RAIB

Rail Accident Investigation Branch

Rail Accident Report

Derailment at Princes Street Gardens, Edinburgh 27 July 2011

Department for Transport

Report 18/2012
August 2012

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.

Derailment at Princes Street Gardens, Edinburgh, 27 July 2011

Contents

Summary

At about 17:52 hrs on 27 July 2011, an empty passenger train derailed while traversing points in the Princes Street Gardens area, on its approach to Edinburgh Waverley station. The leading bogie of the third coach of the three-coach train derailed and travelled derailed for approximately 110 metres. The derailment occurred at slow speed and the train remained upright. The driver and conductor, the only occupants of the train, were uninjured. The derailment affected two lines which were closed until 29 July 2011.

The investigation found that the first wheel to derail was not correctly steered by the moveable switch rail to the correct route. Instead the wheel climbed over the rail, pulling the other wheels of the bogie into derailment.

The most likely cause of the derailment was that the angle of the switch rail, possibly aided by an increase in friction, enabled the wheel to climb the switch rail.

Three days prior to the accident the left-hand switch rail had been identified as having the potential to cause derailment. Although it was worn beyond repair by grinding in accordance with the company standard, a grinding repair was attempted. The subsequent inspection process did not find the switch to be unsafe and it remained in service.

The required prior scoping of the repair, which might have identified the unsuitability of the switch rail for repair by grinding, was not carried out.

The local practice of maintaining points to safety limits and the lack of guidance on when a switch rail is unrepairable by grinding were underlying factors in this accident.

The RAIB has made five recommendations to Network Rail relating to:

- the provision of maintenance intervention limits on switches;
- the need for a review of the relevant standard to provide assurance that it addresses all potential derailment mechanisms on switches and to clarify its requirements;
- the development of a more accurate method for gauging the angle of switch rails;
- the increased use of automatic lubrication on switches vulnerable to wear; and
- the need to review and address the recurrence of factors in this accident which were previously identified by the RAIB in investigations of similar derailment.

Introduction

Preface

1 The purpose of a Rail Accident Investigation Branch (RAIB) investigation is to improve railway safety by preventing future railway accidents.

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

Key definitions

3 All dimensions in this report are given in metric units, except speed and locations which are given in imperial units, in accordance with normal railway practice. Where appropriate the equivalent metric value is also given.

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

The accident

Summary of the accident

5 At around 17:52 hrs on 27 July 2011, train 5P37, which formed the 17:10 hrs *empty coaching stock* service from Cowdenbeath to Edinburgh Waverley, was derailed while running at 19 mph (30 km/h) on its approach to Waverley station (figures 1 and 2). The three-coach train was traversing *points* 167B in the *facing direction* and was directed to the right-hand route when the leading axle of the third coach took the left-hand route, causing both axles of the leading *bogie* to derail (figure 3). The train continued for approximately 110 metres before coming to a stand.

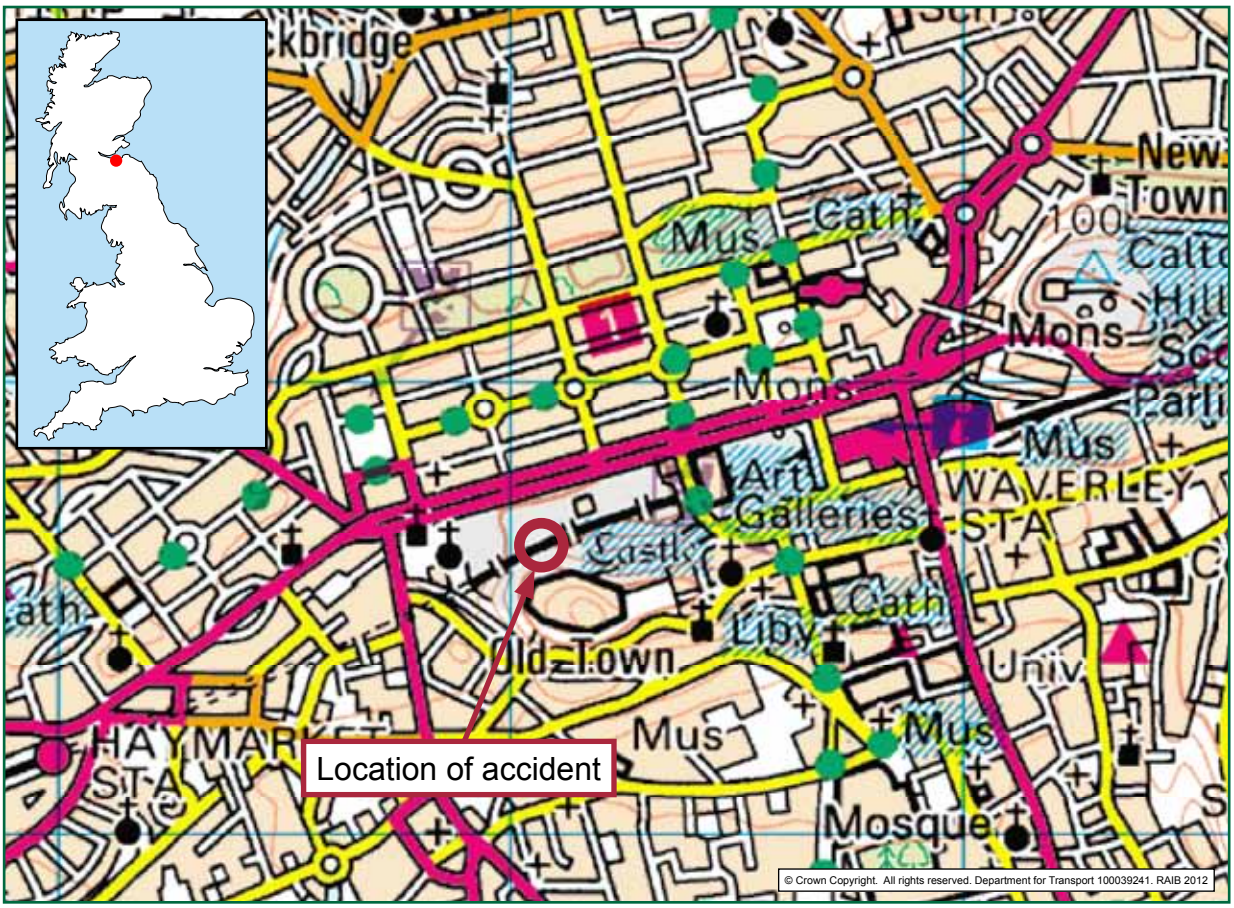


Figure 1: Extract from Ordnance Survey map showing location of accident

6 The driver and conductor, who were the only occupants of the train, were uninjured. The derailment caused damage to points 167B and to two further sets of points beyond, which were in the path of the derailed wheels. The track was pulled out of alignment where the derailed *bogie* was drawn across it and there was damage to track fixings and *bearers*, signalling cables and to a drainage pit. The train also suffered significant damage to the bogie and underframe equipment, and to the connecting corridor between the second and third cars. A significant spillage of oil from the final drive gearbox, which is situated on the trailing axle, occurred at the *crossing nose* (figure 3).

7 Services into and out of Edinburgh Waverley were disrupted while the derailed train was recovered and repairs were undertaken to the affected track. The lines were reopened for normal service on the morning on 29 July 2011.

Context

Location

8 Points 167B are located at 0 miles 792 yards[1], between Haymarket and Mound tunnels, in the area known as Princes Street Gardens. The railway runs in a cutting with the municipal gardens to the north and Edinburgh castle to the south (figure 2).

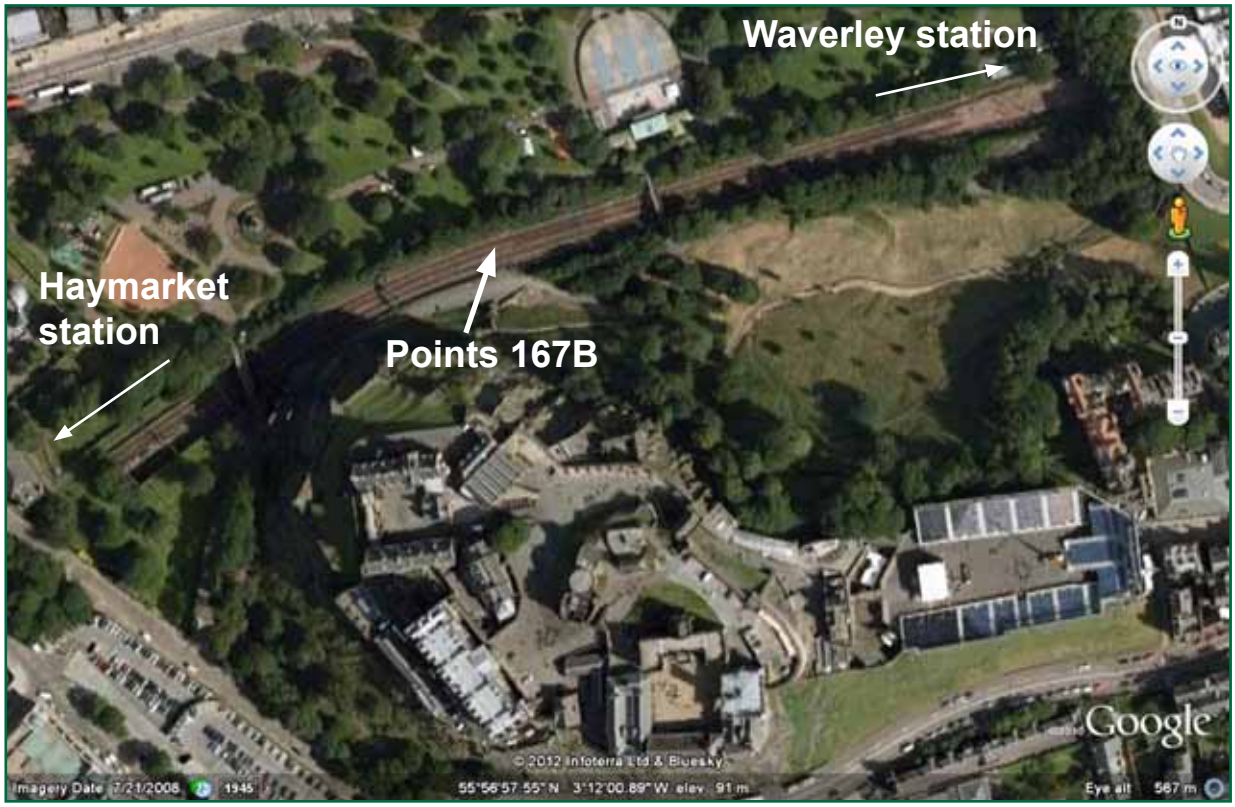


Figure 2: Map showing location of derailment (courtesy of Google Earth)

9 There are four tracks in this area, two north lines and two south lines, separated by a *wideway* (figure 3). The *Sectional Appendix* gives the lines the notations 'Z' (*up* north), 'Y' (*down* north), 'X' (up south) and 'W' (down south).

10 All lines are electrified by means of overhead line equipment; this played no part in the accident.

Organisations involved

11 Network Rail owns and maintains the infrastructure. Maintenance of the infrastructure, including switches, was carried out by the Edinburgh Central East section based at Slateford, which was part of the Edinburgh Delivery Unit.

12 First ScotRail operated and maintained train 5P37 and employed its driver and conductor.

[1] Datum point at Edinburgh Waverley station.

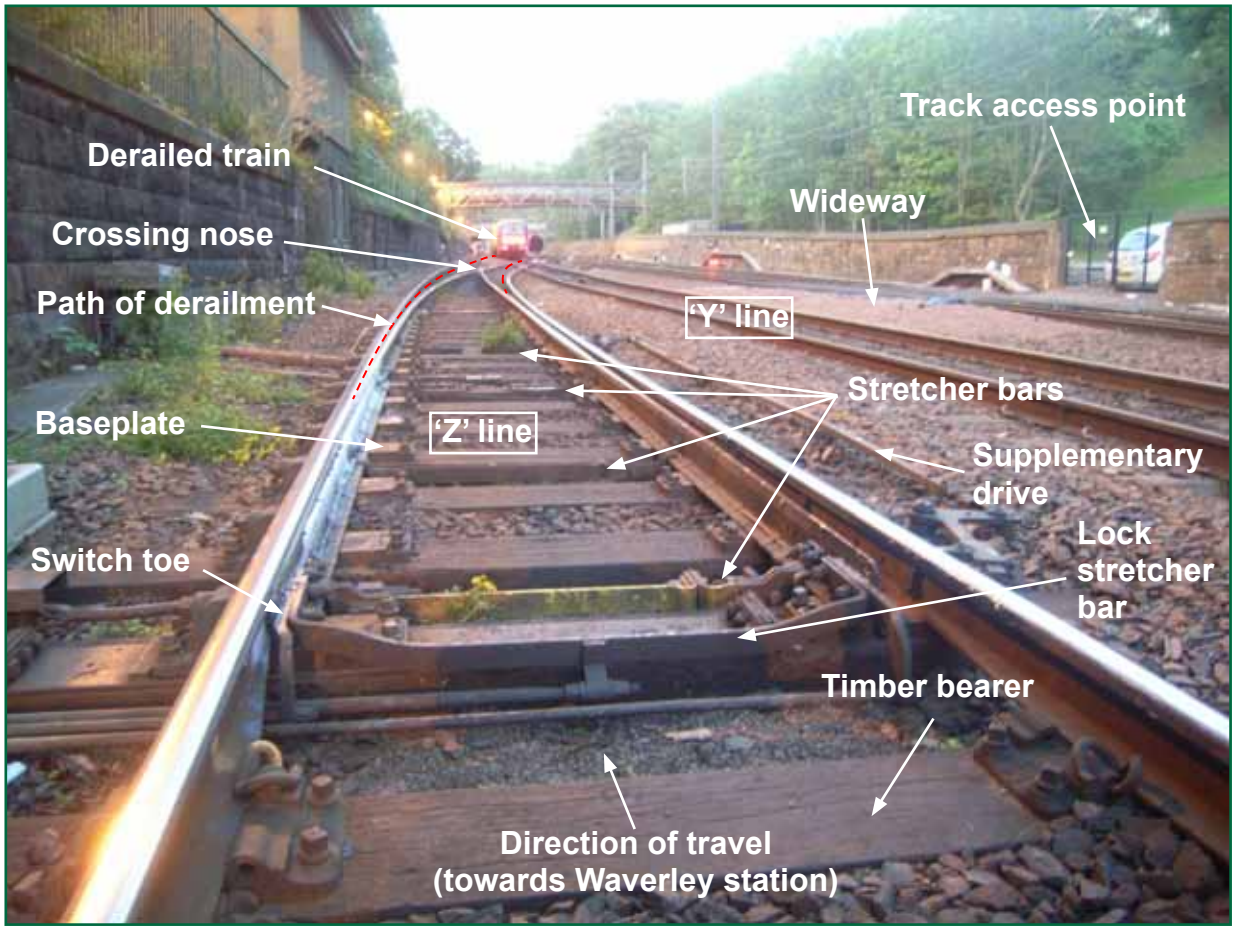


Figure 3: Points 167B

13 Porterbrook Leasing Company owned the train. It had no involvement in the investigation.

14 Both Network Rail and First ScotRail freely co-operated with the investigation.

Train involved

15 The train involved was a three-coach Class 170 'Turbostar' *diesel multiple unit* (DMU) number 170393, built by Bombardier Transportation, at Derby, in 2004.

16 The *wheel profile,* which defines the shape of the running surface and the *flange*, was designated as P8 and is in common use on passenger rolling stock. The wheels were last turned on a wheel lathe to restore the correct profile in February 2011. The train had subsequently travelled 55,000 miles. At the time of the derailment the dimensions of all wheels were within the tolerances of Railway Group Standard GM/RT2466 'Railway wheelsets'.

17 After the derailment, the train was tested in accordance with First ScotRail's post incident procedures. There was no evidence that any deficiencies in the design, maintenance or driving of train 5P37 contributed to the derailment.

