Rail Accident Investigation Branch

Rail Accident Report

Derailment due to a landslip, and subsequent collision, Watford
16 September 2016

Report 11/2017
August 2017

This investigation was carried out in accordance with:

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

Any enquiries about this publication should be sent to:

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

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

Preface

The purpose of a Rail Accident Investigation Branch (RAIB) investigation is to improve railway safety by preventing future railway accidents or by mitigating their consequences. It is not the purpose of such an investigation to establish blame or liability. Accordingly, it is inappropriate that RAIB reports should be used to assign fault or blame, or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

The RAIB's findings are based on its own evaluation of the evidence that was available at the time of the investigation and are intended to explain what happened, and why, in a fair and unbiased manner.

Where the RAIB has described a factor as being linked to cause and the term is unqualified, this means that the RAIB has satisfied itself that the evidence supports both the presence of the factor and its direct relevance to the causation of the accident. However, where the RAIB is less confident about the existence of a factor, or its role in the causation of the accident, the RAIB will qualify its findings by use of the words 'probable' or 'possible', as appropriate. Where there is more than one potential explanation the RAIB may describe one factor as being 'more' or 'less' likely than the other.

In some cases factors are described as 'underlying'. Such factors are also relevant to the causation of the accident but are associated with the underlying management arrangements or organisational issues (such as working culture). Where necessary, the words 'probable' or 'possible' can also be used to qualify 'underlying factor'.

Use of the word 'probable' means that, although it is considered highly likely that the factor applied, some small element of uncertainty remains. Use of the word 'possible' means that, although there is some evidence that supports this factor, there remains a more significant degree of uncertainty.

An 'observation' is a safety issue discovered as part of the investigation that is not considered to be causal or underlying to the event being investigated, but does deserve scrutiny because of a perceived potential for safety learning.

The above terms are intended to assist readers' interpretation of the report, and to provide suitable explanations where uncertainty remains. The report should therefore be interpreted as the view of the RAIB, expressed with the sole purpose of improving railway safety.

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

This page is intentionally left blank

Derailment due to a landslip, and subsequent collision, Watford, 16 September 2016

Contents

Summary

Just before 07:00 hrs on Friday 16 September 2016, a London-bound passenger train operated by London Midland struck a landslip at the entrance to Watford slow lines tunnel. The leading coach of the 8-car train derailed to the right. The train came to a halt in the tunnel about 28 seconds later with the leading coach partly obstructing the opposite track. About nine seconds later, the derailed train was struck by a passenger train travelling in the opposite direction. The driver of the second train had already received a radio warning and had applied the brake, reducing the speed of impact. Both trains were damaged, but there were no serious injuries to passengers or crew. However, had the first train been derailed only a short distance further to the right the consequences would have been much more severe.

The landslip occurred during a period of exceptionally wet weather. Water from adjacent land flowed into the cutting close to the tunnel portal and caused soil and rock to wash onto the track. The site had not been identified by Network Rail as being at risk of a flooding-induced landslip. Such a landslip had occurred at the same location in 1940, also causing a derailment. Drawings from the 1940s relating to a structure subsequently constructed to repair the slope were held in a Network Rail archive, but were not available to either Network Rail's asset management team or the designers of a slope protection project which was ongoing at this location at the time of the accident. As a consequence, this project made no provision for drainage.

Both trains were crewed by a driver and a guard. The drivers each contacted the signaller to inform him of the accident and request the evacuation of passengers. The guards checked on their passengers to confirm that there were no casualties, and made regular announcements to keep passengers informed.

The RAIB has made six recommendations. Four recommendations are addressed to Network Rail relating to the improvement of drainage, improvement in the identification of locations vulnerable to washout, access by the emergency services, and to expedite a project intended to identify all drainage assets. One recommendation is made to the Rail Delivery Group, in conjunction with RSSB, to promote a review of the circumstances when bogie or infrastructure design could provide derailment mitigation. One recommendation is made to Siemens, the manufacturer and maintainer of the trains, to address issues relating to the securing and location of emergency equipment which came loose in the driving cabs of both trains when they collided.

The RAIB has also identified three learning points relating to issues identified during the investigation.

Introduction

Key definitions

1 Metric units are used in this report, except when it is normal railway practice to give speeds and locations in imperial units. Where appropriate the equivalent metric value is also given.

2 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. Sources of evidence used in the investigation are listed in appendix C.

3 References to left and right are relative to the forward motion of the train being described.

The accident

Summary of the accident

4 At about 06:56 hrs on Friday 16 September 2016, the 06:19 hrs London Midland service from Milton Keynes Central to London Euston (train reporting number[1] 2K04) struck a landslip on the approach to the north portal of Watford slow lines tunnel. The train was travelling on the *up slow* line at 66 mph (106 km/h) and all wheels of the leading coach derailed. The train remained upright and, after travelling 380 metres into the tunnel, stopped, partly obstructing the adjacent *down slow* line. Approximately nine seconds later, the leading coach was struck a glancing blow by train 2Y59 which was travelling in the opposite direction.

5 Train 2Y59, the 06:34 hrs London Midland service from Euston to Birmingham was already in Watford slow lines tunnel and approaching on the down slow line at 79 mph (127 km/h) when its driver received an emergency stop message triggered by the driver of train 2K04. The driver of train 2Y59 applied the brakes which reduced the speed of the train to about 34 mph (55 km/h) by the time the collision occurred. Train 2Y59 did not derail and stopped alongside the derailed train (figure 2).

6 The right-hand cab doors of both trains were torn off during the collision and the leading vehicles of both trains were damaged. The driver of train 2K04 and two passengers on this train were slightly injured. There were no injuries on train 2Y59.

