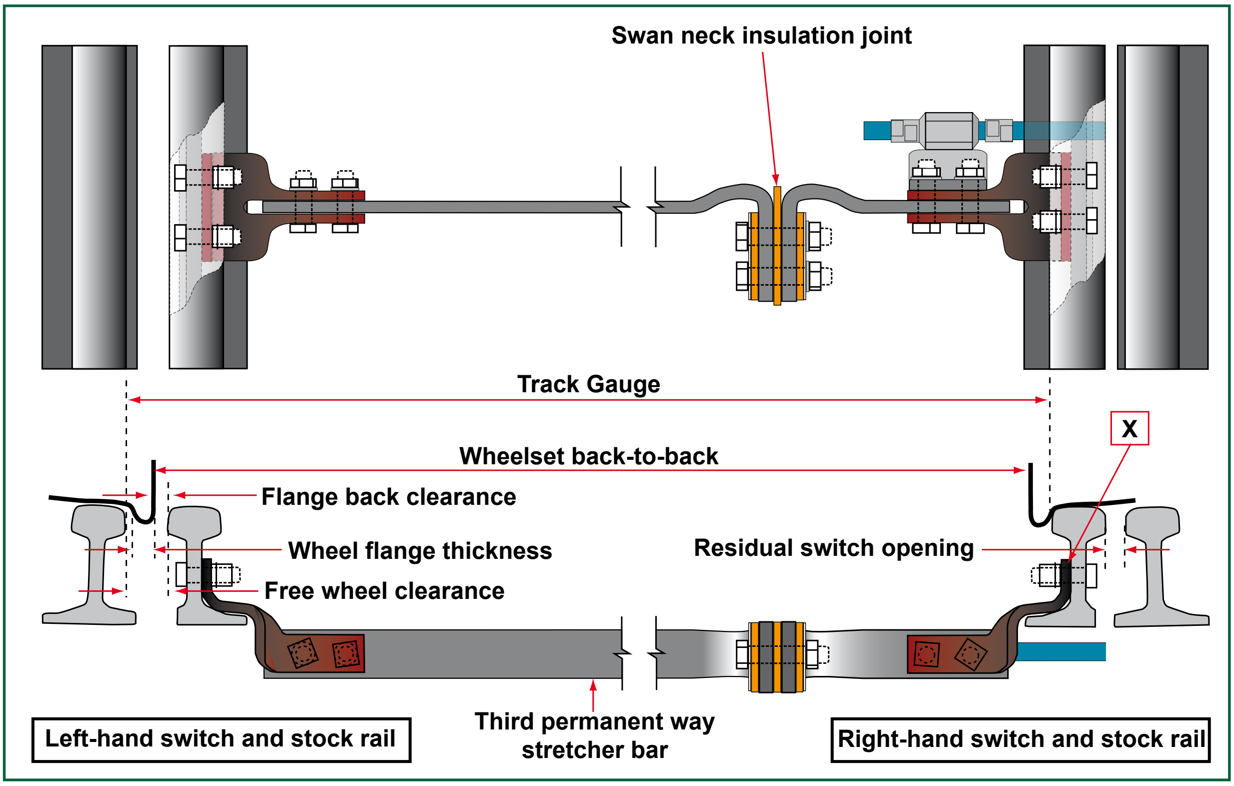


Figure 43: Schematic diagram of points indicating key terms

7 This design of stretcher bar was introduced over 50 years ago, and each bolted joint associated with the stretcher bars is provided with two threaded fasteners (bolts, nuts and spring washers). Network Rail relies on its inspection regimes, both to identify and retighten any loose fasteners, and to identify failed stretcher bars for repair.

8 The number of permanent way stretcher bars depends on the length of the switch, which in turn depends on the speed of trains taking the reverse route through the points. The length of a switch is classified by a letter of the alphabet, with A representing the shortest switch, usually only used in sidings. In the case of 2B points the switches were classified CV (the V standing for vertical) and were fitted with three permanent way stretcher bars.

Flange-back contact, free wheel clearance and residual switch opening

9 The role of the supplementary drive on points is to assist with the movement of the switch rails. For 2B points the supplementary drive is connected to the third permanent way stretcher bar. The setting of the supplementary drive along with the installed length of the stretcher bar determines the positions of the switch rails relative to the stock rails, the amount of free wheel clearance and the residual switch opening on the points.

10 On 2B points the permanent way stretcher bars were set, and the supplementary drive adjusted, to hold the left-hand switch rail open when the points were set for the 'normal' position. This allowed train wheels to pass between the left-hand switch and stock rails without the backs of the wheels contacting the switch rail. Such contact is known as flange-back contact and it leads to additional deflections and forces being generated in the points components.

11 Flange-back contact occurs when the dimension called 'flange-back clearance' becomes zero or less (Figure 43); the degree of contact is dependent on the dimensions of each wheelset passing through the switch. Contact is a minimum for wheelsets with the longest allowable axle length and thickest wheel flanges and a maximum for wheelsets with the shortest allowable axle length and the thinnest permissible wheel flanges.

12 Flange-back contact cannot be practically measured, so a dimension known as free wheel clearance is used (Figure 43). The degree of free wheel clearance required is related to the track gauge, the lengths of the stretcher bars when installed, the flexing shape of the switch rails, the operating throw of the points machine and the setting of the supplementary drive at the third stretcher bar position.

13 The free wheel clearance on 2B points at its minimum location, which is found 260 mm beyond the third permanent way stretcher bar, was set in excess of the 50 mm minimum required by Network Rail company standard NR/GN/SIG/11772.

14 There is an escapement joint at the point of connection between the supplementary drive and the third permanent way stretcher bar (Figure 44). Clearances within this joint, known as lost motion, isolate the supplementary drive and the toes of the switches from any switch rail movements and associated forces induced by trains that could cause damage.

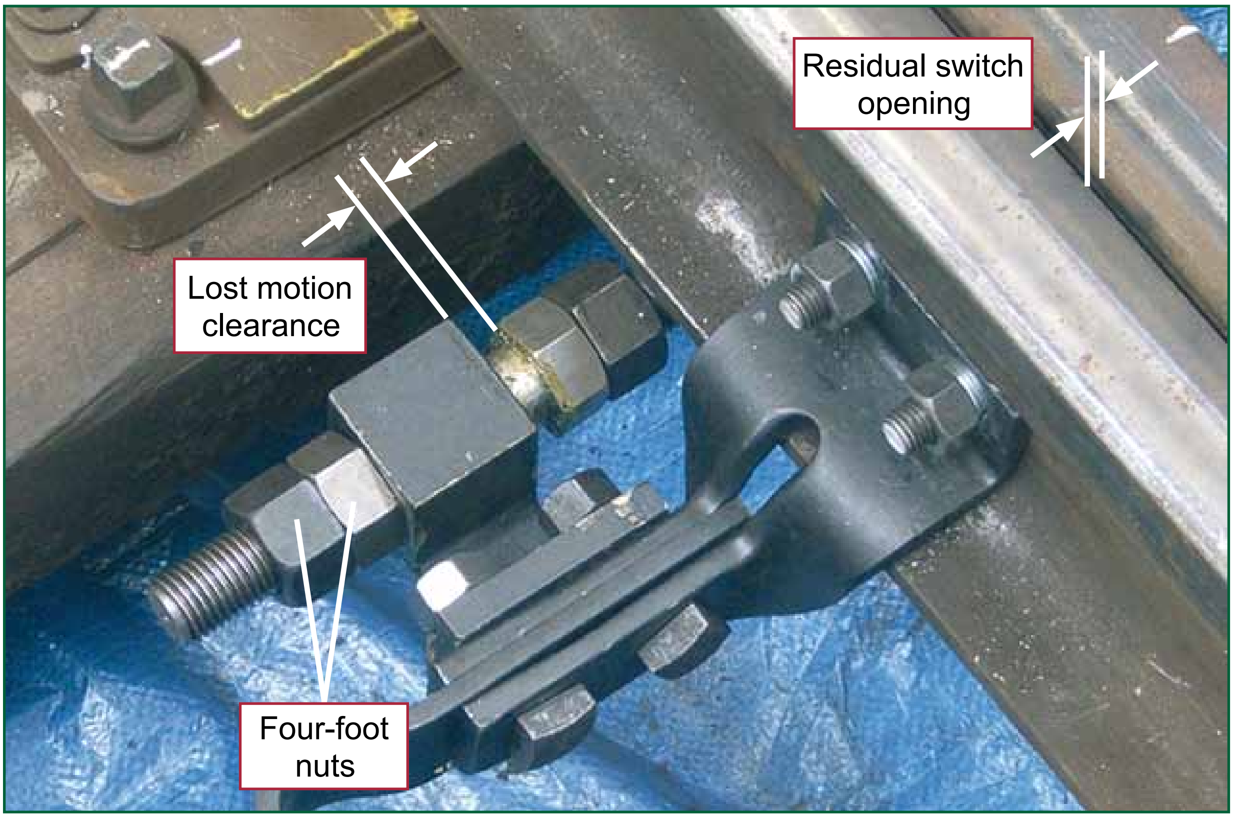


Figure 44: Escapement joint on a reconstructed stretcher bar

15 The adjustment of the clearance at the escapement joint allows installers and maintainers to alter the position of the closed switch rail relative to its adjacent stock rail. Any gap present between the two rails at this location is known as the residual switch opening (Figures 43 and 44). Network Rail found from experience that it was beneficial to have a small gap present between the rails at this location to prevent the points from seizing due to changes in temperature affecting the supplementary drive. Standard NR/GN/SIG/11772, applicable at the time of the accident, stated that the residual switch opening should be 1.5 mm; however, no tolerance or maximum figure was specified.

16 It can be seen from Figure 43 that with a set length of stretcher bar the degree of static free wheel clearance on the left-hand switch rail is affected by the amount of residual switch opening between the right-hand rails. However, passing trains are likely to close the residual switch opening, thus increasing the free wheel clearance as the left-hand switch rail is pulled further open by the stretcher bar.

17 If the joint between the stretcher-bar bracket and the right-hand switch rail fails (marked as X on Figure 43), the left-hand switch rail will tend, due to its natural flexure, to relax towards its stock rail and hence reduce the free wheel clearance. The position the rail now adopts is controlled solely by its connection to the supplementary drive, and by the remaining stretcher bars. When trains pass with the stretcher bar in this condition, the closing of the residual switch opening will no longer increase the free wheel clearance, increasing the likelihood of flange-back contact. The degree of flange-back contact will be related to the position of the four-foot nuts of the escapement joint (Figure 44) since this determines the amount of residual switch opening prior to any joint failure.

Appendix E - Bolted joints

1 The effort used in tightening a threaded fastener is known as torque, and results in the length of the bolt under tension (the clamped length) extending as the surfaces are clamped together. The resultant longitudinal tensile force in the bolt is known as the preload. The reaction to this force results in a clamping force within the joint (Figure 45).

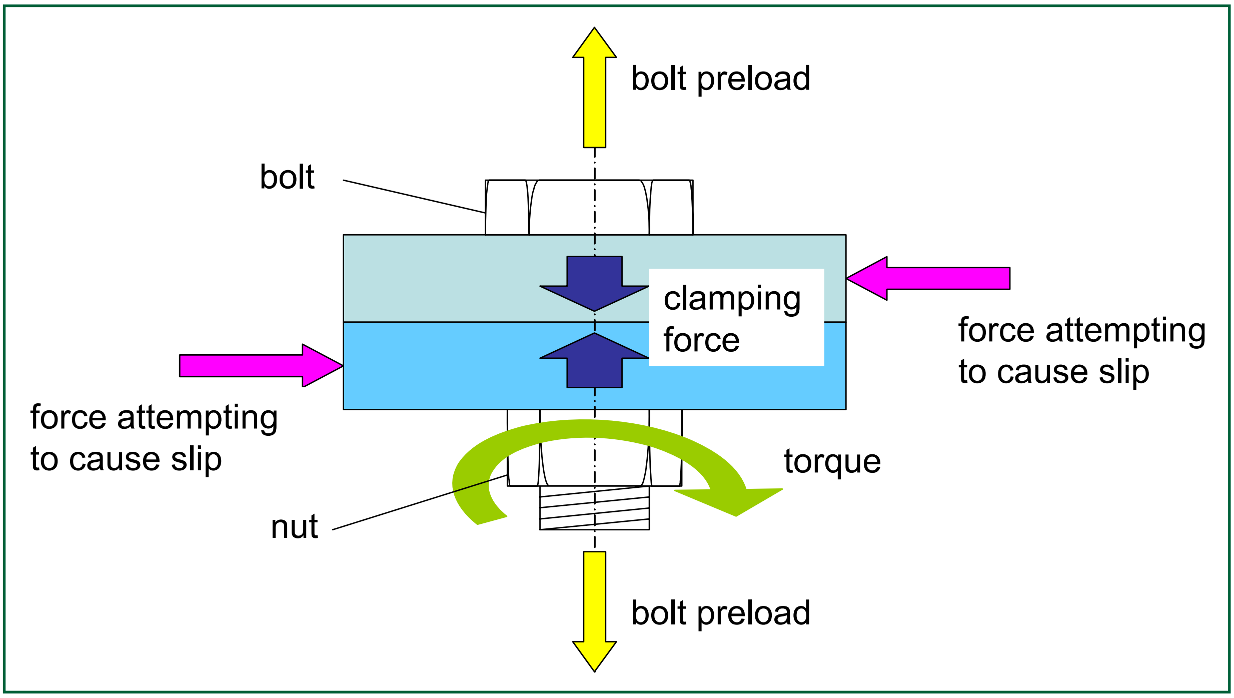


Figure 45: Bolted joint key terms

2 Some of the torque applied when tightening a fastener is used in overcoming the friction both between the threads of the nut and the bolt and between the nut and the clamped part with which it is in contact. A typical range for the *coefficient of friction* for steel components is between 0.1 and 0.4[45]. For the threads, the amount of friction is dependent upon the condition of the thread (which generally deteriorates with reuse and retightening), and any lubrication or contamination present. For a given value of torque, higher thread friction will result in less preload, and hence less clamping force will be generated within the joint.

