RAIB
Rail Accident Investigation Branch

Rail Accident Report

PROGRESS REPORT:
Derailment at Grayrigg, Cumbria
23 February 2007

Department for Transport

Report IR2/2007
October 2007

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.

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

Introduction

The Rail Accident Investigation Branch (RAIB) investigation

1 The RAIB[1] is responsible for conducting independent investigations into rail accidents in the UK. The purpose of its investigations is to improve safety by establishing the causes of the accident and making recommendations to reduce the likelihood of similar occurrences in the future.

2 The RAIB is not a prosecuting body; its investigations are focused solely on safety improvement and do not apportion blame or liability. The police and safety authorities investigate breaches of legislation; none of their statutory duties are changed by the RAIB investigation.

3 The RAIB has the lead responsibility for the investigation into the cause of the accident at Grayrigg on 23 February 2007, and this is running independently of the concurrent investigations by the *British Transport Police* (BTP), *Her Majesty's Railway Inspectorate* (HMRI), and the industry parties.

4 The purpose of this report is to provide an update on the RAIB investigation. It follows the interim report published on 26 February, which detailed the RAIB's initial findings from the first two days of its investigation. It also provides information on:

- the scope of the investigation to date;
- the areas that have been discounted as not contributing to the accident;
- matters that are subject to further analysis; and
- the actions already taken by the industry.

As the investigation is ongoing this report does not contain final conclusions or recommendations. These will be contained in the next report by the RAIB which is currently expected to be published in the early part of 2008.

[1] Further information regarding the RAIB can be found at www.raib.gov.uk

Summary

5 At 20:12 hrs on 23 February 2007, train 1S83, the 17:15 hrs service from London Euston to Glasgow operated by West Coast Trains Ltd, part of Virgin Rail Group, derailed on 2B *points* at Lambrigg *Emergency Ground Frame* (EGF), located near Grayrigg in Cumbria, while travelling at 95 mph (153 km/h). All vehicles of the train, which comprised a nine-car Class 390 Pendolino unit, number 390 033, were derailed (Figures 1 and 2).

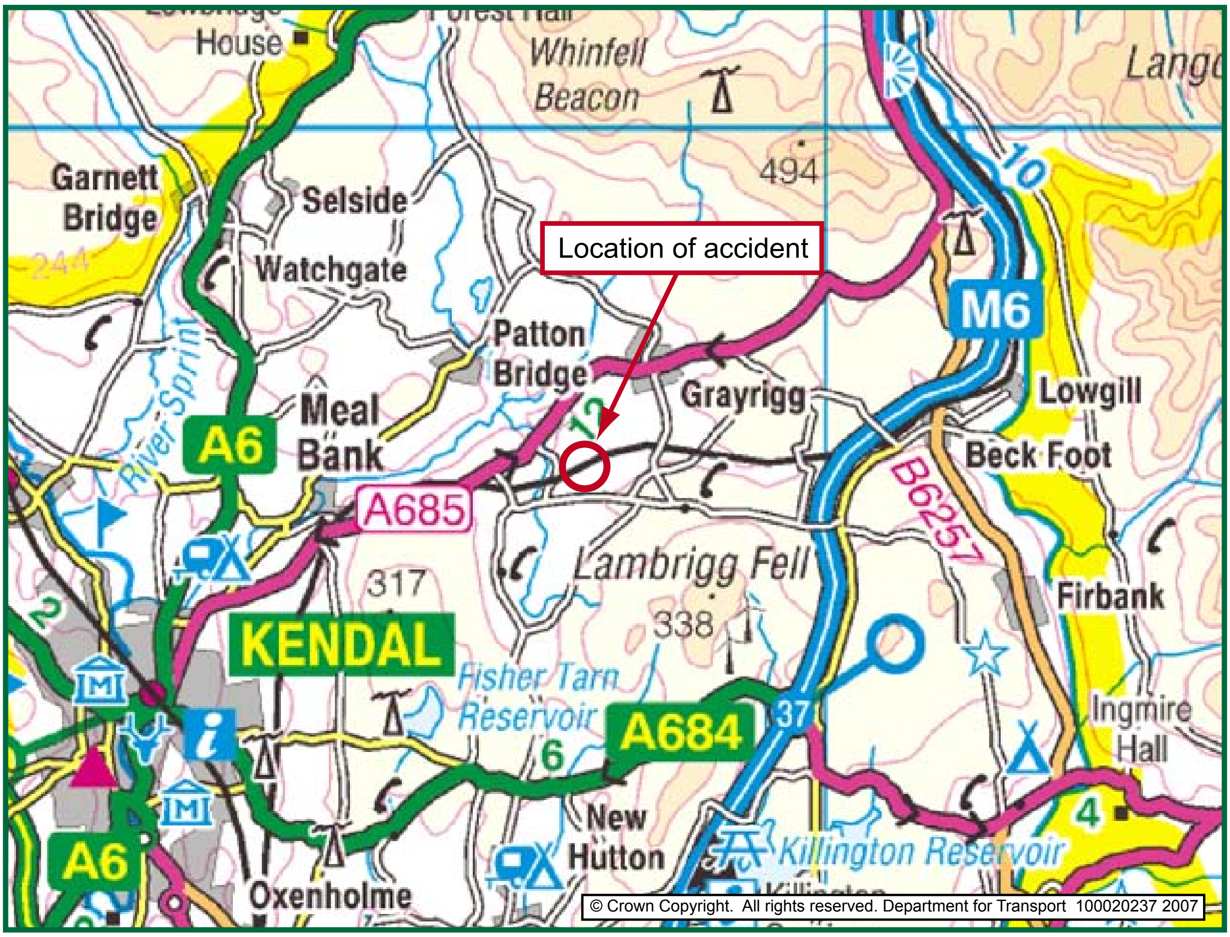

Figure 1: Location of accident

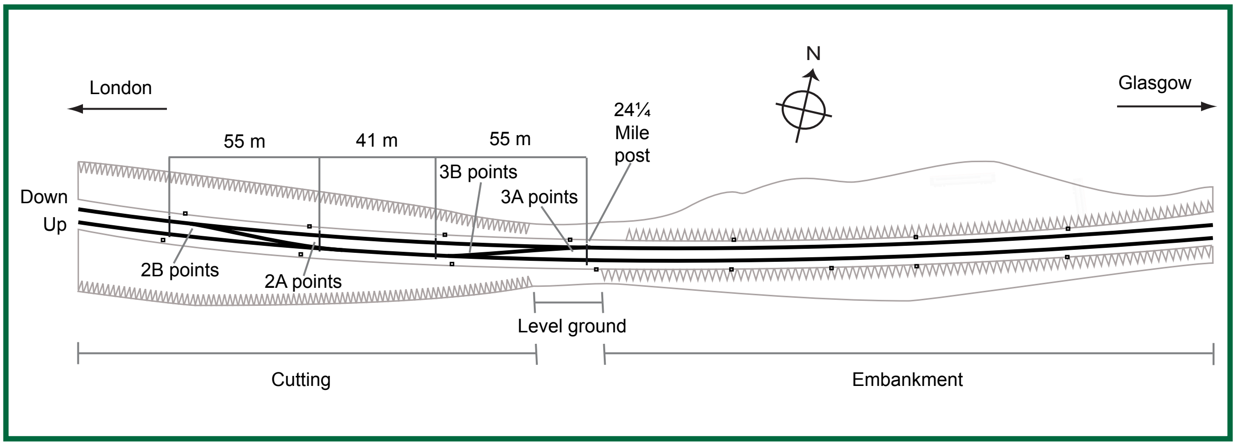

Figure 2: Layout of points at Lambrigg

6 The train is known to have carried four crew and at least 105 passengers at the time of the accident. It is possible that there were other passengers who may have left the site before the arrival of the emergency services.

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

8 After the rescue of those on board the train, the railway line through the area remained closed until 12 March 2007 to allow for accident investigation, vehicle recovery and repairs to the infrastructure.

The industry parties involved in the accident

9 The railway infrastructure is owned and maintained by Network Rail.

10 The train was owned by Angel Leasing Company Ltd and operated by West Coast Trains Ltd (referred to as 'Virgin Trains' in the remainder of this report), a division of the Virgin Rail Group.

11 Network Rail employs the *signallers* at Carlisle, the *electrical control room operators* at Crewe and the staff who were responsible for inspecting, maintaining and repairing 2B points at Lambrigg EGF, together with their managers.

Location

12 Lambrigg EGF was located on the London to Glasgow *West Coast Main Line* (WCML), near to the village of Grayrigg. The nearest stations were Oxenholme, approximately five miles to the south, and Penrith, approximately 27 miles to the north. Although the general orientation of the WCML is on a north-south axis, at Lambrigg trains running from London to Glasgow are travelling eastward (Figure 1).

13 Locations on the UK national rail network are described by their distance in miles and *chains* from stated zero datum points. Mileages at Lambrigg are measured from a zero datum point at Lancaster, with 2B points, the location of the derailment, being 24 miles and 12 chains from Lancaster. There are 80 chains in one mile.

14 Approximately 60 trains per day pass northbound through Lambrigg on a typical weekday, including 34 express passenger trains, two sleeper trains and 24 freight or *engineering trains*.

The infrastructure

15 Lambrigg EGF was located on a section of two-track railway and controls two *crossovers*, which are described in more detail below (see paragraph 25).

16 *Four-aspect colour light signalling* is provided, controlled from Carlisle *power signal box* (PSB).

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

18 The maximum permitted line speed on the *up* and *down* lines is 95 mph (153 km/h) for tilting trains authorised to run at *enhanced permissible speeds* (EPS) and 85 mph (137 km/h) for other rolling stock. EPS was introduced in December 2005 as part of the upgrade to the West Coast Main Line.

The points

19 Points (Figure 4) move trains from one track or route to another. The diversion is carried out by having two rails that move from one side of the track to the other, and select the route. These movable rails are known as the *switch rails* and are designed to abut against static rails known as *stock rails.* In the UK the two switch rails are maintained a set distance apart and are made to move at the same time by a series of *stretcher bars*. The total assembly of switch and stock rails with stretcher bars are referred to as 'the switches', and together with a crossing comprise the points, which are also known as '*switches and crossings*' (S&C). The bar at the *toes* of the switches (ie the movable end) is connected to *detection equipment,* which indicates to the *interlocking* whether the switches are correctly positioned; this equipment is known as a *lock stretcher bar* and *detector rods*. The other bars are known as *permanent way stretcher bars*. *Facing points* are where two routes diverge in the direction of travel, and *trailing points* where two routes converge.

20 The design of the facing points at Lambrigg had three permanent way stretcher bars, made of flat spring-steel. To allow for the operation of *track circuits*, stretcher bars are divided into two parts, joined by an insulated joint, commonly known as a *swan neck* (Figure 3). The two sections of the stretcher bar are of unequal length.

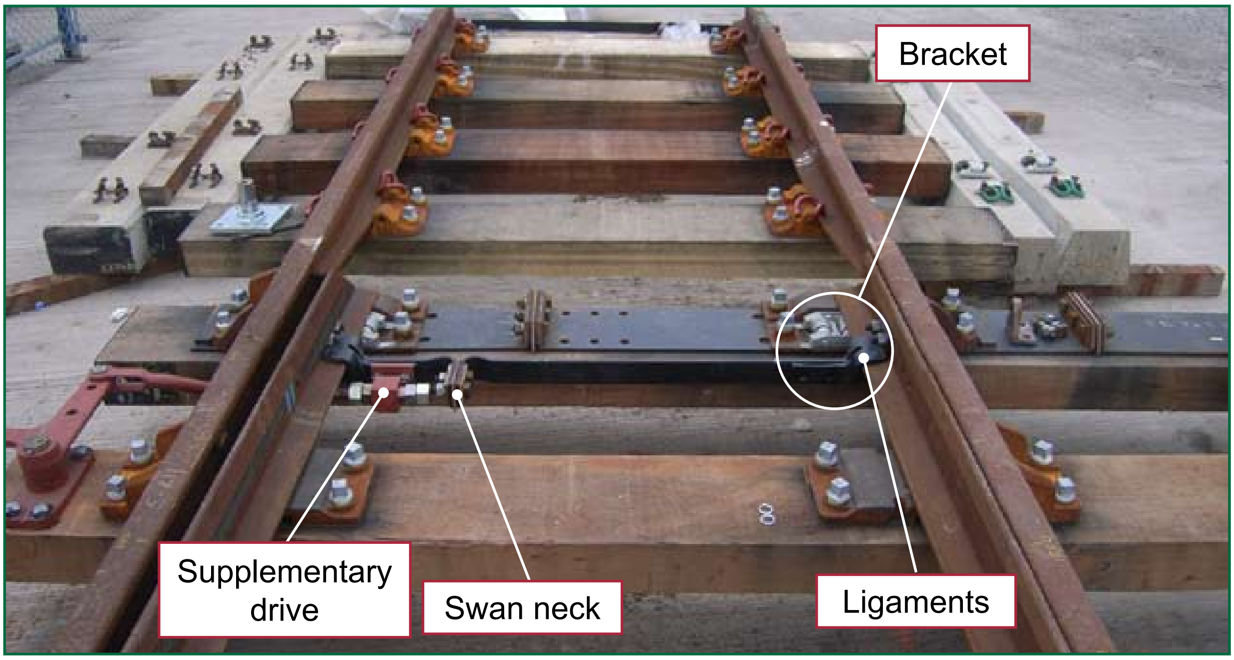

Figure 3: Stretcher bar and swan neck insulated joint

21 The *fasteners* in stretcher bars are subject to considerable vibration from the passage of trains. When the present design of stretcher bar was introduced, over 50 years ago, all the bolted joints were provided with two bolts. Inspection and patrol regimes are designed to ensure that any loose bolts are identified and corrected. The RAIB has been unable to establish any failure of this design of system leading to a derailment since the introduction of the system, although loose *fastenings* and single fractured stretcher bars have been regularly identified. Related failures are described in paragraphs 99 - 103.