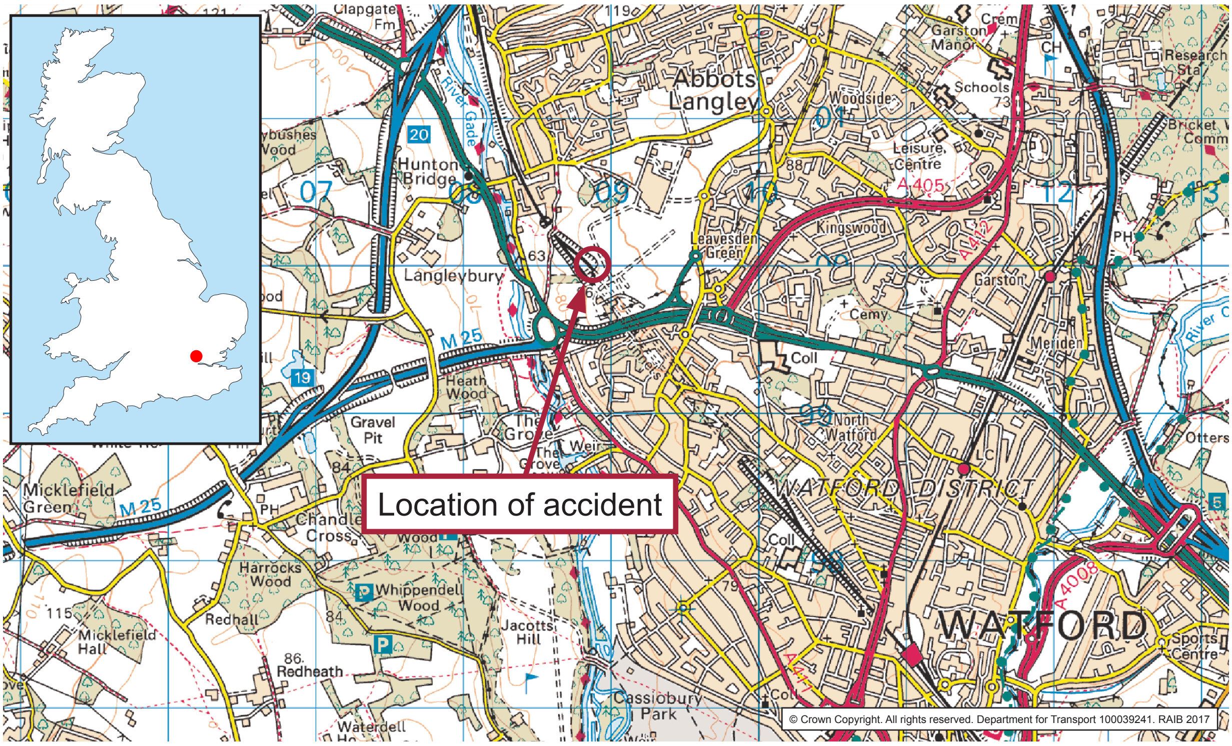


Figure 1: Extract from Ordnance Survey map showing location of accident

[1] An alphanumeric code, known as the 'train reporting number', is allocated to every train operating on Network Rail's infrastructure.

Figure 2: Rear of train 2Y59 (left) stopped inside the tunnel adjacent to derailed train 2K04 (photograph courtesy of British Transport Police)

Context

Location

7 The Watford tunnels are located between Watford Junction and Kings Langley on the west coast main line. The tunnels are in Hertfordshire, although they are in an area which forms part of the London conurbation and is within the M25 orbital motorway. There are two parallel double track tunnels at this location, carrying the up and down fast, and up and down slow lines respectively. The tunnels are separated by approximately 60 metres (figure 3) and carry both passenger and freight services.

8 The landslip occurred close to the north portal (entrance) of the slow lines tunnel and obstructed the up slow line at 19 miles 946 yards[2]. This tunnel was opened in 1874 as part of a scheme to widen the route to four tracks and increase capacity. The tunnel is straight and 1990 yards (1820 metres) long.

9 Approaching from the north, the slow lines diverge from the fast lines at Gypsy Lane bridge, 400 m north of the tunnels. There is pedestrian access to the railway from Gypsy Lane at this point. The slow lines then follow a *reverse curve* with a 70 mph (113 km/h) speed restriction through a steep sided *cutting* leading to the tunnel. At the approach to the tunnel, the line speed increases to 90 mph (145 km/h).

10 To the east of this cutting, the ground rises slightly to the summit of a flat-topped hill. This area was previously a military, then civilian, airfield. It now forms part of a studio complex and is used for outdoor film sets.

[2] Track mileages are measured from London Euston station.

11 A project to protect the railway from rock falls, and prevent the line being obstructed by rock, soil and trees falling from the cutting slope, was ongoing at the time of the accident. This involved clearing vegetation and covering the whole of the cutting slopes with wire mesh netting and the upper part of the slope with erosion protection matting.

12 All four lines form part of the west coast main line and are equipped with overhead line electrification equipment. The signalling system uses *axle counters* to detect trains.