3 The failure of a joint can be defined as slip. Slip occurs when the load on the joint exceeds its clamping force and allows the joint surfaces to separate or move relative to each other. The occurrence of slip leads to a reduction in clamping force and therefore further slip will occur under lower successive loads, eventually leading to a complete loss of clamping force. Once clamping force has been lost, a plain nut will be loose and free to unwind off the bolt under dynamic conditions.

Embedding

4 No component has surfaces that are absolutely smooth even if very flat. The roughness of surfaces (surface finish) is dependant upon the process used in its manufacture eg rolled, forged, machined, etc.

5 When two components are clamped together permanent deformation of the local contact points between mating surfaces occurs. This is known as embedding and is on a microscopic scale.

[45] Machinery's Handbook, 27th Edition, 2004, Industrial Press Inc

6 The effect of embedding is that over time the surfaces move closer together and therefore the extension of the bolt is reduced. The bolt relaxes which results in lower preload and a reduction of the joint's clamping force. The RAIB has not investigated the relationship between the load and the time over which embedding occurs.

7 A 3/4" diameter Whitworth bolt will extend between 0.036 mm and 0.129 mm (36 to 129 µm) when subject to a 250 Nm torque; the range of extension varies depending upon the values of thread friction present (paragraph 2).

8 For flat contacting surfaces, where bearing stresses are generally within their elastic limits, the degree of embedding loss is of the order of 0.023 mm (or 23 µm)[46]. This could lead to a loss in bolt preload, and joint clamping force of between 17 % and 63 %.

9 For joint surfaces that have high bearing stresses, caused by a lack of squareness, flatness eg localised raised areas, plastic deformation of the materials can occur and can continue with each application and removal of load. This can lead to an increased loss of clamping force over that from solely embedding.

10 The bolt's preload and extension is related to the pitch of the bolt thread, and therefore to the number of turns of the nut. For the case of a 3/4" diameter Whitworth bolt in a rigid joint, the extension of 0.129 mm is achieved in as little as 1/19th of a nut rotation. This is indicative of the small amount of nut rotation between the bolt having its nominally upper level of achieved preload and none at all.

[46] Analysis based on VDI 2230 – Systematic calculation of high duty bolted joints. Verein Deutscher Ingenieure, 2003.

Appendix F - On-train recording of infrastructure features

On-train recording of infrastructure features

1 Network Rail's visual track inspection regime, as detailed in Table 4, is complemented by train-based monitoring of the condition of the infrastructure. Each system uses computer technology to record large amounts of data, for analysis, which is often difficult or impractical to gather manually. Several trains are used, each recording differing features of the infrastructure. None of the train-based monitoring systems referred to in the main body of the report is designed to detect and flag automatically the type of defects found in the S&C at Lambrigg. However, the RAIB has been able to analyse the output and extract relevant data. The following sections briefly describe each train, and the evidence that it has provided for the investigation.

Omnicom video recording train

2 The Omnicom train is a converted 1960s self propelled unit, and is used for high quality video recording of the infrastructure. It uses a set of seven calibrated cameras to record the view from its front and sides, and the rails, and is calibrated so that measurements can be taken from the videos. Data from all runs is recorded, and that for 2B points was passed to the RAIB after the derailment.

3 It is possible to make scaled measurements from the Omnicom video and these can be calibrated against a known dimension in the photo.

4 During 2004, the Omnisurveyor3D route photography train ran past Lambrigg on the down line. The RAIB's study of the video taken on that run showed that all three stretcher bars in 2B points were in place, and that there was a residual switch opening in the vicinity of the third stretcher bar (on the closed side) that was between 4 and 8 mm.

5 A still photograph taken by a Network Rail engineer in May 2006, during a routine inspection of the track, gives evidence that an excessive gap was still in existence at that time (Figure 46).

Figure 46: Lambrigg 2B points, May 2006 (courtesy of Network Rail)

Structure Gauging Train

6 The SGT uses a white light system to relate the location of fixed structures such as bridges and platforms to the rails. Its purpose is to measure the clearance between the track and structures. However, as it scans the rails' positions as a reference point it is possible to analyse the position of rails in the track relative to each other, and in particular measure flangeway clearance.

7 Analysis of the output from the SGT run on the night of 12 February 2007 shows a free wheel clearance at the third permanent way stretcher bar of 2B points no greater than 40 mm. The requirement for free wheel clearance at this position is for a minimum of 50 mm. The recorded measurement is a maximum value of the minimum free wheel clearance because of the way in which the SGT measures and also that the wheels of the SGT may have held the left-hand switch rail open as it passed through the reduced flange way. This recorded value of free wheel clearance indicates that the third permanent way stretcher bar was providing no restraint to the left-hand switch rail at this position at this time.

8 The SGT is also fitted with a video system, which recorded on 12 February 2007 a forward-facing video of the down line and a rear-facing video of the up line. The recordings showed the location of the scrap rail hit by the train to be behind the location cabinets located in the down cess at 3A points.

New Measurement Train

9 Network Rail introduced its New Measurement Train in order to be able to record the geometry of the track on a frequent basis. The train is converted from a passenger High Speed train, and can run at speeds of up to 125 mph (201 km/h).

10 Data from Network Rail's line-side and on-train monitoring systems is collected by the Network Rail Engineering Support Centre (ESC) at Derby. The NMT recorded the down line at Grayrigg, including 2B points, on 21 February 2007, two days before the derailment.

11 The NMT is fitted with an ImageMap LaserRail 3000 track geometry recording system, which records gauge, cross level and alignment. The RAIB study of the track data showed that there was no evidence of any gross geometric defect in the track that might have contributed to the derailment.

12 The NMT is fitted with forward and rearward facing video systems. These are provided for Network Rail engineers to relate geometrical records to physical locations, and are neither used nor intended for condition analysis. In May 2006 the NMT front-facing video was taken in good lighting conditions on a run on the up line. It shows points 2B to have all three permanent way stretcher bars present. The approach to the former crossing at Lambrigg, where the site access was located, can be seen clearly and a length of rail can be seen behind the location cabinets on the down side (Figure 47).

13 On 3 January 2007, the NMT ran in early-morning poor visibility with the rear-facing camera operational. Points 2B appear to have all three permanent way stretcher bars intact. The length of scrap rail behind the location cabinets is still present in the same position as in May 2006.

Figure 47: Approach to Lambrigg viewed from the up line in May 2006. Scrap rail behind location cabinet is visible

Figure 48: Points 2B viewed from the front of the NMT on 10 January 2007

14 On 10 January 2007, the NMT ran in slightly better lighting conditions than the previous week and the front-facing camera was working. Points 2B appear to have all three permanent way stretchers present (Figure 48). The NMT is fitted with a laser-based six-foot scanning system. This measures the distance from the scanner to any object in its path beneath the train. The data from this system was analysed by the RAIB to derive the relative positions of the switch and stock rail at 2B points. The six-foot scanner data shows the minimum free wheel clearance (Appendix D, paragraph 12) to be of the order of 60 mm.

15 A few days before 21 February 2007, Network Rail had commissioned a *Cybernetix IVOIRE III* high resolution linescan camera system on the NMT; the recording run on this date was one of its first recordings. This system is being developed to allow analysis of plain line track components, and is not intended for use on S&C. However, the output on 21 February 2007 included vertical photography of the track, which showed the second permanent way stretcher bar on 2B points was missing. There were bolts in the ballast where it used to attach to the left-hand switch rail. The third permanent way stretcher bar was present but the minimum free wheel clearance had closed up considerably, indicating failure of the third permanent way stretcher bar (Figure 49). Measurement from the photograph shows this opening to be about 16 mm. Video from the wheel/rail interface camera shows the rear of the wheel on the left side of the train pushing the switch rail aside. Another picture shows an insulated stretcher bar joint with two bolts intact lying in the position that one was found after the derailment. This was almost certainly the joint from the third permanent way stretcher bar.

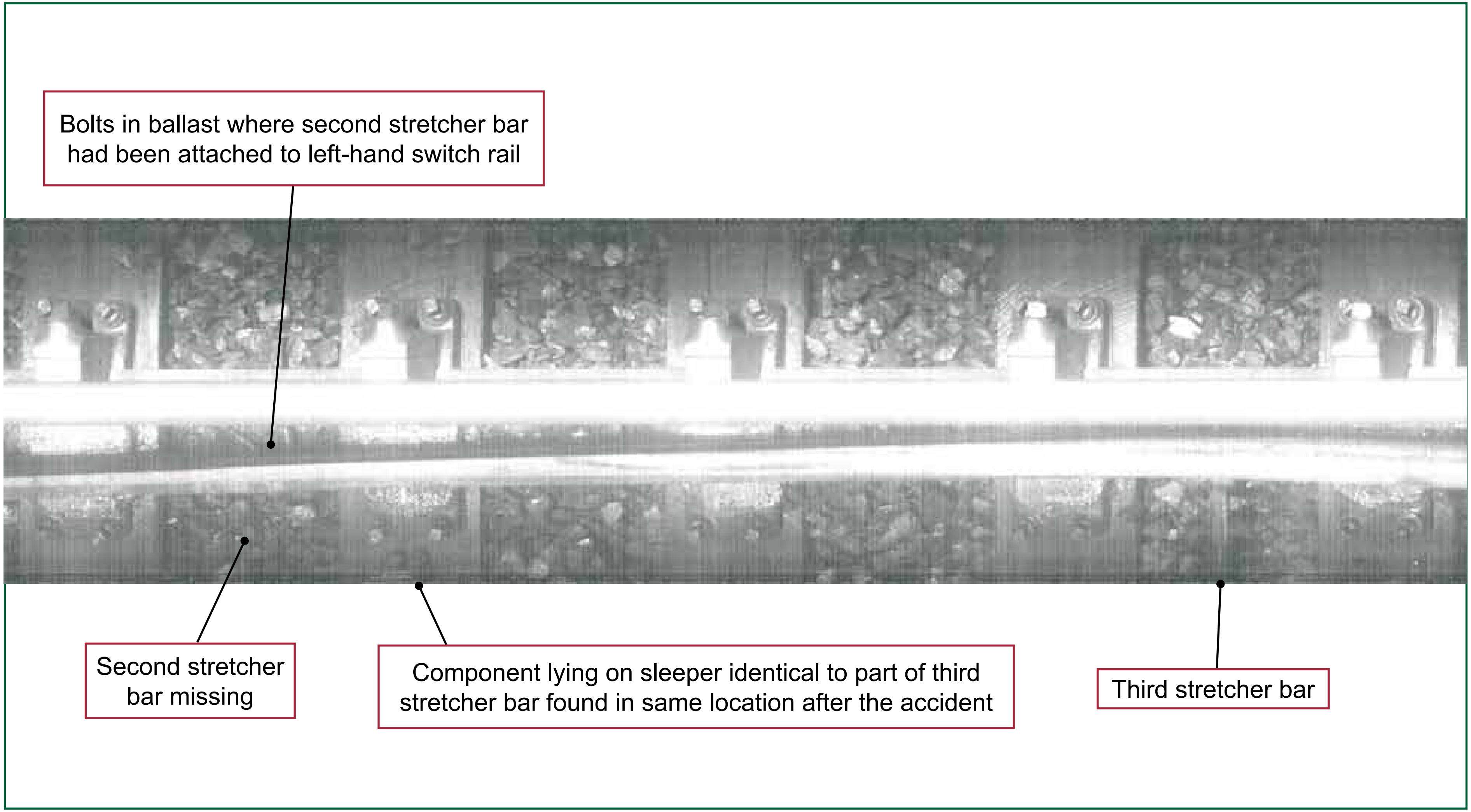


Figure 49: Cybernétix IVOIRE III image from NMT run on 21 February, showing part of left-hand switch rail

Appendix G - Definition of cant and cant deficiency

1 Railway tracks are canted through curves by raising the outside rail higher than the inside. This is done to counteract centripetal force. For a given speed and radius a cant can be calculated at which the vertical forces from the train's weight and the horizontal centripetal forces resolve so that the forces on the canted rails are equal, and perpendicular to the plane of the rail surface. The cant required to achieve this status is known as equilibrium cant.