Infrastructure

18 Figure 4 illustrates some key components of a typical set of points.

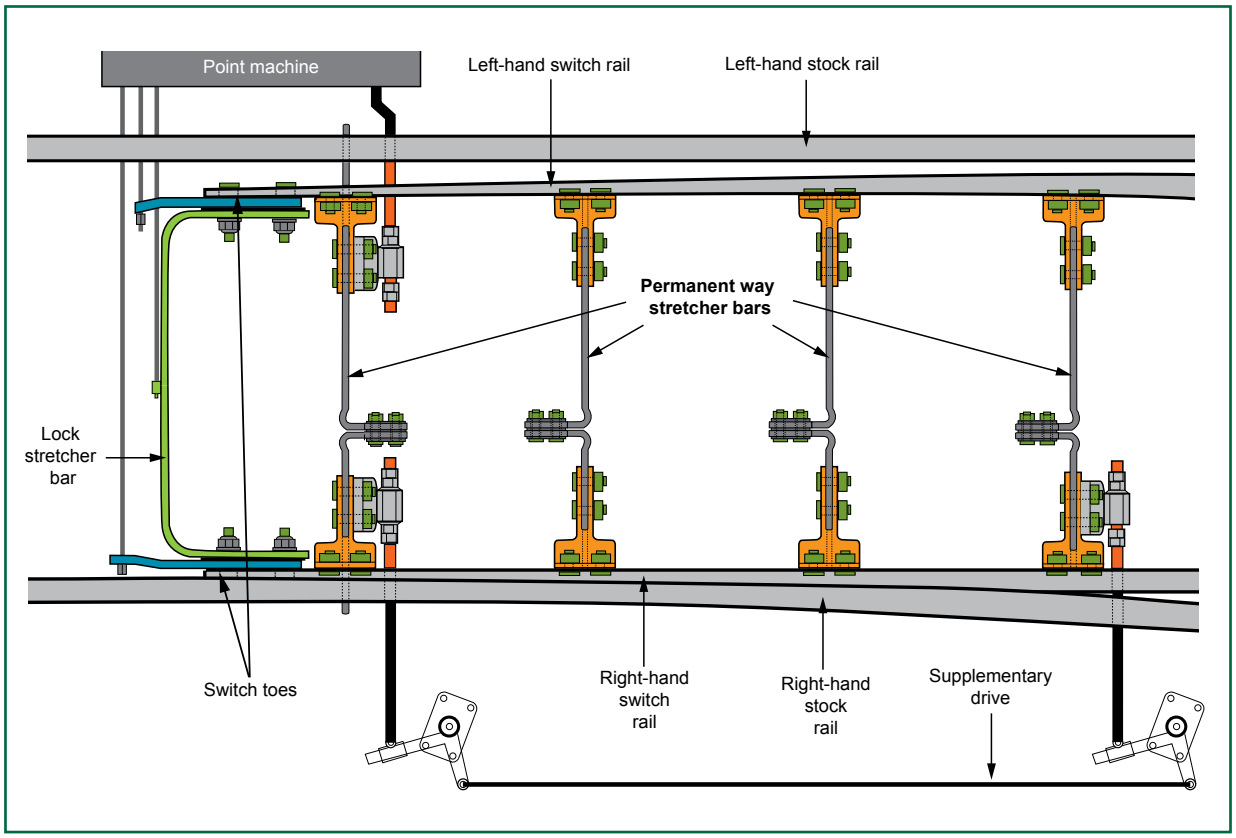


Figure 4: Simplified diagram of a set of points (not to scale)

19 Points 167B were located on a right-hand curve of around 450 metres radius. They were laid with 50 mm of positive *cant* on the outer (left-hand[2]) rail of the curve at the switch toes (figure 4), decreasing to 25 mm of positive cant at the crossing nose.

20 Points 167B were fitted with *switch type* 'E*', vertical* design, *full depth, chamfered* switches manufactured from *BS113A Grade A* rail and installed in 2002. The switches were mounted on timber bearers and operated on *base plates* fitted with *slipper bearings*. The *switch rails* were connected by four permanent way *stretcher bars* which maintained the designed distance between the two rails (figure 4).

21 The points enabled a train travelling towards Waverley station on the Z line to cross over to the Y line. When the right-hand switch rail of points 167B was closed against the *stock rail* to route a train straight-on, the points were defined as being in the *normal* position; when the left-hand switch rail was closed against the stock rail to direct a train to the turnout route, the points were defined as being in the *reverse* position.

22 The movement of points 167B from their normal and reverse positions was operated by an electric point motor which also operated a *supplementary drive* (figure 3).

23 The speed limit through points 167B is 20 mph (32 km/h). The signal authorising the movement of trains through the points from the direction of Haymarket to Waverley station is E504, which is located approximately 40 metres on the approach to the points.

[2] In the direction of travel of train 5P37.

24 All lines in Princes Street Gardens are bi-directional but the direction of traffic over points 167B was predominantly in the Haymarket to Waverley direction with approximately 70% to 85% of trains using the straight-on route[3].

25 There was no history of *hogging* of the switch rails of points 167B and no indications of *voiding* under the switch bearers at the time of the derailment. Network Rail's New Measurement Train, which records track geometry, ran over the Z line on 22 July 2011. The data recorded in the area of the points 167B, which would include voiding, fell within acceptable tolerances.

26 Witness evidence was that points 167B were due to be replaced in December 2011 as part of Network Rail's planned renewal of track in Princes Street Gardens.

27 The signalling on all lines through Princes Street Gardens is *four-aspect, track circuit block* controlled by the signaller at Network Rail's Edinburgh Signalling Centre. Neither the signalling equipment nor the operation of it contributed to the derailment.

28 The lines in the Princes Street Gardens area are listed in the *National Hazard Directory* as '*red zone working prohibited'*. This means that access to the track for inspection and maintenance purposes is normally restricted to times when trains are not running, and was usually carried out on a Saturday night/Sunday morning.

Staff involved

29 The driver of train 5P37 had booked on duty at his depot in Dundee at 14:15 hrs and had worked services from Dundee to Edinburgh and from Edinburgh to Cowdenbeath before returning the empty coaching stock to Edinburgh. The conductor, who was also based at the Dundee depot, was travelling in the rear cab of train 5P37 at the time of the derailment.

30 Personnel from the Edinburgh Central East section were involved in the prior inspection and maintenance of points 167B. These included the following:

- The *track maintenance engineer* (TME) who had over 30 years of track experience and had worked as a TME since 2001. He had worked for the Edinburgh Delivery Unit since 2009.
- The assistant track maintenance engineer (ATME) who had 30 years of experience of inspection and maintenance of track and switches.
- The *track section manager* (SM[T]) who had been in post (in an acting capacity) for five months, and had 10 years experience of inspecting track. He was not competent to inspect switches in accordance with Network Rail's company standard NR/L2/TRK/0053 'Inspection and repair to reduce the risk of derailment at switches' (053 standard).
- A technical officer who had five years of railway experience. He had completed an apprenticeship in track maintenance and had held the competence to inspect switches in accordance with the 053 standard for two years.

[3] The percentage varied depending on the timetable and the actual routeing of trains.

31 A Network Rail former grinding supervisory manager (GSM) was involved in a grinding repair and associated inspection of points 167B in the three days prior to the derailment. He was an experienced grinding operative and had been promoted to the GSM post in Slateford depot in 2008. In April 2011, he was displaced from this post when the GSM role was removed from Network Rail's organisational structure as part of a national restructuring of its maintenance delivery function. Since being displaced the former GSM had been employed on other types of work, including vegetation clearance and track renewals. He had, however, retained the competence to inspect and repair switches to the 053 standard. The former GSM was also a qualified *controller of site safety* (COSS) and acted as the COSS for grinding repair work to points 167B on 25 July 2011.

32 A grinding team from Network Rail's Motherwell Delivery Unit carried out a repair to points 167B prior to the derailment. The team had three members:

- A grinding team leader, who had ten years' experience of grinding, (mainly relating to *rolling contact fatigue*). He was not qualified to undertake inspections and repairs to the 053 standard.
- A grinding technician, who had worked as a grinder since 2001, and had held the post of senior grinding supervisory manager in a former employment. In 2006 he became a member of a specialist inspection team which was solely responsible for the inspection and repair of switches. This team was later disbanded and the grinding technician displaced as part of Network Rail's restructuring of its maintenance delivery function. Since April 2011 he had worked as a member of a grinding and welding team. The grinding technician held the Network Rail qualification to inspect and repair switches to the 053 standard.
- An apprentice, who assisted with the grinding repair to points 167B on 25 July 2011, but who had no relevant involvement in the causal chain.

External circumstances

33 The weather on the day of the derailment was warm and sunny with good visibility. The maximum daytime temperature recorded just over 10 km away at Edinburgh airport was 20ºC, and was 18ºC around the time of the accident. The day followed a spell of warm, dry weather in which similar temperatures had been reached.

34 There is no evidence to indicate that any thermal effects on the track geometry played a part in the derailment.

Events preceding the accident

35 In the early morning of Sunday 24 July 2011, the ATME was in the Princes Street Gardens area and observed the condition of points 167B (paragraphs 77 to 78). He saw evidence of significant wear and an unusual running pattern left by wheels running on the left-hand switch rail. The ATME arranged for a detailed inspection of points 167B to the 053 standard, which was conducted by a technical officer about two hours later.

36 The technical officer found the left-hand switch rail of points 167B was not compliant with the 053 standard because it failed to meet certain safety limits (paragraphs 79 to 80). The main concern was that the *flange contact angle* that the switch rail presented to the wheel flange was too shallow (figure 5) and therefore had the potential for causing a derailment. Consequently, an urgent grinding repair was organised for the following night shift on 24/25 July 2011 to restore a steeper angle on the switch rail that would meet the standard (paragraphs 82 to 83). In the interim, the switch rail remained in use for traffic.

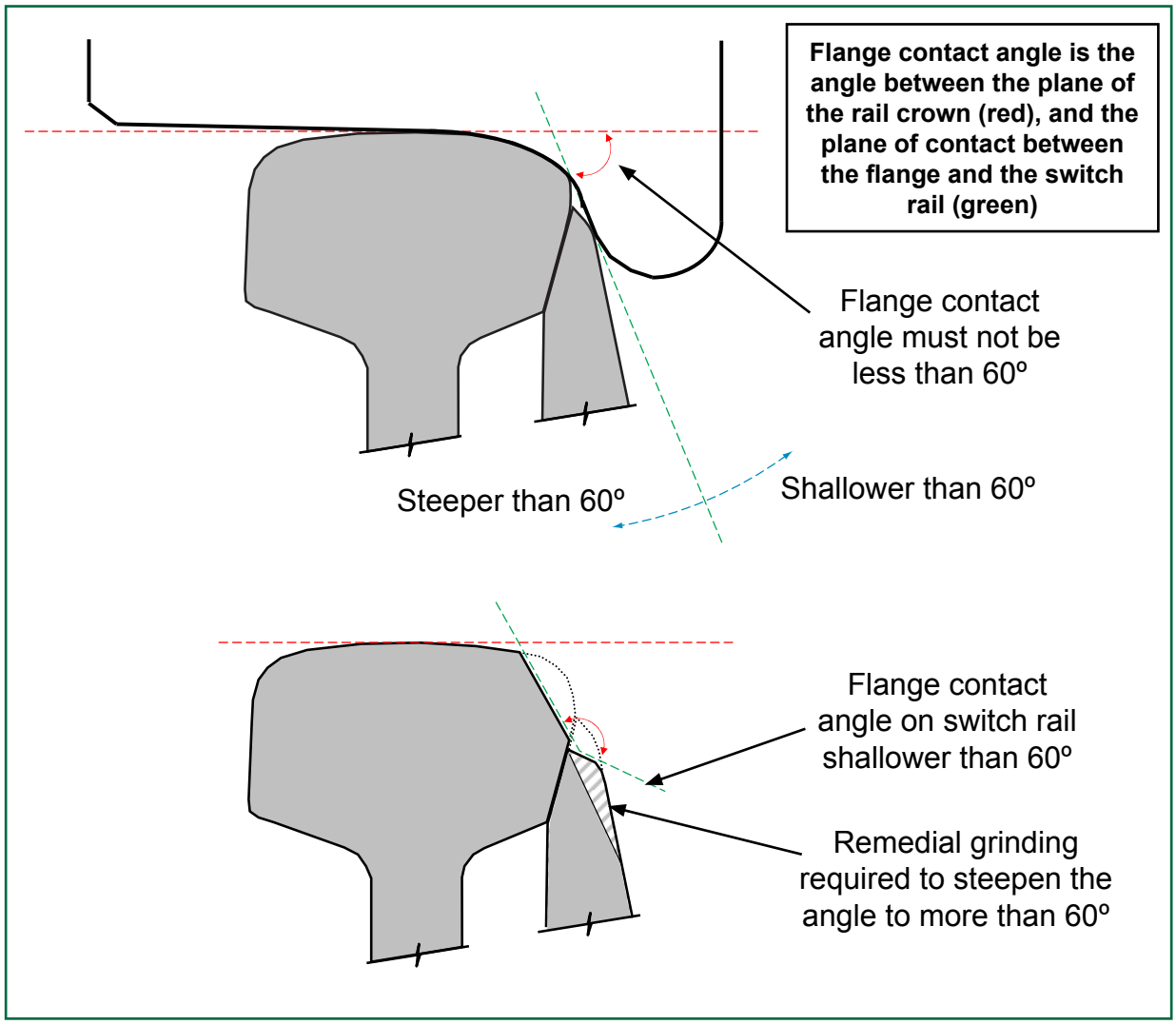


Figure 5: Illustration of derailment hazard 2 as defined by standard NR/SP/TRK/053 (issue 5)

37 After the repair was carried out, the former GSM deemed the switch rail to be compliant with the 053 standard and safe for traffic. This was confirmed by another inspection of the switch by the former GSM, carried out the following night of 25/26 July 2011 (paragraphs 89 to 92).

38 In the period between the grinding repair to points 167B on 25 July and the derailment on 27 July, the points were used by a total of 387 trains with 84 trains (22%) using the turnout route from Z line to Y line. All movements over the points were in the direction from Haymarket to Waverley.

Events during the accident

39 At around 17:50 hrs on 27 July, train 5P37 was brought to a stand at signal E504 which was showing a red (stop) aspect. At 17:51 hrs the signalling system operated points 167B to the reverse position to route 5P37 from the Z line to the Y line. Train 5P37 moved off when signal E504 changed from a red to a proceed aspect with the *route indicator* informing the driver that the train was being routed via the points to the Y line.

40 The *on-train data recorder* (OTDR) recorded that the driver accelerated the train to achieve a maximum speed of 19.2 mph (31 km/h) before coasting for 16 seconds. Around this time the driver reported seeing the *wheel slip prevention* warning indicator flashing and felt a pulling sensation from the train. He immediately brought the train to a stand with the rear of the train approximately 89 metres beyond the toes of points 167B.

41 The conductor felt the coach tilt to the left when the derailment occurred and had to brace himself but was uninjured. He contacted the driver using the on-train communication equipment to advise him that the trailing coach was derailed.

Events following the accident

42 The driver made an emergency call to the signaller via the *national radio network* (NRN) advising that his train was derailed and requesting that the signaller stop all trains. The driver and the conductor protected the train in accordance with the Rule Book (Railway Group Standard GE/RT8000)[4].

43 The south lines, W and X, which were unaffected by the derailment, were reopened to traffic at 18:29 hrs.

44 The RAIB was notified of the accident at 18:33 hrs and attended site to gather evidence.

45 The RAIB witnessed a further inspection of points 167B to the 053 standard as part of the site examination. This found that the left-hand switch rail failed the inspection because the angle presented to the wheel flange was still too shallow, commencing around one metre from the switch toe and extending for approximately 800 mm (figure 5). A *facing point lock* test was also conducted and confirmed that the switch toes were being locked in the right position and this was being correctly detected by the signalling system[5].

46 During the night of 28/29 July all movement of trains was blocked to allow the replacement of both *half-sets* of points 167B and to recover the derailed train back to Haymarket depot. The north lines were reopened for the start of service on 29 July.

47 During the 2011-12 Christmas and new year period points 167B were again replaced as part of a major track renewal project in Princes Street Gardens.

[4] The Rule Book, published by RSSB, details the procedures to be used for operating and working on the railway. It is available at www.rssb.co.uk.

[5] When a train passes over points in the facing direction there is a risk of derailment if the switches are not in the correct positions or if the forces exerted by the passage of a train cause the switches to deflect under the train. A facing point lock is therefore provided to physically lock the switches in the right place with an independent detection mechanism to positively prove that the switches are in their required position before the signalling system permits a train to pass over the points.