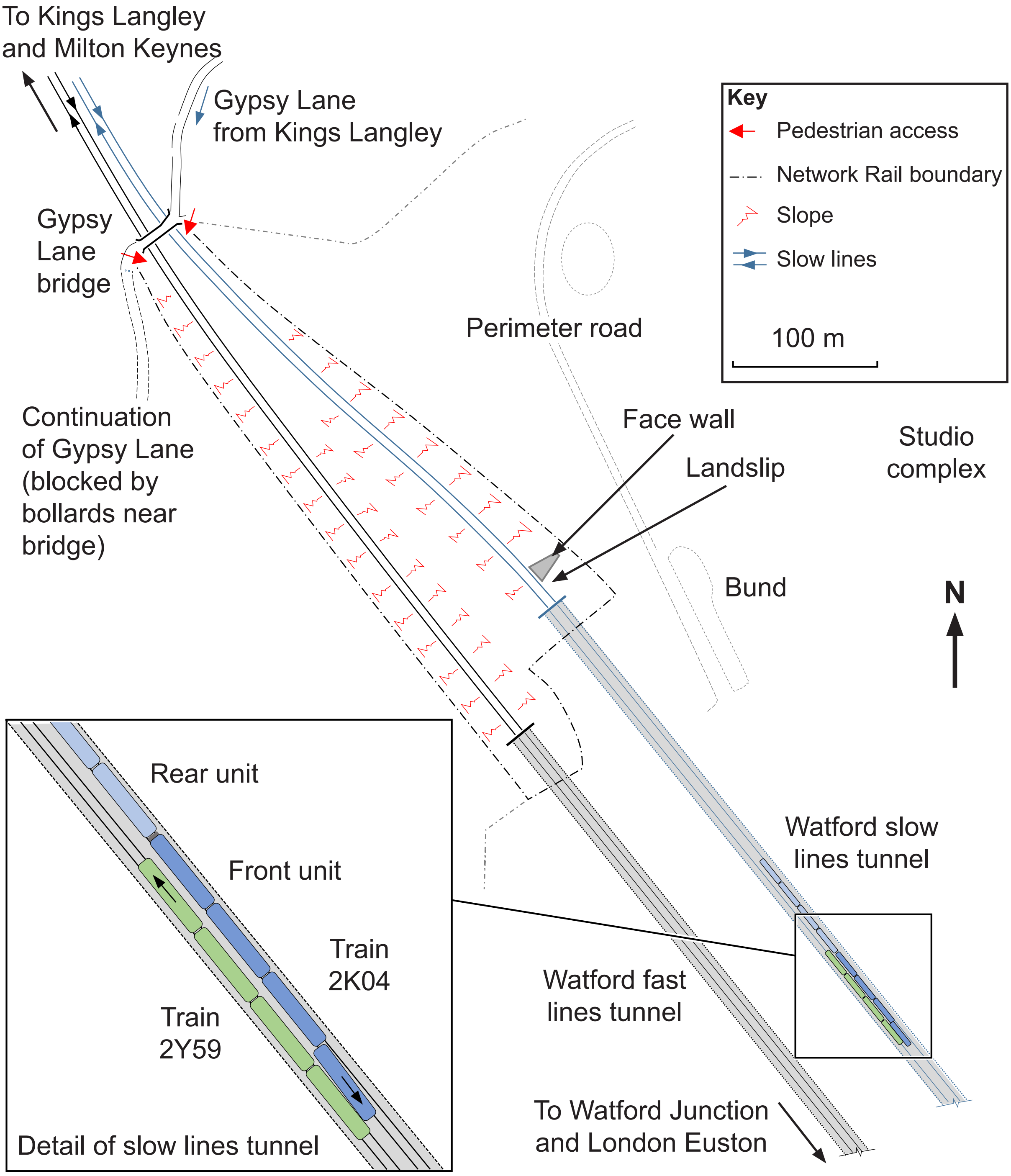


Figure 3: Diagram showing layout of track and tunnels

Organisations involved

13 Network Rail's London North Western (LNW) Route[3] was the owner and maintainer of the railway infrastructure at Watford, and the employer of the civil engineers responsible for inspection and maintenance of the cutting, track maintenance staff, signallers and route controllers. It also employed the staff who undertook the *earthworks* examinations at the accident site. Network Rail's Infrastructure Projects division was responsible for procuring and managing the slope protection works ongoing at the time of the accident.

14 London & Birmingham Railway Ltd., trading as London Midland, operated some passenger services using the Watford tunnels including both trains involved in the collision. It was also the employer of the train crew on these trains.

15 Virgin Trains West Coast operated other services through the tunnels and provided a rescue train and crew.

16 J. Murphy and Sons Limited (Murphy) was undertaking the cutting slope protection work on behalf of Network Rail.

17 Amey plc was employed by Murphy to design the slope protection works. Although Amey undertook most earthworks inspections for LNW Route including examination of the slow lines cutting, Network Rail started doing these in September 2016 because of access limitations at this location.

18 Siemens AG was the manufacturer and maintainer of both trains involved.

19 Warner Bros Entertainment UK Ltd was the owner of the Leavesden Studios complex located adjacent to the railway cutting.

20 All the above parties freely co-operated with the investigation.

Trains involved

21 Train 2K04 was formed of a class 350/2 and a class 350/1 Siemens Desiro electric multiple unit (EMU), respectively numbered 350264 and 350117. This 8-car service was carrying approximately 240 passengers and 2 crew.

22 Train 2Y59 was formed of a class 350/2 Siemens Desiro EMU unit, numbered 350233. This 4-car service was carrying approximately 35 passengers and 2 crew.

23 Class 350/2 units are equipped with a pantograph to obtain electrical power from the overhead line. Class 350/1 units are dual voltage and equipped to obtain power from either the overhead line or from the *third rail* depending on the route on which they are being operated. On the class 350/1 units operated by London Midland, the shoegear equipment has been removed as the units do not currently operate over third rail routes.

24 Trains which operate on the national rail network are equipped with *GSM-R* radio equipment to allow communication between train drivers and signallers. This equipment also allows train drivers to issue emergency stop messages to other trains in the surrounding area.

---

[3] In 2012, Network Rail devolved responsibility for day-to-day operation of Britain's main line railway to eight strategic routes. London North Western Route manages the west coast main line between London Euston and the Scottish border at Gretna.

Staff involved

25 Each of the two trains involved in the accident was staffed by a driver and senior conductor (guard).

26 The signaller was located at the Watford workstation within Wembley Mainline signalling control centre. LNW operations (route control) staff, responsible for regulating the train service, were located at Rugby Route Operations Centre.

27 The cutting slope was among the earthworks managed by the Route Asset Manager - geotechnics (RAM (geotechnics)) for London North Western Route. The *on-track* and *off-track* drainage was managed by the Route Asset Manager – drainage (RAM (drainage)).

External circumstances

28 The landslip occurred during a prolonged period of intense rainfall. The rain commenced just after 03:00 hrs on 16 September 2016, with the landslip occurring nearly four hours later at first light when visibility was poor.

The sequence of events

Events preceding the accident

29 Several days of hot, dry weather preceded the accident. The weather changed on the night of 15/16 September 2016 with heavy overnight thunderstorms across south-east England. At 03:10 hrs on the morning of 16 September, a period of heavy rain started in the Watford area. During the following four hours, over 50 mm of rain fell, equivalent to the 2009-2016 average for the whole of September in the Watford area. Significant amounts of water ran over the surface of the ground to the east, which slopes down towards the railway cutting.

30 The running of trains was unaffected by the severe weather and, before the accident, both train 2K04 and train 2Y59 were running to time. Five trains had passed the site in each direction following an overnight *possession* of the up and down slow lines, without their drivers reporting anything unusual. Preceding trains passed the site 12 minutes earlier on the up slow line and 8 minutes earlier on the down slow line without incident. This indicates that most, possibly all, of the landslip struck by train 2K04 slid down the cutting face after these earlier trains had passed.

31 The landslip was located immediately beyond a signal (number WT5126) which was showing a *double yellow* aspect (figure 4). As train 2K04 approached the tunnel at 66 mph (106 km/h), its driver did not see the debris on the track until just before the train hit it.

Figure 4: Image from forward-facing CCTV camera on train 2K04. The headlight of train 2Y59 can be seen in the tunnel ahead.

Events during the accident

32 At 06:55:44 hrs, train 2K04 passed signal WT5126 and hit the landslip on the track. The impact caused the leading coach to lift and derail to the right, towards the down slow line. Some passengers in the leading coach fell from their seats and luggage fell from the overhead racks. The derailment caused a vacuum circuit breaker (VCB) to open on the front unit (350264). This caused its pantograph to lower and disconnect from the overhead power supply. The pantograph on the rear unit (350117) remained raised as the train entered the tunnel.