2 Trains run at differing speeds on the system, for example as a result of freight and high speed passenger traffic operating on the same line. It is thus usually not possible to set the cant at the equilibrium value for the fastest train. The difference between the actual cant and the equilibrium cant is known as cant deficiency. It is normal practice to design curves with cant deficiency as the ride of the train is better when it is held against one rail, and experience has shown that the human body is more comfortable with a small amount of deficiency present, so that an outward lateral force is felt as the body leans into a curve.

3 Network Rail currently applies cant values ranging from zero (on straight track) to 180 mm in increments of 5 mm, though 150 mm is the usual maximum value. It permits conventional (ie non-tilting) trains to run at a cant deficiency of up to 6º (equivalent to 150 mm). This limit has been determined through years of operational experience to be a level that retains reasonable passenger comfort and keeps track forces within safety limits for trains of conventional design and weight.

4 Tilting trains are designed with light weights and a smooth-running suspension. They can run at higher cant deficiencies without placing excessive forces on the track, whilst the tilt mechanism adjusts the angle of the vehicle body so that those inside do not experience the full cant deficiency, and hence remain comfortable.

Appendix H - Access restrictions at Lambrigg

1 This appendix describes the decisions and circumstances that led to almost the whole of the WCML in the area under the control of Network Rail's infrastructure maintenance manager, Lancashire and Cumbria, being inspected before 10:30 hrs on Sunday mornings from April 2006 to the time of the accident. In winter this slot was limited to the order of two to three hours, between sunrise and the end of the possession.

National issues

2 The regime for inspection and routine maintenance that applied to Lambrigg is described in Table 4 of the main text. The arrangements that apply on Network Rail infrastructure for any activity involving personnel working on, or in close proximity, to the track are laid down in the rule book and supporting documentation.

3 The principal hazard for anyone working on or near the operational railway is that of being struck by a train. Network Rail has procedures which must be in place if inspection or maintenance is to take place while trains are running. Work that involves anything other than patrolling, inspection, and examination of the infrastructure, the taking of measurements or the most basic maintenance work cannot be undertaken without special measures being imposed to prevent the approach of a train on the affected line during the activity. This is done to secure the safety of both trains and those undertaking the work.

4 For work that does not constitute a risk to train operation, but only to those undertaking the work, Network Rail imposes a hierarchy of control measures, with a preferred approach of the activity taking place only when no trains are operating. This is referred to as 'green zone' working. The least desirable method of working (at the bottom of the hierarchy) is 'red zone', which applies if inspection or basic maintenance activity is taking place when trains are operating normally.

5 Red zone working is only permitted where staff working on or in the vicinity of the track have adequate warning of the approach of a train in order that they can stop work and move to a position of safety, at least 1.25 metres from the nearest rail, and be there at least ten seconds before the train approaches and passes.

6 Workers will normally have a lookout with them who is responsible for warning of the approach of trains. If the sighting distance is not adequate, additional lookouts can be provided in an advanced position to increase the available sighting distance, but there are limits to the number of additional lookouts that can be provided. Automated equipment can also be used to detect the approaching train and provide the necessary warning time.

7 If, taking all of these options into account, it is not possible to provide adequate warning time for the sighting distance available, restrictions are applied in the Hazard Directory. A 'red zone restricted' site is one where there is an accessible position of safety but where adequate warning cannot be given by the use of unassisted lookouts. A 'red zone prohibited' site is one where there is no position of safety accessible, either because it is too far away or because it would be necessary to cross intervening tracks in order to reach it.

8 Each section of Network Rail features in a hazard directory, which identifies specific hazards in the locality, including whether a section of line is red zone restricted or red zone prohibited. Lancashire and Cumbria area

9 Towards the end of 2003, the West Coast Route Modernisation project prepared a Business Plan, identifying and making allowance for additional costs that might arise from implementation of EPS over the upgraded infrastructure. The Business Plan, which did not include any allowance for the impact of restricted access on maintenance and inspection because the impact was not evaluated, was signed off in January 2004.

10 In summer 2005, Network Rail re-evaluated the WCML north of Preston in preparation for the commissioning of EPS. The enhanced speeds increased the sighting distance required, and resulted in an increase in red zone restrictions from 25 % to 86 % of the route. Implementation of the hazard directory requirements from August 2005 had an immediate effect; inspection and maintenance of the WCML in this area were confined to times when the railway was closed to normal traffic. Although the route was only red zone restricted, there was no automated equipment available to permit inspection and maintenance in a red zone.

11 As it became apparent during the summer of 2005 that access to the track would reduce, the infrastructure maintenance manager sought the assistance of the West Coast Route Modernisation project to develop solutions. He also sought recognition of the costs that would arise from the need to focus resource for inspection and maintenance on Sunday mornings. When the 'Proof of maintainability' document was signed, permitting the introduction of EPS operation, it was endorsed 'Patrolling / Inspecting / Examining – Project to work with IMM to produce long term sustainable method of carrying out P/I/E.' However, these issues were not resolved by the time of the introduction of EPS on 23 October 2005, and the infrastructure maintenance manager continued to develop and review options for achieving a sustainable solution to patrolling and maintenance of the upgraded infrastructure. With the upgrading north of Preston substantially complete, the project team began to disband and the specific issue of access to the railway was subsumed into a more general discussion about sustainability, which was progressed at headquarters level.

12 There were no additional resources to meet the commitment of patrolling the whole of the Carnforth section on Sunday morning. Although patrollers were rostered for eight weekend turns every 13 weekends, the requirement to resource so many inspections in parallel following the introduction of the new hazard directory left Network Rail dependent on staff changing shifts or volunteering for overtime to cover inspections. In addition, the need for all patrolling to take place on Sunday mornings reduced the availability of staff to undertake maintenance activities, which could also only be undertaken in the same possessions, as the same group of staff carried out inspection and maintenance activities.

13 From the beginning of April 2006, a planned change in possession arrangements resulted in the period of closure of the WCML north of Preston being reduced from 29 hours at the weekend to approximately 11 hours on Saturday night to Sunday morning. This was the first time that reduced possession durations had coincided with the new access restrictions (short possessions had been in force before the hazard directory had been revised in preparation for EPS, but it mattered less when there were fewer restrictions on access).

14 The safety of patrollers inspecting within a possession but outside worksites was considered within the infrastructure maintenance manager's area during 2006 because normal line speeds and the normal limitations imposed by the hazard directory theoretically applied. Following a review within the infrastructure maintenance manager's area, a brief issued by the infrastructure maintenance manager's Area Workforce Safety Adviser on 17 March 2006 required patrolling to be considered within the overall possession plan, patrollers to book in with PICOPs and the speed of trains running in the possession but outside worksites to be restricted to 20 mph (32 km/h). This was subsequently changed in a further brief issued on 17 July 2006, relaxing the speed of trains to 40 mph (64 km/h). These arrangements were eventually formalised on a national basis by the rule book changes that occurred in December 2006. Patrollers were required to have lookouts unless there were no train movements in the possession. Rail borne items of engineering equipment that could only be used in a worksite were not classified as train movements in a possession and the requirement to have lookouts did not apply if they were the only vehicles operating. However, in the infrastructure maintenance manager Lancashire and Cumbria's area, it was considered necessary to provide lookouts even under these circumstances, in case such an item of equipment ran away out of the worksite[47]. As a consequence it was normal practice to plan that all patrols would require lookouts resulting in between fifteen and twenty two staff being needed for patrolling and related lookout duties each week that movements were planned in a worksite or in the possession.

15 Patrolling can only be undertaken during daylight unless derogation from the relevant requirements of Network Rail company standard NR/SP/TRK/001 has been secured. From autumn 2006, and into winter, with the onset of daylight becoming progressively later, but the time at which the possession given up being fixed, the time-window for patrolling narrowed. Although the scheduled time for hand-back varied depending on the duration of the possession, the variation was small and hand-back was normally scheduled between 10:00 hrs and 11:00 hrs. First light is after 08:00 hrs in parts of December and January.

16 From the beginning of April 2006 the concentration of all work into the 11 hour possession on a Sunday morning created significant pressure on resources; the only way that all the work could be accomplished on Sunday was if non-rostered staff were prepared to work overtime. In May 2006, limitations were placed on the amount of overtime that could be booked, resulting in few staff being available for maintenance activities as the weekly inspection was a non-negotiable activity (failure to complete an inspection would have led to the line having to be closed for inspection during daylight in the following week as Network Rail's standards did not allow a weekly inspection to be missed).

17 This had a further impact on the maintenance backlog, although from the end of August 2006 extra resources were provided to reduce it, as described in paragraph 244 of the main report.

[47] On 15 February 2004, four members of the Tebay gang (in the Carnforth section) lost their lives when a runaway trailer from another worksite ran through the location where they were working without warning.

Appendix I - Signalling maintenance standards

1 SMS PA00 'Point Equipment: General' contained general requirements relating to points equipment, including new instructions introduced in April 2006 requiring that 'any defects found or repairs and/or adjustments made to correct defects should be reported to your supervisor and details entered on the work order'. Before this, only defects not repaired at the time were required to be reported to the supervisor. Local supervisors were not given instructions on how to implement the new reporting requirements. It was not until December 2007 that final instructions were implemented requiring any corrective maintenance to be reported to an infrastructure fault control and detailed on a Work Arising Identification Form for input to Ellipse.

2 SMS PA11 'Point Inspection', required every three months (Table 4), was substantially changed in the April 2006 revision. The previous version dated February 2005 contained items for attention by track engineering staff as well as those for attention by signalling technicians. The work items for track engineering staff were removed in the later version, as they were already covered in the Handbook NR/WI/TRK/001 for track engineering staff. Also removed was the specific requirement in the February 2005 version to 'check the closed switch will accept a 1.5 mm gauge at each mechanical back-drive (supplementary drive) position (clearance fit)'.

3 SMS PF01 'Point Fittings' included the maintenance every three months (Table 4) of non-adjustable stretcher bars. The integrity of stretcher bars and their brackets was required to be checked, including the tightness of the nuts. PF01 stated 'the nuts should not move by application of a short spanner'. The free wheel clearance and the toe opening were also to be checked and the back of the switch blades examined to see whether flange-back contact was occurring.

4 Prior to the revision in April 2006, SMS PF01 required that if any stretcher bar nuts required tightening, it was to be done using a suitable, calibrated torque spanner. The values were shown on a diagram – 200 Nm for nuts fixing the stretcher bar to its brackets and at the insulation joint, and 250 Nm for nuts fixing the brackets to the web of the rail.

5 After April 2006, there was no longer a reference in SMS PF01 to tightening nuts using a torque spanner so this was no longer mandated. However, the torque values were still included in the section containing reference values (part Z02) of the signalling maintenance specifications, although there was no cross reference between SMS PF01 and SMS Z02. Network Rail's senior signal engineers cited concerns that torque spanners were not freely available to all maintenance staff and that the amount of tools and equipment signal maintenance staff were expected to carry was onerous given that staff may have to walk some distance alongside the railway in order to reach the equipment requiring maintenance.

6 Also introduced in the April 2006 SMS PF01 was a requirement that 'if any component is found to be loose, broken or requires adjustment, the cause for it must be investigated'. No instructions were issued to staff about how this requirement to investigate was to be carried out and none was expected.

7 The April 2006 SMS PF01, clause 2.8, required that 'Should any cracked or broken bars or brackets be found, the signaller must be informed immediately and a 20 mph emergency speed restriction shall be imposed for up to 36 hours, providing all nuts were secure and tight. If these conditions cannot be met or if it is considered unsafe, blocked the line.'