The investigation

Sources of evidence

48 The following sources of evidence were used:

- witness statements;
- the on-train data recorder (OTDR);
- site photographs and measurements;
- weather reports and observations at the site;
- data from the signalling system;
- personal training and competence records;
- track inspection records and records from Network Rail's Ellipse maintenance database;
- training course material relating to the 053 standard;
- results of post-derailment testing on DMU 170393;
- maintenance history of wheel sets on DMU 170393;
- information from the train service database in *TRUST*;
- *vehicle dynamics modelling* carried out by Network Rail;
- CCTV recordings from the New Measurement Train;
- voice recordings of telephone contacts with the Edinburgh Signalling Centre; and
- signallers' *line blockage* forms for access to points 167B.

Key facts and analysis

Background information

Train wheel wear

49 Measurements taken by Network Rail of the train's wheel dimensions showed that the first wheel to derail, the leading left-hand wheel on the leading bogie of the third coach, had around 2 mm of wear to the wheel flange thickness, with minimal wear to the wheel *tread.* All other wheels on the train showed a similar pattern of wear, although the first wheel to derail had marginally the thinnest flange. The flange thickness of this wheel was, however, well within the limits provided by the Railway Group Standard (paragraph 16) measuring 26.1 mm compared with the minimum limit of 24 mm.

50 The wear to the flange occurred in the flange root area (figure 6).

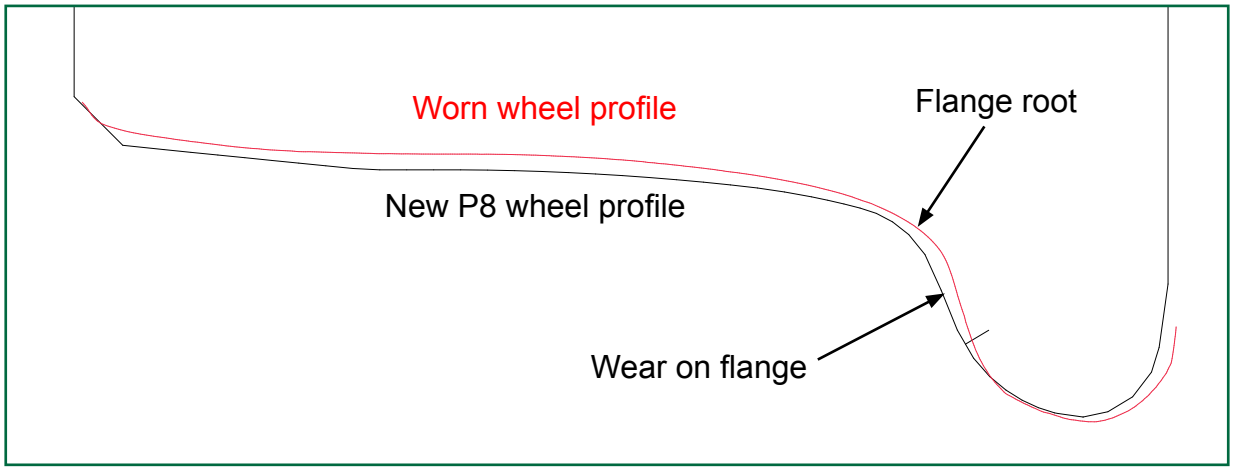


Figure 6: Wear to the flange thickness on first wheel to derail compared with new P8 wheel

Key points from the Network Rail company standard NR/L2/TRK/0053 'Inspection and repair to reduce the risk of derailment at switches'

51 The stated intention of the standard is:

> '… to make switches that have become excessively worn safe for the passage of trains however experience shows that taking action only in the event of failure, or imminent failure, to meet this specification will not be an effective way to manage switch wear whereas regular planned removal of *lipping*, early repair of damage and regular re-building of wear by welding will prolong switch life'.

52 The 053 standard addresses five recognised derailment hazards, numbered 1 to 5, which are each subject to specific checks (appendix D). For each hazard there are intervention limits with remedial actions to mitigate the risk of derailment.

53 Derailment hazard 2 applied to points 167B because both the left-hand stock and switch rails had experienced *sidewear* from contact between wheel flanges and the rail. The risk of derailment is increased where the wheel flange is making contact with the stock rail on the approach to the switch. The amount of sidewear on the stock rail on the approach to the switch (known as the stock rail front) is measured using a dimensionless step gauge (appendix D and figure 14a).

54 The first intervention point for sidewear on the stock rail front is when the sidewear gauge measures 'step 12' anywhere within one metre before switch toes on the stock rail front[6]. When this level of sidewear is reached, the standard requires the frequency of inspections to the 053 standard to be reviewed against certain criteria and if necessary increased.

55 A change in the flange contact angle to present a shallower angle to the train wheel (figure 5) in the early part of a sideworn switch (where the switch rail is steering the wheel to the turnout route) can increase the risk of derailment. Wheels that encounter such a change of contact angle may, depending on such factors as the amount of friction between the switch rail and wheel, vehicle suspension characteristics, and the speed of the train, climb up the *gauge face* of the switch rail. This is known as 'flange climb'. From there wheels can either drop back down or continue on to the top of the switch rail and take the other route. Wheel flanges usually leave visible marks on the switch rail to indicate where this is happening.

56 The Network Rail TGP8 gauge has the profile of a P8 wheel and is used to show where the wheel flange can contact the switch rail (appendix D and figure 14c). There is a line marked on the gauge representing a flange contact angle of 60º which is the intervention limit for derailment hazard 2[7]. A switch will fail a detailed inspection to the 053 standard if there is contact below the 60º line on the TGP8 gauge for more than 200 mm on the rail. The limit changes, however, after a grinding repair, where any single contact on or below the 60º line causes the switch to fail the inspection.

57 The TGP8 gauge is normally applied in the first metre of the switch rail where the wheel flange makes first contact with the switch rail. However, switch rails that are reduced in height because they have previously been ground or worn near the toe may not make first contact with the wheel flange until further into the switch and it will then be necessary to check the flange contact angle beyond the first metre. The need to extend the length of switch rail inspected is determined by gauge 2. If gauge 2 passes over the switch rail (appendix D and figure 14d) in the first metre, then the distance over which the TGP8 gauge is applied increases from one metre to three metres.

58 After a grinding repair, a switch is deemed to have conditionally passed the post-grinding inspection if a flange contact angle steeper than 60º has been restored but gauge 2 passes over the top of the undamaged switch rail. Under these circumstances, the conditions for permitting the switch to be used for traffic are that the switch is lubricated, it is inspected monthly, and within 13 weeks it is either further repaired by welding or replaced. The concept of a conditional pass was introduced in issue 4 of the 053 standard in 2007 to prevent repeated short-term grinding repairs to worn switches and to place a realistic time limit on achieving a longer-term solution.

[6] A new rail, for comparison, would have a sidewear measurement of around step 18.

[7] A flange contact angle of at least 60º or steeper (ie more than 60º) minimises the risk of a derailment occurring should a high coefficient of friction develop between the wheel and the rail (figure 5).

59 The procedure in the 053 standard for manually lubricating switches is to apply approved lubricant by brush at three prescribed locations approximately 1.2 metres apart; on the switch fronts, at the switch toes and on the switch rails beyond the switch toe. This is often referred to as the 'three dabs' procedure. However, after a grinding repair lubricant should be applied to all surfaces that have been subject to grinding before the line is re-opened to traffic.

Inspection regime for points 167B

60 Points 167B are part of a route classified by Network Rail as Category 4 (based on the speed of trains operating over it and the annual tonnage carried). A hierarchy of visual inspection types for a Category 4 track, with minimum inspection frequencies, is specified in the Network Rail company standard NR/L2/TRK/001 'Inspection and maintenance of permanent way'.

61 The purpose of visual track inspections is to identify defects which, if uncorrected, could affect the safety or reliable operation of the railway before the next inspection. With regard to switches and crossings, features to be observed include broken, cracked, defective or worn switch rails and evidence of an irregular running contact on the switch rail.

62 A basic visual inspection is required at weekly intervals to identify any immediate or short term actions required. This is normally undertaken by track patrollers, walking in the *four-foot* and observing the condition of track components. No measurements are required to be taken during a basic visual track inspection.

63 A supervisor's visual track inspection is required at 13-weekly intervals at which the SM[T] is required to review trends in condition, and to check the effectiveness of basic visual and detailed inspections to Network Rail standards, including inspections of switches to the 053 standard and of *cast crossings* to the 054 standard[8]. The supervisor is also required to assess the need to initiate a detailed inspection in accordance with the 053 standard. This assessment is done with the aid of the TGP8 gauge to visualise the wheel flange path along the switch rail and, in some circumstances, may require the switches to be checked in both normal and reverse positions. No further information is provided in the 053 standard on when such circumstances arise. The training of supervisors on track inspection provides them with the competence to exercise judgement on when a switch should be inspected in the closed position.

64 Additionally, the supervisor is required to give particular attention to signs of new, changed or aggressive wear patterns and to identify items with longer term potential to affect the safety and performance of the railway.

65 Supervisors' inspections are supplemented by visual inspections by the TME, carried out every two years. According to Network Rail's company standard NR/L2/TRK/001/A01 inspections by the TME are for asset management purposes and include the development of a maintenance and renewal strategy for the location. The TME inspection, however, is also required to check that other inspections are adequate and effective.

[8] NR/SP/TRK/054 'Inspection of Cast Crossings and Cast Vees in the track'.

66 In addition to visual inspections, supervisors and engineers are required to undertake periodic inspections while riding in a train cab, and recordings of track geometry and integrity are regularly taken using inspection vehicles, such as the New Measurement Train. There are other less frequent track inspections carried out for asset management rather than safety purposes which are not discussed in this report.

67 Until 2008, points 167B received a detailed inspection every 13 weeks as prescribed by the then current 053 standard. In October 2007 issue 4 of the 053 standard changed the requirement for fixed frequency detailed inspections, providing for a regime based on risk assessment. At that time the ATME and SM[T]s together determined that points 167B, along with all points in the Princes Street Gardens area, should receive a detailed inspection to the 053 standard every 24 weeks. They considered that this inspection frequency was commensurate with high derailment risk at points 167B and with the historical rate of wear. These inspections were also supplemented by the supervisors' visual inspections (paragraph 63).

68 These detailed inspections were originally carried out by a specialist switch inspection team and then, following the disbandment of these teams, by technical officers and others with the competence to inspect switches to the 053 standard.

Inspection history for points 167B

69 In the year before the derailment, points 167B received a basic visual inspection by track patrollers on 51 occasions; roughly weekly. None of the reports completed by the patrollers mention the condition of the switch rails of points 167B.

70 Supervisors' inspections over the same period were conducted at intervals shorter than the prescribed 13 weeks, generally around eight weeks until March 2011, when there was a gap of 14 weeks. There were, however, two detailed inspections to the 053 standard of points 167B during this interval, on 1 and 25 May[9]. The track engineering forms (TEF) completed by supervisors to record the findings of their inspections contain no references to the condition of points 167B. The last supervisor's inspection of points 167B prior to the derailment was carried out by the then acting SM[T] on 17 July. The acting SM[T] was not competent in the 053 standard[10] but had been trained in an awareness of the types of derailment hazards on switches and to be able to determine whether a detailed inspection to the standard was required. There were no adverse comments recorded on the TEF relating to the left-hand switch rail of points 167B and there were no actions arising. This inspection and all supervisors' inspections in the previous year were carried out with the left-hand switch rail in the normal (open) position.

[9] The explanation given for carrying out two inspections within a short time was that the work orders for inspections generated by the Ellipse and other maintenance databases were out of sequence.

[10] Network Rail company standard NR/SP/CTM/011 'Competence and training in track engineering' which establishes the competence profile for generic job roles, lists the competence in detailed inspection of switches as optional for supervisors. However, supervisors undergo the same training course in the 053 standard as persons who go on to develop the competence in detailed inspection.

71 The TME carried out his track inspection, which included points 167B, in January 2011. He recorded a number of measurements relating to the geometry of the switch which found that it was out of specification for *free wheel clearance* and track gauge at the fourth stretcher bar. The track geometry meant that there was limited scope for adjustment and the TME stated that some of the recorded non-compliances may have been present since the switch was installed. At his inspection the TME did not observe any indications that the switch was unsafe and no remedial action was deemed necessary.

72 In October 2009, points 167B had a sidewear reading of step 12, which is the intervention point in the 053 standard for sidewear, and were accordingly made subject to an increased inspection regime. This meant that in addition to the routine detailed inspections at 24-weekly intervals, inspections were also being carried out at intervening eight-weekly intervals.

73 The last 053 inspection prior to the derailment was carried out on 25 May. Another inspection was due on 20 July but it had not been done before 24 July when the ATME intervened and called for a detailed inspection (paragraphs 77 to 78).

74 Evidence of the condition of points 167B is contained in comments on the switch inspection forms. In May 2010 the technical officer recorded that the left-hand switch rail was 'concaved badly worn very thin', in October 2010, that it was 'concaved plus very thin!!!', and again in March 2011 that it was 'concaved + very thin'. At all 053 inspections, however, the marked up 'check boxes' on the switch inspection forms for the left-hand switch rail recorded the switch as being compliant with the 053 standard.

Maintenance history for points 167B

75 The left-hand switch rail of points 167B had been welded in August 2010 to repair damage to the top edge of the rail. A piece of metal, measuring about 200 mm long and 7 mm deep, had broken out of the rail at a position 1.3 metres from the toe. There were no reports or evidence of any other previous welding or grinding repairs.

Track access

76 The limited access to the track in the Princes Street Gardens area meant that almost all inspections were carried out at night using light from head torches and from the fixed lighting in the area. A risk assessment had been prepared and approved by Network Rail some years earlier to support this practice. It is not considered to be a significant factor in the events leading to the derailment because the level of lighting provided by the fixed lighting was good.

Inspection and maintenance of points 167B in the days leading to the derailment

77 At around 03:30 hrs on Sunday 24 July 2011 the ATME was carrying out inspections in relation to renewal works in the Waverley and Haymarket areas and took advantage of a *possession* in Princes Street Gardens to take a general look at the track infrastructure. While he was there, he noticed the condition of the left-hand switch rail of points 167B and was concerned. He reported that wheel flanges appeared to be running high on the rail and that the top of the rail was flattened out and shiny. He was also concerned about the level of wear on the switch rail.

78 The ATME decided to call for a detailed inspection of the switch to the 053 standard and arranged for a technical officer to be immediately released from his work elsewhere so that the inspection could be done while the track remained under possession. The routine Saturday night possession of the track in Princes Street Gardens usually extended to around 05:30 hrs on Sunday morning.

79 The technical officer arrived at Princes Street Gardens shortly before 05:00 hrs and arranged access to points 167B. The inspection procedure detailed in the 053 standard requires the application of specified gauges to the closed switch rails of switches to assess their condition against intervention limits (appendix D). The technical officer first conducted an inspection of the right-hand switch rail which he found to be compliant with the 053 standard. He then arranged with the signaller for the points to be moved to the reverse position so that he could inspect the left-hand switch rail with it closed against the stock rail. He found the left-hand switch rail failed the TGP8 gauge (paragraph 56, appendix D and figure 14c) because there was contact for more than 200 mm between the gauge and the switch rail below the 60º line marked on the gauge. He completed a TEF 3029 'switch inspection form' to record that the left-hand switch rail had failed inspection and included the comment that the left-hand switch rail was very worn and low and that this may cause problems when grinding. His concern was that there was not enough of the switch rail remaining to achieve a compliant angle without grinding the original unworn part of the switch rail, which could be difficult for the frame mounted grinding machine.

80 The technical officer also found that gauge 2 was able to pass over the top of the switch rail (paragraph 57) in the first metre which meant that the dimension over which the TGP8 gauge was to be applied needed to be increased from one metre to three metres. At the end of his inspection, the technical officer applied lubrication to the switch as required by the 053 standard and reported his findings to the ATME.

81 Points 167B remained open to traffic pending a grinding repair to restore a profile on the left-hand switch rail that would pass the TGP8 gauge. The 053 standard requires the repair to be carried out within 36 hours of the inspection. The technical officer put together the paperwork for the grinding repair, including a copy of the completed switch inspection form and a TEF 3037 'Report of a rail defect found'.