33 The driver applied the *emergency brake* and, as the train slowed, pushed the GSM-R emergency button which automatically sent an emergency message[4] instructing all train drivers in the Watford area to stop their trains. He also switched the train's headlights into flashing, hazard warning, mode.

34 At 06:55:55 hrs, train 2Y59 and all other trains in the Watford area received the GSM-R emergency stop message. Train 2Y59 was already in the tunnel, travelling at 79 mph (127 km/h) towards the derailed train. The driver of train 2Y59 applied the train's *full service brake* (refer to paragraph 103).

35 At 06:56:12 hrs, train 2K04 stopped. Although the driver of train 2Y59 could see the hazard lights from train 2K04 ahead, he was unaware that it was derailed and partly obstructing the line on which his train was travelling.

36 At 06:56:23 hrs, train 2Y59 collided with train 2K04 at a speed of 34 mph (55 km/h). The force of the impact broke off the right-hand cab door, sometimes known as the second-man's door, on both trains. Train 2Y59 did not derail, but all four of its coaches scraped along the side of the leading coach of train 2K04 before stopping 10 seconds later at 06:56:33 hrs. The whole incident from the derailment of train 2K04 to train 2Y59 stopping occurred in less than 40 seconds.

Events following the accident

Actions of the train crew – train 2K04

37 Immediately after the collision, the driver of train 2K04 contacted the signaller by GSM-R radio to report that his train had derailed and been struck by a train travelling in the opposite direction, and to request emergency assistance. The signaller informed the driver that his train was protected by signals and to await further instructions. The signaller asked the driver if there were any injuries, but the driver was unable to provide this information immediately. Numerous alarms sounded in the cab after being triggered by passengers.

38 The driver could not leave his cab and enter the passenger saloon because the sliding doors between the cab and saloon (the cab-saloon doors) had become jammed in the part-open position as a result of the accident. The left-hand (driver's) outside door was undamaged but the driver decided to remain in the cab so that he could continue to communicate with the signaller via GSM-R.

[4] GSM-R emergency messages are sent using the emergency group call function.

39 A cab warning light informed the driver of train 2K04 that the pantograph on the front unit had lowered and was no longer connected to the overhead power supply (paragraph 32). He decided not to try and put the pantograph back up because he didn't know if there was damage to the overhead wires or if the train was on fire. Immediately after the train stopped, the driver switched off the heating, ventilation and air conditioning (HVAC), as he was concerned that this equipment could help to spread any fire.

40 The guard on train 2K04 was in the centre of the train when the derailment occurred. She walked forwards when the train stopped, but was unable to enter the leading coach because of a sharp bend in the gangway connection between the first and second coaches which had occurred as a result of the derailment. She then walked towards the rear of the train, checking on the passengers. From the rear cab, she could see the north end of the tunnel. She attempted to contact the driver using the train's intercom in order to check that the emergency services had been contacted. The driver did not respond immediately as he was talking to the signaller.

41 Shortly afterwards, the driver contacted the guard by intercom and asked if anybody was hurt so that he could inform the signaller. She confirmed that there were no serious injuries in the rear seven coaches. The driver, by speaking to passengers through the gap in the cab-saloon door, confirmed that there were no serious injuries among passengers in the front coach. The guard, after consulting the driver, then placed *track-circuit operating clips* on the track behind her train.

42 The guard then made an announcement to passengers and assured them that the driver was unharmed, and walked through the train again, checking on passengers and reassuring them. This time she managed to enter the front coach where she found a male passenger who was sitting on the floor and had hurt his back, and a female passenger who was suffering from shock.

43 Later, after passengers had been moved to the rear unit of train 2K04, the guard opened internal doors and partially opened some external doors to improve ventilation. She identified and briefed a passenger to stand inside each door to prevent other passengers leaving the train through these doors.

44 The driver remained in his cab for about an hour after the accident. During this time, he started to experience back pain and was assisted to climb into, and walk through, train 2Y59. He was then assisted by the driver of train 2Y59 and emergency services personnel into the rear unit of train 2K04.

Actions of the train crew - train 2Y59

45 The driver of train 2Y59 contacted the signaller after his train stopped to report the collision. The driver then spoke to the guard on his train who confirmed that there were no injuries. He also spoke to the guard on train 2K04 through an open window before walking to the back of his train and across the track to check on the driver of train 2K04.

46 The driver of train 2Y59 placed *detonators* on the track 300 yards behind his train to protect it in accordance with Module M1 of the railway rule book[5] in case a rescue train arrived from this direction.

---

[5] GE/RT8000/M1 Rule Book Module M1 issue 3 published September 2015 'Dealing with a train accident or train evacuation'.

47 The guard on train 2Y59 checked on his passengers and, after checking with the driver, informed them that the train was safe. He counted the passengers and volunteered this information to emergency services when they arrived. He assisted with the later evacuation of passengers from his train into the rear unit of train 2K04 and then checked the train was empty. The pantograph on train 2Y59 stayed raised and connected to the overhead power supply which remained live on both lines throughout.

Post-accident response

48 Network Rail's LNW Route Control was informed of the accident by the signaller. At 07:05 hrs, route control staff contacted a local mobile operations manager (MOM) and asked him to attend site. A British Transport Police (BTP) officer, who was already working with the MOM, sent a radio message to alert the BTP control room. Route control also contacted Network Rail track maintenance staff from Watford depot and asked them to attend.

49 At 07:08 hrs, LNW route control staff contacted the British Transport Police (BTP) using an internal emergency line set up for this purpose. The BTP control room which received the call was responsible for identifying and notifying the local emergency responders. The BTP call handler understood that the accident had occurred in Watford tunnel.

50 At 07:17 hrs, a member of BTP control room staff notified Hertfordshire police electronically by sending them a copy of the BTP incident log. This facility was not available for fire and rescue (FRS) or ambulance services which had to be contacted by telephone.

51 At 07:17 hrs, a member of BTP control room staff telephoned the East of England ambulance service. The ambulance service log shows that the initial call was for information only and that there were no injuries reported. At 07:33 hrs, the ambulance service controller decided to dispatch a vehicle so that the crew could assist with movement of passengers if required. Due to the time being taken to answer ambulance service questions, a second member of staff began to assist with handling the incident. At 07:29 hrs, BTP control room staff contacted Hertfordshire FRS. Hertfordshire FRS considered the initial report to be vague, so it dispatched one appliance at 07:34 hrs in order to assess the situation (refer to paragraph 124).

52 At 07:20 hrs, the MOM arrived at the Gypsy Lane access gate located adjacent to Gypsy Lane bridge about 400 metres north of the tunnel (figure 7). The MOM was appointed as the Rail Incident Officer (RIO) to facilitate access for the emergency services when they arrived.