8 SMS PF02 'Mechanical Supplementary Drives', requiring checking of the supplementary drive every three months, was also revised in April 2006. The previous version, dated February 2005, contained, within its Appendix 'A', a description of crank-operated supplementary drive travel adjustment. This included that 'the closed switch rail should just stand clear of the stock rail (approximately 1.5 mm) at the rear drive position'. The evidence from Network Rail's senior engineers was that this residual switch opening was a nominal value and required to prevent the supplementary drive being over-strained, and that no maximum value was defined.

9 In the April 2006 version of SMS PF02, this content was removed and cross reference made instead to a separate work instruction NR/WI/SIG/00111 'Points General – Supplementary Drives – Mechanical' and to a guidance note NR/GN/SIG/11772 'Supplementary Point Drives and Detection'. This followed a policy decision by Network Rail, after the accident at Potters Bar, to re-format the signalling maintenance specification to give the tasks that were required to be done, with the content on how to carry out the tasks removed to separate work instructions. This was to prevent the signalling maintenance specification becoming too large a document. Both the work instruction and the guidance note required that there should be a gap of 1.5 mm between the closed switch rail and the stock rail, and the installation section of NR/WI/SIG/00111 states that the final adjustment should be with a 1.5 mm gauge inserted between the stock and switch rails to be a sliding interference fit. The maintenance section of the document only referred back to 'appropriate NR/SMS tasks/tests' and gave no equivalent guidance about the residual gap. The previous, February 2005, version of SMS PF02 did not cross refer to either NR/WI/SIG/00111 or NR/GN/SIG11772.

10 After April 2006 therefore, there was no specific reference to the residual switch opening in the signalling maintenance specifications; only in separately referenced work instructions. The residual switch opening value was also not contained in SMS Z02 of the signalling maintenance specifications containing reference values.

11 NR/GN/SIG11772 also contained instructions about the adjustment of *supplementary detector*s. It contained a requirement to adjust them so that when a 6 mm gauge was inserted between the switch and stock rails, the detection remained made, but when an 8 mm gauge was inserted, the detection was broken. This requirement was to ensure correct functioning of the detection equipment for the points. Supplementary detectors were not fitted to 2B points at Lambrigg.

12 In its discussions with a sample of signal engineers, both internal and external to Network Rail, the RAIB found a general misunderstanding that the setting for the residual switch opening was between 6 and 8 mm and that there was an assumption the supplementary detection setting referred to in paragraph 11 was the residual switch opening value. Given this misunderstanding, it is possible that local maintenance staff were also under the impression that the correct residual switch opening value was between 6 and 8 mm, which was the dimension found in 2B points.

Appendix J - Compliance & Assurance

1 Network Rail's compliance regime in February 2007 consisted of, in summary:

- A suite of track, signalling and electrification and plant compliance indicators (AS7), which measured key aspects of compliance with standards at Delivery Unit, Area and Territory.
- A system known as Risk Identification and Management, which it intends to identify, score and prioritise, and record risks at area, route/territory and HQ levels of Network Rail.
- Compliance checks, inspections and monitoring carried out by managers (eg a track maintenance engineer) within the maintenance area. These included physical checks of infrastructure condition and surveillance of maintenance activities.
- Self-certification of compliance with the requirements of Network Rail's safety management system by line managers at all levels of the organisation (in accordance with a process laid down in Network Rail standard NR/SP/ASR/032).
- A structured process for obtaining authority, in special circumstances, not to comply with standards (Network Rail/LS/P/045).

2 Network Rail's assurance regime (audit and reporting) in February 2007 is summarised below:

- **Functional audits**

  These audits were carried out by engineering functions, and would typically be undertaken annually on a number of delivery units (each delivery unit would normally be subject to audit once every two years). The scope of functional audits would be defined by the territory and area management teams on the basis of their assessment of risk, taking into account the findings of compliance checks that had been carried out. The general requirement was that all key controls identified in Network Rail's safety case and safety management system should be audited 'at a frequency commensurate with the risk of failure of the control'. Not all depots in an infrastructure maintenance manager's area of control would receive an annual audit. Inspections of assets and work activities were not mandated.

- **National Core Audits Programme**

  Those parts of the National Core Audits Programme affecting infrastructure maintenance were developed by the Head of Maintenance Assurance and Compliance, endorsed by the Territory Maintenance Directors and Director Maintenance, and approved by the Network Rail Tactical Safety Group. The programme was based on a combination of national and local intelligence on safety performance and aligned with a core audit programme developed by the headquarters assurance function. Inspection of assets and work activities were not mandated as part of these audits.

  National Core Audits Programme audits were normally undertaken by senior auditors, reporting to the Audit Manager, and then the Head of Assurance and Compliance, and by managers or engineers from outside the area. The scope of these audits would frequently include maintenance procedures.

3 The relevant audits that were carried out in the infrastructure maintenance manager Lancashire & Cumbria's area in the 18 months before the derailment at Grayrigg, and findings that might have had a bearing on the accident, are listed below (in date order):

- **National Core Audits Programme audit of infrastructure maintenance manager Lancashire & Cumbria's maintenance area undertaken from 28/11/2005 to 16/12/2005.**

  Focused heavily on Preston. Neither the track maintenance engineer nor track section manager at Carnforth were audited directly (although there was some examination of their activities). The audit identified that 25-30 % of signalling staff in the infrastructure maintenance manager Lancashire & Cumbria's area did not have a current IRSE licence. This is discussed in paragraphs 204 to 208 in the main report.

- **Maintenance compliance and assurance audit in July 2006**

  Undertaken by track maintenance engineer at Carnforth and included Carnforth track engineering depot. The relevant audit findings are discussed in paragraph 209 of the main report.

- **National Core Audits Programme (management systems) audit of infrastructure maintenance manager Lancashire & Cumbria's maintenance area from 08/01/2007 to 26/01/2007.**

  The only major non-conformances relevant to management systems identified relate to the recording of safety critical hours and fire safety. One of the minor non-conformances related to the briefing process.

- **National Core Audits Programme (signalling technical) audit of infrastructure maintenance manager Lancashire & Cumbria's area from 08/01/2007 to 26/01/2007.**

  Undertaken by the Scotland East Area. Picked up expired IRSE licences, a national issue, and insufficient surveillance by the signalling maintenance engineer at Carlisle.

- **National Core Audits Programme (track technical) audit of infrastructure maintenance manager Lancashire & Cumbria's area from 15/01/2007 to 19/01/2007**.

  Undertaken by the Scotland East Area. Audit included track maintenance engineer and track section manager Carnforth. Only non-conformances identified specifically relating to Carnforth were: inappropriate forms being used for TRK/053 inspections and action taken following reports of cyclic top exceedances not being signed off. The final report is dated 09/05/2007.

Appendix K - Overview of the relationship between Network Rail's engineering and maintenance organisations

1 Network Rail's organisation, as it existed immediately before 23 February 2007, reflected a division between the engineering function and the delivery of maintenance. Figure 50 illustrates this relationship.

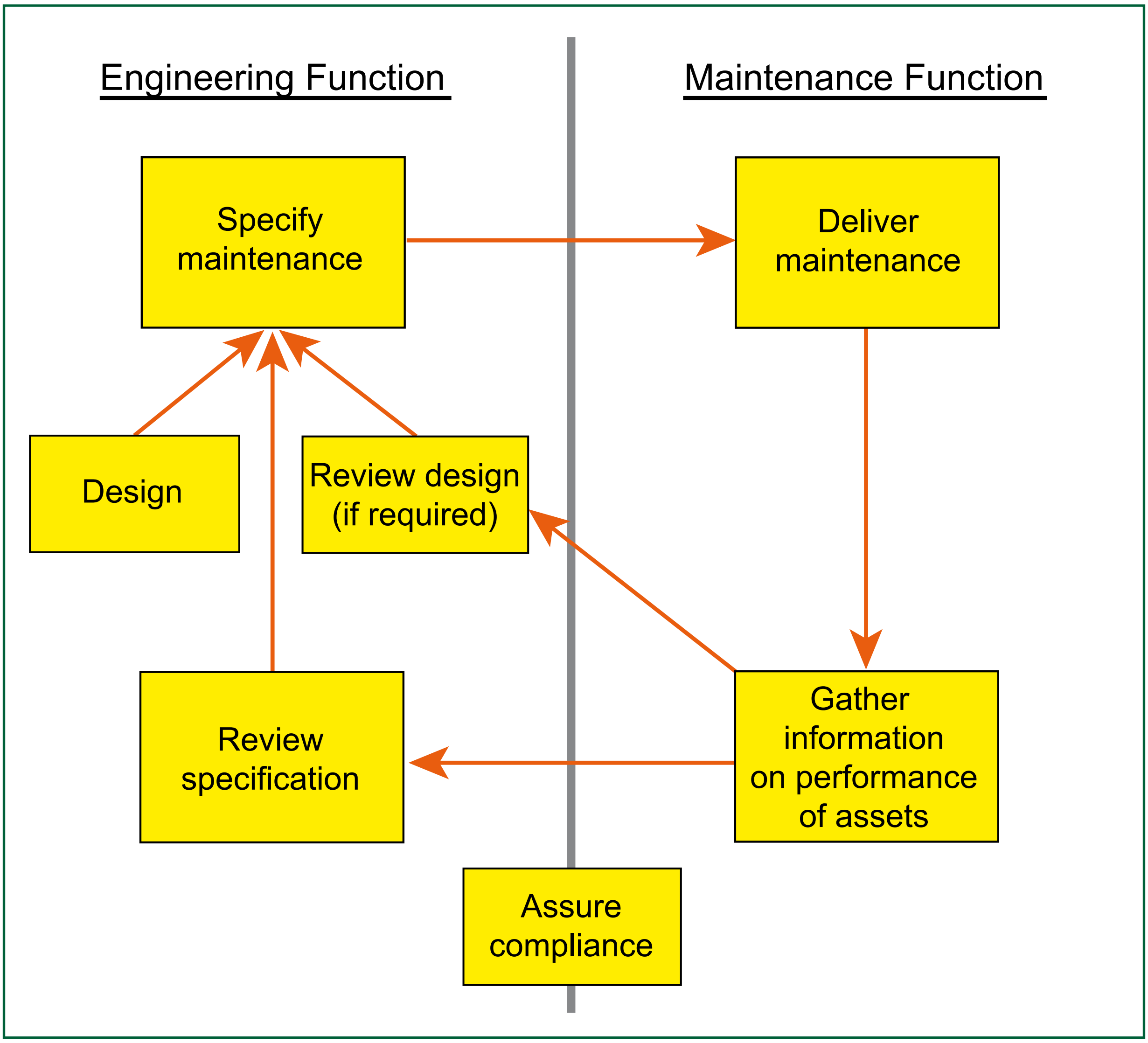


Figure 50: Overview of the relationship between Network Rail's engineering and maintenance organisations

2 The engineering function was headed by the chief engineer who in turn reported to the projects and engineering director.

3 The maintenance function was headed by the director maintenance, who in turn reported to the deputy chief executive. Both the projects and engineering director and the deputy chief executive reported to the chief executive.

The engineering function

4 The chief engineer was responsible for providing leadership in engineering and technical matters within Network Rail. His specific responsibilities included:

- the determination of suitable policies for the management of assets to deliver the business performance required by the Board;
- the preparation of technical specifications within the engineering discipline;
- the specification of maintenance regimes and work instructions;
- the management, maintenance and publication of engineering standards;
- ensuring that his team provided technical support to maintenance units;
- the sponsorship of research and development in engineering; and
- management of processes for the formal review and acceptance of new and modified systems and components (in conjunction with appropriate specialists).

5 The chief engineer headed a team of ten engineering managers, including a lead manager for each technical discipline, the professional head. The primary responsibility of a professional head was to provide leadership and guidance to a team of technical specialists. In this role professional heads were accountable for the quality of technical advice and support provided to the business, and for providing technical input to, and stewardship of, designated Network Rail standards.

6 Of particular relevance to this investigation are the head of signal engineering and the head of track engineering. The former's responsibilities included the leadership of the team that was responsible for the management of technical standards for the adjustment, inspection and maintenance of stretcher bars, and associated competency standards. The latter's responsibilities included leadership of the team that was responsible for matters associated with the design and correct installation of stretcher bars.

7 Reporting to each of the professional heads were out-based territory engineers. Their responsibilities included acting as the professional expert for their discipline and as the asset steward for their area of control. The territory engineers were also responsible for the dissemination of knowledge on maintenance regimes and providing assurance to the professional head that the assets on the territory were in a condition commensurate with the performance required.