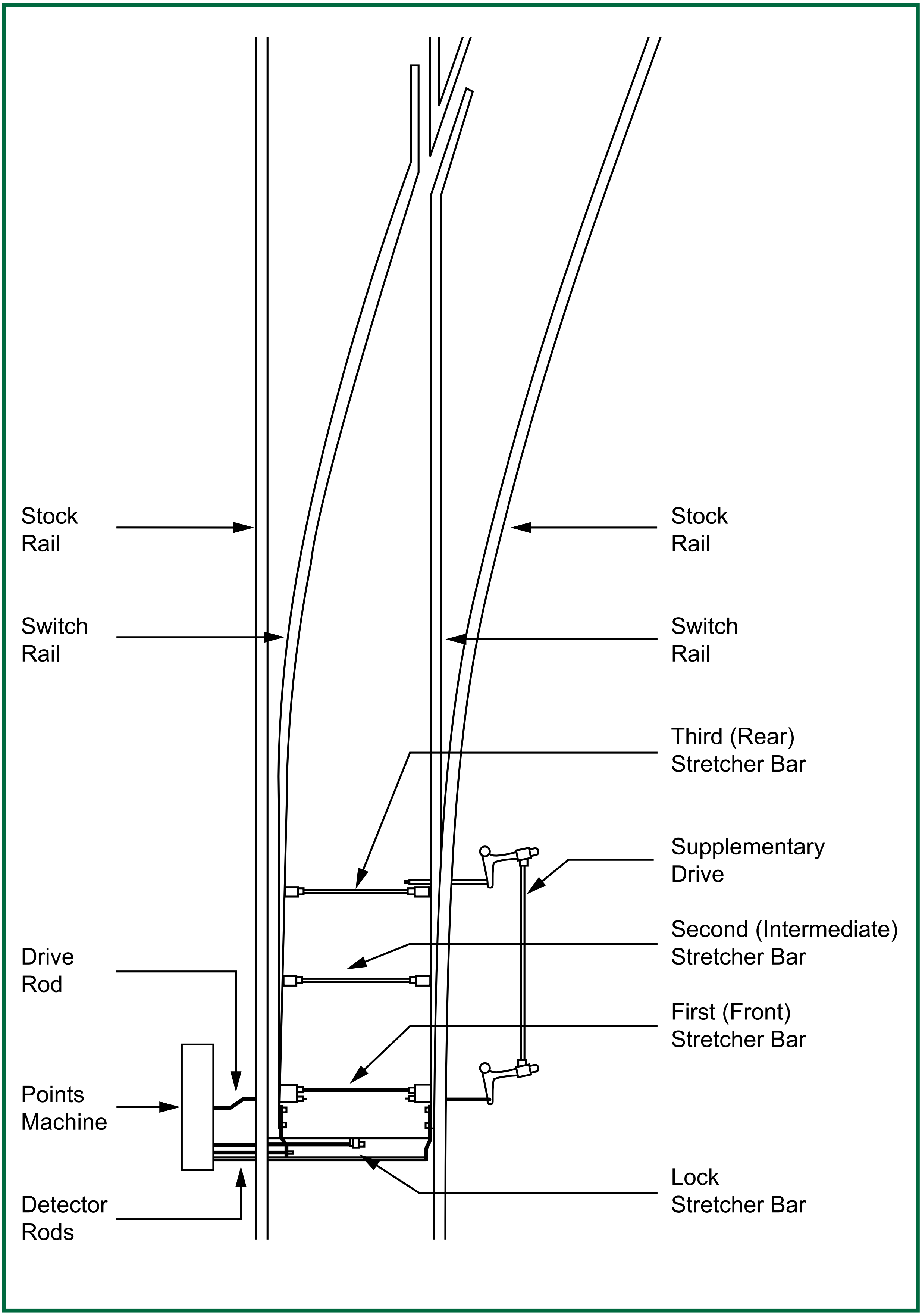

Figure 4: Layout of points showing switch and stock rails and stretcher bar

22 The number of permanent way stretcher bars is governed by the length of the switch rail, which in turn is set by the speed of trains taking the diverging route through the points. Switches of the length used at Lambrigg are classified[2] as C switches, one of the shortest types used on running lines, and only suitable for low *turnout speeds* no higher than 27 mph (43 km/h). Such switches are commonly only used for *emergency crossovers* and entry to engineering sidings. Lambrigg 2B points are illustrated in Figures 4 and 8.

23 The points at Lambrigg are made of *BS 113A FB* rail section, laid vertically, and the switches are strengthened by cast iron blocks bolting the switch rails to the stock rails to transmit the longitudinal thermal loads that arise from the use of *continuously welded rail* (Figure 5). The BS 113A FB vertical design of S&C was the standard design for British Rail and Railtrack from approximately 1970 to the late 1980s when *UIC54 shallow depth switches* began to be used as well as the vertical design. From approximately 2000, another new design began to be used for new installations on the most heavily trafficked routes. The new design uses a heavier section of rail, which is also being introduced on *plain line*. This reduces rail wear and rail failures under heavier traffic, and improves the ride of trains through S&C, again reducing wear and increasing passenger comfort.

Figure 5: Cast iron blocks joining switch and stock rails

24 The designed *track curve radius* at Lambrigg is 1487 metres with the track curving to the left[3] in the direction of travel for Glasgow bound trains. The designed *cant* is 95 mm.

25 There are two crossovers between the two lines at Lambrigg (Figure 2). Each crossover consists of two points. One crossover faces the direction of travel while the other is trailing. 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. Points 2B are located in a section of track in a *cutting* that curves gently to the left.

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[2] For classification of switch lengths refer to Chapter 21 of 'British Railway Track' (6th Edition), October 1993, published by the Permanent Way Institution.

[3] All references in this report to left and right-hand are made as if facing Glasgow unless stated otherwise.

26 The two crossovers were initially installed in 1971 as part of the WCML modernisation and electrification programme. They were provided to allow 'emergency' movements from one line to the other and for use by engineering trains during *possessions*. They were controlled from a *ground frame* cabin within the local relay room at Grayrigg and required an *electrical release* by Carlisle PSB before they could be operated. They could not be operated directly from Carlisle PSB.

27 At 3A points, the cutting ends in a short section of level ground at the site of a former level crossing. Continuing towards Glasgow, the railway is carried on an *embankment* which is 15 metres high at its maximum point on the northern side. Half 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.

28 The *speed restriction* when the route was set through 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 was permitted across them. Points 2B were of a *contraflexure* configuration, with a right-hand turnout on a left-hand curve. Network Rail has identified 120 contraflexure points on lines operating at speeds of over 80 mph (128 km/h) on their system; this is out of a total population of some 22,000 signalled points in the network.

The train

29 The train involved was a nine-car Class 390 'Pendolino' Electric Multiple Unit designed and manufactured by Alstom Transport and assembled at Washwood Heath. This class of train first entered passenger service in July 2002.

30 Class 390 Pendolinos were designed for a maximum operating speed of 140 mph (225 km/h) and run, among other routes, on the WCML between London Euston and Glasgow. The design features a tilt system to provide a comfortable passenger environment when the train is negotiating curves at higher speeds than conventional rolling stock. *Route acceptance* and a Certificate of Authority to Operate were granted in accordance with *Railway Group Standard* GE/RT 8270, Route Acceptance of Rail Vehicles including changes in Operation or Infrastructure.

31 The train was designed to be compliant with the technical standards for *crashworthiness* in force at the time (Railway Group Standard GM/RT2100, Structural Requirements for Railway Vehicles). The train incorporated safety features for operation above 100 mph (161 km/h) with passengers in the leading vehicle. Safety features that are of particular relevance to passenger safety in this derailment are the double skin bodyshell construction, the structural partitions at the 1/3 and 2/3 points, the laminated bodyside windows, and the enhanced *coupler* strength (see paragraphs 87 and 88).

Events during the accident

32 Train 1S83 left London Euston on time at 17:15 hrs and the journey north to Preston was uneventful. A scheduled change of driver and *train manager* took place at Preston and the train then continued its journey. It was running at 95 mph (153 km/h) under *automatic speed control* with no faults recorded as present, when it approached the Lambrigg EGF.

33 As the train passed through 2B points it derailed as the left-hand switch rail was not in the open position it should have been in. Some of the train wheels were thus guided by both switch rails and set on a course where the *gauge* was narrowing as the train moved forward. Unable to follow the narrowing route, these wheels climbed over the switch rails into a derailed state. The track damage caused by this initial derailment derailed other wheels, in turn causing more damage which led to the eventual derailment of the whole train. The derailment mechanism is further explained in paragraph 85.

34 The driver was unable to react to the emergency before he was thrown out of his seat by the motion of the derailed train. He sustained serious injuries during the course of the derailment of the leading vehicle, ending up unconscious on the right-hand side wall of the cab once the vehicle came to rest on its right side.

35 The *emergency brake* was applied automatically when continuity of the brake control circuit was lost, probably as a result of the coupler, connecting vehicles one and two, separating as vehicle one jack-knifed (see paragraph 37). The train slowed due to a combination of:

- the derailed *bogies* running through the *ballast*;
- the subsequent ploughing of vehicles through earthworks and vegetation;
- the applied emergency braking being effective on those vehicles yet to derail;
- the derailed bogies distorting the track; and
- the collision of some vehicles with overhead line *stanchions*, their foundations and other lineside features on the embankment.

36 All the vehicles came to rest within a maximum distance of 320 metres from the toes of 2B points.

37 During this period, the leading vehicle (vehicle one) became detached from the second vehicle (vehicle two) and came to rest at the foot of the northern side of the embankment facing the opposite direction to the way it had been travelling. It is probable (subject to further work by the RAIB), that once derailed, vehicle one rotated because jack-knifing occurred at its interface with vehicle two. This had developed as a result of an earlier misalignment between these vehicles as they ran derailed (see paragraph 38), increasing as vehicle one was pushed by the trailing vehicles. Since the leading end of vehicle one was not coupled to another vehicle, it was free to deviate from the track.

38 Based on marks on the track and indications of impact damage between the vehicle and the overhead line stanchions, the trailing bogie of vehicle one and the leading bogie of vehicle two are believed to have run derailed close to or in the up line. These bogies were being guided towards the up line by the turnout in the early stages of their derailment. The effect of this was that vehicles one and two became misaligned. Confirmation of this is subject to ongoing investigation. Vehicle two came to rest on the embankment at ninety degrees to its original direction of travel with its trailing end at the bottom of the embankment and its leading end overhanging the track of the up line. The coupler between vehicles two and three parted at its central connection shortly before these vehicles came to rest.

39 Vehicles three to nine stayed attached to each other and followed vehicle two running derailed mainly on the down line, before sliding over the edge of the embankment and coming to rest at various positions along its northern slope. At some point late in the train's trajectory, the coupler between vehicles three and four parted.

40 Vehicle nine, the last vehicle in the train, ran derailed on the down line attached to vehicle eight and stopped with its front part-way down the embankment's northern slope, coming to rest with its cab just past 3A points. Figure 6 shows the train in the position where it finally stopped.

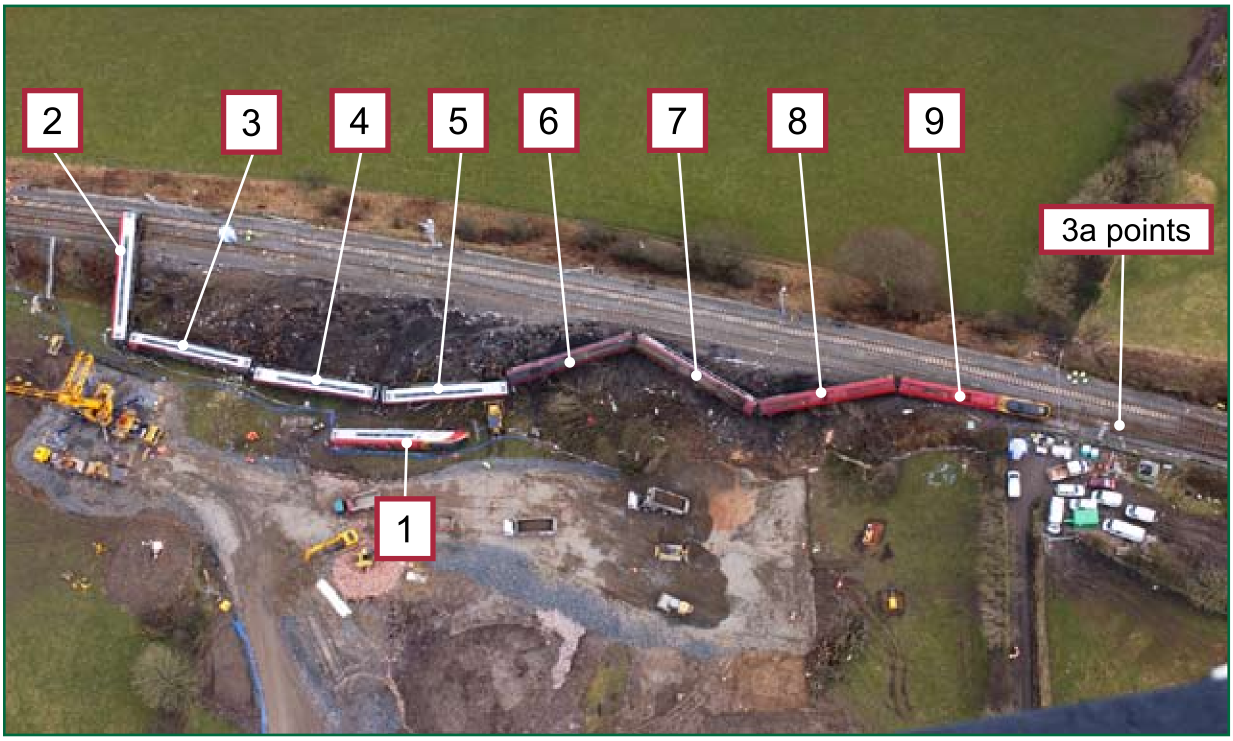

Figure 6: The train in its final position

Events following the accident

41 As a result of the damage and disruption to the signalling system, all signals in the immediate vicinity were set automatically to *danger* (the *fail-safe* condition). This led to a southbound train being stopped at signal CE75 seven minutes after the derailment occurred. Signal CE75 was located 245 metres from the derailed train.

42 Upon regaining consciousness, the driver of the Pendolino, despite his extensive injuries, used 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 to arrange for trains to be stopped on the up line. The RAIB commends the driver for his presence of mind.

43 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 service manager* and *customer service assistant* provided information to the emergency services regarding the train and the number of passengers on board. They then assisted the passengers and the emergency services to the best of their ability, despite being unable to move readily through the train, and in one case being injured.

44 Staff in the Network Rail electrical control room at Crewe and the signaller at Carlisle were both immediately aware of problems in the Lambrigg area from indications on their display panels, but they were unable to determine the cause. Both implemented procedures to secure the safety of the accident site – isolation of the overhead line supply and all signals set to danger.

45 The emergency services were notified of the accident by a number of passengers on the train and also by two local residents who heard a loud noise and went to investigate. Cumbria Police and Cumbria Fire & Rescue Service and the Ambulance Service were the first responders, followed shortly by the BTP.