53 At 07:32 hrs, track maintenance staff arrived on site and reported that debris was still falling onto the up slow line, that the down slow line was also affected, and that flood water was up to rail height in the cutting (figure 5).

54 Until 07:37 hrs, all trains remained stopped in the Watford area. After obtaining confirmation from the RIO that the fast lines were unaffected, the signaller reopened the up and down fast lines at caution (reduced speed). This restriction continued until 09:24 hrs to protect people accessing the accident site.

Figure 5: View of landslip and debris on track. The adjacent masonry structure is a face wall (refer to paragraph 90).

55 At 07:40 hrs, BTP officers arrived at the Gypsy Lane access gate. They reported that Gypsy Lane, a single-track residential road, was a dead end and not suitable for multiple vehicles. At 07:42 hrs, BTP officers contacted their control room to advise that the best rendezvous point (RVP) was at the junction between Gypsy Lane and Hunton Bridge Road, and asked for the fire and rescue service and ambulance service to be advised. The new RVP was 450 m further from the access gate and about 850 m from the tunnel.

56 At 07:45 hrs, the first FRS appliance and the first ambulance service vehicle arrived at the RVP. Additional resources from both emergency services arrived later to provide additional resources and medical capability.

57 At 07:51 hrs, BTP officers reported that they were entering the tunnel and that radio communications were poor. An officer was posted at the tunnel portal to relay messages because both trains were entirely in the tunnel, with the rear of train 2K04 about 230 metres from the portal.

58 At 07:55 hrs, the driver of train 2K04 removed the driver's key and vacated the leading cab. This followed the failure of the power supply to the leading cab which caused the GSM-R radio to stop working although the cab lights remained on.

59 Subsequent events were affected by the gradual loss of power in train 2K04 as the emergency batteries discharged[6] with effects described in table 1.

Time	Front unit	Rear unit
06:56 hrs	Accident damage causes pantograph to lower and disconnect from the overhead electrical supply. Emergency power & lighting initiated (known as 'battery-normal').	Pantograph remains raised so unit electrical supply continues from overhead line.
07:40 hrs (estimated)	Power and GSM-R radio lost in leading cab.	
07:56 hrs	Lighting reduces to minimum emergency lighting (known as 'battery-direct'), a design feature to conserve battery power.	Change in status of front unit from battery-normal to battery-direct causes the vacuum circuit breaker (VCB) latching circuit to be lost. This causes the VCB to open, disconnecting both units from the overhead electrical supply. Emergency power & lighting initiated (battery-normal).
08:32 hrs	Unit completes phased shut down as emergency power/ lighting lost after 97 minutes.	
08:59 hrs	No power/lighting	Lighting reduces to minimum emergency lighting (battery-direct)
09:24 hrs	No power/lighting	Unit completes phased shut down as emergency power/lighting lost after 88 minutes.

Table 1: Summary of how electrical shut-down sequence affected train 2K04

60 At 08:05 hrs, the RIO advised Route Control that the front unit of train 2K04 was leaning on train 2Y59 and could not be moved.

61 At 08:30 hrs after examining the train, BTP declared that the accident was a low speed collision with no serious injuries, and that it did not meet the criteria of a *major incident*. BTP's priority was to work with the RIO to develop an evacuation plan. The intention was to move all staff and passengers into the rear four coaches of train 2K04, and then to uncouple this unit and use it to transport all passengers to the north portal of the tunnel. From there, they would leave the train and walk past the landslip to join a rescue train provided by Virgin Trains. This was a diesel powered class 221 Super Voyager, which had formed the 06:20 hrs Virgin trains service from Rugby to London Euston. The passengers on the train were disembarked at Hemel Hempstead before the train crossed onto the slow lines and travelled south towards the accident site.

[6] The class 350/2 fleet was introduced in December 2008 and was required to comply with Railway Group Standard GM/RT2176 issue 1 December 1995 'Air Quality and Lighting Environment for Traincrew Inside Railway Vehicles'. This requires a train's batteries to be able to provide the specified emergency lighting levels for at least 90 minutes after the failure of the vehicle's primary power source.

62 The guards, assisted by the emergency services, transferred passengers from both trains to the rear four coaches of train 2K04. Passengers from train 2K04 were able to walk through their train, but passengers from train 2Y59 had to cross the track. They were helped to exit train 2Y59 via the driver's cab door which has a fixed ladder, then enter train 2K04 using a short wooden ladder secured by a rope through passenger doors which the guard had opened for this purpose.

63 The driver of train 2Y59 attempted to separate the rear and front units of train 2K04 at 08:37 hrs using uncoupling controls in the driving cab at the front of the rear unit. The attempt was unsuccessful because uncoupling can only be achieved using driving cab controls when the unit is being powered from the overhead line supply and this had been lost at 08:32 hrs (see table 1). Without this supply, uncoupling could only have been achieved manually from track level.

64 The difficulty of uncoupling meant that, at 08:50 hrs, the evacuation plan was changed. Passengers and crew remained in the rear unit of train 2K04 while arrangements were made to bring the Virgin rescue train into the tunnel running in the wrong direction on the down slow line to allow a direct train-to-train transfer. At 09:24 hrs, the battery supply on the rear unit of train 2K04 shut down, extinguishing all lights. The emergency services provided battery lights to avoid passengers sitting in darkness.

65 At 09:00 hrs, three London Midland managers arrived on foot at the south end of Watford tunnel intending to walk through the tunnel to assist and support their staff. Access was denied by Network Rail on safety grounds.

66 At 10:07 hrs, the rescue train entered the tunnel at low speed and stopped with its leading passenger doors opposite the rear passenger doors on train 2K04. Shortly afterwards, passengers and crew were transferred from train 2K04 to the rescue train using a horizontal ramp with the assistance of other London Midland staff who had arrived on the rescue train, and the emergency services. At 10:40 hrs, nearly four hours after the accident, the rescue train left the tunnel conveying between 270 and 290 passengers and crew. Some passengers left this train at Kings Langley, including a passenger needing medical attention for chest pains who was treated by the ambulance service. The remaining passengers were conveyed to Hemel Hempstead and Milton Keynes where further London Midland staff were waiting to provide assistance.

67 The slow lines remained blocked until Monday 19 September during which time the trains were removed from the tunnel, the cutting slope was stabilised and the up slow line repaired.