82 During the morning of Sunday 24 July the ATME made arrangements for a grinding team from the Motherwell Delivery Unit to carry out a grinding repair on the night of 24/25 July. The ATME also asked the former GSM to supervise the grinding repair which included carrying out an inspection of points 167B in accordance with the 053 standard on completion of the repair. The ATME considered the former GSM to be an experienced supervisor of grinding repairs to switches although he was aware that the GSM competence was no longer required for this work. This role would normally be performed by a technical officer but there were no technical officers available at that time.

83 Later that same day, the grinding team from Motherwell travelled to Edinburgh to meet up with the former GSM at Slateford depot, arriving at around midnight. The team consisted of a team leader, a grinding technician and an apprentice. The former GSM provided the grinding technician with the copy of the switch inspection form for points 167B and the defect report (paragraph 80) that had been prepared by the technical officer. The latter report contained the information that the defect was located 200 mm from the toe but there was no indication of the extent to which the switch had failed with the TGP8 gauge.

84 The former GSM and the grinding team travelled to the track *access point* on the opposite side of Princes Street Gardens from points 167B (figure 3). The former GSM arranged with the signaller in Edinburgh Signalling Centre for a line blockage to stop trains while the repair work was undertaken.

85 The signaller granted a line blockage of the Z and Y lines for one hour at 01:30 hrs on 25 July. The grinding team leader and the apprentice carried the equipment across all four tracks to the site of work. The equipment included a track mounted grinding machine, an angle grinder, a generator, lights, inspection gauges, lubrication oil, white spray paint, and a straight edge. The former GSM and grinding technician went to assess the work to be done on points 167B.

86 The former GSM and the grinding technician reported to the RAIB that they were shocked by the condition of the left-hand switch rail. The grinding technician described it as one of the worst switches he had seen on a main line. He noted that it was very low relative to the stock rail in the first metre but with no damage in this area. When he stripped the lubrication from the switch rail he also noticed a previously unidentified crack about 140 mm long, starting approximately 1.5 metres from the toe and running close to the top of the switch rail (figure 7). Although the grinding technician was unsure about whether the switch was repairable by grinding, work proceeded to attempt to restore a profile that would pass the TGP8 gauge and to remove the crack.

87 At 02:16 hrs the former GSM telephoned the signaller to request an extension to the line blockage, which was due to end at 02:30 hrs. This was needed because of the extra work arising from the removal of the crack and the difficulty of restoring a compliant profile in this area. The request was agreed. At 02:41 hrs the signaller rang the former GSM to request an update on progress and was told that the work would take approximately another 10 minutes. The signaller agreed 'another ten minutes at the most'.

Figure 7: Crack in left-hand switch rail of points 167B at 1.5 metres from switch toe

88 When grinding work was complete the switch rail was sprayed with white paint to facilitate a follow-up inspection (paragraph 90) and lubrication was applied. The grinding team departed at 02:48 hrs leaving the former GSM to meet with a signalling team who confirmed that the grinding work had not affected the correct locking positions of the points (see footnote 5). The former GSM gave up the line blockage at 03:07 hrs and points 167B were reopened to traffic.

89 A switch inspection form was completed by the former GSM to record the findings of a post-grinding inspection. The form indicated that the left-hand switch rail passed the TGP8 gauge. It also recorded the presence of substantial hogging of the switch rail with a gap of 7 mm at bearers 3 and 4 and lesser gaps at bearers 1, 2, 5, 6 and 7. The former GSM reported his findings to the ATME, describing the job as having been 'a nightmare'.

90 At some point during the day on 25 July, the ATME contacted the former GSM again and requested that he carry out a follow-up inspection of points 167B. A follow-up inspection[11] is mandated by the 053 standard to check how train wheels are running on the newly ground switch rail.

91 At 01:47 hrs on 26 July the former GSM took a line blockage of all four lines in Princes Street Gardens to carry out his follow up inspection of points 167B. The former GSM applied the TGP8 gauge and observed the running pattern of wheel flanges in the white paint. He stated that he did not notice any signs of irregular wheel behaviour and was satisfied that the switch was safe to remain open to traffic. The line blockage was given up at 02:00 hrs.

[11] The timescale for a follow-up inspection varies between 24 hours and seven days, depending on the category of track. A follow-up inspection for track category 4 is required within 72 hours, but was carried out within 24 hours of the grinding repair.

92 The former GSM filled out another switch inspection form which almost exactly replicated the results from the post-grinding inspection of the night before. Although the TEF to record the inspection was fully completed, a full inspection had not been carried out as this is not required by the 053 standard for a follow-up inspection.

Identification of the immediate cause[12]

93 **The left-hand switch rail of points 167B did not correctly steer the leading left-hand wheel of the third coach to the turnout route; instead the wheel climbed over the switch rail, pulling the corresponding right-hand wheel and the trailing axle into derailment.**

94 Marks on the switch rail and damage to switch components and bearers were consistent with the leading left-hand wheel of the third coach climbing over the switch rail at a point 2.8 metres from the switch toe (figure 8), deflecting the switch rail towards the four-foot and dropping down between the switch and stock rails. This pulled the corresponding right-hand wheel into contact with the open right-hand switch rail and squeezed the switch rails together, damaging the third and fourth stretcher bars. The right-hand wheel of the leading axle was subsequently pulled into derailment, dropping between the right-hand stock and switch rails, approximately 14 metres from the switch toes.

95 The trailing axle of the leading bogie on the third coach was correctly routed to the turnout route but was drawn into derailment around the crossing nose.

Figure 8: Witness mark of wheel flange climbing over switch rail at 2.8 metres from switch toe

[12] The condition, event or behaviour that directly resulted in the occurrence.

Identification of causal[13] and underlying factors

Derailment mechanism

96 **The leading left-hand wheel of the third coach climbed the switch rail within the first two metres from the switch toe.**

97 There were insufficient witness marks on the switch or stock rails to clearly indicate where the wheel had begun to climb. As a result, there are three possible explanations for the derailment:

a. The worn wheel flange made contact with the switch rail at a flange contact angle of less than 60° in the first metre of the switch rail

This is suggested by the following evidence:

- The switch rail in the first metre was compliant with the TGP8 gauge (but failed gauge 2 because gauge 2 was not making contact with the switch rail in this area). However, there was a running band in the lubrication commencing close to the switch toe which indicated that contact was being made between wheel flanges at a point low down on the flange and the switch rail. Also, when the lubrication was removed, there was a score mark on the switch rail, commencing around 35 mm from the switch toe and running close to the top of the switch rail (figure 9). This score mark was coincident with the point at which worn flanges were contacting the switch rail.
- Analysis by the RAIB and supported by Network Rail's vehicle dynamics modelling analysis, found that, unlike a new P8 wheel, the worn profile of the first wheel to derail was able to make contact with the switch rail at a contact angle of less than 60° in the first metre from the switch toe. This was because the worn wheel conformed more closely with the profile of the stock and switch rails than would be the case for an unworn P8 wheel.

Figure 9: Score mark close to top of switch rail and marks left by grinding

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

- The dynamics modelling analysis predicted the occurrence of a flange climb derailment risk from a worn wheel in the area 400 mm to 800 mm from the switch toe under high friction conditions.
- The grinding repair left the switch rail with a compliant flange contact angle in the first metre of the switch (although little grinding was found to be needed in this area) and would not therefore have contributed to a flange climb derailment, except possibly to increase the friction in this area (paragraph 124).

b. *The first wheel to derail immediately climbed on top of the switch rail on entering the switch*

This is suggested by the following evidence:

- After the derailment, the switch toe was found to be approximately level with the bottom of the *sidewear scar* on the stock rail within the first 200 mm of the switch rail. This condition would fail the 053 standard for derailment hazard 1 (appendix D) because of the risk of the switch rail presenting a ramp to train wheels (but see paragraph 158, penultimate bullet point).
- It is possible, therefore, that the wheel flange ran on to the toe of the switch rail and remained at the top of the switch rail until it derailed. This could explain the lack of a distinct climb mark on the switch rail.

c. *The first wheel to derail encountered a shallower flange contact angle on the switch rail, commencing around 1.1 metres from the switch toe*

This is suggested by the following evidence:

- There were marks observed at the top of the switch rail starting around 1.1 metres from the switch toe, in the area where the switch rail was found to be non-compliant with the TGP8 gauge (figure 10), and becoming more prominent around 1.7 metres from the switch toe. Figure 11 shows a TGP8 gauge placed on markings on the switch rail to replicate the likely position of wheel flanges when they made these marks. There were also at least two running bands on the switch rail starting in this area.
- From around 2 metres from the switch toe there was an emerging pattern of flange markings left by wheels taking a rising path on the switch rail, coincident with the increasing height of the switch rail. There were also distinct marks of flanges having dropped down the gauge face from the higher to lower running bands. At least six ‘drop down’ marks were observed on the switch rail, indicating that other wheels had tried to climb the switch rail (figure 12).
- The lubrication on the switch rail was observed to become increasingly thin as it was spread along the rail.
- Network Rail’s dynamics modelling analysis predicted a high derailment risk for both new and worn wheels in the area from 1.2 to 1.5 metres from the switch toe where the contact angle on the switch rail ranged from 40º to 48º for a new wheel and from 44º to 51º for a wheel with the worn profile of the first wheel to derail. The risk for the worn wheel was higher because the circumstances favourable to a wheel climb existed over a longer distance.

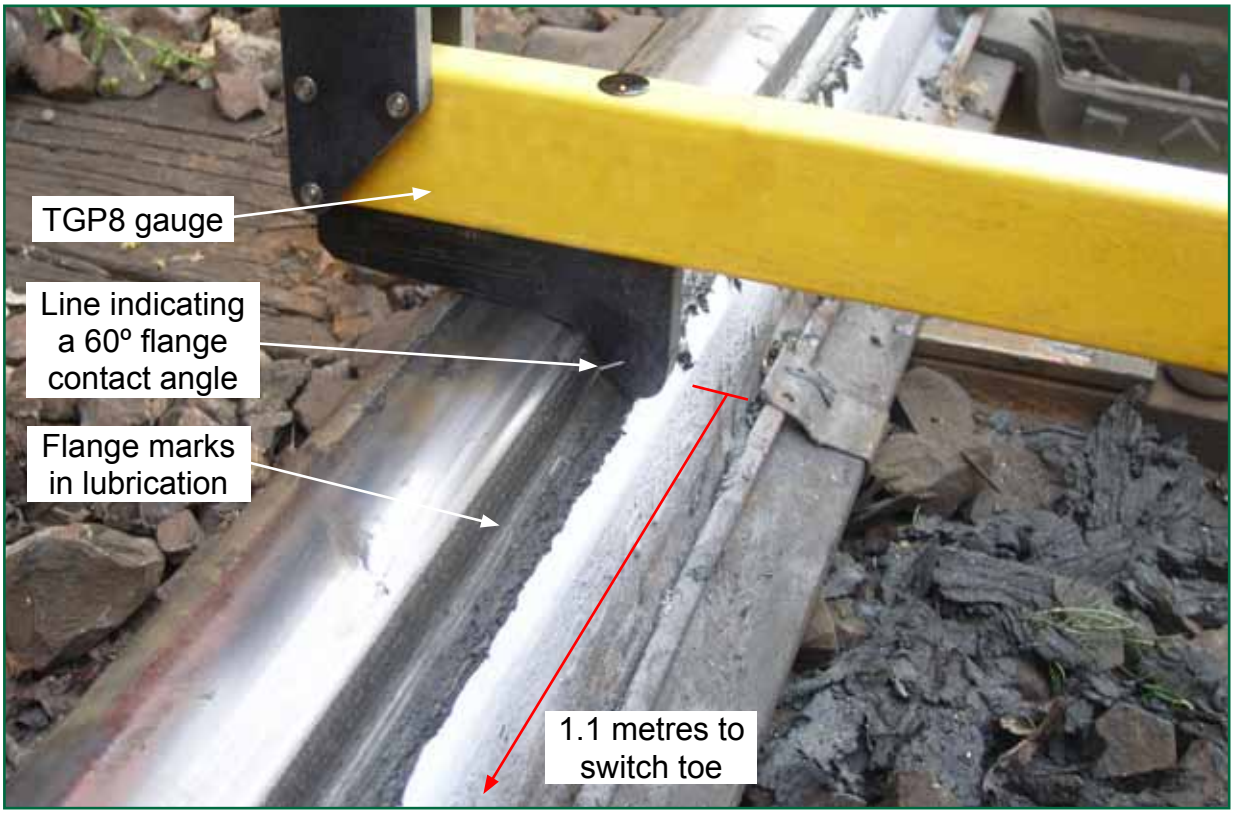


Figure 10: TGP8 gauge applied to left-hand switch rail of points 167B 1.1 metres from the switch toe

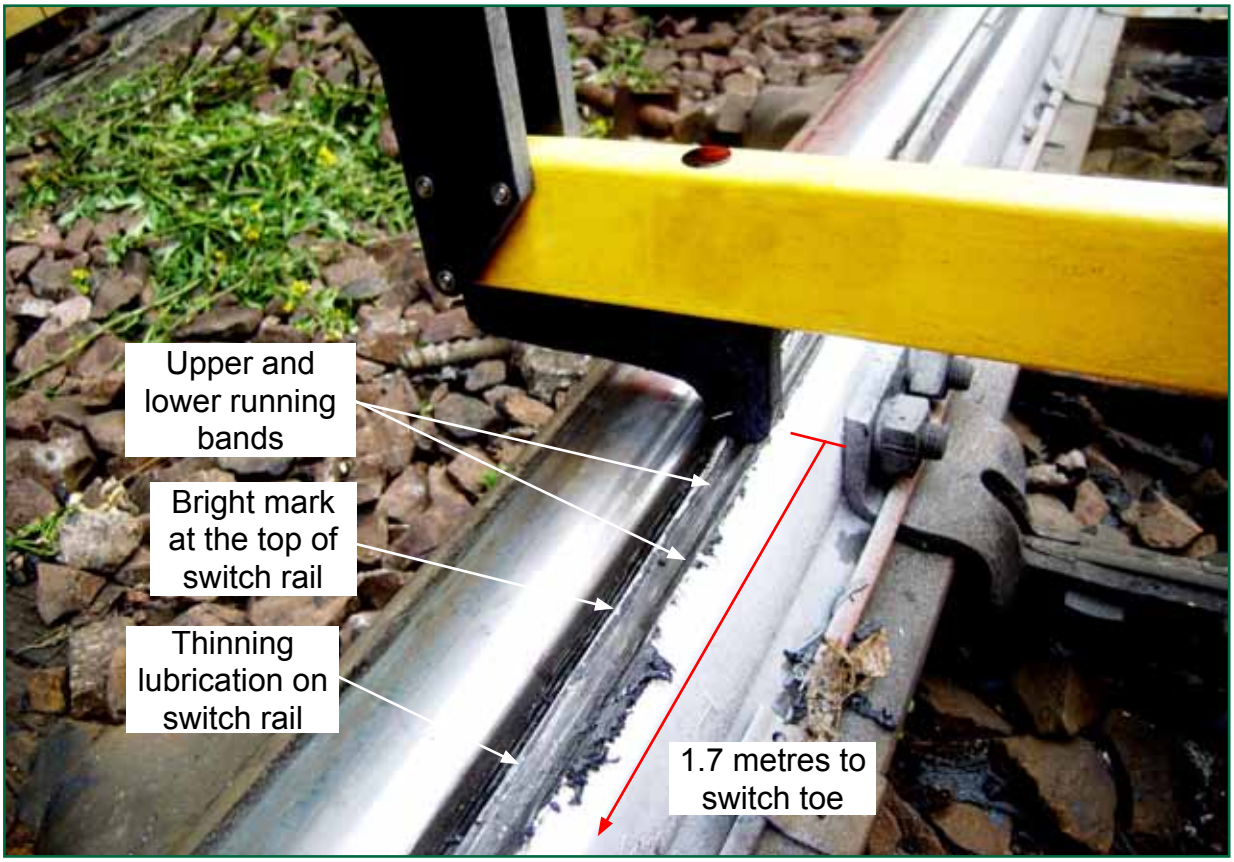


Figure 11: TGP8 gauge applied on markings on left-hand switch rail of points 167B 1.7 metres from the switch toe