46 The train was located by the first fire and rescue crew from Kendal, who then provided the location details for the other appliances and services.

47 Network Rail and Virgin Trains staff attended to ensure the safety of the site and the train for the rescue and subsequent investigation, recovery, and reconstruction phases.

48 Fifty four passengers, the train driver and one other crew member were taken to hospital by road or by air.

49 Thirty five passengers and two crew members were assessed at a field *triage* set up near the accident site, treated by medical staff there and released to continue their journeys in specially-arranged transport. The remaining passengers were able to continue their journeys without medical attention.

50 Road closures and traffic restrictions were imposed on the A685 and local minor roads in the vicinity of Grayrigg village for ten days while recovery of the railway took place (see paragraph 8). Further periods of disruption occurred for several weeks as large plant was moved.

The investigation process

51 The RAIB investigation focuses on three main areas:

- establishing how 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 in the network;
- identifying if there are any similarities between this accident and other relevant accidents or incidents, including the derailment at Potters Bar on 10 May 2002; and
- establishing the behaviour of the train as and after it derailed, and in particular how the casualties occurred.

52 At any stage during an investigation, the RAIB can issue an *urgent safety advice* to the industry if it becomes aware of information that it considers may have an important or immediate impact on safety. An urgent safety advice was issued on 6 June 2007 (see paragraph 93).

53 Fourteen of the RAIB's current establishment of twenty two inspectors are engaged in the investigation, supported, where necessary, by external specialists in key disciplines such as materials science.

54 In total, 1048 items of evidence from the accident site and other locations remote from the site have been collected. These have been recorded and entered onto the RAIB evidence tracking system for the purposes of control and continuity of evidence.

55 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 7) was secured for transport and removed as a complete panel to a secure laboratory to allow testing and analysis.

Figure 7: Points 2B switch section in laboratory

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

57 In the post-site investigation phase the RAIB has, to date:

- carried out over 75 interviews;
- reviewed relevant industry documents;
- recreated the switch rail configuration as it was at Lambrigg;
- undertaken physical testing of the points;
- analysed and modelled the likely behaviour and failure mode of the switches; and
- tested the loadings in stretcher bars (in co-operation with Network Rail) on the operational railway.

58 In accordance with the Railways (Accident Investigation and Reporting) Regulations 2005 the RAIB has shared evidence (but not the identity of people interviewed by the RAIB or the contents of their statements) with the BTP and HMRI in order to facilitate their own investigations. The RAIB has had regular liaison with the industry parties involved to ensure they are aware of emerging findings that may affect their ongoing responsibility for safety, as far as the ongoing investigation has permitted.

> The RAIB has not concluded its investigation and what follows is a description of the circumstances and facts found to date. The extent, if any, that these matters may have contributed to the derailment is still under review and no early conclusions should be taken as implied.

The track maintenance and inspection regime

59 The section of route through Lambrigg EGF is inspected and maintained by Network Rail's *Infrastructure Maintenance Manager*'s (IMM) organisation for the Lancashire and Cumbria area, based at Preston.

60 The points were subject to Network Rail's structured inspection and maintenance regime with responsibility for the different aspects being split between Network Rail's signal engineering department and the track engineering department.

61 Network Rail's company standards set out the requirements for this regime. The relevant standards for 2B points are:

Standard	**Title**
NR/SP/TRK/001	Inspection and maintenance of permanent way
NR/SP/TRK/053	Inspection and repair procedures to reduce the risk of derailment at switches
NR/SP/SIG/10660	Implementation of signalling maintenance specifications

62 Table 1 below summarises the key elements of the inspection regime and identifies which department carried out the work.

Department	Scheduled Periodicity	Summary of Scope
Signal Engineering	Three monthly*	▪ General condition check including free movement of points (adequate lubrication of moving components and no obstructions) ▪ Check condition and functioning of point machine and connections to points including *back drive* ▪ Check condition and functioning of points *detection* ▪ Stretcher bars including fixings and insulation – visual check and test bolt tightness with short spanner ▪ Measure dimensions between switch and stock rails at switch toe and in vicinity of back drive including *free wheel clearance* ▪ Test functioning of *facing point locks* to ensure switches cannot open more than specified by insertion of a series of go/no-go gauges
	Monthly	▪ Test functioning of facing point locks to ensure switches cannot open more than specified by insertion of a series of go/no-go gauges
Track Engineering	Three monthly*	▪ Visual check of condition of switch blades and adjacent stock rails and their inter-relationship
	Eight weekly supervisory	▪ General condition check (visual check of alignment faults, gauged check of *twist* and gauge, visual check of condition of components such as stretcher bars, *sleepers* and *baseplates* and missing or broken bolts and fastenings) ▪ Measure clearances between switch and stock rails within points, including those at switch toe and in vicinity of back drive
	Weekly basic visual check	▪ 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 fastenings)
	Three monthly	▪ Ultrasonic inspection of rails (examination for defects in metal)
Network Rail Headquarters	Three monthly minimum	▪ Track geometry check using mechanised equipment carried on board a dedicated measurement train (*New Measurement Train* (NMT))

Table 1: Inspection regime

* At Lambrigg, and throughout the Lancashire and Cumbria area, these activities were undertaken by a Joint Points Team which included personnel from both the signal engineering and track engineering departments.

63 Part of the constraints on when access to the points could be achieved for the purpose of inspection is dictated by the *Hazard Directory*. Prior to implementation of EPS various revisions were made to the Hazard Directory. These revisions followed a review of the route to re-assess the warning time for trains, and the availability of places of safety for staff working on the line when open to traffic. The revisions led to an increase in *red zone* restrictions for undertaking work on the track. As a result, access for staff to work on the line when open to traffic became difficult (only short visits of some minutes could be carried out). The Hazard Directory changes were implemented in August 2005 and from that time on, virtually all inspection activities at Lambrigg had to be undertaken on Sunday mornings (as this was the only time that the railway was closed to traffic), with no effective access for the rest of the week. From spring 2006, the route was re-opened to traffic on Sunday mornings at some time between 10:00 hrs and 11:00 hrs. This meant that in winter 2006/2007, patrolling of the line had to take place between first light and the time at which the railway was re-opened to traffic. Maintenance activities which could take place under artificial light had to be undertaken during Saturday nights and Sunday mornings, up to the re-opening time.

Train-based monitoring of the points

64 The visual inspection regime, as detailed in Table 1, was complemented by train-based monitoring of the condition of the infrastructure. Although there was a requirement for the line to be examined by the train-based inspection regime at intervals of three months, in practice, measurement trains ran on a more frequent basis. In particular the New Measurement Train (NMT) (see paragraph 69) operated over the West Coast route every two weeks in order to develop Network Rail's strategy of predicting deterioration of track and preventing it occurring rather than repairing faults after they have developed. The train produces a high volume of data, and automatically calculates and identifies exceedences against various standards for the criteria measured. It then automatically flags these exceedences up to the maintainer so that any necessary steps can be taken.

65 None of the train-based monitoring systems referred to in paragraphs 66, 68 and 69 was designed to automatically detect and flag the type of faults found in the S&C at Lambrigg. However, in the light of the derailment, the data has subsequently been used to aid the RAIB investigation.

66 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 a *residual switch opening* in the vicinity of the third stretcher bar (on the closed side) in 2B points that was between 6 and 8 mm. This exceeded the nominal 1.5 mm gap specified by Network Rail in standard RT/E/C/11772, Supplementary Point Drives and Detection, clause 4.1.2. For longer switches of type F[4] (turnout speed 45 mph - 54 mph (72 km/h to 86 km/h), depending on the crossing angle) and above, *supplementary detection* is provided at the stretcher bar attached to the *supplementary drive*. Standard RT/SMS/Test/016 specifies that the supplementary detection must operate when the opening is 6 mm, but must fail when it is 8 mm. Whilst this implies that the residual switch opening can be of this magnitude, the RAIB has been unable to find any evidence that these dimensions were specified other than in consideration of the correct functioning of the supplementary detection system.

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[4] For classification of switch lengths refer to Chapter 21 of 'British Railway Track' (6th Edition), October 1993, published by the Permanent Way Institution.

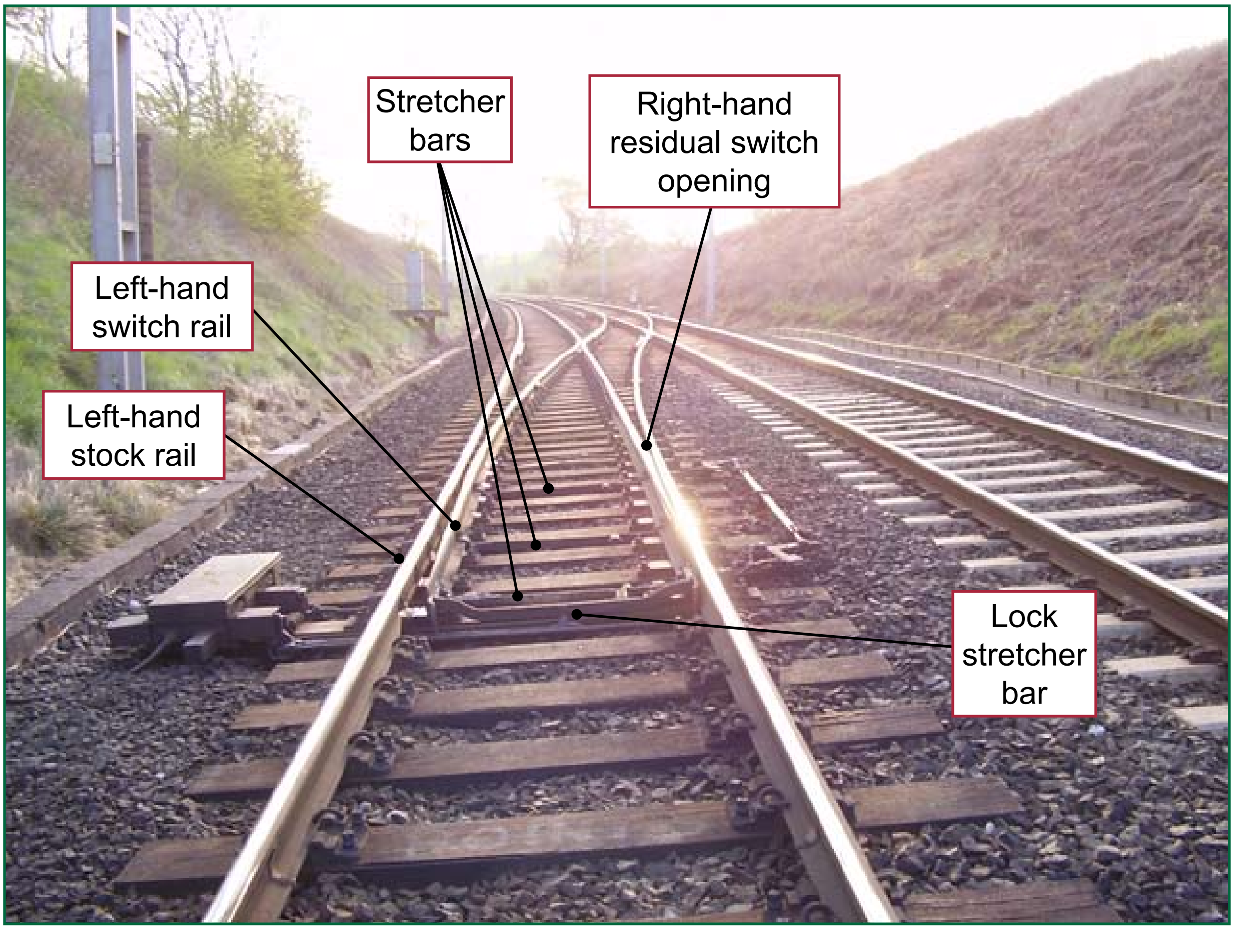

Figure 8: Lambrigg 2B points, May 2006 (Courtesy of Network Rail)

67 A still photograph taken in May 2006, during a routine inspection of the track, gives evidence that an excessive gap was still in existence (Figure 8).

68 On 12 February 2007 the *Structure Gauging Train* (SGT) ran. Analysis by the RAIB of the output from that run shows a reduction in the free wheel clearance at the third stretcher bar to approximately 40 mm (50 mm is the design minimum) and indicates that this stretcher bar had become disconnected from the right rail and that it was broken by that date.

69 On 21 February 2007, the NMT ran through Lambrigg on the down line. The NMT is equipped to measure various parameters, and was additionally fitted with experimental *Cybernétix IVOIRE III* equipment, which had only become operational shortly before the run on 21 February 2007 (having been on trial until then). The output from this equipment included vertical photography of the track and shows the second stretcher bar on 2B points to be missing. The photographs also show bolts in the ballast where the second stretcher bar used to be attached to the left-hand switch rail. The third stretcher bar is present but had failed. Its failure is indicated by a reduced free wheel clearance of 20 - 25 mm compared with a design minimum of 50 mm. One photograph from the NMT (Figure 9) also shows a component lying on a sleeper that is identical to the part of the third stretcher bar found in the same location after the accident, confirming that this stretcher bar had failed prior to the accident. The NMT was also equipped with a video camera that recorded the wheel – rail interface, and the recording of 21 February 2007 shows the wheel pushing the switch rail clear of its path as it runs through the switch, confirming the reduction in the free wheel clearance.