Key facts and analysis

Background information

Management of the cutting

68 The slow line northern approach cutting is up to 15 m deep with side slopes rising steeply at an average gradient of between 50 and 55 degrees. Locally, the gradient increases to 65° as recorded in Network Rail's earthworks examination reports. The angle reduces to approximately 42° in the vicinity of the landslip which occurred adjacent to an existing masonry wall (refer to figure 6 and paragraph 91). A design options report by Amey (May 2015) associated with the design of the slope protection scheme identified that the ground conditions at the crest of the slope comprised topsoil over natural clayey flint gravel over chalk. Inspection of the cutting by the RAIB showed the lower part to comprise chalk rock.

69 Network Rail managed the risk of failure at its earthworks assets (ie cuttings and embankments) by a process of examinations, followed by evaluation of examination findings in accordance with Network Rail standards NR/L3/CIV/065[7] and NR/L2/CIV/086[8].

Figure 6: Photograph of cutting taken in July 2016 following vegetation clearance looking east (courtesy of Network Rail). The white dashed line indicates the profile of the cutting crest with the low point marked 'A'. The location of the future landslip is marked 'B'.

[7] Network Rail standard NR/L3/CIV/065 issue 5 published December 2014 'Examination of Earthworks'.

[8] Network Rail standard NR/L2/CIV/086 issue 4 published September 2014 'Management of Earthworks'.

70 Separation of the fast and slow line alignments at the Watford tunnels was an unusual arrangement which resulted in the slow lines cutting being omitted from LNW Route's asset inventory list until 2013. The original asset inventory was based on the fast lines alignment which omitted the slow lines in this area.

71 The first recorded examination of the northern approach cutting on the slow lines was undertaken in August 2013 as part of the 2013/14 examination programme. This examination was incomplete because the steep side slopes were covered in dense vegetation and required the use of rope access for which there was no provision. However, it identified that there was a risk of blocks of chalk falling onto the line from the lower part of the cutting slope. The presence of trees on this slope increased this risk as it provided the potential for *root jacking* to occur.

72 Network Rail evaluated the risk associated with cutting failure by combining a hazard category and an asset criticality score. The Earthworks Hazard Category (EHC) ranged from 'A' (statistically least likely to fail) to 'E' (statistically most likely to fail) and was determined using standard NR/L3/CIV/065. The Earthworks Asset Criticality Band (EACB) ranged from 1 (low consequence) to 5 (high consequence) and was determined using standard NR/L2/CIV/086. Network Rail inspects and evaluates its earthworks in short (5 *chain*, 100 m) lengths but manages each cutting or embankment as a whole by considering the scores for all 5 chain lengths within the earthwork.

73 Following an examination in August 2014, the 5 chain length where the failure occurred, which has a slope angle of about 45°, was deemed to have an EHC of 'B'. Other steeper lengths were considered to present a greater hazard and were given an EHC of 'E' and so the whole cutting was managed on the basis it contained high risk sections. The criticality of the earthwork was recognised by allocating it an EACB of '5'. As a result in November 2014, the RAM (geotechnics) team issued a remit for design and construction of remedial works to reduce the risk to trains from the deteriorating chalk cutting. The project scope was to develop a scheme to 'provide a long term reduction of risk from earthwork failure to the safe running of trains'.

74 Subsequent design work led to a scheme involving removal of trees and large vegetation, followed by installation of rock-fall netting over the whole slope and erosion protection matting over the upper slope. The netting was intended to constrain blocks of rock and other material falling from the cutting face so that they stopped at the toe of the cutting slope and did not roll onto the railway lines. The netting and matting was to be secured by *ground anchors* at the top (crest) of the slope. In addition to allowing installation of netting and matting, removal of trees removed the risk of the line becoming obstructed by fallen trees. It also reduced further root growth with the associated risk of root jacking displacing blocks of rock. The surface of the slope, and roots binding the soil and rock layers, were left undisturbed.

75 An evaluation of surface water run off was made by the design consultant in their Geotechnical Assessment Report which led to the conclusion that drainage for surface water run off was not required (paragraphs 95 to 98 and figure 7).

Figure 7: View of slow lines cutting from above tunnel portal, looking north-west towards Gypsy Lane bridge on 16 September 2016. The partly completed slope protection works are visible. The landslip is marked 'B'.

Identification of the immediate cause

76 **Train 2K04 derailed as a result of colliding with a landslip.**

77 The landslip occurred suddenly during the 12 minutes since the preceding up train had passed (paragraph 30). The driver of train 2K04 approached the landslip at 66 mph (106 km/h), just below the maximum permitted speed of 70 mph (113 km/h), in poor visibility with no warning of its presence. The train struck the landslip and derailed to the right.

Identification of the causal factor

78 **There was no *crest drainage* or sub-surface drainage at this location which meant intense rainfall led to a *washout failure* on the cutting slope.**

Source of surface water leading to low point

79 The *catchment area* to the east of the slow lines cutting comprises a flat-topped hill within the studio complex. Following the accident, the RAM (drainage) made an initial estimate suggesting that a catchment area of around 30 hectares (300,000 m^2) could exist east of the cutting, leading to a low point above the landslip location (figure 6). An area of this size would have accumulated over 15,000m^3 of water (equivalent to six Olympic-size swimming pools) over the four hour period from 03:00 hrs on 16 September. The unsurfaced ground was dry and hardened following a period of hot weather, so initially, there was limited opportunity for rainfall to percolate into the ground. An inspection of the site by the RAIB and representatives of the studio complex on 16 September 2016 found evidence that a significant volume of water had flowed towards one location above the cutting (figure 8). The local topography created a water concentration feature, and the resulting flow over the edge of the cutting, possibly in combination with sub-surface flows (paragraph 83), caused a washout failure of the cutting slope (figure 9).

Figure 8: Aerial photograph of catchment area on 16 September 2016 showing water paths. Part of this image has been deliberately blurred.

Figure 9: Crest of cutting above landslip showing erosion matting displaced by surface water flow

80 Aerial photographs indicate that, in recent years, there had been an increase in built over and surfaced areas near the slope crest and elsewhere within the catchment area, associated with development of the studio complex. An existing airfield perimeter road had recently been repaved in concrete and provided with drainage. Due to work involving the construction and dismantling of film sets, earthmoving and temporary building construction took place on a regular basis. This included the construction of an earth bund adjacent to the perimeter road.

81 Although these changes will have had an effect on the way that water flowed across the site, the RAIB found no evidence that this would have exacerbated the risk of water flowing towards the railway boundary. The constructed areas nearest the railway used granular material, which would have remained relatively porous despite the dry weather. The recently installed drainage alongside the perimeter road would have diverted some water from the ground surface into the ground, but it was not designed to accommodate the high flows associated with the intense rainfall on 16 September 2016 and would therefore have had little overall effect.