The maintenance function

8 The director maintenance was tasked with the safe delivery of maintenance to the laid down standards and procedures.

9 The director maintenance had an HQ team, which included:

- the head of maintenance compliance and assurance; and
- the head of maintenance workforce safety.

10 The director maintenance had five territory maintenance directors reporting to him. Maintenance activities within the London North Western territory, which included the WCML at Grayrigg, were the responsibility of the territory maintenance director based in Birmingham.

11 The delivery of track and signalling maintenance activities in the areas had previously been undertaken by contractors. However, in 2003, Network Rail decided that the delivery of this task was best managed directly; in transferred many of the existing contractors' staff and managers into new Network Rail managed area maintenance teams the following year. Each team was headed by an Infrastructure maintenance manager reporting directly to the relevant territory maintenance director. Each infrastructure maintenance manager was tasked with ensuring that the infrastructure was compliant with the standards set by the engineering function and available for operational use by best use of available resources. Grayrigg came within the area of responsibility of the infrastructure maintenance manager, Lancashire and Cumbria. This infrastructure maintenance manager's geographical area of responsibility extended from Standish in the south to just beyond the Scottish border in the north.

12 Maintenance delivery in the Lancashire and Cumbria was managed by two maintenance delivery unit managers, reporting to the infrastructure maintenance manager, Lancashire and Cumbria, and designated 'north' and 'south'. They were responsible for the delivery of maintenance and inspection activities in line with financial, technical and safety targets agreed with the infrastructure maintenance manager for geographical sections within his area. Lambrigg 2B points fell within the domain of the maintenance delivery unit manager north.

13 Also reporting to the infrastructure maintenance manager were:

- an area track engineer; and
- an area signal engineer.

14 The two area engineers were part of the infrastructure maintenance manager's team. They were required to monitor maintenance standards and delivery, carry out investigations into asset-related incidents and provide technical advice to other members of the infrastructure maintenance manager's team.

15 Area engineers were also tasked with providing professional briefings to area staff and maintaining records of asset configuration and condition.

16 Although they reported via the infrastructure maintenance manager, the area engineers had a responsibility to provide assurance to the equivalent territory engineer that standards of delivery were being met. This meant that there was a professional reporting line from the area engineer to the professional head at HQ, via the territory engineer.

17 Reporting to each maintenance delivery unit manager was a track maintenance engineer and signal maintenance engineer at each local depot. The track maintenance engineer and signal maintenance engineer were responsible for providing line and professional leadership to the maintenance teams at the depot. The track maintenance engineer and signal maintenance engineer also had a professional reporting line to the area track engineer and the area signalling engineer.

Assurance

18 The development and direction of Network Rail's assurance policy was the responsibility of the director safety & compliance. The translation of this policy into an overall assurance framework and the development of an integrated national audit programme was the responsibility of the head of corporate assurance and accident investigation. This involved interfaces with the engineering functions, the head of maintenance assurance and compliance and the territory/area teams.

Appendix L - Actions taken by Network Rail in response to the Potters Bar investigations

1 For the purpose of this report the Potters Bar recommendations are identified as follows:

- recommendations published in the second PBIB interim report are identified as HSE 2.n (there were no recommendations in the first interim report);
- recommendations published in the third PBIB interim report are identified as HSE 3.n; and
- recommendations published in the RSSB formal inquiry report are identified as RSSB nn.

2 The first column of Table L1 shows the RAIB summary of the topic that is covered by a recommendation or group of recommendations. Each summary is described as a 'theme'.

3 The second column of Table L1 shows the associated recommendation numbers. The full text of the recommendations is given in Table L2.

4 The third column shows the current status of each recommendation according to Network Rail's own assessment. Where this is shown as 'Complete' it means that Network Rail has concluded that the actions required to address the recommendation have been taken.

5 The fourth column shows the current status of each recommendation as assessed by HMRI in its capacity as the safety regulator It should be noted that when HMRI defined a recommendation as being closed, this could have three possible meanings:

- the recommendation is known to have been completed; or
- the recommendation has not been completed, but actions are ongoing and HMRI proposed to track progress through the *Delivery Plan* mechanism (see Appendix H); or
- because the wording of the recommendation is open-ended it will not therefore be possible to demonstrate closure, so closure is noted by HMRI on the basis of their perception that progress is being made.

6 The fifth column shows a summary of the status of actions against each theme (RAIB's assessment of the situation in February 2007).

7 The sixth column shows how each of the themes relates to the precursors of the derailment at Grayrigg.

8 The last column of the table identifies those RAIB recommendations following the investigation into the derailment at Grayrigg that cover similar themes.

Table L1 - Relevance of Potters Bar recommendations to Grayrigg precursors

1. Recommendation relates to points with adjustable stretcher bars but gave rise to a response that encompassed other types of points;
2. Recommendation does not refer to any specific type of points (but was made in the context of the specific system failures identified at Potters Bar);
3. Recommendation relates to general safety issues, excluding regulation, that are associated with all safety critical components/systems (including, but not restricted to points, rails, signals, etc);
4. Recommendation relates to general safety regulation issues;
5. Recommendation process issues relating to investigations and recommendations handling.

Themes identified by the RAIB as relevant to the investigation into the accident at Grayrigg	**Associated recs.** (the full text of each recommendation is contained in Table L2)	**Status of rec. (as of Feb 2007)**		**Summary of status in February 2007 (RAIB assessment)**	**Relevance of recs. to Grayrigg precursors**	**RAIB recs. (following the investigation of the derailment at Grayrigg) that cover similar themes.**
		Network Rail status	**ORR (HMRI) status**			
1. The need for systematic design and safety analysis (focused on points with adjustable stretcher bars)	HSE 2.1 HSE 2.3	Complete (Dec 04)	Open (minded to close)	In discussions with the Potters Bar Investigation Board, Network Rail committed itself to extending its safety and design analysis to include all types of stretcher bar. Consequently, consultants performed a preliminary FMEA of non-adjustable stretcher bars. However, this analysis was very high level and some elements of the analysis contained incorrect assumptions. Network Rail intended that the above analysis be extended to other equipment by application of a risk based methodology known as Business Critical Configuration Management (BCCM). However, priority was given to applying the process to a new design of S&C and BCCM was never applied to existing assets.	1	Rec. 1

Themes identified by the RAIB as relevant to the investigation into the accident at Grayrigg	**Associated recs.** (the full text of each recommendation is contained in Table L2)	**Status of rec. (as of Feb 2007)**		**Summary of status in February 2007 (RAIB assessment)**	**Relevance of recs. to Grayrigg precursors**	**RAIB recs. (following the investigation of the derailment at Grayrigg) that cover similar themes.**
		Network Rail status	**ORR (HMRI) status**			
2. The need for a review of standards for installing, setting, adjusting, maintenance, inspection and testing of points and	HSE 2.4	Open	Open (minded to close)	Network Rail issued a 'Good Practice Guide' to cover mechanical supplementary drives and adjustable stretcher bars. Later clarification was given in the December 2004 standards update (RT/E/C/10179 'the set up and maintenance of adjustable stretcher bars'). Network Rail had recognised the need for a package of training material for signalling staff carrying out maintenance and adjustment of non-adjustable stretcher bars and supplementary drives. This was under review at professional head level at the time of the Grayrigg derailment (and issued in April 2007).	1	Rec. 4
Ensuring that standards were available, clear and understood by staff	HSE 2.6	Open	Open (minded to close)	In general, the standards relevant to points with non-adjustable stretcher bars that were updated following the derailment at Potters Bar were available to staff. Nevertheless, insufficient guidance was given on the tightening of bolts and no guidance was given to staff as to how they should discharge the requirement to investigate loose or missing components and some key maintenance items such as checking the dimension of the residual switch opening were moved from the signalling maintenance specification to supporting standards, thereby requiring the maintainer to look at multiple documents to discharge their duties. Training on the set-up and adjustment of supplementary drives had still to be delivered in February 2007.	2	Rec. 6 – Rec. 9

Themes identified by the RAIB as relevant to the investigation into the accident at Grayrigg	**Associated recs.** (the full text of each recommendation is contained in Table L2)	**Status of rec. (as of Feb 2007)**		**Summary of status in February 2007 (RAIB assessment)**	**Relevance of recs. to Grayrigg precursors**	**RAIB recs. (following the investigation of the derailment at Grayrigg) that cover similar themes.**
		Network Rail status	**ORR (HMRI) status**			
3. The need for a review of the requirements and arrangements for the reporting, recording, reviewing and acting upon deficiencies and safety related events associated with points	HSE 2.7	Complete (Dec 04)	Open (minded to close)	Network Rail had continued to develop its management information systems: ○ FMS (for the management of faults) ○ SINCS (for the recording of signalling incidents) ○ ELLIPSE (for work bank items) However, these systems were not configured to permit efficient identification and analysis of types of failures, and identification of trends, across a large population of S&C. The requirement to report and record loose or missing bolts on points was introduced in April 2006. The missing bolts on the third stretcher bar that were discovered at Lambrigg ground frame on the 07 January 2007 were reported and replaced.	2	Rec. 5 Rec. 10 Rec. 14
4. Arrangements for independent inspection of points	HSE 2.8	Complete (Dec 04)	Closed	Network Rail saw this recommendation as related to the management of contractors and therefore not applicable now that maintenance was managed ‘in-house’.	2	Rec. 15

Themes identified by the RAIB as relevant to the investigation into the accident at Grayrigg	**Associated recs.** (the full text of each recommendation is contained in Table L2)	**Status of rec. (as of Feb 2007)**		**Summary of status in February 2007 (RAIB assessment)**	**Relevance of recs. to Grayrigg precursors**	**RAIB recs. (following the investigation of the derailment at Grayrigg) that cover similar themes.**
		Network Rail status	**ORR (HMRI) status**			
5. Undertake a comprehensive management review by mapping existing roles, responsibilities and arrangements against the management model to ensure safety critical components are fit for purpose and to ensure that no gaps remain.	HSE 3.4	Complete (Nov 06)	Open (minded to close)	Following the accident at Potters Bar, Network Rail had clarified management responsibilities in respect of the design, installation, testing, maintenance and inspection of S&C. These responsibilities and the interfaces between disciplines were understood at a senior management level and reflected in business processes and standards. However, the understanding of the formal responsibilities in respect of S&C in general, and stretcher bars in particular, did not extend to all managers and staff in the Lancashire and Cumbria Maintenance Area. (paragraphs 256 and 261) However, Network Rail's management arrangements did not deliver effective monitoring of the actual performance of existing non-adjustable stretcher bars or seek to carry out a detailed assessment of the adequacy of the design and inspection/maintenance arrangements (paragraph 450).	❸	Rec. 18, Rec. 20

Themes identified by the RAIB as relevant to the investigation into the accident at Grayrigg	**Associated recs.** (the full text of each recommendation is contained in Table L2)	**Status of rec. (as of Feb 2007)**		**Summary of status in February 2007 (RAIB assessment)**	**Relevance of recs. to Grayrigg precursors**	**RAIB recs. (following the investigation of the derailment at Grayrigg) that cover similar themes.**
		Network Rail status	**ORR (HMRI) status**			
6. The need for the development of a risk-based approach to procurement, installation, inspection and maintenance of points based on an understanding of the design and safety requirements.	HSE 3.5	Open	Open (minded to close)	Network Rail's signal engineering function had been developing a risk-based approach to the development of its maintenance standards since at least 2000. There was no requirement for this approach to be applied to validate existing maintenance regimes. The number of maintenance standards that had been developed using this approach was limited to eight. These did not cover the maintenance of non-adjustable stretcher bars and supplementary drives. Network Rail intended to apply a risk-based approach to the development of standards for most of its signalling assets. In the case of track assets Network Rail decided to apply a risk-based approach to the development of a new design of points. By February 2007 this process had not been applied to existing S&C assets.	2 + 3	Rec. 1 - 4 Rec. 20

Themes identified by the RAIB as relevant to the investigation into the accident at Grayrigg	**Associated recs.** (the full text of each recommendation is contained in Table L2)	**Status of rec. (as of Feb 2007)**		**Summary of status in February 2007 (RAIB assessment)**	**Relevance of recs. to Grayrigg precursors**	**RAIB recs. (following the investigation of the derailment at Grayrigg) that cover similar themes.**
		Network Rail status	**ORR (HMRI) status**			
7. The need for HMRI and Network Rail to formally agree on applications of good engineering practice (to promote a risk informed preventative maintenance strategy)	HSE 3.10	Complete (Nov 05)	Open (minded to close)	Network Rail had sought agreement with HMRI. HMRI has stated that it was not their role to formally agree on the application of good engineering practice. See item 1 at Appendix N for further information on HMRI's approach to recommendation HSE 3.10.	❸ + ❹	Rec. 20
8. The need to review and clearly define the roles and responsibilities of track and signalling maintenance staff to ensure the safety of critical components	HSE 3.14	Complete (Oct 05)	Open (minded to close)	Network Rail had reviewed functional responsibilities for each part of the S&C sub-system. These were published in an 'Asset Responsibility Matrix'. The agreed split was now reflected in all standards and work instructions (but was not always understood by staff on the ground in the Lancashire and Cumbria area or in local procedures elsewhere, as reflected in theme 5).	❸	Rec. 18