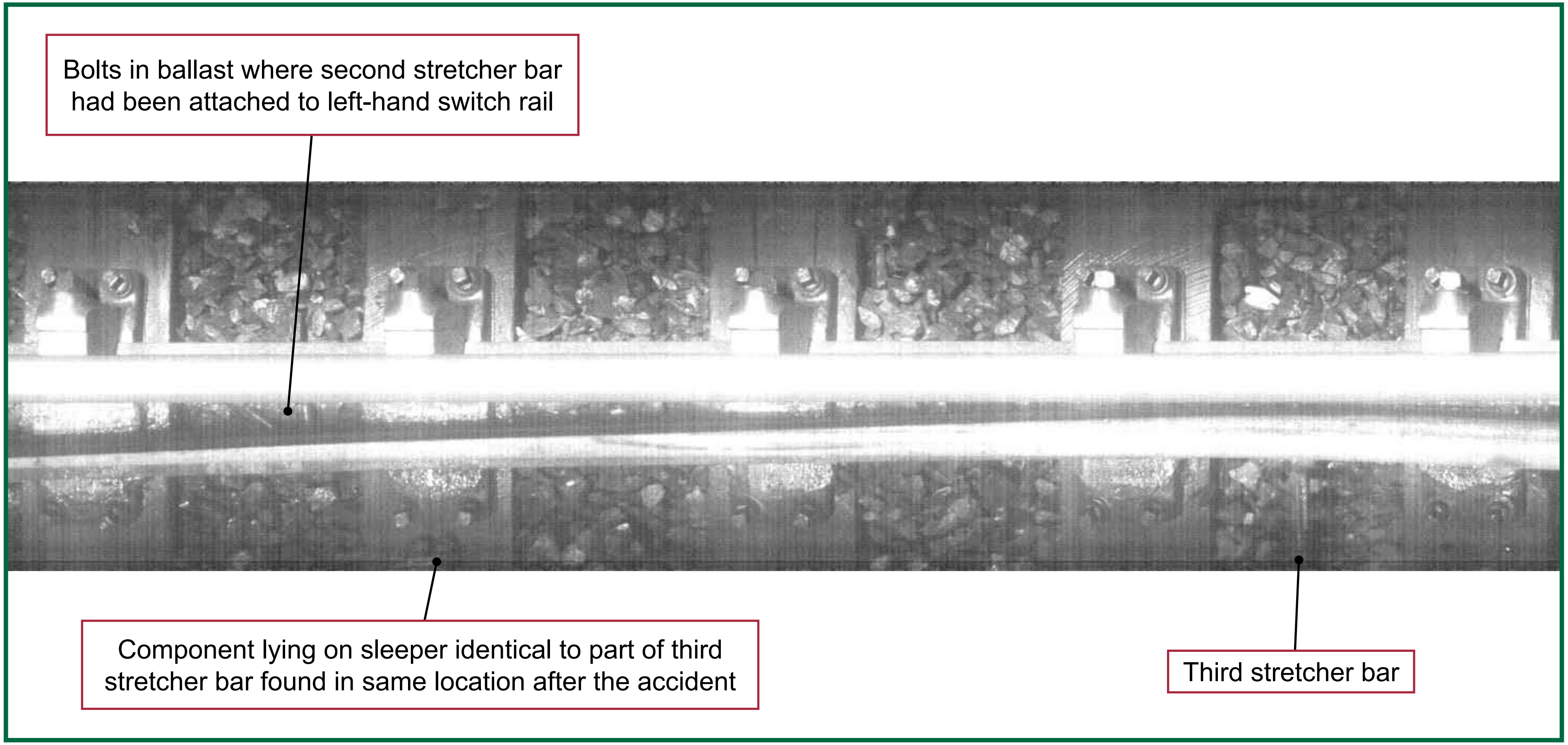

Figure 9: Cybernétix IVOIRE III *image taken on 21 February 2007 showing second stretcher bar to be missing*

Maintenance of the points

70 There is no evidence of any alteration to the supplementary drive settings, which might have altered the residual gap (paragraph 67) between May 2006 and 23 February 2007.

71 To address an alignment issue on the up line, which had resulted in an 80 mph (128 km/h) speed restriction being imposed, *tamping* was undertaken at Lambrigg EGF on 2 December 2006. The opportunity was also taken to address some alignment issues on the down line that had first been identified six months earlier (affecting ride quality rather than safety of the line).

72 The track engineering department undertook general maintenance at Lambrigg EGF on the morning of 7 January 2007, which did not affect the stretcher bars or their fastenings. Those carrying out this work did not notice anything amiss in Lambrigg 2B points; there was no specific requirement for them to inspect the stretcher bars.

73 After the maintenance team had departed, but still in the morning of 7 January 2007, the weekly patrol by a member of the track engineering team found two bolts undone from the third stretcher bar on 2B point ends. The patroller reported the fault directly to Network Rail's infrastructure control at Birmingham and stated that two nuts were missing but that the bolts were still in position. As a result, a signal engineering fault team was dispatched from Carlisle to repair the points later that day. The fault team replaced the nuts and the bolts at the *six-foot* end of the third stretcher bar.

74 Network Rail standard NR/SMS/PF01, Point Fittings, states, 'If any component is found to be loose, broken or requiring adjustment, the cause for it must be investigated.' No such investigation was undertaken by Network Rail.

Inspection of the points

75 All inspections that were scheduled in December 2006, January 2007 and up to 11 February 2007 are recorded as having taken place, although there are some inconsistencies in the records of these patrols.

76 Between December 2006 and 11 February 2007 inclusive, no inspection other than that of 7 January 2007 (see paragraph 73) identified any issues for attention in any of the four sets of points at Lambrigg. The last recorded inspection of the S&C at Lambrigg took place on Sunday 11 February 2007. The next inspection should have taken place on Sunday 18 February.

77 A team of ultrasonic rail flaw detector operators examined the plain line in the vicinity of Lambrigg EGF during the early hours of 18 February 2007. This examination excludes S&C, so they did not examine 2B switches and did not observe anything out of the ordinary with them. They did detect a rail flaw in the up line approximately 25 yards on the London side of the 2B points' switch toe (which is located in the down line); at 07:00 hrs they requested that the defect be clamped. A team of permanent way staff attended the site and fitted clamps to the up line at approximately 15:00 hrs; they did not observe any problem in 2B points on the down line.

78 On 18 February 2007 a supervisor from the Lancashire and Cumbria maintenance area, who was undertaking a *supervisor's plain line inspection* on that morning, also planned to cover the weekly track patrol through Lambrigg. Such substitution of a basic visual inspection by a supervisor's inspection is permitted by Network Rail Company Standards.

79 Supervisors' inspections on Network Rail are permitted to have different boundaries to the areas covered by the weekly track patrol. Separate supervisory inspections are carried out for plain line and for switches and crossings. At Lambrigg, the supervisor's plain line inspection boundary stopped before the points were reached, whereas the track patrol incorporated the points. In undertaking a track patrol and supervisory plain line inspection simultaneously, the supervisor should take account of the differences in boundaries. On 18 February 2007, this difference was not accommodated in the substitution, and as a result the Lambrigg crossovers were not inspected on this date.

80 Between the operation of the Omnisurveyor3D train in 2004 and the date of the accident in 2007, no action was taken to adjust the residual switch opening to the correct nominal value of 1.5 mm laid down in the signalling standards (see paragraph 66). There is no specific requirement in Network Rail's signalling maintenance specifications for signalling maintenance staff to check the residual switch opening dimension during inspections; only to check that the supplementary drive is correctly set up and operating with details being provided in a separate work instruction. This states that there should be a gap of 1.5 mm between the closed switch and the stock rail at each rear and intermediate drive position, but does not give guidance on how this is to be achieved should the gap measured not be 1.5 mm. A separate standard (see paragraph 66) describes how adjustments should be carried out.

Status of 2B points immediately before and after the accident

81 The following is a summary of the condition of key components in 2B points immediately following the derailment (Figure 10):

- The lock stretcher bar and the left-hand detector rod connection were detached from the left-hand switch rail by a failure of the two threaded fasteners. These fasteners are ¾-inch Whitworth bolts with Aerotight prevailing torque nuts and plain washers. All fastener components were present in the vicinity of the switch toes, with the exception of one of the bolts which was not found despite a full search. The photographs from the NMT taken on the 21 February 2007 (see paragraph 69) clearly showed both the bolts and their nuts to be present (Figure 12).

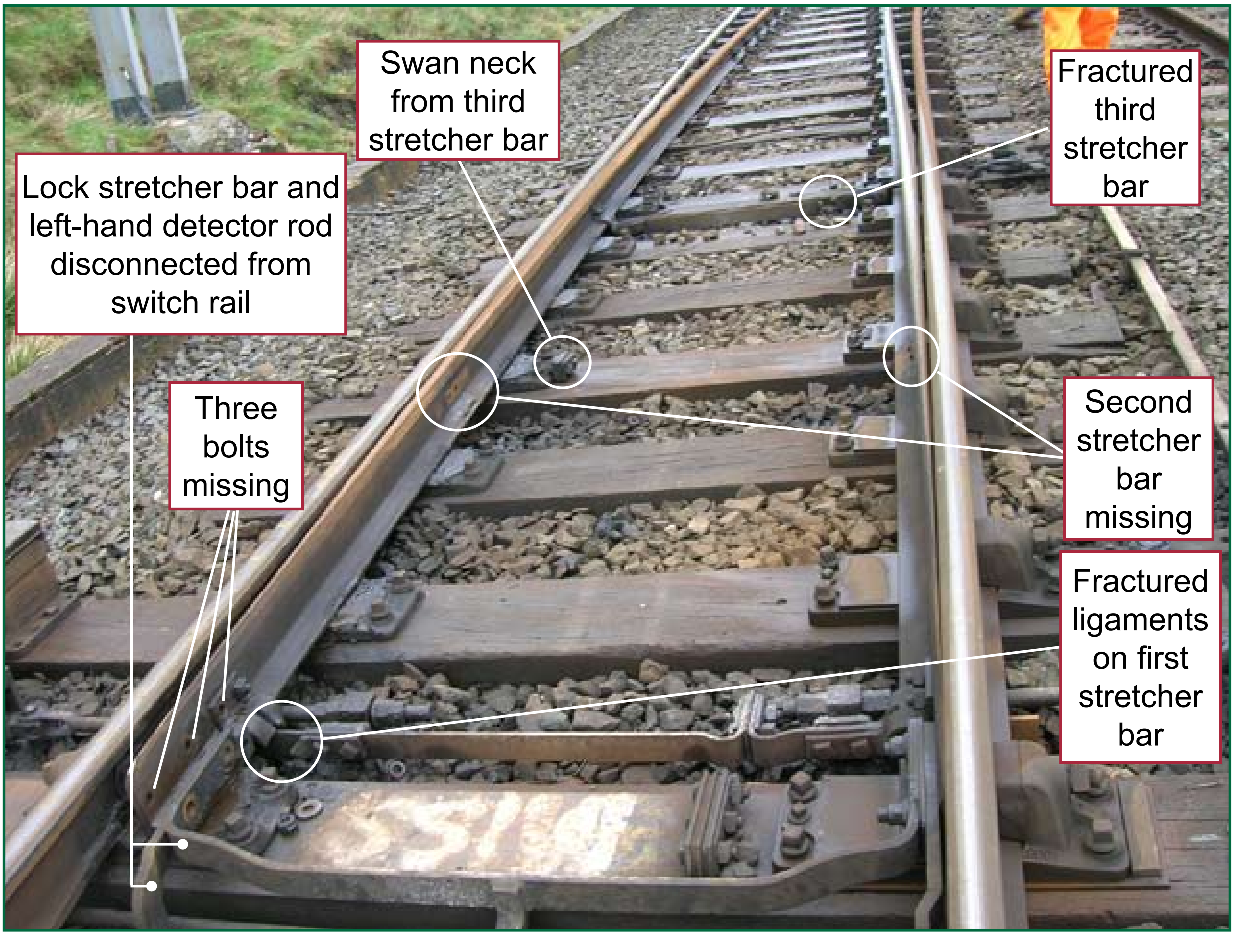

Figure 10: 2B points on 24 February 2007 (Courtesy of Network Rail)

- The first permanent way stretcher bar was found to be broken on both *ligaments* of its left-hand switch rail bracket close to where it is bolted to the stretcher bar itself. The fasteners are ¾-inch Whitworth bolts and nuts made of mild steel with a single coil *spring washer* and are used for all permanent way stretcher bar fasteners on this type of points. One of the fasteners was not present between the bracket and the switch rail, while the other fastener was assembled, but only finger tight. A bolt, nut and spring washer from the bracket connection were found under the switch rail lying on the ballast (Figure 11). The photographs from the NMT taken on the 21 February 2007 (see paragraph 69) similarly showed both the bolts and their nuts to be present, although it is possible that one of the nuts may have been loose (Figure 12).

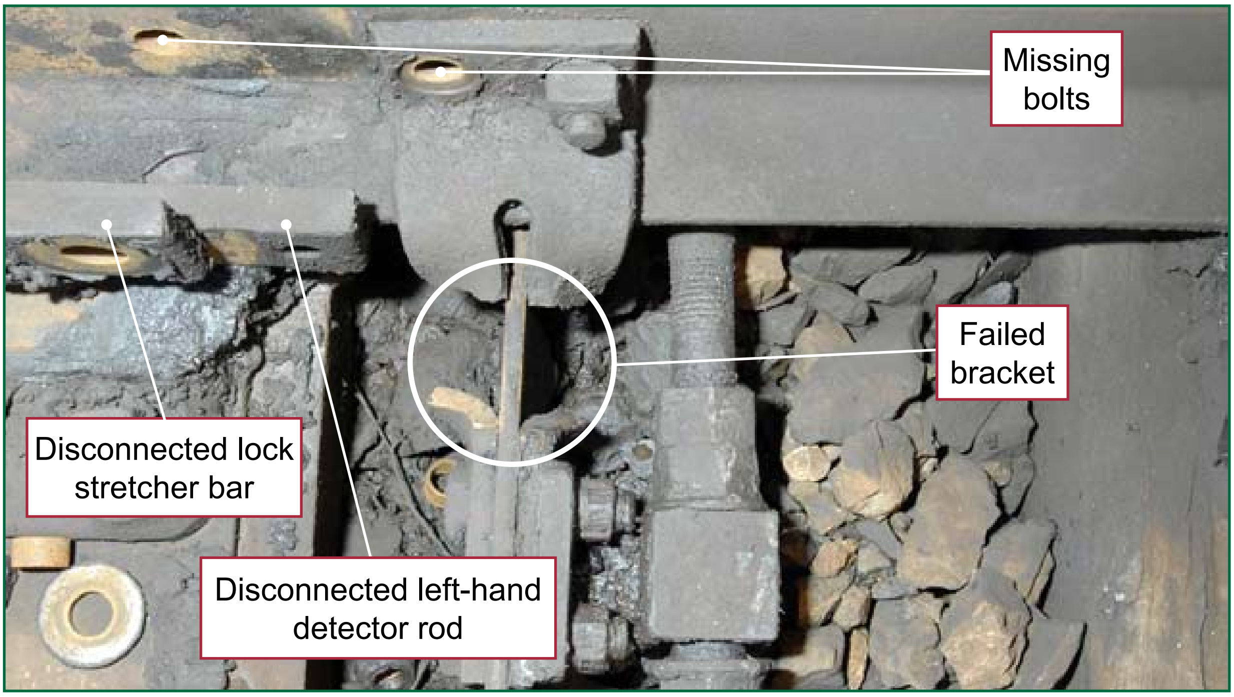

Figure 11: Failed bracket and missing bolt from first permanent way stretcher bar (24 February 2007)