82 Although there was evidence of surface water flow disrupting the partly fixed erosion protection matting (figure 9), there is no evidence that construction work significantly affected water flows (refer to paragraph 99).

Sub-surface water

83 There is evidence that some water flowed through ground to emerge at the cutting face. Photographs and a video taken from track level by one of the first members of Network Rail staff to arrive on site on 16 September, show a large volume of water appearing to emanate from a point about half-way up the slope (figure 10). This location was adjacent to the south side of an existing masonry structure built to support the cutting face and known as a face wall (refer to paragraph 90).

Figure 10: Image showing water emanating from part-way down the cutting slope (courtesy of Network Rail)

84 Historic Ordnance Survey mapping and a Network Rail inspection of the studio site in November 2016 show that a low wall, apparently straddling a drainage pipe, was built between 1939 and 1962 typically 15 m east of the railway boundary fence. It is uncertain whether this feature is associated with remedial works carried out after a landslip at this location in February 1940, and there is no evidence of any significant modifications in recent years. The function of the drainage is unclear and it is uncertain whether it played any part in the 2016 slip. It is possible that sub-surface water was a factor in both the February 1940 slip and the September 2016 slip.

Identification of underlying factors

85 **The topography forming a water concentration feature, and the associated risk of a washout failure, was not recognised as a significant risk.**

86 In 2010, Network Rail introduced a 'washout and earthflow risk mapping' (WERM) process to supplement the earthworks examination process. The purpose of this model was to identify risks to the network from water concentration features and other topographic and water features. The RAM (geotechnics) team used this information to assess the vulnerability of its cutting slopes to water damage, and to enable the company to extend its risk management beyond the confines of its own land boundaries. The WERM was based on a digital model of the terrain adjacent to the railway corridor, and included information on geology and catchment areas for a strip 500 m wide; 250 m on either side of the railway centreline.

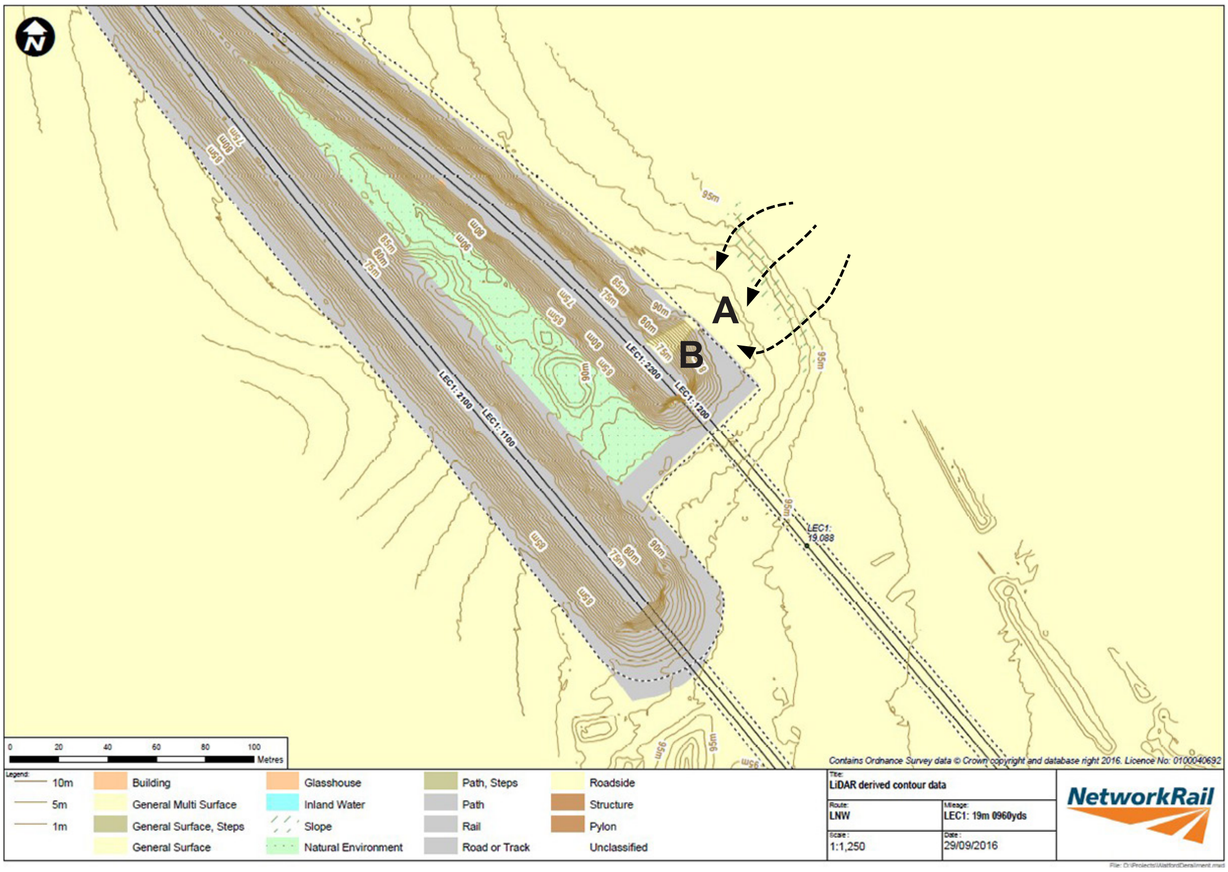


Figure 11: Network Rail LIDAR survey drawing showing contours adjacent to the tunnel portals. The low point is marked 'A' and the position of the landslip is marked 'B'. The approximate surface water flow paths are also shown.

87 The first WERM analysis for the Watford area was undertaken before the slow lines cutting was included on LNW Route's asset inventory list (paragraph 70), and was based on the fast lines alignment. The slow lines cutting was not assessed.

88 In 2014, data from the WERM project was used to develop an upgraded version of the tool known as WERM2. The WERM2 data was derived from a national Light Detection and Ranging (LIDAR) survey model and the analysis was undertaken by a consultant on behalf of Network Rail. This was used to re-assess the existing data but, as the slow lines were still not included, it is not known whether WERM2 would correctly identify the risk at the slip location.

89 Establishing whether the WERM2 is capable of recognising water concentration features such as that at the accident site is important because the site is close to the top of a hill and with no evidence of water flow or obvious water source. If the concentration feature is not recognised, the site could easily, and wrongly, be considered to be a low risk location (see Recommendation 2).