Themes identified by the RAIB as relevant to the investigation into the accident at Grayrigg	**Associated recs.** (the full text of each recommendation is contained in Table L2)	**Status of rec. (as of Feb 2007)**		**Summary of status in February 2007 (RAIB assessment)**	**Relevance of recs. to Grayrigg precursors**	**RAIB recs. (following the investigation of the derailment at Grayrigg) that cover similar themes.**
		Network Rail status	**ORR (HMRI) status**			
9. The requirement for flangeway gaps and supplementary drive settings on points to be checked together at defined intervals as part of maintenance.	RSSB 9	Complete	Not applicable	In April 2006 the requirement to carry out flangeway gap checks was mandated in RT/SMS/PF02 (Service A - item 1.2) and for supplementary drive settings in RT/SMS/PF02 (Service A - item 1.1). These checks were to be carried out at 3 monthly intervals. Despite this, the reduced flangeway gap was not detected in the period prior to the derailment at Grayrigg. There was no documentary evidence that the flangeway gap had been measured in the period prior to the derailment at Grayrigg. **<u>Note</u>** Following the derailment at Grayrigg it was identified that the formula for free wheel clearance did not allow for gauge widening (this has now been corrected).	2	Rec. 6
10. The need to better manage track patrols to ensure that:				Network Rail clarified track inspection requirements in standard NR/SP/TRK/001 and management arrangements in NR/PRC/NR/TK0075 and incorporated additional S&C checks into standard NR/SP/TRK/001. The above clarification of the standards and process was not sufficient to avoid deficiencies with the quality of patrolling, and the management process, observed at Carnforth depot in the period before the Grayrigg derailment.		
○ they take place as planned	RSSB 18	Complete	Not applicable		2	Rec. 10 and Rec. 11
○ they are properly planned and recorded	RSSB 19	Rejected			2	Rec. 10 and Rec. 11
○ patrollers are competent in respect of points	RSSB 20	Complete			2	Rec. 12

Table L2 -Full text of Potters Bar recommendations directed at Network Rail judged by the RAIB to have relevance to the accident at Grayrigg

Recommendation	Full text
HSE 2.1	Undertake a short-term (within one month) review of the design and safety analysis of points with adjustable stretcher bars to identify any immediate modifications (such as changing the locking nut arrangements) to better ensure that the component can fulfil its safety functional requirements. This should take account of the present and reasonably foreseeable future operating environment, the achievement of safety by design, the practicability of testing, maintenance, setting and adjusting, and any other relevant factors.
HSE 2.3	Undertake a more in-depth review of the design and safety analysis of points with adjustable stretcher bars including consideration of replacing them with a points system that is more inherently safe by design. (One aim should be to minimise the need for maintenance work on operating railways and hence reduce the exposure of workers to hazardous environments.) And, implement any changes as required to further rail safety.
HSE 2.4	Undertake a review of the standards for installing, setting and adjusting, maintenance, inspection and testing against the requirements of the design and safety analysis with a view to ensuring that good practice is consistently achieved across the rail network. And, implement any changes as required to further rail safety.
HSE 2.6	Ensure that those responsible for and undertaking any safety-related work associated with points have copies of and understand the relevant standards, drawing, specifications, and other documentation required to enable points to be installed, set and adjusted, maintained, inspected and tested to the identified requirements
HSE 2.7	Review the requirements and arrangements for reporting, recording, reviewing and acting upon any deficiencies or safety-related events associated with points; and implement any changes as required to further rail safety.
HSE 2.8	Review their arrangements for independent inspection of points and implement any changes as required to further rail safety.
HSE 3.4	Network Rail should undertake a management review, by mapping existing roles, responsibilities and arrangements against a management model for ensuring that safety critical components and systems are fit-for-purpose, to ensure that no significant gaps exist that may compromise safety. This may reveal opportunities for improving business as well as safety.
HSE 3.5	Network Rail should continue to develop the use of a risk-based approach to the procurement, installation, inspection, maintenance, etc of railway points, based on an understanding of the design and safety functional requirements, to the mutual benefit of operating the rail network more reliably and more safely.
HSE 3.10	Network Rail and HMRI should formally reach agreement on the application of "good engineering practice" to safety critical components and systems on the rail network, in particular by promoting a risk informed preventative maintenance strategy rather than a reactive approach. This should be mutually beneficial to minimising the downtime of the network, as well as improving safety.

Recommendation	Full text
HSE 3.14	Network Rail, in conjunction with the infrastructure maintenance controller, should review the roles and responsibilities of permanent way and signalling personnel to ensure that those roles and responsibilities are clearly defined, comprehensive and appropriate to the setting up, inspection and maintenance necessary to ensure safety in the functioning of safety critical components. A key objective should be the elimination of confusion and unnecessary duplication in those roles and responsibilities.
RSSB 9	A requirement should be introduced for flangeway gaps and supplementary drive settings on points to be checked together at defined intervals as part of maintenance.
RSSB 18	Periodic monitoring procedures should be established to verify that basic visual inspections, as prescribed in RT/CE/S/103, have been carried out as recorded and signed for.
RSSB 19	The planning, operating, and recording of basic visual inspection procedures, as prescribed in RT/CE/S/103, should be reviewed. Revised Track Inspection Sheets and Track Patrol procedure documents should be produced that: • Mandate the exact procedures that staff are required to follow. • Include instructions as to how recording and signing should be carried out, particularly in terms of recording the track in which staff walk, and the finding of no new or changed defects. Include specific allowance for those stretches of line where the distance between tracks is greater than a standard ten-foot. If it is decided to continue using patrolmen in pairs, the recording and signing process for this method should be prescribed.
RSSB 20	Consideration should be given to enhancing the competence of CE[48] patrolmen, by the provision of additional training, to enable them to recognise and report emerging problems such as loose nuts and off-centre threads on adjustable stretcher bars, during basic visual inspections.

[48] Civil engineering

Appendix M - The Role of the Safety Regulator

The ORR's description of its role as safety regulator is:

1 ORR is the independent health and safety regulator for the railway industry, including metros, light rail and heritage railways. ORR assumed responsibilities for health and safety regulation on 1 April 2006.

2 ORR's health and safety strategy is to secure the the proper control by dutyholders of risks to the health and safety of employees, passengers and others who might be affected by the operation of Britain's railways.

3 Within ORR, *Her Majesty's Railway Inspectorate* (HMRI) has a key role in meeting Great Britain's obligations to enforce European and domestic health and safety law, focusing effort on the most serious risks and the areas where intervention will have most effect. ORR's overall strategy for supervising health and safety performance in the industry is implemented through HMRI's activity and set out in detailed plans at national and local level year on year.

4 The inspectorate is organised within ORR on the basis of national and regional groupings.

5 The activities of ORR's inspectors are wide-ranging and include statutory work, planned inspection (through delivery plans), investigation, expert advice and enforcement[49]. Each year the priority ranking of these activities is considered and resources are allocated accordingly. First priority is given to meeting ORR's statutory obligations such as the Railways and Other Guided Transport Systems (Safety) Regulations 2006 (ROGS) Safety Management System authorisations/certificates, interoperability authorisations, and responding to recommendations from the RAIB.

Delivery plans

6 A significant proportion of the inspectorate's time is spent on targeted delivery plans (formerly known as intervention plans). These plans set out the inspections that the inspectorate is going to undertake proactively. Some will be targeted at Network Rail, but there will also be delivery plans for the activities of other railway bodies such as train operators.

7 Long-term issues that HMRI wishes to pursue with a duty holder are key inputs to the delivery plans. In terms of Network Rail, the constant themes pursued since the first intervention plan was prepared for 2002/2003 are:

- risk control;
- asset management; and
- competence.

8 Risk profile topic strategies[50] were introduced from April 2006, using data contained within the RSSB's Safety Risk Model to identify the higher risk areas. Each of the risk topics has its own strategy (eg track, stations, level crossings) and individual sub-topics highlight higher risk areas. For track the higher risk area was judged to be switches and crossings.

[49] A description of the full range of activities performed by ORR can be found at http://www.rail-reg.gov.uk

[50] Current topic strategies can be found at http://www.rail-reg.gov.uk/server/show/nav.1340

9 The delivery plans include a list of topics and guidance on how the topic should be addressed. The plans are developed at national level, but the contents are discussed with those who will implement them (national or regional inspectors). There is also a briefing process for the implementers at the time the delivery plans are issued, provided by HMRI lead staff. For any specific topic, HMRI nationally will nominate which of the regional teams will be involved in its implementation, attempting to spread the workload between those teams and ensure representative national coverage.

10 For Network Rail, there may be 15 or more topics in any one year's delivery plan. During the years 2002 to 2007, the topics included a number of assignments under the headings of track and signalling, but only two topics directly relating to switches and crossings. In the 2002/2003 plan there was a network-wide inspection assignment on the maintenance of switches and crossings, and this was followed up by further work in the 2004/2005 plan.

11 Following the completion of the inspection activity, the area team feeds the output back to HMRI at national level, where the outputs from each of the areas are consolidated into a report that reflects the overall picture. The outcome from implementation of the plans is then fed back to the relevant duty holder at a senior level to ensure action on identified weaknesses.

Appendix N - Actions taken in response to recommendations from the Potters Bar derailment that were directed at HMRI

1 For the purpose of this report the Potters Bar recommendations are identified as follows:

- recommendations published in the second PBIB interim report are identified as HSE 2.n (there were no recommendations in the first interim report).
- recommendations published in the third PBIB interim report are identified as HSE 3.n.
- recommendations published in the RSSB formal inquiry report are identified as RSSB nn.

2 The first column of Table N1 shows the RAIB summary of the topic that is covered by a recommendation or group of recommendations. Each summary is described as a 'theme'.

3 The second column of Table N1 shows the associated recommendation numbers. The full text of each recommendation is given in table N2

4 The third column of the Table shows the current status of each recommendation according to Network Rail's own assessment (where appropriate)

5 The fourth column of the table shows the current status of each recommendation as assessed by HMRI. It should be noted that when HMRI defined a recommendation as being closed, this could have three possible meanings:

- the recommendation is known to have been completed; or
- the recommendation has not been completed, but actions are ongoing and HMRI proposed to track progress through the delivery plan mechanism (see Appendix M); or
- because the wording of the recommendation is open-ended it will not therefore be possible to demonstrate closure, so closure is noted by HMRI on the basis of their judgement that progress is being made.

6 The fifth column shows a summary of the status of actions against each theme (RAIB's assessment of the situation in February 2007).

7 The last column of the table shows how each of the themes relates to the precursors of the derailment at Grayrigg.

Table N1 - Relevance of Potters Bar recommendations to Grayrigg (see categorisation in last column);

❹ Recommendation relates to general safety regulation issues;

❺ Recommendation process issues relating to investigations and recommendations handling.