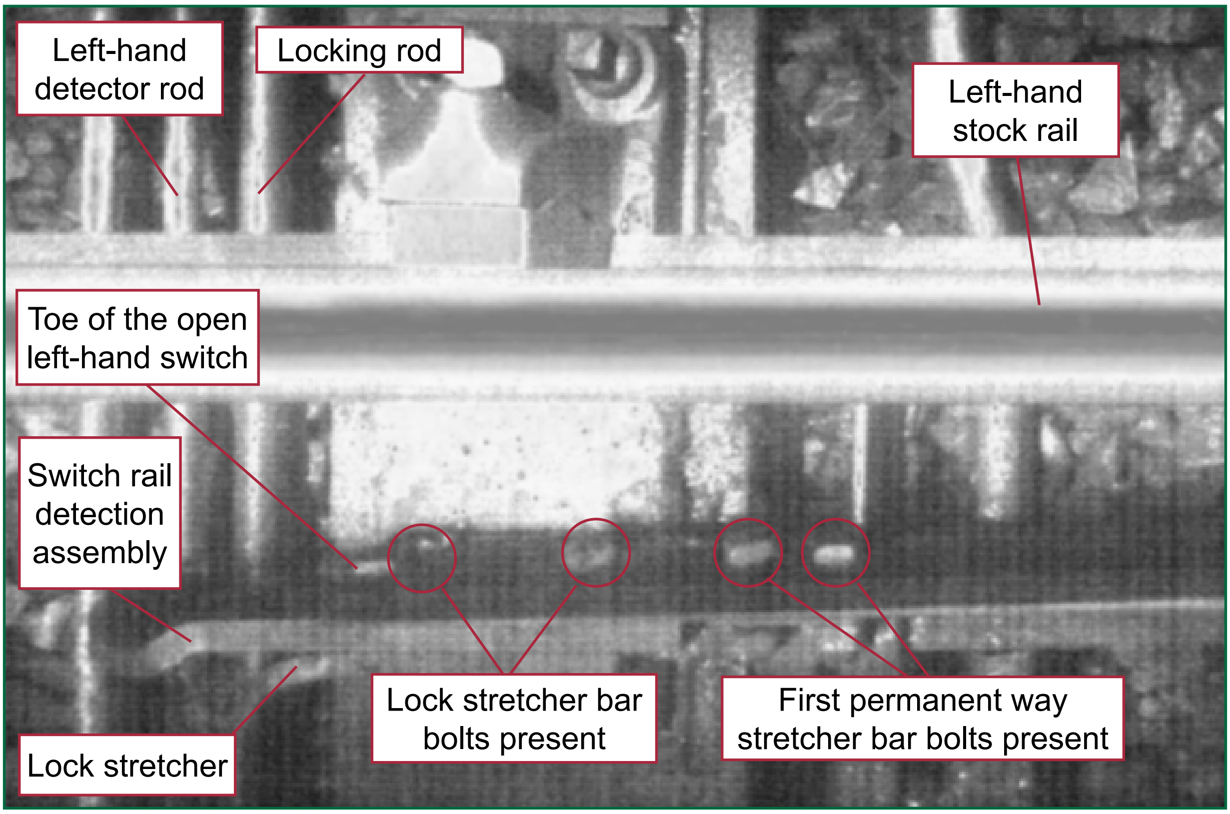

Figure 12: Picture of left-hand switch toe taken by Network Rail NMT (21 February 2007)

- The second permanent way stretcher bar was found to be missing from the points. All fastener components were present in the ballast in the vicinity of where the bar would have been, with the exception of the right-hand switch rail bolts which were still within the right-hand switch rail bolt holes. A short section (see paragraph 20) of a stretcher bar was found 50 metres towards Glasgow from the points. A long section was found on the embankment slope close to the train. The matching of length and fracture surfaces of these two sections indicates that it is most likely that they were the two sections of the second stretcher bar from 2B points (Figure 13). Metallurgical analysis shows that the two sections had failed by overload, and not by fatigue.

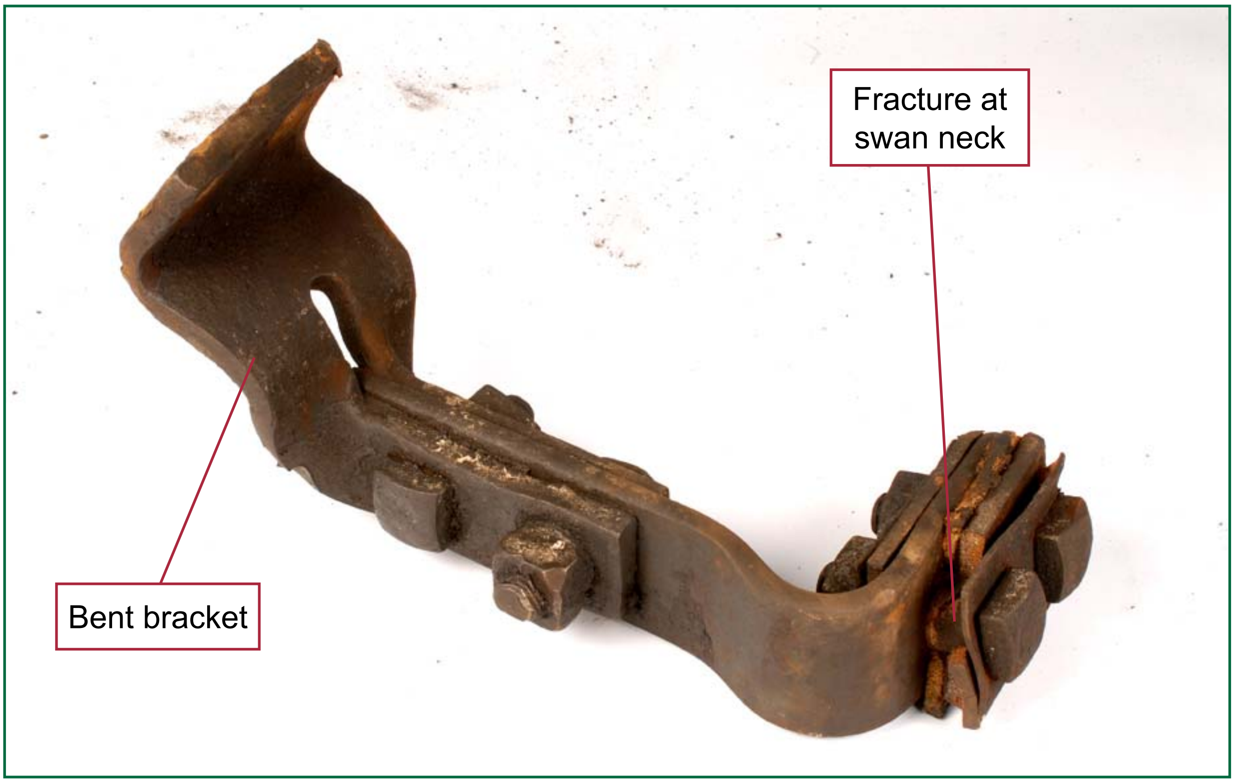

Figure 13: Short section of second permanent way stretcher bar

- The third permanent way stretcher bar was found in place but broken (Figure 14). There were two points of fracture, both at vertical planes through the respective bolt holes between the short, right-hand end and the long, left-hand end within the *swan neck insulation* assembly. The fractured end of the swan neck insulation assembly was found in the *four-foot* on the third *bearer* before the third stretcher bar close to the left-hand *slide chair* (Figure 15). In addition, the bracket at the right-hand end of the bar was not connected to the switch rail (Figure 14). The bolts that had been fitted on 7 January 2007 were found in the ballast below the switch and stock rails, with the nuts and washers also in the same vicinity. The condition of the nuts and bolts (damaged from progressively working free from the bolt holes) indicates they had wound undone, and had neither broken nor had the nuts been pulled off the threads (Figure 16).
- Examination of the supplementary drive indicated that it was undamaged.

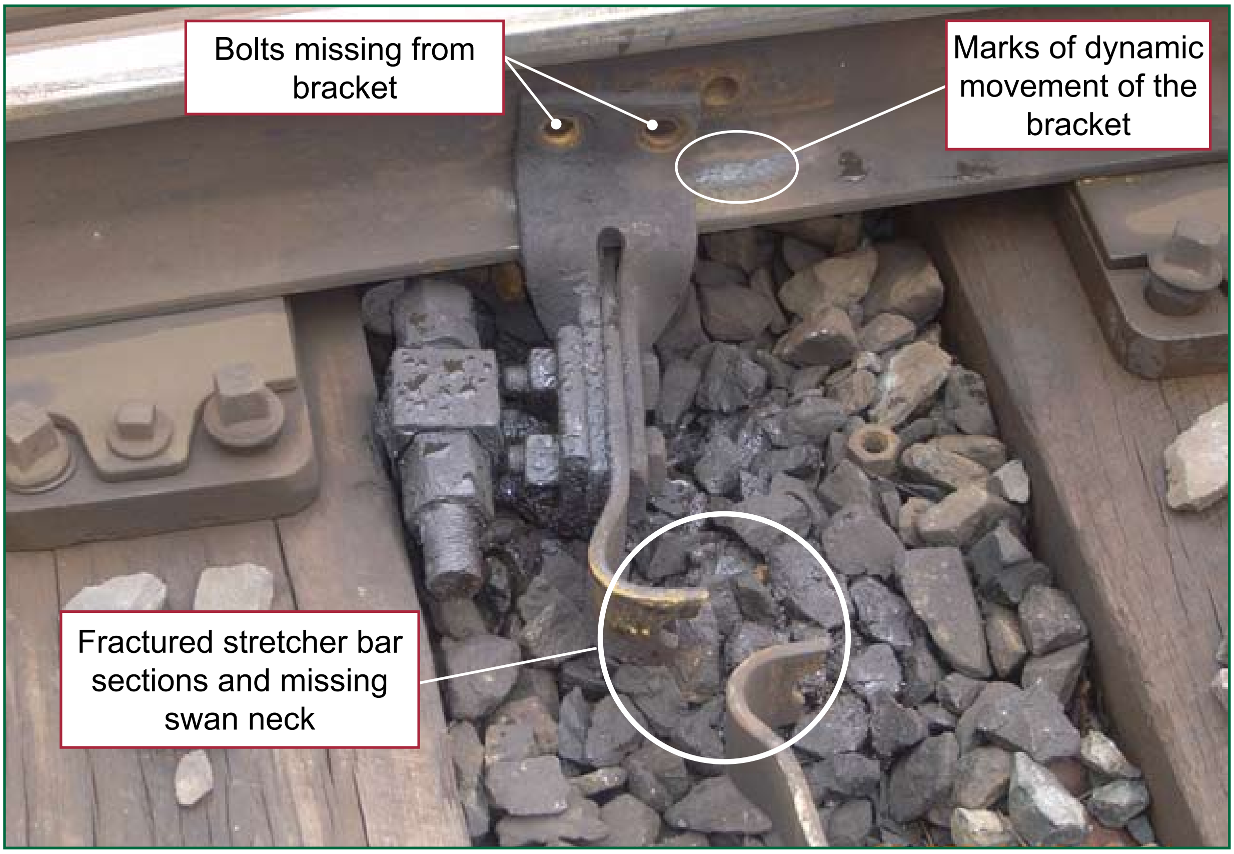

Figure 14: Failed third permanent way stretcher bar (25 February 2007)


Figure 15: Swan neck from third stretcher bar lying on bearer (24 February 2007)

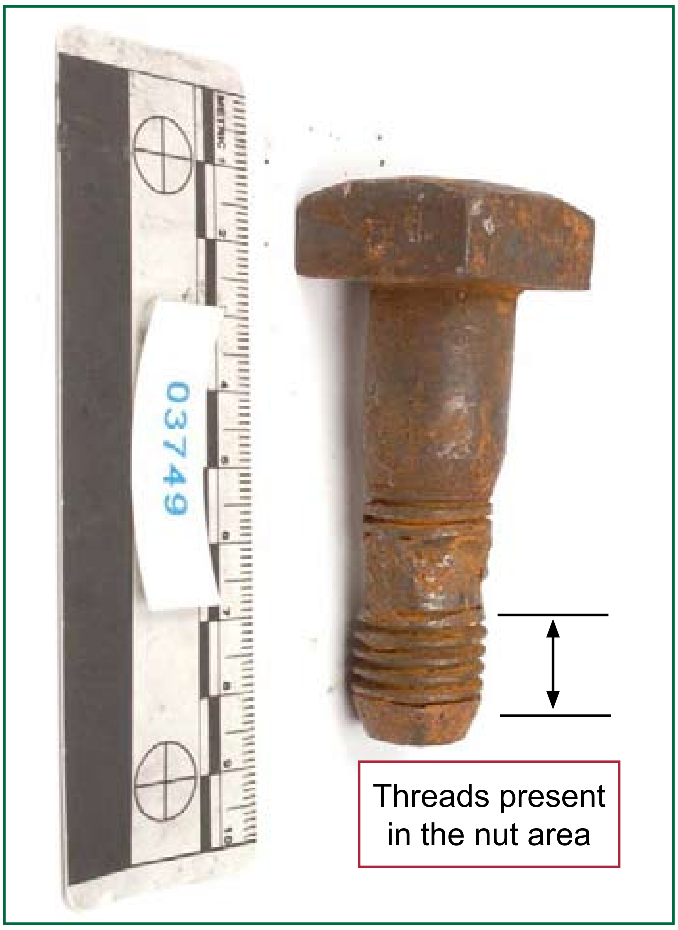

Figure 16: Damaged bolt from right-hand end bracket of third stretcher bar

82 There was therefore no complete stretcher bar in place between the switch rails immediately before the derailment. As a result, the left-hand switch rail was free to move towards the left-hand stock rail while remaining detected open, while the right-hand switch rail remained correctly closed, locked, and detected against the right-hand stock rail. The use of a single fastener system to attach the lock stretcher bar and the detector rod to the left-hand switch rail meant that the failure of this system resulted in the simultaneous loss of the security normally provided by the locking and detection of the left-hand switch rail.

83 Before carrying out tests on the points in the laboratory, the RAIB checked their set up against the 'in-track' measurements. The panel containing the switches was set up with the same cant as it had when installed on site, but the longitudinal thermal stresses in the panel that would have been present at Lambrigg and the ballast bed were not replicated. These constraints effectively precluded full dynamic testing but permitted static and *quasi-static testing* to be performed together with forensic analysis of the panel containing the switches and its components. The RAIB considers that these limitations did not critically affect its tests and an understanding of the process of the deterioration of 2B points was achieved. Forensic analysis included study of fracture surfaces, wear and impact marks, wear on bolts, and grease marks where bolts had come free. From the laboratory tests and the analyses of physical evidence, the following observations about the condition and probable behaviour of 2B points at various times can be made:

- Immediately after 7 January the critical dimension of the free space between the left-hand wheel-backs and the open left-hand switch rail in the region of the minimum free wheel clearance position was in the order of 8 mm, a positive figure and hence acceptable.