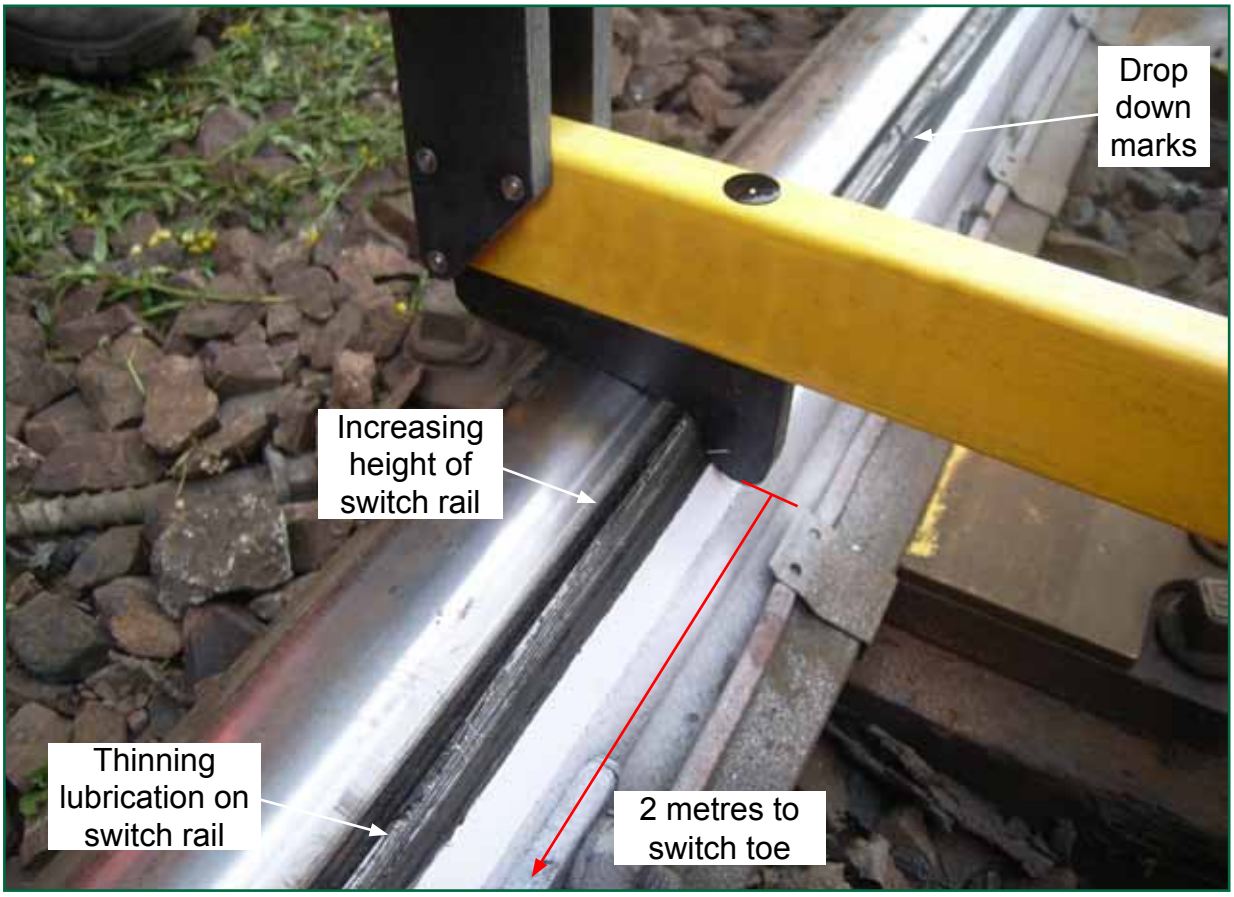


Figure 12: TGP8 gauge applied to left-hand switch rail of points 167B 2 metres from the switch toe

98 Although there is credible evidence of the derailment initiating in the early part of the switch rail, on balance, the evidence that it started from around one metre from the toe is more likely (option c, paragraph 97). Previous wheels had taken a similar path but had dropped down the gauge face, possibly due to the lubrication then present. There were no indications of wheels climbing or riding along the top of the switch rail, or having dropped down the gauge face, in the early part of the switch rail.

99 The risk of derailment predicted by Network Rail's vehicle dynamics modelling analysis in the first metre of the switch only occurred in conditions of high friction. The heavy lubrication that was observed in this area would have mitigated this risk of derailment.

100 There is no known history of flange climb on switches that have a flange contact angle steeper than 60º (when measured using the TGP8 gauge). Also, flange wear of the type and extent present on the derailed wheel is not untypical and many trains will have wheels with greater wear negotiating numerous *facing switches* on a daily basis.

Grinding repair

Scoping of the grinding repair work

101 **The grinding repair to points 167B was not scoped before the grinding team and the former GSM arrived on site. This was a possible causal factor.**

102 The 053 standard calls for grinding repairs to be scoped by the SM[T] in consultation with persons with grinding expertise to advise on the practicability of a grinding repair and the time required, and to consider factors such as how long a repair is likely to last. The SM[T] is also required to prepare a proposed work package for the endorsement of the TME before any work is planned or carried out.

103 The grinding work for the repair of points 167B was not scoped in advance of the work taking place. The investigation learned that it was not practicable for the Edinburgh delivery unit to scope grinding repairs with short deadlines in sites like Princes Street Gardens with limited access. This was because there was not enough time to obtain a line blockage to visit the site prior to the repair. Neither the ATME nor the technical officer had the competence to scope grinding works and were relying on the grinding team and the former GSM to do this on their arrival on site. This was an accepted practice within the delivery unit.

104 The inability to scope the work prior to the repair removed the opportunity for consultation with grinding experts on the suitability of a grinding repair. Also, an inspection for scoping purposes could have identified the crack so that this could also have been included in the assessment.

105 The grinding team had limited ability to scope the repair on the night as intended by the 053 standard. They were not provided with the inspection and maintenance history of points 167B and were unaware that the left-hand switch rail had previously been weld repaired. They also did not have adequate written information about the extent to which the switch rail had failed the TGP8 gauge and about the condition of the switch. This meant that when they arrived on site it was too late to plan a viable alternative to a grinding repair.

Decision to permit points 167B to continue in use for facing traffic

106 **The decision not to impose a ban on facing moves on a switch that was beyond repair by grinding in accordance with the 053 standard was causal.**

107 According to the 053 standard, when a switch rail fails the TGP8 gauge, in addition to steepening the angle on the gauge face, the required remedial action also includes grinding the switch toe so that it is 2 mm below the bottom of the sidewear scar on the stock rail and blending into the un-ground switch rail at a gradient of no more than 1:600. This was not done as part of the grinding repair to points 167B because the grinding technician considered the toe to be already low relative to the stock rail and did not know how much lower it was safe to take it.

108 Grinding the toe of the left-hand rail of points 167B so that it was 2 mm below the bottom of the sidewear scar on the stock rail and blending out at a gradient of 1:600 was not, in any event, realistically achievable. Figure 13 shows the height profile of the switch rail after the derailment. The height, which was measured at 137.2 mm at the toe, dipped down to 133.7 mm at one metre from the toe. If a line representing a 1:600 gradient is drawn so that it passes through this lowest point, the switch rail would need to be reduced to a height of 131.8 mm at the toe. This would entail the removal of an unrealistic amount of metal and leave the switch rail so low that it would be unable to engage with the wheel flange to steer the train for a considerable distance from the toe.

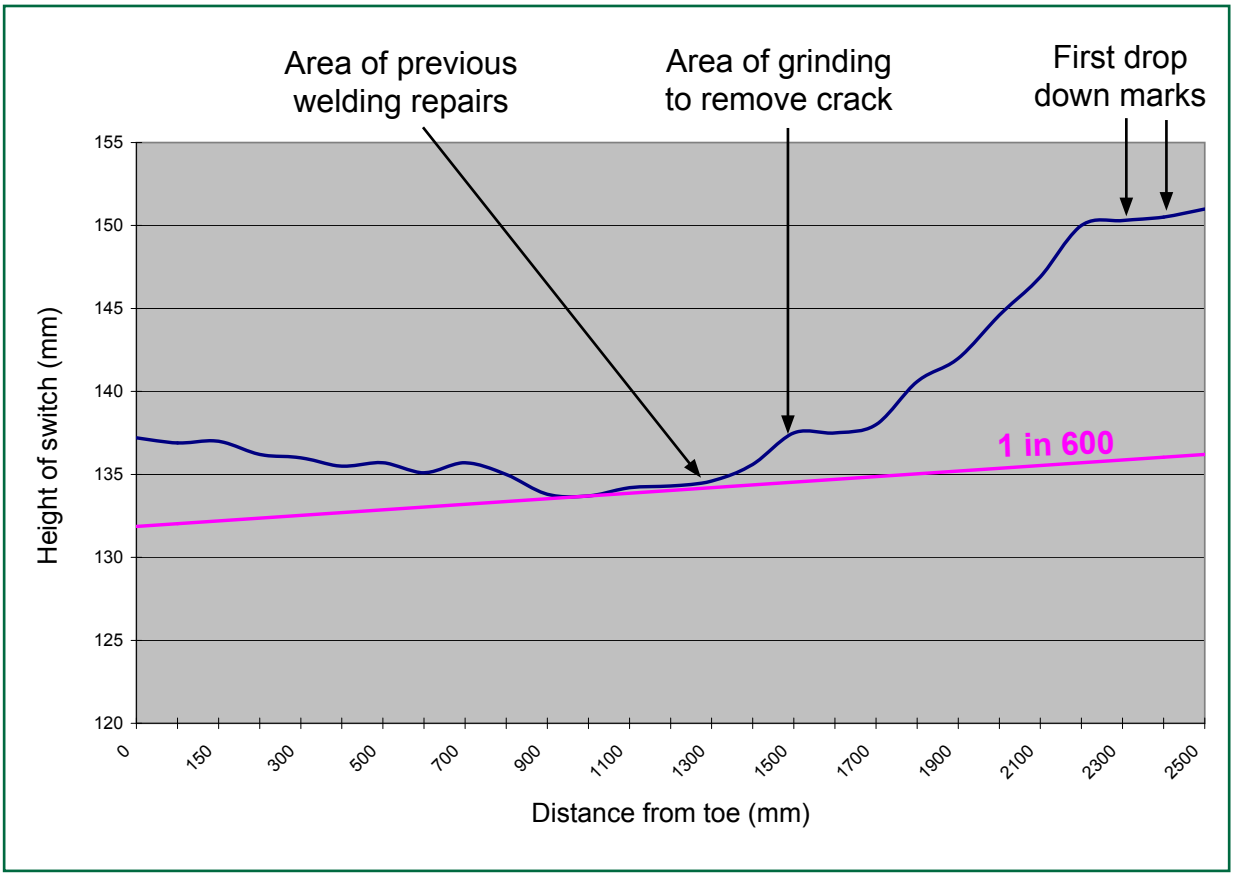


Figure 13: Points 167B - profile of top of switch rail

109 The grinding repair to remove the crack was also not blended into the unaffected part of the switch rail at a gradient of 1:600 as required by the 053 standard (figure 13). Instead the technician used a straight edge to get a line to grind to. This was stated by the grinding technician to be partly because of the lack of time but mainly because he felt it was not practicable to blend out at the required rate without taking the switch toe too low. The switch was ground from the area of the crack towards the switch heel for as far as could be achieved in the time available.

110 Both the ATME and the technical officer stated that they were uncertain whether the switch rail was repairable by grinding but they followed the process in the 053 standard. This placed the responsibility for a decision to impose a ban to facing moves on the former GSM.

111 However, the former GSM and the grinding team stated that they believed that banning the switch to facing moves would have severe operational consequences. Points 167B allowed trains on the Z line to be routed to platforms 8 to 20 in Waverley station; a ban on facing moves (ie moves using the turnout route) would restrict the routeing of trains to platforms 15 to 20 and disrupt the service timetable.

112 The team was also aware that points 167B were due to be replaced at the end of the year and that a grinding repair would be a temporary measure to give the delivery unit more time. If the switch could achieve a conditional pass of the 053 standard, the delivery unit would have 13 weeks in which to carry out a welding repair or plan an orderly replacement of the switch half set (paragraph 58).

113 The grinding technician stated he felt uneasy about carrying out the repair to the switch rail because he was conscious that it was low relative to the stock rail and was already thin. The discovery of the crack added to his unease but he decided to proceed and this was not challenged by the former GSM. This was not an unreasonable decision because if the repair had been unsuccessful, there remained the opportunity to impose a ban on facing moves.

Contact angle on the switch rail

114 **It is unlikely that the grinding repair to the left-hand switch rail of points 167B restored a flange contact angle steeper than 60°. This was probably causal.**

115 Although the grinding team stated that the ground switch narrowly passed the TGP8 gauge, after the derailment the contact angle on the switch rail was found to be less than 60º for at least 800 mm, starting around one metre from the switch toe, with the lowest being 40º around 1.2 metres from the toe.

116 The work of the grinding team was curtailed to fit the time available. The grinding technician reported that he normally set his grinding machine to achieve a grinding angle of 75º on the switch rail so that the profile achieved was much steeper than the 60º limit. However, the amount of metal that needed to be removed to reach this angle was not possible in the time available so he reset the machine to grind to a lesser angle.

117 It is possible that there was an increased rate of wear following the grinding repair because the removal of metal from a switch rail changes the flange contact area on the gauge face and the pattern of wear on the switch rail (figure 12). However, the switch failed the TGP8 gauge by a considerable margin after the passage of only 84 trains on the turnout route. It is unlikely that the switch could have worn from a compliant to the non-compliant profile found after the derailment with such low use.

Post-grinding inspection

118 **The former GSM did not inspect points 167B in accordance with the procedure in the 053 standard for post-grinding inspection to establish whether the switch was safe to be opened to traffic. This was probably causal.**

119 The former GSM did not conduct his own inspection to confirm that the switch was compliant with the 053 standard before he opened the line to traffic. The switch inspection form was completed from measurements taken by members of the grinding team for their own purposes during the course of the work. The former GSM took the word of the grinding technician that the switch passed the TGP8 gauge and did not check it himself.

120 Although witnesses state that the switch rail passed the TGP8 gauge the investigation could not establish with certainty that the correct rule for a switch that had been ground was being applied, namely that all contact between the switch rail and TGP8 gauge had been above the 60º line.

121 The measurements taken using the TGP8 gauge were also potentially inaccurate because the grinding technician did not take necessary account of the hogging that had been recorded. The 053 standard requires that, each time the TGP8 gauge is applied, compensation is made for hogging under the switch rail by effectively raising the stock rail by the same amount. This is achieved by placing the TGP8 gauge on top of the metric stepped gauge so that the TGP8 gauge is raised by an amount equal to the size of the gap created by hogging of the switch rail at that point. Compensation for hogging is necessary because the switch rail will be pushed down under the weight of the train and it allows the TGP8 gauge to measure the flange contact angle that train wheels actually encounter. If hogging is not accounted for, there is a risk that a switch rail could falsely pass the TGP8 gauge. The evidence of witnesses is that compensation for hogging was made when taking one reading with the TGP8 gauge.

122 The former GSM did not carry out his own inspection because he deferred to the grinding technician, whom he regarded as very experienced and competent. The former GSM's supervisory role and status had been removed as part of Network Rail's reorganisation and he reported feeling demotivated by the nature of some of the work he had been doing since being displaced. These factors may have influenced his behaviour.

Friction

123 **It is possible that there was an increase in friction on the switch rail due to thinning lubrication and scoring from the recent grinding. This was possibly causal.**

124 The amount of friction generated between the wheel and the switch rail is a variable component of derailment risk. An increase in the *coefficient of friction* increases the risk of a wheel that is engaged with the switch rail being able to climb. Lubrication mitigates the risk of derailment by flange climb, by lowering the coefficient of friction between the rail and wheel flange.

125 Following the grinding repair the grinding team leader lubricated the switch using the prescribed procedure (paragraph 59) for the routine lubrication of switches, with additional lubrication in the first metre of the switch rail. He did not, however, apply lubrication to the area of grinding associated with the removal of the crack (paragraph 59). This may have been because the grinding team leader was not competent to the 053 standard. No further lubrication was applied prior to the derailment[14].

[14] The lubrication of switches was one of the tasks undertaken by the track patroller during routine patrols, and would have been done at the next planned patrol.