Themes identified by the RAIB as relevant to the investigation into the accident at Grayrigg	Associated recs. (the full text of each recommendation is contained in Table N2)	**Status of rec.** (as of Feb 2007)		**Summary of status in February 2007 (RAIB assessment)**	**Relevance of recs. to Grayrigg precursors**
		Network Rail status	ORR (HMRI) status		
1. The need for HMRI and Network Rail to formally agree on applications of good engineering practice (to promote a risk informed preventative maintenance strategy)	HSE 3.10	Complete (Nov 05)	Open (minded to close)	Network Rail sought to agree their approach with HMRI. HMRI had stated that it was not their role to agree formally on the application of good engineering practice. HMRI said that this was because they believed that good engineering practice changes over time and they did not see any value in making an agreement which only represented a snapshot in time. HMRI's judgement on whether good engineering practice was being applied was based on actual performance. HMRI's overall observation was that the quality of engineering management had improved since Network Rail had taken over management of the railway network.	❹
2. HMRI to improve focus on the prevention of catastrophic events by reviewing: ○ regulatory structure	HSE 3.17		Open (minded to close)	The Delivery Plans in 2002/3 and 2004/5 included special focus on matters related to the design and maintenance of S&C. However, S&C did not feature as an area of specific concern in the Delivery Plans for 2003/4, 2005/6 and 2006/7. HMRI's risk profile topic strategy for track 2006-7 to 2008-9 included mention of S&C defects as one of a number of precursors which give focus for the actions to be taken; the introduction to the Risk Profile Topics identifies S&C as the highest risk element within the track topic. However, the list of strategic aims did not identify S&C design or maintenance as a specific area of concern. Since Potters Bar, HMRI has reviewed and authorised the Network Rail safety management system in accordance with either the relevant Railway Safety Case Regulations or latterly the 'Railways and Other Guided Transport Systems (Safety) Regulations 2006'. HMRI stated that their process for the review of the safety management system has always included the consideration of the prevention of catastrophic risk as a major element.	❹
○ targeting of resources	HSE 3.18		Closed		❹
○ safety case assessments arrangements	HSE 3.19		Closed		❹

Themes identified by the RAIB as relevant to the investigation into the accident at Grayrigg	Associated recs. (the full text of each recommendation is contained in Table N2)	**Status of rec.** (as of Feb 2007)		**Summary of status in February 2007 (RAIB assessment)**	**Relevance of recs. to Grayrigg precursors**
		Network Rail status	ORR (HMRI) status		
3. HMRI to confirm that there are no significant gaps in the rail industry's management arrangements for ensuring that safety critical components or systems are fit for purpose or that reasonably practicable improvements are appropriate.	HSE 3.21		Open (minded to close)	HMRI continued to examine the activities of Network Rail and measure performance against the requirements of the safety management system on the basis of sampling and selected systematic reviews. This process of examination included proactive inspection against topics defined in the Delivery Plan and reactive inspection as specific topics arise. HMRI judged that Network Rail's engineering safety management systems had improved significantly since 2002. They recognised that there was more to be done but were minded to close the recommendation on the basis of the progress made.	4
4. Network Rail and HMRI to agree a strategy and timetable for addressing recommendations	HSE 3.25		Open (minded to close)	Such a joint strategy and timetable was not developed.	5
5. HMRI to periodically review implementation of the recommendations from the second and third Health and Safety Executive reports and publish its observations	HSE 3.26		Closed	ORR has set up a senior body to review recommendations, which has included the Potters Bar recommendations in its work (paragraphs 476 to 482). However, The Health and Safety Executive, and later ORR, has decided not to publish its observations on the progress with the recommendations until all the recommendations were closed.	5

Table N2 -Full text of Potters Bar recommendations directed at HMRI

Recommendation	Full text
HSE 3.10	Network Rail and HMRI should formally reach agreement on the application of "good engineering practice" to safety critical components and systems on the rail network, in particular by promoting a risk informed preventative maintenance strategy rather than a reactive approach. This should be mutually beneficial to minimising the downtime of the network, as well as improving safety.
HSE 3.17	HMRI should review its regulatory strategy to see whether it can be more closely aligned to regulating for the prevention of catastrophic events using hazard minimisation and risk assessment principles.
HSE 3.18	HMRI should review the priority and targeting of its resources to see whether they can be more closely focused on regulating work streams associated with precursors of catastrophic events.
HSE 3.19	HMRI should review its safety case assessment arrangements to see whether they can be more closely aligned with the prevention of catastrophic events.
HSE 3.21	HMRI should obtain, as part of its on-going work on improving safety management systems in the rail industry, confirmation that there are no significant gaps in the rail industry's management arrangements for ensuring that safety critical components or systems are fit for purpose or that reasonably practicable improvements are appropriate.
HSE 3.25	HMRI should agree with Network Rail, and others affected, a strategy, including a valid timetable, for addressing the recommendations made in this report and publish that strategy.
HSE 3.26	Recommend that HSE periodically reviews progress in the implementation of the recommendations from our July 2002 Progress Report and those of this report, and publish its observations.

Appendix O - Network Rail SIN 97, 99 and 101 results

1 During the period since the accident Network Rail have issued three Special Inspection Notices (SINs) relating to points with flat-bottom rail and full depth non-adjustable permanent way stretcher bars: NR/SIN/097, NR/SIN/099 (three issues) and NR/SIN/101.

2 On 27 February 2007 Network Rail issued NR/SIN/097, requiring examination of:

- all facing and trailing points fitted between Crewe and Motherwell (inclusive), on the West Coast Main Line where the line speed is 80 mph (128 km/h) or greater; and
- all facing and trailing points across all territories that have flat-bottom, full-depth, vertical switches driven by points machines and fitted with non-adjustable stretcher bars where the line speed is 80 mph (128 km/h) or greater.

3 This instruction required inspection of the following items:

- checking that the fixings and lock nuts for items fixed to the stock or moveable length of switch rails are secure and tight by ensuring the nuts do not move by the application of a short spanner;
- examination of permanent way stretcher bars and their brackets to identify any cracking or deformation, check the insulations and check whether all of the fasteners are tight;
- examination of lock stretcher bars to identify any cracking or deformation, check the insulations and check whether all of the fasteners are tight;
- confirming all bolts were of sufficient length to accommodate lock nut thread, where appropriate; and
- measuring the minimum free wheel clearance where the line speed is greater than 80 mph.

4 The instruction for this examination stated that any identified defects were to be repaired within 36 hours of being found. Network Rail records indicate that all identified defects were repaired.

5 A total of 1437 sets of points were inspected. No points were found to be in a similar state of degradation to 2B points. However, in some cases there were early indications of some of the precursor situations. The Network Rail results are summarised below:

- 34.7 % of the points examined had one or more loose bolts, ie when there was rotational movement detected on the application of a short spanner;
- 16 % of the points examined required at least one defective stretcher bar component to be replaced – this included 3.7 % of stretcher bars replaced to correct the free wheel clearance;
- 8.9 % of the points examined had a free wheel clearance less than 45 mm, and 10.7 % of the points examined had the free wheel clearance adjusted; and
- 11.2 % of the points examined displayed more than one of the above conditions and 51 % showed none of them.

6 The results demonstrated that defects in stretcher bars are found in all territories across Network Rail infrastructure.

7 In response to the first urgent safety advice issued by the RAIB, described in Appendix P, Network Rail issued and implemented NR/SIN/099 Issue 1, in June 2007, requiring examination of all contraflexure points where the line speed was 80 mph (128 km/h) or greater; a total of 115 sets of points.

8 The instruction required the items listed below in addition to those specified in NR/IN/097:

- checking that there was no gap between the supplementary drive stretcher bar lug and the lost motion adjuster nuts on the open switch side;
- measuring residual switch opening at the position of the rear permanent way stretcher bar (ie the bar furthest from the switch toe);
- measuring minimum free wheel clearance between the back of the switch rail and the stock rail face on the open side of the switch rail; and
- measuring track gauge at point of minimum free wheel clearance.

9 The instructions for this examination stated that any identified defects were to be repaired within 36 hours of being found or a speed restriction applied. In five cases it was necessary to impose a 20 mph (32 km/h) speed restriction until faults to the track gauge, free wheel clearance or stretcher bars were rectified. All identified defects have now been rectified.

10 The findings from NR/SIN/099 Issue 1 were:

- In total, 62 % of the points examined had the potential for flange-back contact based on the limiting free wheel clearance.
- In total 38 % of the points had one or more loose fasteners.
- In total, 1.8 % of all bolts checked were found to be loose, as defined in paragraph 5.
- In total 67 % had residual openings greater than the 1.5 mm specified.

11 In July 2007, on completion of the above activities, Network Rail issued NR/SIN/099 Issue 2 which required correction of the free wheel passage on points inspected under NR/SIN/099 Issue 1. This included correction of track gauge, sidewear and the residual switch opening, as appropriate. NR/SIN/099 Issue 2 required all such defects to be rectified by 24 September 2007.

12 In July 2007 Network Rail issued Technical Instruction, TI/070 Issue 1, 'Set-up and Tolerance of Stretcher Bars'. This clarified the procedure for the setting of stretcher bars allowing for tolerances defined in track standards, including measurements of track gauge, residual switch opening and the calculation of free wheel clearance.

13 In addition to these examinations, Network Rail has replaced all the stretcher bars on the examined 115 sets of points and implemented the following changes to the fastener arrangement:

- upgrading the stretcher bar to switch rail bolt to Grade 8.8;
- replacing the spring washers with serrated lock washer pairs under the nut and the bolt head;
- replacing the nuts with alternative metal torque prevailing nuts;
- specifying 250 Nm tightening torque;
- using only clean, undamaged bolts.

14 Network Rail revisited these points after between four and six weeks after the initial installation and retightened the fasteners to 250 Nm with the aid of a torque wrench. Nut movement indicators were then fitted to the nuts.

15 After between two and five months from the initial installation, Network Rail made checks of the tightness of the fasteners on 16 sets of these points by application of 250 Nm torque to the nut with the bolt restrained. Of the 322 bolts tested, 12 % were deemed to be 'loose', defined by Network Rail as being any rotational movement between the nut and the restrained bolt.

16 Additionally, Network Rail collected 78 stretcher bars, including their rail brackets, from points and undertook detailed metallurgical examinations of them. This included first and rear-most permanent way stretcher bars, and lock stretcher bars. Network Rail found 37 cracks not visible to the naked eye in the switch rail brackets and the swan neck insulations in these permanent way stretcher bars. It was found that cracking was more significant with points where flange-back contact was present.

17 In October 2007 Network Rail issued NR/SIN/099 Issue 3. This was concerned with the measurement and correction of the free wheel passage on 112 points identified by Network Rail's fault management system as having had four or more stretcher bar failures since January 2005. Nine of these points had also been within the scope of NR/SIN/099 Issue 2. Findings included:

- 80 % of the points exhibited flange-back contact, with the highest value being 32 mm; based on the limiting free wheel clearance; and
- 30 % of the points had a residual switch opening greater than 4 mm and 85 % of these exhibited flange-back contact based on the limiting free wheel clearance.

18 Where necessary, correction to the free wheel clearance and residual switch opening was to be completed within 8 weeks of issue of the SIN. Other timescale constraints were applied where there was a need to correct gauge.

19 In February 2008 Network Rail issued NR/SIN/101 to measure and analyse the residual switch opening and free wheel passage on running lines fitted with non-adjustable stretcher bars. This work is on-going and by June 2008, findings on a sample of 2418 sets of points (18 % of the total asset) included.

- some 146 sets of points with either a bent/cracked stretcher bar or a cracked/broken stretcher bar bracket (6 % of the sample);
- 62 sets of points with one or more switch rail bracket bolts loose by more than ¼ turn when tested with a short spanner or torque wrench (2.6 % of the sample);
- 1668 points with a residual switch opening of greater than 1.5 mm (69 % of the sample); and
- a high level of non-compliance of the points' geometries with standards. For example, 1886 of the points (78 % of the sample) had theoretical flange-back contact as determined by measurements in accordance with TI 070 (then at Issue 2).

Network Rail are undertaking remedial works, based on their prioritisation, which is determined by the degree of geometry non-compliance and the line speed.

Appendix P - Urgent Safety Advice issued by RAIB

First Urgent Safety Advice issued by the RAIB, on 6 June 2007

1. Incident Description			
Lead Inspector		**Contact Tel. No.**	
Incident Report No	0185	**Date of Incident**	23rd February 2007
Incident Name	Grayrigg		
Type of Incident	Derailment of a passenger train		
Incident Description	Pendolino derailed on Lambrigg 2B points		
Supporting References			

2. Urgent Safety Advice	
USA Date:	6 June 2007
Title:	S&C stretcher bars
System / Equipment:	113A full depth switches, plus associated stretcher bars and the S&T lock stretcher bar; any similar switches and crossings
Safety Issue Description:	1. A train derailed by running into gauge constraint after the uncommanded closure of a normally open switch rail against its adjacent cess-side stock rail. The switch was a facing right-hand unit in a left-hand curve of 1240 metres radius and 95 mm of cant. 2. Locking and detection were present for both the six-foot-side switch blade and the cess-side switch blade in line with the signalled route at that time (the normal route). The left-hand switch blade had, though, become completely detached from the locking and detecting mechanism and was therefore free to move on its own without loss of detection. 3. All stretcher bars were found to be in a failed condition, as follows: i. The lock stretcher bar was detached from the cess-side switch rail because of the loss of its two fasteners. The nuts on these fasteners were of the prevailing torque type known as 'Aerotight' nuts. ii. The No.1 permanent way stretcher bar cess-side switch rail bracket (ear) was totally fractured, close to where it attaches to the stretcher bar itself. This was caused by a combination of fatigue and overload failure. iii. One of the bracket-to-rail fasteners was not present, with the other in a loose state. iv. The No.2 permanent way stretcher bar was not present; it had failed due to the bracket-to-rail fasteners becoming loose. At some time during its failure sequence it moved to a position where a train or trains struck it prior to the accident, fractured it into two parts at its 'swan-neck' insulation, and carried the two parts to separate locations where they were found some distance from the points. v. Both swan-neck ends of each half of the No.3 permanent way stretcher bar were fractured through the line of a bolt hole inside the 'swan-neck' insulation assembly. The failure was a fatigue failure on one side followed by an overload failure on the other. The short end of the stretcher bar had lost its two bracket-to-rail fasteners at the connection to the six-foot-side switch rail. One of the bracket-to-rail fasteners on the stretcher bar's long end at the connection to the cess-side switch rail was in a loose state. vi. Fatigue cracking was also present on the long end's bracket close to where it attaches to the stretcher bar itself.
Circumstances:	4. A passenger train derailed at 95 mph.
Consequences	5. The train ran derailed for 472 metres and fell down an embankment – one fatality and multiple injuries resulted.