- However, at some stage the condition of the points started to degrade, a process that commenced with the nuts on the right-hand side of the third stretcher bar becoming undone. This process of degradation started at some time before the Structure Gauging Train ran on 12 February 2007.

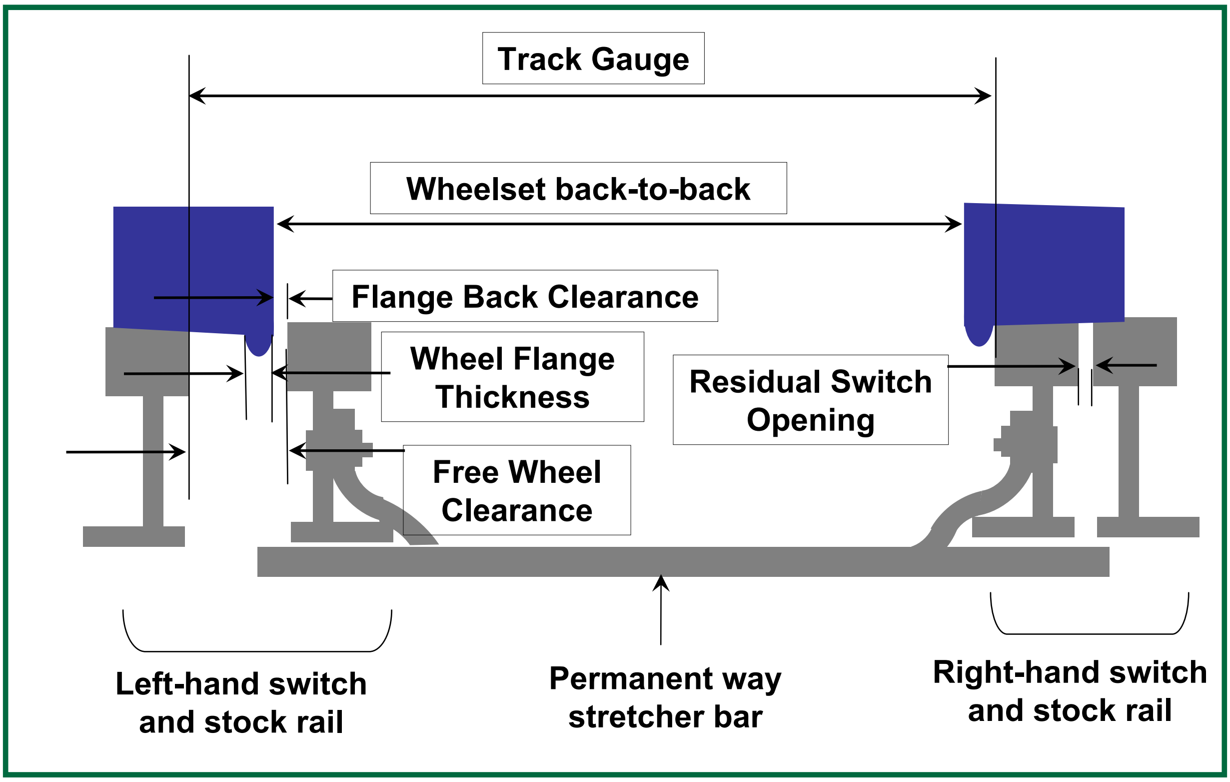

Figure 17: Diagram showing derivation of free wheel clearance

- The *flange back clearance* is influenced by the gauge of the track at that point, the position of the open switch rail relative to the closed switch rail, the residual switch opening distance between the closed switch and its stock rail and the *wheelset back-to-back spacing* (including tolerances) plus one *wheel flange thickness* at its design minimum (Figure 17).
- Although no fault was found in the supplementary drive mechanism, it had been set up to provide a residual gap of 6 mm - 8 mm (paragraph 66). This gap allowed the switch to flex by that amount under the passage of every wheel, as the friction creep forces between wheel and rail result in the wheel pushing the switch rail towards the outside of the curve.
- The failure of the right-hand side fasteners on the third permanent way stretcher bar allowed the left switch rail to relax towards its stock rail to such a degree that wheels passing through this gap were in flange back contact with the left switch rail with an interference of the order of 3 mm. As a result the left-hand switch rail was pushed over by 3 mm by every wheel that ran through the points. This repeated contact between the wheel-back and back of the switch rail generated a *cyclic loading* in the third stretcher bar which resulted in the completion of a *fatigue failure* of the short section of the third stretcher bar (Figure 18). The fracture surfaces show that a fatigue crack had been present to some extent for a long period of time and had been slow growing, but the rate of fatigue had accelerated rapidly in a very short period before final failure. Evidence from the SGT indicated that this fatigue failure of the stretcher bar had occurred by 12 February 2007.

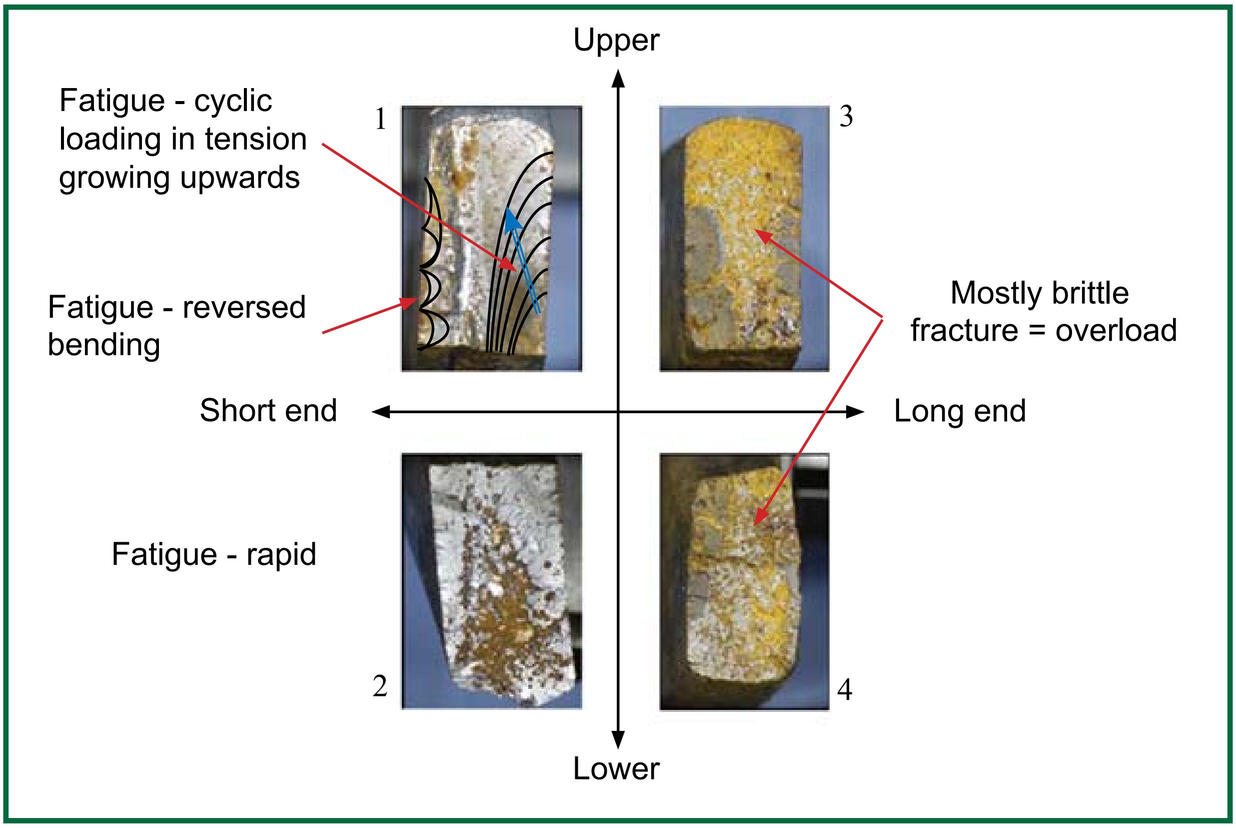

Figure 18: Fatigue failures on third stretcher bar swan neck attachment

- The consequent loss of integrity of the third stretcher bar allowed the left switch rail to relax further towards its stock rail, resulting in the free-wheel clearance now reducing from about 49 mm to 35 mm. This resulted in a more severe interference, with the left-hand switch rail pushed over by 21 mm by every wheel, which imposed higher cyclic loads on the remaining stretcher bars (two and one) and on the lock stretcher bar.
- It is believed that the brackets on both sides of the second stretcher bar became loose as a result of the loads and vibration induced by the repeated wheel strikes, and eventually this stretcher bar became detached from the rails. From the marks on the left and right-hand switch rails (Figure 19), it is likely that, once loose, it dropped and became caught between the switch rails until the subsequent passage of a train caused it to be squeezed up and carried along, fracturing into the two sections (see paragraph 69) which were deposited separately along the track. Evidence from the NMT indicated that this had occurred by 21 February 2007.

Figure 19: Marks on rails showing limits of movement of second stretcher bar

- The loss of restraint by the second stretcher bar allowed the left switch rail to close further resulting in yet greater cyclic loading on the single remaining permanent way stretcher bar (the first stretcher bar) and the lock stretcher bar. This caused the ligament closest to the crossing on the left-hand first stretcher bar bracket to fail due to fatigue, which in turn caused the other ligament (closest to the switch toe) to fail by overload (Figure 20). The fracture surfaces are consistent with this analysis. During the period of time bounded by the second stretcher bar failing and the accident, the left-hand rail fasteners on both the first stretcher bar and the lock stretcher bar became loose with both of the lock stretcher bar fasteners and the fastener closest to the toe from stretcher bar one falling out of the bolt holes in the switch rail. One of the bolts from the lock stretcher bar fell between the switch rail and the stock rail, and remained there until after the derailment (Figure 21). The lock stretcher bar fasteners are longer than the permanent way stretcher bar fasteners. Despite extensive analysis of the bolts, grease marks showing where they fell out, and the fracture surfaces on the failed ligaments, it is not possible to be certain in which order the failures of the ligaments on the first stretcher bar and the fasteners on the lock stretcher bar occurred. However, it is certain that these were the two final failures.

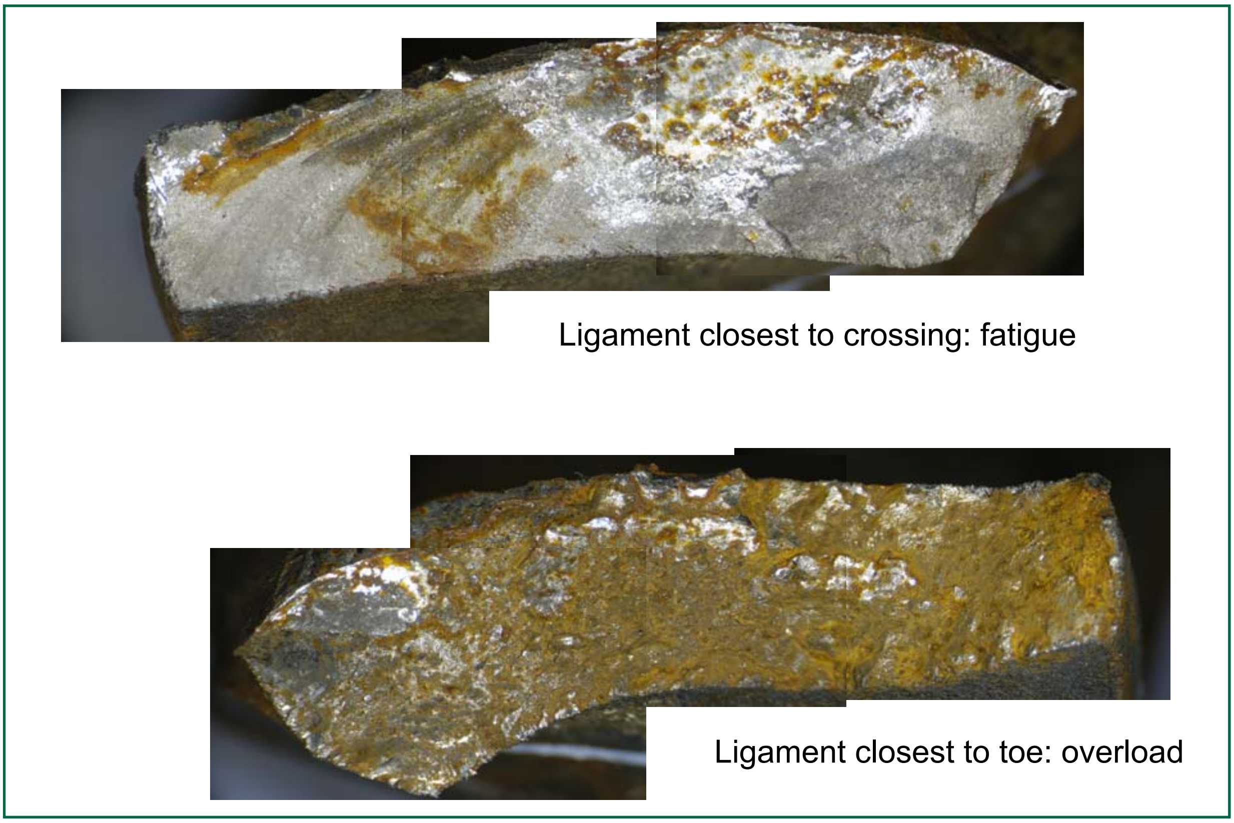

Figure 20: Fatigue and mechanical failure surfaces on ligaments of first stretcher bar bracket