126 After the derailment there was evidence of grease having been spread by the passage of trains to the area beyond the first metre but the amount became progressively thinner (figures 11 and 12). The warm weather would also have contributed to the spreading of the lubrication. It is possible that, in the time between the lubrication being applied and the derailment, the lubrication available reduced to the extent that it was unable to mitigate the risk of a flange climb. This risk would increase as wheels progressed away from the heavily lubricated, early part of the switch and supports the greater likelihood of a flange climb beyond the first metre.

127 The Network Rail standard does not prescribe how much grease should be manually applied as part of the lubrication procedure or whether it is sufficient in all circumstances to maintain a low coefficient of friction in the flange contact area.

128 There was no automatic lubrication on the Z line on the approach to points 167B from Haymarket because it was not required by the Network Rail company standard.

129 The grinding technician reported using a type of polishing wheel to smooth out grinding marks on the switch rail left by grinding wheels. This is a necessary part of the grinding process to prevent wheel flanges 'biting' into sharp scoring marks and climbing up the switch rail. However, when examined after the derailment the switch rail appeared to still have an abraded surface.

Post grinding follow-up inspection

130 **The former GSM did not inspect the switch in accordance with the 053 standard at the follow-up inspection on 26 July and the switch was allowed to remain in traffic. This was probably causal.**

131 The 053 standard does not require a follow-up inspection to be done by someone independent of the grinding repair. The ATME stated that depending on the staffing roster, it was very likely that the same person who carried out the post-grinding inspection would also do the follow-up inspection. In any event, there was no-one else available at the time to do a follow-up inspection.

132 The former GSM stated that he was uncomfortable about doing the follow-up inspection because he had never done a follow-up inspection before and was not sure about what was required. The training he had received to inspect and repair switches (paragraph 137) did not include the conduct of follow-up inspections and he had not been taught or shown how to confirm from the flange path left in the white paint whether the switch met the standard's requirements. This competence is usually acquired as a result of experience. However, the former GSM believed that he would be able to recognise signs of an irregular running pattern on the switch rail. He stated that the marks left in the white paint indicated that train wheels were running through the middle of the grinding repair and there was no evidence of wheels trying to climb.

133 The former GSM applied the TGP8 gauge sporadically along the switch rail in the area of the grinding repair. He did not use the mandated 'gliding' motion and did not apply the TGP8 gauge for 3.0 metres as is required when gauge 2 passes over the switch rail (paragraph 57). He did not identify any failures and the switch remained in use for facing traffic.

Training and competence

134 **The former GSM's competence to inspect and repair switches in accordance with the 053 standard had not been assured. This was probably causal.**

135 Although the former GSM was deemed by Network Rail's '*Assessment in the line'* competence management system to be competent to the 053 standard, his competence to repair switches, and to conduct inspections after a grinding repair, had not been assessed in accordance with the requirements of the Network Rail standard NR/L3/CTM/306 'Competence Assurance – assessment in the line (AiTL)'.

136 The AiTL process has three main elements: computer-based knowledge tests, line managers' on-site surveillance checks and line managers' reviews of work experience records (log books).

137 The former GSM had attended a one-day training course to inspect and repair switches to the 053 standard in 2007 and, in accordance with Network Rail company standard NR/SP/CTM/011 'Competence and training in track engineering', subsequently underwent a period of mentoring before being passed as competent. However, the former GSM stated that he received little mentoring before being passed as competent and had not subsequently received any practical re-assessments of his competence. In September 2010 the former GSM had successfully taken an 'open book' computer-based knowledge test as part of the AiTL process. The candidate is permitted access to reference material, such as the 053 standard and training notes when taking the test. Although he correctly answered a question about the maximum gradient for blending out of grinding repairs, after the derailment he had come to understand that the blending out of grinding repairs only applied to grinding to remove rolling contact fatigue and not to switch repairs.

138 The investigation learned that in practice, line managers did not generally carry out practical assessments of their staff. This was because the system was very bureaucratic and managers found the burden of paperwork involved left little time for practical site surveillance of their staff. Log books were also not routinely kept or reviewed. One possible outcome of this was that the former GSM's non-compliance with the mandated procedure for applying the TGP8 gauge in a gliding action and for compensating for reported hogging when using the TGP8 gauge, had not been identified. After the derailment, Network Rail found that these types of non-compliances were common among persons holding the 053 competence (paragraph 186).

139 The amount of paperwork associated with the AiTL process inhibiting the ability of line managers to spend sufficient time observing the performance of their staff on site, was identified as a factor in the RAIB report 'Two incidents involving track workers between Clapham Junction and Earlsfield 8 March 2011' (RAIB Report 03/2012). The report also notes that the computer-based knowledge test has a multiple choice format which provides prompts to the right answers and is significantly different from the situations in which that knowledge must be applied. See paragraph 187 for actions already being taken by Network Rail on this matter.

Identification of underlying factors[15]

Switch maintenance and repair

Maintenance limits for switches

140 **The maintenance of switches was driven by compliance with the safety limits of the 053 standard rather than proactive re-building of worn switches by welding before the limits were reached. This was an underlying factor.**

141 The local practice in Edinburgh Central East was to carry out welding and grinding repairs to switches, for example to remove lipping and to rebuild areas of damage, when identified during an inspection to the 053 standard. These defects have specified actions and time limits for repair in the standard.

142 However, the regular proactive rebuilding of switches by welding to manage wear on switches (paragraph 51), advocated by the 053 standard, was not routinely carried out on switches that were otherwise compliant with the standard. This was partly because there are no specific intervention limits on general wear of switch rails but more importantly because the rebuilding of switches that are at or close to their safety limits, can be unrealistic in practice. There were several reasons for this. The mechanised process that had been used successfully for weld-repairing crossing noses had not yet proved suitable for repairing switch and stock rails and so the rebuilding of switches had to be done using traditional techniques. The Network Rail company standard NR/L2/TRK/0132 'Maintenance Arc Welding of Rails, switches and crossings' requires that sideworn stock and switch rails are repaired together in the same possession. This can be a lengthy process, frequently comparable with, or longer than, the time needed to replace a half-set. In an area like Princes Street Gardens with limited access for repairs, the replacement of a half set of switches at the end of their serviceable life is a more practicable option. The welding resource in the Edinburgh Delivery Unit was, in any event, fully engaged in the repair of rail defects, which had increased substantially after the severe winter of 2010-2011.

143 The technical officer had raised his concerns about the thinness of the left-hand switch rail on points 167B with the TME around May 2011. However, the TME considered that points 167B would remain safe for traffic until their planned replacement at the end of 2011 because the development of sidewear, which in the 053 standard is a limiting factor of switch life, was relatively slow. From when it had been installed in 2002, it had taken seven years for the sidewear on the left-hand stock rail front to wear from an original sidewear reading of about step 18 to step 12, and almost two years to reduce from step 12 to step 10. According to the 053 standard the switch could remain in service until the sidewear reached step 6, when the points would be banned to facing moves. The control of wear on the switch rail itself did not become an issue until the switch rail failed the TGP8 gauge.

[15] Any factors associated with the overall management systems, organisational arrangements or the regulatory structure.

144 In practice, switches in the Edinburgh Delivery Unit were replaced when they reached a sidewear of step 8, to ensure a margin of safety but the inspection history of points 167B suggested that this level of sidewear would not be reached before the switch was due to be replaced. As such, there were other switches in the Princes Street Gardens area that were considered to be of higher risk than points 167B and these were given higher priority.

145 One of the consequences of not rebuilding worn switch rails before they failed an inspection to the 053 standard was that the switch rail of points 167B appeared to have suffered significant damage to its top, due to its thinness. This occurred sometime between 25 May 2011 when gauge 2 was not able to pass over the switch rail in the first metre, and 24 July 2011 when gauge 2 was able to pass over the switch rail by up to 5 mm. It is likely that the passage of trains smoothed out the damage and it went undetected by visual inspection. This may have been because the switch rail was not seen closed against the stock rail but also because it was widely known that the switch was on an increased inspection regime and receiving detailed inspection by others.

Guidance on limits of grinding repair

146 **There is no guidance in Network Rail company standards about conditions that will make it difficult, or impossible, to restore a switch to compliance with the 053 standard. This was an underlying factor.**

147 Network Rail company standards do not assist decisions as to whether switches will be successfully repaired by grinding. For example, there is little guidance on the depth of cracks and their distance from the toe, that are suitable for grinding repair. Also, where the height of the switch rail varies such that a 1:600 maximum gradient from the switch toe cannot realistically be achieved there is little advice in standards on the appropriate course of action. In the absence of prior scoping, grinding operatives were expected to make a decision on whether a switch is repairable by grinding on the basis of their training and experience. In comparison, standards for welding provide limits on when a switch is beyond repair.

Discounted factors

Hogging

148 The investigation could not establish a satisfactory explanation of the 7 mm of hogging that was recorded on the switch inspection form after the grinding repair. The maximum amount of hogging previously recorded for points 167B was on 24 July 2011 when the technical officer measured a 2 mm gap under bearers 4 and 5. After the derailment the independent inspection to the 053 standard measured a maximum of 1 mm of hogging, at bearers 5 and 8.

149 If proper account is not taken of hogging when applying the TGP8 gauge, it is possible to achieve a ‘false pass’ of the gauge. This could possibly explain how the switch rail was found to be compliant with the TGP8 gauge after the grinding repair.

150 However, track engineers in the Edinburgh Central East section stated that they were unfamiliar with a transient hogging of switches and that, in their experience, once a switch was hogged it remained hogged.

151 There was some evidence that the left-hand switch rail was subject to thermal expansion because there was a groove worn into the slipper of the base plate at the switch toe indicating longitudinal movement had taken place. However, there was no evidence that this movement had been constrained to cause the switch rail to hog.

152 Therefore, in the absence of evidence to substantiate the presence of switch hogging, this factor is discounted.

Factors affecting the severity of consequences

153 The train was not in passenger service at the time of the derailment and there was no risk to members of the public. The train was also travelling at slow speed and remained upright in derailment.

154 The consequences could have been more severe if the train had derailed when carrying passengers. There was the potential for injury to be caused to passengers while the train was running derailed, and particularly to any passengers in the connecting corridor which was badly damaged during the derailment.

Observations[16]

Network Rail Standard NR/L2/TRK/0053

Sideworn stock and switch rails

155 **Although there is no known history of derailments on switches that comply with the 053 standard, Network Rail has been unable to provide a technical justification to demonstrate that the 053 standard adequately controls all derailment mechanisms arising from sideworn stock and switch rails.**

156 Although there is no evidence that the 053 standard does not control the risks described below, Network Rail has been unable to provide a technical explanation to show how the standard achieves this. Particular issues identified by the RAIB include:

- It is not clear how the 053 standard controls the derailment risk from flange contact with worn wheels below a 60º flange contact angle.
- There is an apparent risk of a ramp being created where a switch rail that is failing gauge 2 in the first metre increases in height and is introduced between the stock rail and wheel flange from below, particularly where there is flange contact between train wheels and the stock rail.
- It is not known how far into a switch rail the point of first contact can occur before it becomes unsafe. The point of first contact can be moved along a switch rail as a result of a grinding repair or from aggressive wear on the switch rail. However, the further into the switch it occurs, the greater the *angle of attack* from the wheels meeting the switch rail as it curves towards the turnout and the greater likelihood of wear and switch damage.

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

Interpretation of the 053 standard

157 **The 053 standard was not interpreted and applied uniformly.**

158 The investigation found several examples of different interpretations of the 053 standard being applied to the inspection of switches and also cases where the requirements of 053 had not been understood:

- The significance of gauge 2 passing over a switch rail in the first metre to the distance over which the TGP8 gauge was applied, was not universally appreciated. One interpretation being applied was that the switch rail passed the inspection with gauge 2 if it contacted the switch rail within the first 3 metres from the toe.
- The requirement in the 053 standard to compensate for any hogging of the switch rail when using the TGP8 gauge was not routinely applied during 053 inspections.
- There were differences of opinion, in the absence of clear guidance, on whether there was a requirement for a full detailed inspection to be carried out at an increased inspection, or for just the sidewear on the stock rail fronts to be measured and recorded. Track engineers were of the opinion that inspectors were only required to measure the sidewear on the stock rail front at an increased inspection (which did not require switch rails to be moved). However, inspectors had the discretion to carry out a full inspection if they considered it necessary from their observation of switch condition.
- The requirement for a transition from the newly ground rail to the un-ground rail at a maximum gradient of 1:600 was not universally understood by those involved in carrying out grinding repairs to switch rails. There is, in any case, no requirement in the 053 standard for this to be measured as part of a post-grinding inspection.
- The standard's requirements for a switch toe that is level with, or above, the bottom of the sidewear scar, were not being interpreted in the same way. The investigation found a widely held view among maintenance personnel that a switch toe that was level with the bottom of the sidewear scar, was compliant with the standard (appendix D). However, the RAIB was advised by a member of Network Rail staff involved in the development of the standard, that this condition would always fail inspection to the standard. The different interpretations may have arisen because the remedial action is different depending on whether the condition occurs on a switch with a sideworn stock rail and a little used switch rail, or on a switch where both the stock and side rails are sideworn. In the first case the remedial action is to reduce the switch toe 2 mm below the bottom of the sidewear scar, in all circumstances. In the second case, this action is not specifically required until either the switch rail fails the TGP8 gauge or the sidewear on the stock rail measures between steps 9 and 7. This different treatment of the same derailment hazard is an apparent inconsistency in the standard.

- An attempt was made in the briefing material that accompanied issue 4 of the 053 standard, and in subsequent training material, to differentiate the more serious failures of switch rails for derailment hazard 2. A diagram was included showing a 2 mm dimension below the 60º line on the TGP8 gauge with the instruction that where contact for more than 200 mm is made with the switch rail below the 60º line plus 2 mm, the switch should be banned to facing moves. In practice, this interpretation of the 053 standard was not being applied because it is more onerous than is required in the standard, and because the 2 mm dimension is not marked on the TGP8 gauge. The consequence is that switches that fail the TGP8 gauge, regardless of the severity of the failure, may be lubricated and remain in service pending a grinding repair within 36 hours.

Use of the TGP8 gauge

159 **Users of the TGP8 gauge considered it to be difficult to apply.**

160 Nearly all persons spoken to during the investigation who used the TGP8 gauge as part of detailed switch inspection, expressed an adverse opinion on the TGP8 gauge. It was found to be ergonomically difficult to use, particularly if used as mandated in a 'gliding' motion, because it was very hard to keep the gauge square to the rails. Some users had developed their own methods, such as applying the gauge at 100 mm intervals. Also, it could sometimes be difficult to see the 60º line on the gauge and pass or fail decisions were considered to be open to subjective interpretation.

161 Strong opinions were also voiced on the difficulty of using a piece of paper with the gauge in rainy or windy conditions, and on the need for a more robust alternative for making safety critical decisions. An alternative gauge is not currently available.

162 The use of the TGP8 gauge by supervisors to visualise the path of train wheels through a switch had, however, been found to be a useful aid to their decision-making.

Protection from moving trains during the grinding repair

163 **The system of work for protecting the grinding team from moving trains did not provide for safe passage through the 'red zone working prohibited' area to the site of work.**

164 When the grinding repair was undertaken, a line blockage was in place for the Z and Y lines only (paragraph 85). The W and X lines remained open while the grinding equipment was carried over them and the members of the grinding team walked to and from the site of work. During the work, two trains approached on the open lines.

165 The Railway Group Standard Rule Book GE/RT8000/HB7[17] 'General duties of a controller of site safety (COSS)' lists types of work that affect the safety of the line and for which the line should be blocked. The list includes carrying heavy or awkward equipment or materials across or along the line.

[17] The Rule Book, published by RSSB details the procedures to be used for operating and working on the railway. It is available at www.rssb.co.uk.

Non-destructive testing following grinding work

166 **The requirement in the 053 standard to check for surface cracking after a grinding repair was not complied with.**

167 After a grinding repair to a switch the 053 standard requires that the work is checked using a non-destructive testing method to reveal any surface cracking that could be propagated by the passage of trains. This check was not done after the grinding repair because both the former GSM and the grinding technician considered that the crack had been completely removed (see paragraph 189 for further information on actions already taken on this matter).