REASONS FOR ISSUE:	6. Based on the RAIB investigation findings to date it is highly likely that the initiating event for this sequence of failures was an opening between the closed six-foot-side switch rail and its adjacent stock rail, at the position of the No. 3 permanent way stretcher bar, when the route was set to normal. It closed and opened under traffic, thereby introducing cyclic loading into the No.3 permanent way stretcher bar. A likely cause is believed at this stage to have been an incorrectly set supplementary drive that allowed the switch rail to stand off the stock rail at the minimum free wheel clearance position on the closed rail side. 7. The RAIB's view is that cyclic loading led to the failure of the No.3 permanent way stretcher bar bracket-to-rail fasteners, which then resulted in the cess-side switch rail at the point of minimum free wheel clearance moving closer to its stock rail. This increased the dynamic loading on the stretcher bar leading to the fatigue fracture. 8. The No. 2 permanent way stretcher bar subsequently failed by the loosening of its bracket-to rail fasteners. This bar became detached and was struck by an unknown train and moved away from the points at least 48 hours before the derailment. 9. In the 48 hours up to the derailment, the fastenings in the lock stretcher bar along with one of the fastenings between the cess-side switch rail bracket (ear) in No. 1 permanent way stretcher bar, came undone with the nuts off. One side of the cess-side switch rail bracket ear in the No 1 permanent way stretcher bar failed by fracture, the other side due to overload. 10. RAIB's fracture surface analysis indicates that the time from the visibly detectable failure of the No. 3 stretcher bar to the derailment could have been less than seven days. 11. During investigation of 622B points at the Grayrigg Freight Loops (done as part of the Lambrigg 2B points investigation) the RAIB found one permanent way stretcher bar that showed signs of advanced fatigue failure in the upper face of the 'swan neck' insulation joint. Such fatigue cracking can also occur on the lower face, which is not visible to routine inspection techniques. This stretcher bar had previously been examined in-track and deemed acceptable under Network Rail's Special Inspection Notice 97 (SIN 97). RAIB's modelling of this area indicates that high stresses can occur at this position on the stretcher bar.
ADVICE:	The RAIB wishes to draw the attention of infrastructure owners and maintainers to: A. The risk of progression to failure of this design of S&C resulting from an opening between the switch and stock rail on the through (normal) route in the vicinity of the No. 3 permanent way stretcher bar; the opening may arise from an incorrectly adjusted supplementary drive (ref paras 3 to 9, and particularly para 6). B. The speed with which the switch's remaining stretcher bars degraded following the fatigue failure of the No. 3 permanent way stretcher bar (ref para 10). C. The need to review the method and frequency of inspection and maintenance tasks performed to prevent the loss of integrity of stretcher bar fasteners and fractured stretcher bars, particularly in facing points where the consequences of such failure are assessed to be more serious (ref paras 1 to 10). D. The potential inadequacy of current inspection techniques in identifying fatigue failures in permanent way stretcher bars and their associated brackets (ref para 11).

Second Urgent Safety Advice issued by the RAIB, on 26 November 2007

1. Incident Description			
Lead Inspector		**Contact Tel. No.**	
Incident Report No	0185	**Date of Incident**	23rd February 2007
Incident Name	Grayrigg		
Type of Incident	Derailment of a passenger train		
Incident Description	Pendolino derailed on Lambrigg 2B points		
Supporting References	RAIB Report 071003_IR022007_Grayrigg		

2. Urgent Safety Advice	
USA Date:	26 November 2007
Title:	S&C stretcher bar bolted joints
System / Equipment:	Stretcher bars on full depth switches and similar switches and crossings
Safety Issue Description:	1. A train derailed by running into gauge constraint after the uncommanded closure of a normally open switch rail. All stretcher bars were found to be in a failed condition, offering no restraint to the switch rail. 2. The circumstances of the accident and emerging causes of the points failure are presented in RAIB Report 071003_IR022007_Grayrigg “RAIB progress report in a derailment at Grayrigg, Cumbria on 23 February 2007”. 3. This urgent safety advice concerns the design integrity of bolted fasteners in non-adjustable stretcher bar S&C at the stretcher bar to rail connection.
Circumstances:	4. A passenger train derailed at 95 mph.
Consequences	5. The train ran derailed for 320 metres and fell down an embankment – one fatality and multiple injuries resulted.
Reasons For Issue:	6. Based on the RAIB investigation findings to date it is highly likely that the initiating event was the failure of the bolted joint holding the No. 3 permanent way stretcher bar to the normally closed six-foot-side switch rail. 7. The failure of this joint allowed the normally open cess-side switch rail to relax towards its adjacent stock rail. The degree of this relaxation was exacerbated by the presence of a residual switch opening between the closed six-foot-side switch rail and its adjacent stock rail at the position of the No. 3 permanent way stretcher bar. 8. This relaxation allowed wheel flange back contact with the normally open switch rail. The forces from this frequent contact caused a high-load fatigue fracture of the No. 3 stretcher bar ‘swan-neck’ and failure of the bracket-to-rail bolted joints of the No. 2 permanent way stretcher bar. 9. A failure of the switch rail bolted joints of both the lock and the No.1 permanent way stretcher bars followed. In particular, one ligament of the No. 1 permanent way stretcher bar bracket failed by fatigue and the other by overload. 10. Testing and analysis undertaken together with Network Rail has determined a likely load case for a stretcher bar at the No. 3 position in switches of a configuration similar to that found at Lambrigg 2B points (contra-flexure).

REASONS FOR ISSUE (CONTD):	11. The RAIB investigation has considered the design of the stretcher bar-to-rail connection with respect to the load case in 10 above. In the assessment, a joint is defined to have failed when slip (relative movement in any of the mating surfaces) occurs. This is the case for these joints, as once slip occurs the vibration environment will result in the nuts winding off completely. Joint slip is prevented by maintaining the bolts' preload to be greater than the applied load, accounting for any clamping-force losses The preload in a bolt, and any preload loss, is affected by the following factors among others: • bolt material and dimensions; • torque; • thread friction; and • embedding loss (plastic flattening of surface roughness). 12. In this application, with the bolts torque tightened to the specified 200 Nm, high thread friction could result in the bolts' achieved preload being less than the total clamping force required for joint integrity, i.e., that required to withstand normal embedding losses and the applied service loads. High thread friction can occur through the presence of worn, corroded or contaminated surfaces, for example from re-use of fastener components. It was also observed that correct tightening of the joint could only be guaranteed by use of a torque wrench. 13. Additionally, it was observed that the failed No. 3 stretcher bar bracket was seated on raised lettering (branding) on the surface of the rail. The presence of branding can result in very high surface bearing stresses between items clamped together in a bolted joint. The effect of this is a significant, but unpredictable, reduction of preload due to increased embedding losses.
ADVICE:	In light of these findings, and the results from Network Rail SIN 97 and SIN 99 inspections which identified that loose fasteners were present in 49 (41%) of the 120 detailed individual points inspection records supplied to the RAIB , the RAIB wishes to draw the attention of infrastructure owners and maintainers to: A. The need to understand the load cases for bolted joints on full depth switches, especially those between stretcher bar brackets and the rail. B. The need to ensure that any existing and future design solution(s) in use or proposed for such joints will withstand the identified load cases. C. The need to take account of the effect of the mounting of joint components on top of branding (para 13), of tightening methods, and of the re-use of nuts and bolts together with the effects of lubrication (as a means of managing friction) (para 12) on joint integrity. D. The need to assess the efficacy of the frequency, regimes, instructions and assurance activities associated with patrolling, inspection, and examination of the joints to manage their safety and that of the line until such a time that the joints' integrity can be assured for the actual load cases to which they are subjected.

Appendix Q - Summary of egress routes

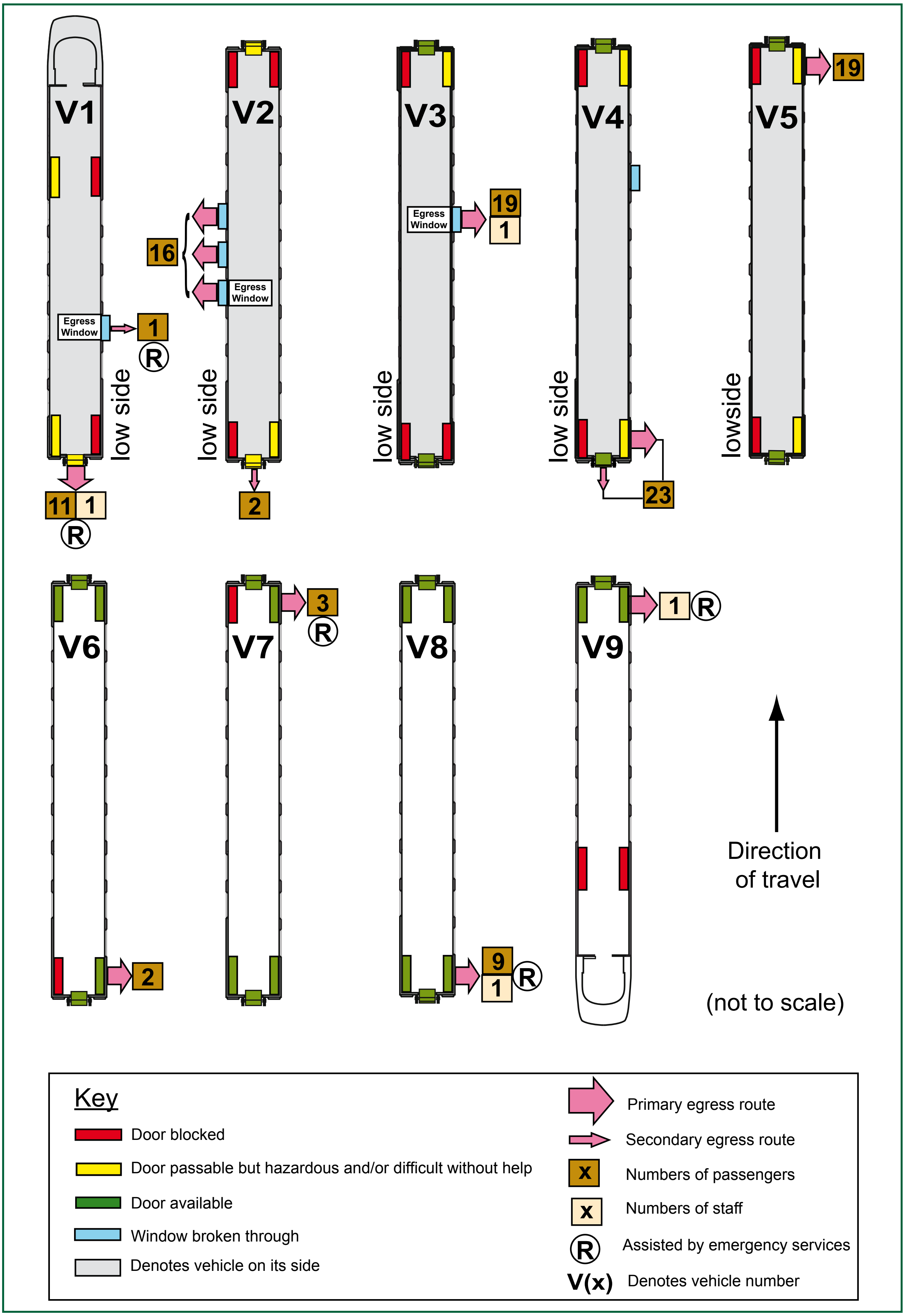


Figure 51: Summary of egress routes

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

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	