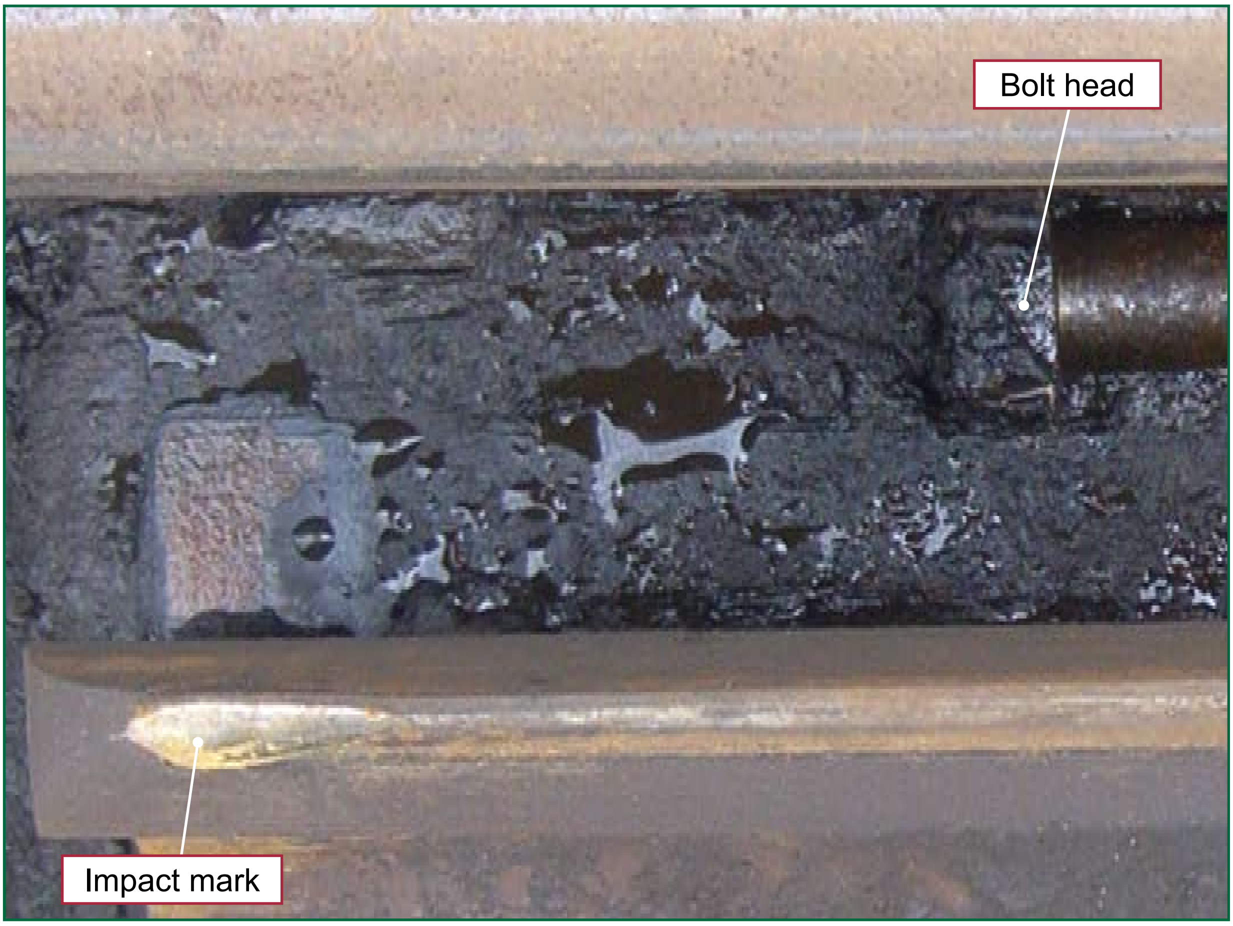

Figure 21: Bolt from lock stretcher bar lying between left-hand switch and stock rails - also shows damage from wheels striking switch toe (24 February 2007)

- The natural spring in the rail of the now unconstrained left-hand switch rail caused it to move so that it closed up to its adjacent stock rail as far as the bolt, trapped between the switch rail and its adjacent stock rail, would allow. This gave a toe opening of about 22 mm; sufficient for left-hand wheel flanges to pass to the right of the left-hand switch rail and be forced into derailment because of the narrowing gauge between the two switch rails.
- The movement of the left-hand switch rail away from the position where it was required to maintain a safe wheel passage did not cause the detection of the *normal* position to be lost; nor was it prevented by the lock within the locking mechanism. This was because neither the lock stretcher bar nor the detector rod had moved when the fasteners came out, only the switch rail. The signalling system therefore had no indication that the left-hand switch rail had moved to a dangerous position after the fastener system at the left-hand switch toe came undone. The *points machine* was examined and found to be undamaged with the lock and the detection contacts intact and detecting that the points were set to the normal direction. There are no indications that the right-hand switch rail had moved or that the points machine and the connections between it and the signalling system contributed to the accident.

Examination of the train

84 The RAIB examined unit 390 033 after the derailment, including its design and maintenance history. The train was maintained in accordance with the schedules laid down by its manufacturer, owner and operator, and no faults were found in design or maintenance that might have contributed to the derailment.

Derailment mechanism

85 The severity of the track damage and the scale of the derailment resulted in a complex pattern of wheel marks and track damage through both of the Lambrigg crossovers.

- There were strike marks where the left-hand wheels of some wheelsets had struck the tip of the left-hand switch blade which had become free due to the failure of the stretcher bars. These wheels were then forced to follow the left-hand switch into the turnout route while the right-hand wheels proceeded along the right-hand switch blade of the down line. As the wheelsets encountered the reducing track gauge (as the switch rails converged), they were squeezed out of the track and into derailment (paragraph 33). Marks on the points showed that at least four wheelsets derailed at 2B points. Work is ongoing to establish which wheelsets derailed in this area.
- Marks and distortion of the track after 2B points show that, after derailing, a number of wheels crossed over and ran close to or in the up line. It is believed that these included the wheels on the trailing bogie of vehicle one and the leading bogie of vehicle two (paragraph 38).
- The work of determining the most likely paths taken by the derailed vehicles is ongoing. This is informed by physical evidence from site, vehicle data recordings and modelling the vehicles' dynamic response.

The effect of the derailment on the train

86 Overall, the Pendolino train exhibited a good standard of crashworthiness and this helped to minimise the number of casualties and the extent of their injuries in the high-speed derailment. The enhanced safety features referred to in paragraph 31 contributed to this good standard.

87 The details of the damage to the train are summarised below:

- Vehicle one suffered damage to the leading and trailing ends, right-hand side, floor and underframe mounted equipment. There was evidence of impact with overhead line stanchions on the *cantrails* and roofs at two positions on the right-hand side and severe scoring of that bodyside. However, there was no significant loss of survival space or penetration of the body structure. The interior of vehicle one remained largely intact except for the detachment of the reading light panels from their mountings on the luggage racks. Only one window was completely broken through as a result of the accident (ie not broken for the purpose of egress). The leading bogie was damaged but remained attached to the body. The trailing bogie became detached immediately before the vehicle reached its final rest position. The coupler between vehicles one and two had parted during the jack-knifing of vehicle one (see paragraph 37).

- Vehicle two sustained damage to both vehicle ends, particularly at the left-hand corner of the trailing end which had been pushed in approximately 320 mm. The left-hand side was scored by sliding on ballast and bowed in by up to about 160 mm over the central third of the bodyside. Three windows on the left side were completely broken through. The interior of the vehicle suffered damage as a direct result of the bodyside bowing in, with five pairs of seats becoming detached from their floor mountings but remaining largely within the vehicle (Figure 22). The detached seats all remained in the general area from which they had come. The coupler attaching vehicle two to vehicle three parted at its central connection (see paragraph 38). Both bogies remained attached to the body.

- Vehicle three suffered damage to both vehicle ends, particularly the leading left-hand corner which had been pushed back approximately 350 mm and inward approximately 250 mm. One window on the right-hand side was completely broken through in the course of the accident. The interior remained largely intact throughout. The coupler attaching vehicle three to vehicle four had fractured (see paragraph 39). Both bogies remained attached to the body.

- Vehicles four to nine suffered relatively minor damage. Only one window, located on vehicle four right-hand side, had broken through completely in the course of the accident. The interiors of these vehicles generally remained intact. All the bogies on these vehicles suffered some damage from running derailed. The trailing bogie of vehicle five became detached in the derailment and its leading bogie was almost detached. Other bogies remained attached to their vehicles but in most cases the wire body-bogie retention straps had fractured leaving the bogies held on by anti-roll bar links and other suspension components.

Figure 22: Dislodged seating in vehicle two

88 In a derailment such as at Grayrigg, the behaviour of the rolling stock structures and the performance of the vehicle interiors have a major effect on the number of casualties. The vehicle structures assisted in minimising injuries, given the speed of the derailment and the presence of a high steep embankment down which the vehicles ran after derailing. In particular, the following aspects of the train's behaviour are noteworthy:

- There was minimal loss of survival space in those vehicles which had rolled over onto their side or struck overhead line stanchions.
- The bodyshells of the leading two vehicles, which had struck overhead line stanchions, resisted excessive damage which could have compromised the passenger compartments.
- Only two of the eighteen bogies on the train became detached and then only once the vehicles had almost come to rest. This enabled the kinetic energy of the train to be absorbed in a relatively controlled manner by a combination of the effect of the bogies braking, and ploughing through ballast on the track and soil on the embankment. Detached bogies can pose a significant risk if they come adrift and collide with vehicle bodies, but this did not happen at Grayrigg.
- Only three of the eight inter-vehicle couplers fractured despite the large relative movements between vehicles. This enabled the train, with the exception of vehicle one, to stay together and, for the most part, 'in line' until late in the derailment trajectory.
- Of the 135 passenger windows on the train, six were completely broken during the derailment. The remainder survived the effect of overturning, contact with trees and impact from spraying ballast without total failure. One passenger in vehicle one was partially ejected, and one in vehicle two was fully ejected from the train. In both cases the ejection probably took place only as the vehicle involved came to rest and injuries sustained were not fatal.
- With regard to the interior of the train, significant damage was limited to vehicles one and two and included six broken luggage rack lighting panels in vehicle one, detached seating units and some fractured table legs in both vehicles (the tables remained in place because the attachments to the side of the vehicle did not fail).

Actions already taken by industry relevant to the investigation

89 Immediately following the accident, Network Rail undertook examination of 1437 sets of points. These included all points installed on *running lines* between Crewe and Motherwell, and all flat-bottom, full-depth, *vertical switches* driven by point machines and fitted with fixed stretcher bars where the line speed is 80 mph (128 km/h) or greater in the remainder of the network. The examinations focused on stretcher bars, stretcher bar fasteners, free wheel clearance and gauge. The instruction for this examination stated that any identified defects were to be repaired within 36 hours of the fault being found.

90 No switches were found to be in a similar state of degradation to those at Lambrigg. In some cases there were early indications of some of the precursor situations. These are summarised below:

- 36 per cent of the switches examined had one or more loose bolts.
- 16 per cent required renewal of the stretcher bar (excluding bolts) because of cracks in the bars and the bracket ligaments, or distortion from mechanical impact.
- 12 per cent had signs of *flange back* contact.
- 13 per cent of the switches displayed more than one of these conditions and 49 per cent of switches showed none of them.

91 All the defects were rectified within two weeks of the instruction being issued on 1 March 2007 for the examination of the points.

92 After the accident, Network Rail removed all four sets of points at the Lambrigg crossovers as they decided that they could satisfactorily operate the railway without them.

Urgent safety advice issued by the RAIB

93 As a result of its concerns about the emerging findings from the investigation, the RAIB issued, on 6 June 2007, an urgent safety advice to Network Rail, and also to Nexus (Tyne and Wear Metro), Northern Ireland Railways and London Underground Limited, who all use similar design switches with spring-steel stretcher bars, indicating:

- there was a risk of progression to failure of this design of S&C resulting from a residual opening between the switch and stock rail on the through (normal) route in the vicinity of the third stretcher bar;
- following a fatigue failure of the third stretcher bar, a switch's remaining stretcher bars could degrade rapidly (subsequently shown to be a period between 12 and 36 days at Lambrigg 2B points); and
- a need for the infrastructure operators 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
  - confirm that their arrangements for inspection are capable of identifying fatigue failures in permanent way stretcher bars and their associated brackets (this relates to the difficulty in observing some possible fatigue cracks in spring-steel flat stretcher bars).

94 As part of their response to the urgent safety advice, Network Rail undertook a further examination of all points with a contraflexure similar to 2B points and where the line speed is 80 mph (128 km/h) or greater; a total of 120 sets of points. The instructions for this examination stated that any identified defects were to be repaired within 36 hours of a defect being found or a speed restriction applied. In six cases it was necessary to impose a 20 mph (32 km/h) speed restriction until faults to the track gauge, free wheel clearance and stretcher bars were rectified.

95 In total, 58 per cent of the points examined had flange back contact, and 30 per cent had one or more loose fasteners; 61 per cent of the points had residual openings greater than the nominal 1.5 mm specified. Analysis of the limited sample of data from these inspections indicates that there is an increase in the percentage of these points with loose fasteners present when the residual gap increases. These defects have been rectified.

96 In addition to these examinations, Network Rail is replacing all the stretcher bars on the 120 sets of points that were the subject of the examination described in paragraph 94. Network Rail is now specifying a higher grade of steel for stretcher bar fasteners and is installing *Vibrolock washers* (instead of spring washers) and *Philidas Turret nuts*. In addition, loose nut tell-tales are to be fitted to assist inspection. Both Vibrolock washers and Philidas nuts are approved for use on more modern designs of S&C on Network Rail's system and both are approved for use in similar loading conditions. This is a staged programme due for completion in October 2007.

97 The samples of switches chosen for testing was selected by Network Rail as being, in their view, those most similar in site layout and loading to Lambrigg 2B switches. Network Rail is now exploring the extension of these modifications to other switches on their system with spring-steel stretcher bars. When the results of a further set of site examinations are received and analysed and the results from stretcher bar load/stress testing are available, Network Rail will consider whether there is a need to modify or upgrade any component designs on other switches.

98 HMRI, as part of its duties as Safety Authority, is monitoring the outcome from Network Rail's response to the urgent safety advice to ensure that the action taken by Network Rail is appropriate.

Comparison with other similar accidents and incidents

99 The spring-steel stretcher bars with forged brackets that were used in 2B points at Lambrigg are of a long-standing design. It has not been possible to establish when the design was first used, but it is thought that it was just before the Second World War. The design was in use by British Railways from at least 1950 onwards as their standard design. During this period of time, based on industry experience, the overall performance of these bars has not been considered high risk by the industry, and only one accident has been reported involving this design of stretcher bar, at Kingham in 1966. There has also been one accident involving a more modern design at Potters Bar in 2002. However, industry literature[5] refers to the risk of stretcher bar fasteners coming loose, and of fatigue in the bars, and also incidents of bolts coming undone have been regularly reported – one example at Wood Green, in North London, is quoted from 2006.

100 **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 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 preparatory to 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 bears no similarity to events at Grayrigg.