Supervisors' visual inspections of switches

168 **All supervisors' visual inspections of points 167B in the year before the derailment had been conducted with the left-hand switch rail in the normal (open) position (paragraph 70).**

169 The left-hand switch rail steers trains towards the turnout route and is more vulnerable to the development of a derailment hazard than the right-hand switch rail. However, the TGP8 gauge, which is used by the supervisor to visualise the flange path through the switch, cannot be applied with the switch rail in the open position (paragraph 63).

170 The investigation found that it can be difficult for supervisors to get switch rails moved for visual inspection. One reason for this is that inspections often take place at the same time as engineering work. During engineering work, switches are not normally under the control of the signaller and a points operator, who is required to wind the points manually, may not be available. Engineering work was taking place when the SM[T] carried out his inspection of points 167B on 17 July 2011. If a supervisor is unable to get the points moved for inspection, they can ultimately impose a ban to facing moves on the switch, but this action is rarely taken.

Summary of conclusions

Immediate cause

171 The left-hand switch rail of points 167B did not correctly steer the leading wheel of vehicle 79393 to the turnout route; instead the wheel climbed over the switch rail, pulling the corresponding right-hand wheel and trailing axle into derailment (**paragraph 93**).

Causal factors

172 The leading left-hand wheel of the third vehicle climbed the switch rail in the first two metres from the switch toe. This was due to the unsafe profile of the switch rail and the presence of one or more derailment hazards (**paragraphs 96 and 97, Recommendation 2**).

173 The decision not to impose a ban on facing moves on a switch that was beyond repair by grinding in accordance with the 053 standard was causal (**paragraph 106, Recommendations 2 and 5**).

174 It is probable that the following factors were causal:

a. the grinding repair to the left-hand switch rail of points 167B did not restore an angle steeper than 60º (**paragraph 114, Recommendation 5**);

b. the former GSM did not inspect points 167B in accordance with the procedure in the 053 standard for post-grinding inspection to establish whether the switch was safe to be used for traffic (**paragraph 118, Recommendation 5**);

c. the former GSM did not properly inspect the switch in accordance with the 053 standard at the follow-up inspection and the switch was allowed to remain in traffic (**paragraph 130, Recommendation 5**); and

d. the former GSM's competence to inspect and repair switches in accordance with the 053 standard had not been assured (**paragraph 134, no recommendation – see paragraph 187**).

175 It is possible that the following factors were causal:

a. the grinding repair to points 167B was not scoped and therefore properly planned before the grinding team and the former GSM arrived on site (**paragraph 101, Recommendation 5**); and

b. there was an increase in friction on the switch rail due to thinning lubrication and scoring from the recent grinding (**paragraph 123, Recommendation 4**).

Underlying factors

176 The maintenance of switches was driven by compliance within the safety limits of the 053 standard rather than proactive re-building of worn switches by welding before the limits were reached (**paragraph 140, Recommendation 1**).

177 There is no guidance in Network Rail company standards about conditions that make it difficult, or impossible, to restore a switch to compliance with the 053 standard by grinding (**paragraph 146, Recommendation 5**).

Factors affecting the severity of consequences

178 The train was not in passenger service; it was travelling at slow speed and remained upright in derailment.

Additional observations

179 Although not linked to the accident on 27 July 2011 the RAIB observes that:

a. although there is no known history of derailments on switches that comply with the 053 standard, Network Rail has been unable to provide a technical justification to demonstrate that the 053 standard adequately controls all derailment mechanisms arising from sideworn stock and switch rails (**paragraph 155, Recommendation 2**);

b. the 053 standard was not interpreted and applied uniformly (**paragraph 157, Recommendation 2**);

c. users of the TGP8 gauge considered it to be difficult to apply (**paragraph 159, Recommendation 3**);

d. the system of work for protecting the grinding team from moving trains did not provide for safe passage through the 'red zone working prohibited' area to the site of work (**paragraph 163, no recommendation – see paragraph 189**);

e. the requirement in the 053 standard to check for surface cracking after a grinding repair was not complied with (**paragraph 166, no recommendation – see paragraph 189**); and

f. all supervisors' visual inspections of points 167B in the year before the derailment had been conducted with the left-hand switch rail in the normal (open) position (**paragraph 168, Recommendation 5**).

Previous occurrences of a similar character and RAIB recommendations relevant to this investigation

Derailments at Waterloo in 2006

180 In 2006 there were two derailments on facing points on the approach to Waterloo station. The RAIB report (44/2007 'Derailments at London Waterloo 11 September and 24 October 2006') noted that both derailments shortly followed unplanned grinding repairs for defects that had not previously been identified by routine inspections.

181 The report stated that there was no requirement for the supervisor to arrange for points to be moved in order to make an assessment of the need to initiate a detailed inspection to the 053 standard. It also made reference to the lack of guidance on the actions to be taken at an increased inspection and an absence of practical assessments of competence undertaken by line managers of persons carrying out 053 inspections.

182 One of the grinding repairs took place during a two hour possession in which the work was also scoped. At the end of the repair work, the post grinding inspection deemed the switch to be compliant with the 053 standard but the switch subsequently failed an inspection for both hazards 1 and 2. The other grinding repair was attempted on a switch rail that was worn beyond the point of effective repair.

183 The RAIB previously made recommendations to Network Rail following its investigation of these derailments at Waterloo station which address factors also identified in this investigation.

Recommendation 1

Network Rail should review and revise the guidance provided for staff undertaking or supervising the standard inspections to make the clear the following:

a. the detailed requirements for visual and increased-frequency inspections, including the use of photographs, and the development of standard forms with suitable prompts for this purpose;

b. the conditions where a switch blade repair cannot be safely achieved such that staff understand the alternative courses of action available; and

c. that work should be suitably planned and organised so that there is time for it to be carried out (with sufficient lighting for individuals to complete necessary inspections).

Status of actions taken as reported by the Office of Rail Regulation

The Office of Rail Regulation (ORR) reported to the RAIB in January 2011 that Network Rail's company standard NR/L2/TRK/053 'Inspection and repair to reduce the risk of derailment at switches' Issue 4 was extensively redrafted to take account of the recommendation. The ORR stated that the redrafting included detailed requirements for visual and increased frequency inspections and made clear the conditions where a switch rail repair cannot be safely achieved and the alternative courses of action available. The ORR was also satisfied that Network Rail's Ellipse work planning process and the Ellipse work management handbook adequately met the intent of the recommendation on the planning and organising of switch repairs. In 2008/2009 the ORR undertook inspections relating to Network Rail's implementation of NR/L2/TRK/053 and found that Network Rail's maintenance teams were managing the risks arising from switch defects as defined by the 053 standard and that competent staff were carrying out switch inspections and maintenance in accordance with the standard.

After reviewing the information received from Network Rail and the outcome of ORR's inspection work, the ORR concluded that Network Rail had implemented the recommendation and did not propose to take any further action unless it became aware that the information it had received from Network Rail was inaccurate.

Relevance to this investigation

The RAIB considers the actions taken by Network Rail to implement this recommendation have not fully achieved its intent. The investigation found there remains an absence of clear guidance on when a supervisor should require a switch to be moved so that it can be inspected in both its normal and reverse positions (paragraph 63) and there is continuing uncertainty about the extent of the inspection required at an increased inspection (paragraph 158, fourth bullet). Also, that there is insufficient guidance on when a switch rail is beyond a grinding repair (paragraph 146), and that Ellipse is not a suitable tool for planning and organising unplanned switch repairs where limited access to the track is an overriding factor (paragraph 103).

The lack of clear guidance to assist a decision on when a switch is not repairable to the 053 standard and the inability to scope the grinding repair in advance were factors in the causal chain of the derailment at points 167B.

Recommendation 5 of this report addresses the need for Network Rail to review the actions it has taken to meet the objectives of Recommendation 1 of RAIB report 44/2007.

Recommendation 3

Network Rail should provide a handbook for use by front-line and supervisory staff which summarises the requirements of standard inspections, post inspection actions, and pre- and post-grinding inspections. This should contain the necessary inspections forms. The handbook should be written in plain English and certified as such.

Status of actions taken as reported by the Office of Rail Regulation

The ORR reported to the RAIB in December 2009 that it had accepted Network Rail's response to deliver the recommendation and would not be pursuing it through inspection work as it had confidence that it would be acted upon.

Relevance to this investigation

The RAIB considers that the actions taken to implement this recommendation have not fully achieved its intent. It has found that although the 053 standard was amended and reissued, a handbook summarising the requirements of each type of inspection, has not been provided. Several witnesses told the RAIB that the 053 standard in its amended format is more difficult to follow than previous issues and is not easy to use as a reference guide on site. The variations in interpretation of the standard and the continued uncertainty about what should be done at an increased inspection (paragraph 157), support the conclusion that there remains a need for a handbook written in plain English to assist the understanding and consistent application of the standard's requirements.

Recommendation 5 of this report addresses the need for Network Rail to review the actions it has taken to meet the objectives of Recommendation 3 of RAIB report 44/2007.

Recommendation 6

Network Rail should introduce the requirement for a follow-up inspection after a standard repair is carried out involving welding or grinding. This should be undertaken by an independent and competent person within a timescale commensurate with minimising the risk of derailment.

Status of actions taken as reported by the Office of Rail Regulation

In January 2011 the ORR reported to the RAIB that post-grinding and follow-up checks had been introduced by Network Rail in the revised and reissued standard NR/L2/TRK/053 (issue 5) and these were required by the standard to be carried out by a competent person. The competence of staff was discharged by Network Rail's Assessment in the line competence management system. However, Network Rail had advised the ORR that it was not reasonably practicable to have independent checks by staff who were not part of the team responsible for completing the work and that the measures Network Rail had introduced met the intention to ensure that post work inspections were effective. These measures had resulted in no further derailments.

The ORR advised the RAIB that inspections carried out by the ORR in 2008/2009 to assess Network Rail's compliance with NR/L2/TRK/053 had found that competent staff were carrying out inspection and maintenance to the required standards. The ORR also reported that it had no legal powers to enforce a follow-up inspection by an independent person where there was an alternative process in place to control the risk.

Therefore, after reviewing the information received from Network Rail and its inspection work the ORR concluded that Network Rail had taken the recommendation into consideration and had taken action to implement it by alternative means.

Relevance to this investigation

The RAIB considers the actions taken to implement this recommendation have only partly achieved its intent. A follow-up inspection carried out by a person who was both competent and independent of the grinding repair, may have averted the derailment (paragraphs 131 to 132).

Recommendation 5 of this report addresses the need for Network Rail to review the actions it has taken to meet the objectives of Recommendation 6 of RAIB report 44/2007.

Recommendation 11

Network Rail should provide sufficient technical resources to select and manage sub-contractors engaged in rail grinding activity effectively. This should include the pre-scoping of any non-routine work and the undertaking of on-site checks including periodic technical audits. Standard 053 repairs should not be attempted unless the work has been scoped in advance by an appropriately experienced and qualified person.

Only the final sentence of the recommendation is of relevance to this investigation.

Status of actions taken as reported by the Office of Rail Regulation

The ORR reported to the RAIB in January 2011 that the relevant part of the recommendation had been implemented, subject to a review of further information which it had requested from Network Rail.

Relevance to this investigation

The RAIB considers the actions taken to implement the relevant part of this recommendation have not fully achieved its intent. The investigation found that the repair of points 167B proceeded without being scoped in advance by an appropriately experienced and qualified person and that such scoping was not practicable for work in areas, such as the Princes Street Gardens, with limited access (paragraph 103).

Recommendation 5 of this report addresses the need for Network Rail to review the actions it has taken to meet the objectives of Recommendation 11 of RAIB report 44/2007.

Derailment near Exhibition Centre station, Glasgow in 2007

184 After the Waterloo derailments there was another derailment on facing points which similarly followed a grinding repair. The RAIB report of the investigation (04/2009 'Derailment near Exhibition Centre station, Glasgow, 3 September 2007') identified the incomplete grinding and incorrect inspection undertaken on completion of the work as one of the causal factors. The lack of independent supervision of grinding and inspection work was found to have been a contributory factor to the derailment.

185 At the time of publication of the report in February 2009, recommendation 6 of the Waterloo report (regarding the need for a follow up inspection of switch grinding repairs by an independent and competent person) had been rejected by Network Rail but was still open pending a response from the ORR. It was decided, therefore, not to re-make the recommendation pending this response (see paragraph 183, Recommendation 6, 'Status of actions taken as reported by the Office of Rail Regulation').

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

Actions reported that address factors which otherwise would have resulted in a RAIB recommendation

186 After the derailment all persons in Scotland with the competence to inspect switches in accordance with the 053 standard attended a one-day course at Network Rail's training school in Larbert to be re-briefed on the standard. This included a practical test of their use of the TGP8 gauge. Anyone who had not attended the briefing was removed from switch inspection duties. Others who had been trained in the 053 standard but who did not conduct detailed inspections (for example, SM[T]s) attended for a half-day briefing on the standard. Copies of a presentation detailing the main points of the 053 standard were also distributed.

187 Network Rail is implementing a revised competence management system that places greater emphasis on practical assessments of competence. A project to change the AiTL system began a phased introduction in January 2012. This is intended to significantly reduce the assessment workload on managers and give them more time to directly observe the competences of their staff on site. In June 2012 the second phase of the project introduced a change from annual computer-based knowledge testing to a system in which the frequency of knowledge testing is commensurate with the risks associated with the work. The second phase will also end the keeping of work experience log books and replace them with self-declarations of work completed. Network Rail expects that the organisational changes associated with the new system will be fully implemented by the end of 2012, but further developments are planned for 2013 and beyond involving the introduction of new technology to improve Network Rail's management of competence.

Other reported actions

188 Network Rail has stated its intention to carry out a technical review of the 053 standard to ensure that it is adequately addressing all derailment mechanisms and to revise the standard if necessary.

189 The RAIB has advised Network Rail of the non-compliances with its company standards and the Rule Book relating to the safe system of work for the grinding repair and the lack of non-destructive testing following the repair and will not be making any recommendations in these areas.

190 The Edinburgh Delivery Unit has reviewed its inspection frequencies of switches on the basis of risk assessment and revised a number of schedules. All switches which were assessed as high risk, for example, because of sidewear, were placed on a 13-weekly, rather than a 24-weekly inspection cycle. Other switches assessed as presenting no risk of derailment were removed from routine detailed inspection. Supervisors will continue to inspect these switches as part of their periodic visual inspections and can request a detailed inspection as necessary.

Recommendations

191 The following recommendations are made[18]:

1 *The purpose of Recommendation 1 is to achieve a standardised procedure for monitoring and recording the degradation of switches at risk of causing derailment and the planning of timely maintenance intervention or renewal of worn components before the limits in the 053 standard are exceeded. This is particularly necessary for switches in high risk areas such as the approaches to busy stations which are exposed to high levels of wear, where access for inspection and maintenance is limited and where their availability for service is critical.*

Network Rail should provide guidance on maintenance intervention limits and their application to manage wear on switch rails as part of its asset management strategy to reduce the likelihood of switches failing the 053 standard and the risk of derailment (paragraph 176).

2 *The purpose of Recommendation 2 is to gain assurance that the mechanisms of derailment are fully understood, that these are fully addressed by the inspection procedures in the 053 standard and that the inspection procedures are uniformly applied as intended.*

a. Network Rail should carry out a thorough technical review of the 053 standard to satisfy itself that it has a full understanding of how the standard addresses the following:

- the risk of derailment from worn wheels on a switch rail that is compliant with the TGP8 gauge (paragraphs 172 and 179a);
- the practicability of achieving a 1:600 gradient when blending-out a grinding repair of switch rail damage, or for removing a derailment hazard 1 (paragraphs 173); and
- the potential risk of a ramp being created by the introduction of a switch rail that is failing gauge 2 in the first metre, between a sideworn stock rail and wheel flange, particularly where the wheel flange is in flange contact with the stock rail (paragraph 172).

continued

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

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

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

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

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

b. In the short term, Network Rail should also review the scope for misinterpretation and inconsistent application of the standard's requirements and take any necessary action, for example, through briefing and its competence management system, to ensure that there is a common understanding and application of the standard's procedures for inspection and repair (paragraph 179b).