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

101 **Potters Bar derailment on 10 May 2002** - A train derailed at facing points at Potters Bar and seven people lost their lives. The 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 involved at Lambrigg. The *Health & Safety Executive*, which was the safety authority at that time, and the *Rail Safety & Standards Board* both carried out investigations into the accident and both made recommendations. The RAIB's full report will include consideration of any relevance of the Potters Bar recommendations to the derailment at Lambrigg.

102 The switches at Potters Bar were subject to fundamentally the same patrolling and supervisory regime as those at Lambrigg, but carried out by a contractor, while those at Lambrigg were carried out by Network Rail's own staff. This change followed Network Rail taking maintenance and inspection of their track 'in house' in 2004. However, the assurance regime for maintenance and inspection has been changed since that date, with the previous process of 'end product checks' carried out by members of Network Rail's zonal engineering teams being replaced by one where maintenance and inspection assurance is carried out by the line of management.

103 **Wood Green incident on 5 July 2006** - Following a report of a rough ride, Network Rail staff found that all the stretcher bars on 2137B points, part of a trailing crossover in the down fast line at Wood Green, were disconnected and the switch rail was able to move freely. As the crossover was a trailing one, the risk of derailment was low compared with that at Lambrigg or Potters Bar. Network Rail investigated the incident at local level, although they did not establish the technical cause of the failure. As a result they introduced ten actions. These include:

- ensure defects were observed, recorded, remedied and investigated; and
- improve quality of stretcher bars by upgrading to more modern materials.

These actions were only implemented locally. Network Rail did not notify the RAIB of this incident as it did not directly meet the criteria of the Railways (Accident Investigation and Reporting) Regulations, 2005.

Confirmed findings to date

104 At this stage of the investigation, it has been established that the following have no relevance to the cause of the derailment of train 1S83 at Lambrigg EGF:

- the way in which train 1S83 was driven;
- the actions of the signaller at Carlisle PSB;
- the design and condition of Pendolino 390 033;
- the functioning of the signalling system, including the points control and detection mechanism;
- the condition of the track on the approach to 2B points at Lambrigg EGF; and
- the condition of the earthworks on and around the railway.

105 The immediate cause of the accident on 23 February 2007 was the derailment of train 1S83 following its interaction with 2B points in a degraded and unsafe state, which forced it into the reducing gauge between both switch rails.

106 Points 2B came to be in an unsafe condition through the failure by fracture of the first and third permanent way stretcher bars and the failure of the fasteners at the right-hand end of the third stretcher bar, all fasteners on the second stretcher bar and the fasteners connecting the lock stretcher bar and the left-hand detector rod to the left-hand switch rail. This combination of failures enabled the left-hand switch rail to move by its natural flexure to an unsafe position close to the stock rail without losing signalling detection or having to overcome the facing point lock.

107 The right-hand side bolts of the third permanent way stretcher bar had become undone, and the bar itself had failed in fatigue, by the time the SGT ran on 12 February 2007.

108 Points 2B at Lambrigg were not inspected for at least 12 days before the derailment.

109 The undone nuts on 2B points on 7 January 2007, which led to the replacement of the nuts and bolts that day, are believed to be an indication that the condition of the points had started to deteriorate some weeks before the derailment occurred.

110 The residual gap between the right-hand switch and stock rails at the location of the third stretcher bar had been in excess of the laid down dimension since at least 2004.

111 The immediate cause of the fatal injury to a passenger in vehicle one was very likely to have been impacts within the train interior as vehicle one moved along its path from derailment to its final stationary position. The investigation of how other passengers and relevant members of the train crew received their injuries is ongoing.

Continuing workstreams

112 The RAIB has not yet finalised its views on what the causal and contributory factors of the derailment are and is continuing its investigation into the derailment, in particular in the following areas:

- concluding the study into the causation of the injuries to the passengers and crew (paragraph 111);
- concluding the study into the behaviour of the train and its structure after it derailed, including its crashworthiness performance (paragraphs 85-88);
- concluding the investigation into the failure mechanism of 2B points, including tests in traffic to establish the effect of loading on the design of the points, in co-operation with Network Rail (paragraphs 81-83);
- concluding the investigation into the maintenance and inspection practices and systems at points, both at national and local level, to determine their relevance to the derailment (paragraphs 59-62);
- considering whether the changed track access regime as a result of the upgrade of the WCML affected the track maintenance and inspection practices (paragraph 63);
- consideration of how the overall balance of design, environment, usage, inspection and maintenance of the BS 113A FB vertical S&C system has been addressed by the industry;
- how all of the factors in the previous bullet point are managed through Network Rail's processes and standards;
- consideration of the relevance and possible effects of the implementation of the recommendations made after the accident at Potters Bar on the points at Lambrigg (paragraph 101); and
- development of recommendations to mitigate the risks identified in the investigation.

Next RAIB report

113 The timing of the next report by the RAIB is dependent on completion of the work listed above. Based on information currently available, the RAIB expects to publish this in the second half of 2008.

114 The RAIB's final report will contain conclusions regarding the causes of the derailment and the casualties and make related recommendations to improve safety.

Rail Accident Investigation Branch

Glossary of terms

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

Automatic speed control	A system which can be engaged by the driver once a certain speed is reached and which will maintain that speed automatically by varying the traction power applied. Analogous to 'cruise control' in a car.
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 in a switch and crossing layout.
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.*
British Transport Police	British Transport Police (BTP) enforces law and order on the railway, including London Underground, Docklands Light Railway and Croydon Tramlink. The BTP works closely with Home Office police forces and is responsible for pursuing any possible criminal prosecutions following a rail accident, other than those relating to the Health and Safety at Work Act.
BS 113A FB	A flat bottom (FB) pattern rail section weighing 113 pounds per yard but having a thicker rail web than its predecessor BS 110 A rail. It has been re-titled CEN54E1.*
Cant	The design amount by which one rail of a track is raised above the other rail, measured over the rail centres.*
Cantrail	The point on a rail vehicle at which the side of the vehicle body meets the roof profile.*
Chain	A unit of length, being 66 feet or 22 yards (approximately 20117 mm). There are 80 chains in one standard mile.*
Continuously	Rail of length greater than 36.576 m (120 feet), (or 54.864 m (180 feet) Welded Rail in certain tunnels), produced by welding together standard rails or track constructed from such rails.*
Contraflexure	A curve of opposite hand to another related curve.*
Coupler	A device used to connect rail vehicles together for haulage purposes.
Crashworthiness	The capacity of a vehicle to protect its occupants during an impact.
Crossovers	Two turnouts (TO) or single leads connected to permit movements between parallel tracks.*

Customer Service Assistant	Member of train crew who assists the customer service manager with on-board catering and retailing activities.
Customer Service 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.*
Cybernétix 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, and a camera on each side looking at a wider view to include the rail fastenings. IVOIRE III is a trademark of Cybernétix SA, France.
Cyclic Loading	A pattern of repeated loading applied to a point in which loads vary between a minimum and maximum value and back again over a given period.
Danger	Universal term for a red signal aspect.*
Detection	A failsafe arrangement that proves 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	In a direction away from London, the capital, or towards the highest mileage.*
Electrical Control Room 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.
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	A brake application that uses a more direct and separate part of the control system, that as a result may be quicker, to signal the requirement for a brake application, than that used for the full service application. On certain vehicles, the retardation rate may be specified to be higher than that of the full service application and is described as ‘enhanced emergency braking’.
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 (GF) controlling one or more crossovers used only in times of emergency or possession.*
Enhanced Permissible Speed	The increased maximum speed above permissible speed at which a particular tilting train may run. This is because tilting trains can tilt to reduce or negate the effects of increased cant deficiency at this higher speed. Each type of tilting train has its own enhanced permissible speed on any given section of track.*
Engineering Train	A train used in connection with engineering works, including On Track Machines.
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 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.*
Fail-safe	A design principle that requires a system to preserve the safety of the line when in its failed state.*
Fasteners	Collective name for the bolts, washers and lock nuts used to secure the stretcher bar components.
Fastening	Any device used to secure running rails into chairs or baseplates or directly to sleepers, bearers or other rail supports.
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.
Flange Back	The “inner” or “back face” of the wheel flange.
Flange Back Clearance	The dimension between the back of a wheel and the back of an open switch rail. This must be positive to allow the wheel on the open switch rail side to pass without contact.
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) – 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.*

Ground Frame	A small group of signal and points levers or a switch panel located close to some isolated and infrequently used facility such as a crossover. These levers or switches are locked by the controlling signal box, and only released when required.
Half set	One switch rail and one stock rail together make a switch half set.
Hazard Directory	A database maintained by Network Rail which contains details of the health, safety and environmental hazards known to exist on Network Rail controlled infrastructure.
Health & Safety Executive	The Health & Safety Executive (HSE) is an enforcing authority which works in support of the Health & Safety Commission, which is responsible for health and safety regulation in Great Britain.
Her Majesty's Railway Inspectorate	Her Majesty's Railway Inspectorate (HMRI) is part of the Office of Rail Regulation (ORR) which is the independent health and safety regulator for the railway industry in Great Britain. HMRI undertakes safety approvals of new works and operators as well as the inspection and audit of rail industry safety management systems. Following a rail accident HMRI is responsible for possible prosecutions under the Health and Safety at Work Act.
Infrastructure Maintenance Manager	The Network Rail (NR) organisation responsible for maintenance of the infrastructure.*
Interlocking	Controls fitted between points and signals that prevent the signaller from setting conflicting routes.*
Left-hand Curve	A curve diverging to the left from the straight when viewed in the direction of travel.
Ligaments	The curved part of the stretcher bar bracket where it bends to connect to the stretcher bar assembly.
Lock Stretcher Bar	A bar located at the toes of the switch which hold them locked in the position to which they have been commanded.
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.
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.*
OmniSurveyor3D	A system which includes 7 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, York.

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.*
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	One or more additional stretcher bars to the Lock Stretcher Bar to assist with maintaining the distance between the switch rails, especially on long switches.
Philidas Turret nut	An all metal locking hexagonal nut designed to provide a prevailing torque between the nut and the bolt threads. The Philidas Turret nut is produced by Philidas Ltd, United Kingdom.
Plain Line	Track without switches and crossings.*
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.
Points Machine	A generic term for any powered device that operates a set of points. Also known as a Points Motor .*
Possession	A period of time during which one or more tracks are blocked to trains to permit work to be safely carried out on or near the line.*
Power Signal Box	A large signal box which controls the points and signals over a large area by electrical means.*
Quasi-static testing	Method of analysis of mechanical systems (interdependent collections of components acting together to provide a defined set of functions) that are subjected to dynamic loads. In this method, static loads are introduced to represent the parts of the full, time-variant, dynamic loads that are constant (or static) and the system studied for its response. It provides useful insight into how the system is likely to behave under full dynamic (time-variant) loading.
Rail Safety and Standards Board	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.*
Red Zone	A site of work on or near the line, which is not protected from train movements. Red zone working can only be used if there is no realistic alternative and is banned in some situations.
Residual Switch Opening	The remaining distance between the stock and switch rails on the closed side of a set of switches.

Reverse	For a set of points this is the other position permitting the passage of trains on the least used route.
Route Acceptance	Approval of an application by an operator, owner, etc. to run a new or modified Rail Vehicle on Network Rail's (NR) Infrastructure.*
Running line	A track other than a siding over which running movements are made.*
Serious Injuries	Physical injuries that are listed in Regulation 2(4) of the Railways (Accident Investigation and Reporting) Regulations 2005
Signaller	A person engaged in operating a signal box.*
Six-Foot	The colloquial 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.
Speed Restriction	Any imposed reduction of permissible speed or enhanced permissible speed.*
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.
Stanchion	The upright part(s) of any overhead line structure.*
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.*
Structure Gauging Train (SGT)	A vehicle based gauging system using white light. The train also includes front facing video and runs at night relying on floodlights for illumination.
Supervisor's Plain Line Inspection (also known as Supervisor Track Inspection)	A regular track inspection carried out by a supervisor in order to determine the actions necessary to respond to reports of basic visual track inspections carried out by the patrollers, review trends in visual conditions and check that basic inspections, maintenance and renewal work are effective.
Supplementary Detection	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.*

Swan Neck	The arrangement within the stretcher where the long and short sections join.
Swan Neck Insulation	A piece of non-conducting material fitted within the stretcher bar assembly to provide electrical isolation between the two switch rails.
Switch (may also be referred to as a Set 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.*
Switches and Crossings	Track consisting of switches and crossings forming connections between lines.*
Tamping	The operation of lifting the track and simultaneously compacting the ballast beneath the sleepers.*
Toe	The movable end of a switch rail.*
Track Circuit	An electrical train detection system, based on the principle of proving the absence of a train. In its basic form, a source of electrical current is connected between the running rails at one end of the section to be detected. At the other end a relay coil (or equivalent) is connected between the rails.*
Track Curve Radius	A measure of the curvature of a track expressed in terms of its radius in metres.
Trailing points	Points aligned in a direction towards the direction to which trains normally depart.*
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.
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.
Triage	The reception and classification of casualties in order to determine the priority of need and treatment requirements.
Turnout Speed	The maximum speed permitted through the turnout route of facing points when they are set for the diverging route.*
Twist	A rapid change in cant or crosslevel.
UIC54 shallow depth switches	A switch assembly in which the switch rail is produced from a UIC 54 rail section of shallower depth than that used for the stock rail allowing the switch rail to pass over the un-machined foot of the stock rail when the switch is in the closed position.*

Up	Moving in a direction towards London, the capital, or the lowest mileage.*
Urgent Safety Advice	Guidance issued by the RAIB to the industry and the safety authority which deals with matters of immediate concern. The aim is to prevent another accident being caused by the particular deficiencies that have been found in the early stages of the investigation. There will be reason to suppose that these deficiencies are not a one-off and could happen elsewhere.
Vertical Switch	A switch in which the vertical axes of the stock rails are at right angles to the plane of the longitudinal axis of the bearers or timbers.*
Vibrolock Washer	A specialist type of washer which utilises a wedge-locking method that resists loosening caused by vibration and dynamic loads.
West Coast Main Line	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.*
Wheel Flange	The extended portion of a rail vehicle's wheel that contacts the rail head and thus provides the wheelset with directional guidance.*
Wheel Flange Thickness	The thickness of the wheel flange measured at a point known as the wheelflange datum (located for UK wheel profiles 13 mm vertically up from the tread datum position on the wheel tread).
Wheelset back-to-back spacing	The spacing apart of the two wheels of a wheelset measured between the wheel back faces.

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