3 *The purpose of Recommendation 3 is to achieve a means for gauging the flange contact angle of switch rails which reduces the reported difficulties of use of the current TGP8 gauge and which engenders greater confidence in the readings obtained.*

Network Rail should investigate potential improvements to the TGP8 gauge for conducting detailed inspections to the 053 standard, or develop an alternative means for assessing the flange contact angle of switch rails. The aim should be to provide a more accurate and objective method for determining a non-compliant flange contact angle on a switch rail and which is more ergonomically suited to on-track conditions of use (paragraph 179c).

Network Rail should then take steps to implement any improvements identified, or introduce any alternative assessment method, and train/brief staff as necessary.

4 *The purpose of Recommendation 4 is to extend the criteria for fitting automatic lubricators to high risk switches which may not qualify for automatic lubrication under current standards.*

Network Rail should consider whether the criteria specified in NR/L3/TRK/3510/A01 for the installation of automatic lubricators on switches should be extended to include the high rails of switches subject to sidewear in areas, such as the approaches to busy stations, where access for maintenance is limited, and where automatic lubrication could slow the development of sidewear and mitigate the risk of derailment (paragraph 175b).

5 *The purpose of Recommendation 5 is to address factors which were also found in the RAIB's investigation of similar derailments at London Waterloo and Exhibition Centre, Glasgow.*

Network Rail should review the actions taken in response to the recommendations in the RAIB report 44/2007 to identify why these were insufficient to prevent the recurrence of issues they were intended to address. The review should include an assessment of how operational expectations of availability for service influence the implementation the 053 standard and consider the need for a reappraisal of how derailment risks at switches are managed to prevent their recurrence in future (paragraphs 173, 174a to 174c, 175a, 176, 177, 179f and 180 to 185).

Appendices

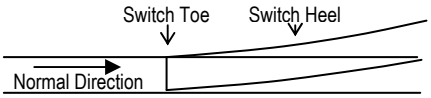
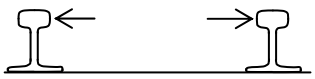
Appendix A - Glossary of abbreviations and acronyms

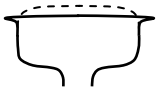
AiTL	Assessment in The Line
ATME	Assistant Track Maintenance Engineer
TEF	Track Engineering Form
CCTV	Closed Circuit Television
COSS	Controller Of Site Safety
DMU	Diesel Multiple Unit
GSM	Grinding Supervisory Manager
NRN	National Radio Network
RAIB	Rail Accident Investigation Branch
SM[T]	Section Manager [Track]
TME	Track Maintenance Engineer

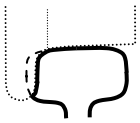
Appendix B - Glossary of terms

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

Access point	A designated point along a railway at which entry to railway property may be made safely.*
Angle of attack	The angle between the running edge of the rail and the plane of the wheel flange.*
Assessment in the line	Part of the competence management system covering Network Rail's employees involving an assessment of competence carried out under the supervision of an employee's line management.
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.*
BS113A	A type of flat bottomed rail which weighs 113 lbs/yd.
Cant	The vertical difference in height of the two rails of a track measured at the centre lines of the heads of the rails. It is positive when the outer rail on a curve is elevated above the inner rail, and negative when the inner rail on a curve is raised above the outer rail.
Cast crossing	A crossing at the intersection of rails made of cast manganese steel.
Chamfered switch	A switch in which the adjacent sides of the heads of the switch rail and stock rail are machined to a matching angle.
Coefficient of friction	The measure of the resistance to sliding of two surfaces in contact, ie in this case, a switch rail and a wheel flange.
Controller of site safety	A railway safety critical qualification demonstrating the holder's competence to arrange a safe system of work.*
Crossing nose	An assembly that permits the passage of wheel flanges across other rails where tracks intersect.*
Diesel multiple unit	A diesel powered passenger train able to run as part of a train with other similar vehicles.
Down	The track on which trains run away from Edinburgh.
Empty coaching stock	The term for a train consisting of empty passenger coaches being moved from one place to another.*

Facing direction	Direction of travel over a set of switches (set of points) in which a vehicle can be directed to one of two or more diverging routes.*
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. Such an arrangement is often incorporated into a point machine.*
Facing switch (also known as facing points)	A set of points or set of switches installed so that: a. two or more routes diverge in the direction of travel; and b. traffic travels from switch toe to switch heel in the normal direction of traffic.* 
Flange	The extended portion of a rail wheel that provides it with directional guidance.*
Flange contact angle	The angle measured between the plane of the crown of the rail and the plane of contact between the wheel flange and the rail. A flange contact angle greater than 60º on the switch rail reduces the risk of a flange climbing derailment.
Four-aspect	Railway signal that uses four coloured lights to indicate whether the driver has to stop, needs to be prepared to stop or can proceed without restriction. The lights may show: ● green - proceed, the next signal may be displaying green or double yellow; ● double yellow - caution, there are two signal sections to the stop signal, the next signal may be displaying a single yellow; ● single yellow - caution, the next signal may be displaying a stop signal; and ● red – stop.
Four-foot	The area between the rails of a railway line.
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.
Full depth	Switch machined from rail the same depth as, and usually the same rail section as, the stock rail.
Gauge face	The side of the rail head facing towards the opposite running rail. 
Grade A	A rail steel with a minimum hardness of 260 Brinell used for its improved wear resistance over normal rail.*
Half-set	One switch rail and one stock rail together make a switch half set.

Hogging	The vertical upward curvature of an unfastened rail due to stresses built into the rail during manufacture. The effect is observed most clearly in switch rails.*
Line blockage	A section of line that is blocked, according to defined rules, so that engineering work affecting the safety of the line can be carried out on the railway.
Lipping	A description of the effect on a running edge being subjected to the rolling action by passing wheelsets, causing plastic deformation of the rail head.* 
National 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.
National radio network	A dedicated national radio network operated and maintained by Network Rail that allows direct communication between driver and network controller.*
Normal (points position)	The points direction setting which carries the dominant traffic flow.
On-train data recorder	Equipment fitted on-board a traction unit which records train speed and the status of various controls and systems relating to the unit's operation.
Points	Points are provided to allow trains to move from one track or route to another. This is achieved using a pair of rails that move from one side of the track to the other and allow the route to be selected, normally by the signaller. These rails are known as switch blades and are designed to abut against static rails known as stock rails, a switch blade and stock rail pair is known as a switch half set. A set of points incorporates a left and a right-hand switch half set. Points are sometimes referred to as switches.
Possession	A period of time during which one or more lines are blocked to trains to permit work to be safely carried out on or near the line. A possession taken for an agreed period without the facility to run trains in the area during that period until such time as the holder of the possession decides to relinquish it. Currently called a T3 possession.*
Red zone working prohibited	A length of track on which work cannot be carried out safely if trains are running. This is normally due to a place of safety not being available in the area.*
Reverse (points position)	For a set of points this is the position permitting the passage of trains on the lesser used route.
Rolling contact fatigue	Collective term for all rail defects directly attributable to the rolling action of a rail wheel on the rail.

Route indicator	An indicator associated with a signal that shows a driver which route is set where more than one route is available.*
Sectional Appendix	An operating publication produced by Network Rail that includes details of running lines, permissible speeds, and local instructions.
Sidewear	A progressive removal of rail metal generally afflicting the high rail on curves, due to the high lateral forces produced when a train negotiates a curve with insufficient cant or high cant deficiency. Eventually the rail head assumes a profile complimentary to the passing wheelsets, increasing the likelihood that wheelsets will climb the rail. Sidewear is measured using a sidewear gauge.* 
Sidewear scar	The imprint left on the rail where metal has been removed by passing wheel flanges.
Slipper bearing	A low friction polymer insert fitted to a slide baseplate to reduce the effort needed to operate the switch. It is not necessary to lubricate this type of baseplate.*
Stock rail	The fixed rail in a switch half set. The other rail is the switch rail.*
Stretcher bar	A bar linking the two switch rails in a set of points connected by a bracket to each rail.
Switch type	Switch types are usually denoted by letters: 'A' being the switch with the greatest switch heel angle, to 'H', which has the smallest switch heel angle.
Supplementary 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. Also called a back drive.*
Switch rail	The thinner movable machined rail section that registers with the stock rail and forms part of a switch assembly.
Track circuit block	A method of signalling trains in a section of line where safety is ensured by the use of track circuits or other means of automatic train absence detection and without the use of block instruments.
Track section manager	The local Network Rail manager directly responsible for managing teams of track maintenance staff.*
Track maintenance engineer	The Network Rail manager responsible for the delivery of track maintenance, and the line management of the Track Section Managers, within a defined area.
Tread	The part of a rail wheel that runs on top of the rail.

TRUST	A computer system that processes reports of train operation and compares it with the scheduled timetable.
Up	The track on which trains run towards Edinburgh.
Vehicle dynamics modelling	A dynamic modelling system for rail vehicles which allows a virtual model of any rail vehicle to be run over real measured track geometry.*
Vertical	A design of switch in which the rails are vertical throughout.
Voiding	A track fault consisting of spaces under sleepers or bearers in the packing area, often caused by inadequate packing or differential settlement between sleepers. Tell tale signs include rounded pale ballast on top of the sleeper ends and pronounced vertical deflection of the track under passing trains.*
Wheel profile	The cross section through the flange and running surface of the wheel.
Wheel slip prevention	A control system fitted to modern locomotives and multiple unit trains that prevents the driving wheels spinning out of control or locking up during times of reduced adhesion. They work by automatically releasing and re-applying the brake on slipping wheelsets in order to find and make use of the maximum level of adhesion available. It is analogous to anti-lock braking and traction control on a motor car.*
Wideway	An interval between tracks that is wider than a tenfoot (3 050 mm).

Appendix C - Key standards current at the time

NR/L2/TRK/053 'Inspection and repair to reduce the risk of derailment at switches', Issue 5, 26 August 2008	Network Rail
NR/L2/TRK/001 'Inspection and maintenance of permanent way', Issue 4, 5 December 2009	Network Rail
GM/RT2466 'Railway wheelsets', Issue 3, February 2010	RSSB
GE/RT8000/HB7 Rule Book ' Issue 1, Dec 2010	RSSB
NR/L3/TRK/3510/A01 'Lubrication of plain line running rails, check rails and S&C', Issue 1, 5 March 2011	Network Rail
NR/SP/CTM/011 'Competence and training in track engineering', Issue 1, December 2006	Network Rail
NR/L3/TRK/1202 'S&C systems – Flat bottom full depth switches – Management of fixed stretcher bar assemblies, lock stretcher bars fastenings and the associated defects', Issue 2, June 2010	Network Rail
NR/L3/CTM/306 'Competence Assurance – Assessment in the line (AiTL), Issue 1, September 2010	Network Rail

Appendix D - Summary of derailment hazards as defined in standard NR/L2/TRK/0053 (issue 5)

Derailment Hazard	Abbreviated inspection criteria	Tell tale signs	Inspection gauges required
Hazard 1 Sideworn stock rail	Check that top of switch rail is below base of sidewear on stock rail. Check for hogging	▪ Switch tip projects above the bottom of the sidewear scar ▪ Switch tip has been struck by wheels ▪ Switch tip has been deformed by wheels into the sideworn stock rail	Plain line NR4 sidewear gauge (figure 14a) Metric stepped gauge (figure 14b)
Hazard 2 Stock rail and switch rail both sideworn	Check that sidewear angle on switch rail is not less than 60° for more than 200 mm. Check for hogging	▪ Switch rail may be more worn and display a flatter sidewear angle than the stock rail ▪ The wheels have formed a ramp on the switch rail ▪ Marking shave been left by the wheel flange as it has begun to climb the switch rail and then slipped back	Plain rail NR4 sidewear gauge Metric stepped gauge TGP8 gauge (figure 14c) Gauge 2 (figure 14d)
Hazard 3 Stock rail headwear with less worn switch rail	Check the relative height of the switch rail compared with the stock rail Check for hogging	▪ The switch tip has been struck by wheels	Gauge 1 (not illustrated) Metric stepped gauge
Hazard 4 Switch blade damage	Check extent and position of any damage to switch rail Check for hogging	▪ Lipping on the gauge face of the stock rail and/or the back edge of the switch rail ▪ Horizontal cracking under lipping on switch rail ▪ Small pieces of metal chipped out of switch rail ▪ Hogging of switch rails associated with lipping	Gauge 2 Metric stepped gauge
Hazard 5 Sharp profile (applies to hardened rails made from MHT and austenite manganese steel (AMS)	Check that square lip has not been formed on switch rail	▪ A noticeable edge or faceted surface at the gauge corner ▪ Metal dust or shavings near switch ▪ Bright marking indicting wheel contact with a sharp radius	Switch rail radius gauge (not illustrated)

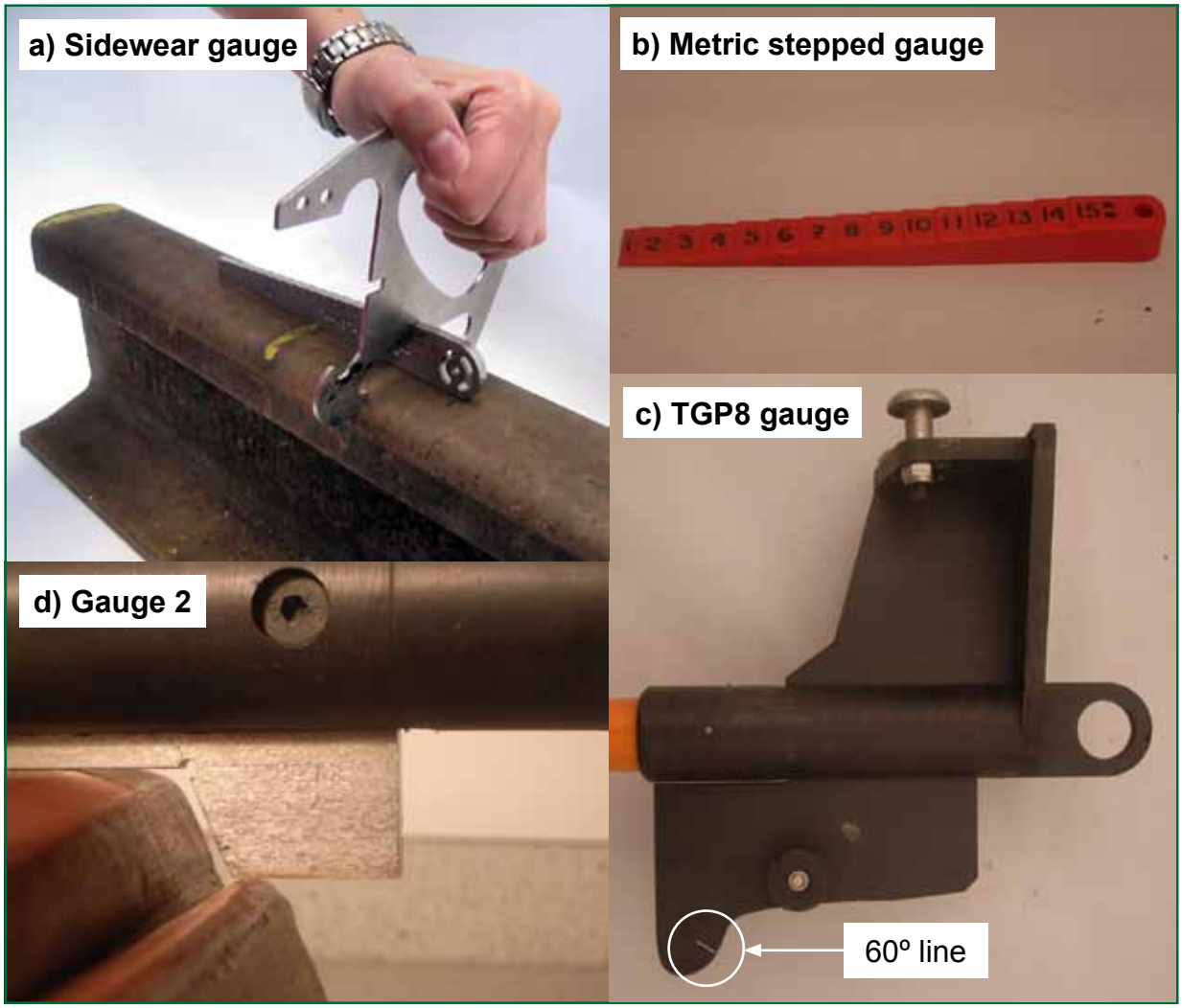


Figure 14: Gauges used in the inspection of switches

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

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