90 **Network Rail's staff responsible for the management of the earthworks were unaware of a historic slip on the immediately adjacent part of the cutting and unaware of the face wall drawings showing that it was intended to have a drainage function.**

91 Network Rail staff were unaware that a serious landslip had occurred at approximately the same location on 4 February 1940. This derailed a train entering the tunnel causing one fatality and six injuries. A contemporary newspaper article[9] reports that the resulting inquest at Watford heard that about 800 tonnes of earth fell in front of the train, and that afterwards, water was seen trickling down the cutting face. The slope was repaired by the then owners of the infrastructure, the London Midland and Scottish (LMS) Railway Company. The repair involved the construction of a large masonry 'face wall' to buttress and protect the slope, and to provide a drainage path to allow water to drain safely from the cutting crest to track level. Details are shown on drawings titled 'Proposed Face Wall to slip in cutting' dated April 1943, and held by Network Rail's National Records Group. The drawings were scanned and uploaded onto Network Rail's document management system[10] in July 2010, and the information was then available for use by staff. However, staff responsible for managing earthworks and drainage at the accident site were not specifically alerted to the existence of the drawings.

92 The drawings indicate that cavities which had formed on the face of the bank were to be filled with rubble behind the masonry. The drawings also show the face wall surmounted by a shallow concrete raft and channel along the crest of the cutting (figure 12). The channel is shown intersecting a ditch, possibly pre-existing, with arrows showing the direction of flow from both ends towards the low point. The RAIB considers that this is sufficient evidence to show that the face wall was intended to have a drainage function, preventing uncontrolled water flow down the cutting face by diverting surface run off onto the face wall where it could flow down to track level. Since the landslip, Network Rail has found evidence of a shallow depression running parallel to the crest of the cutting slope in a position suggesting this could be the remains of a former drainage ditch. An RAIB inspection of the site showed that the depression would not have been sufficient for an earthworks examiner to recognise it as a ditch at the time of the August 2013 examination (paragraph 71), when dense vegetation covered the area.

93 Network Rail staff had not appreciated that the face wall had a drainage role. As a consequence, it was considered only as a retaining wall and was being managed as a structure rather than as a drainage asset at the time of the accident.

[9] The Birmingham Mail, 7 February 1940.

[10] Network Rail's CCMS2 document management system, introduced in 2007.

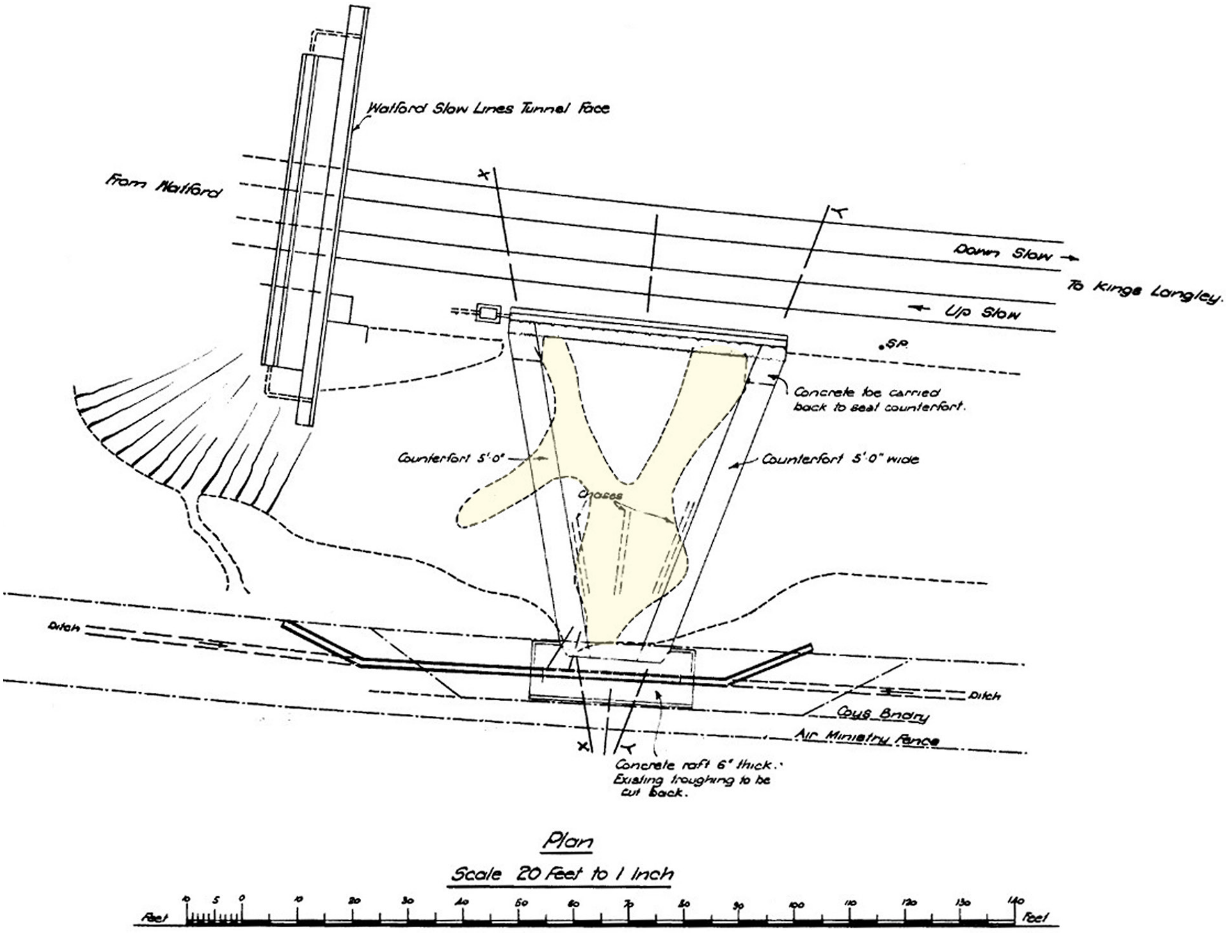


Figure 12: Extract from a historical drawing of the face wall dated April 1943. The position of rubble filled cavities behind the masonry is indicated by shading.

Figure 13: Concrete raft above face wall. Scaffolding boards had been placed inside the raft to remove a tripping hazard during the slope protection works.

94 The drawings should have been located, and the drainage function of the face wall identified in the early part of the slope protection project. Network Rail's Infrastructure Projects group was responsible for preparing a pre-construction information pack (PCIP) for the scheme in accordance with the Construction (Design and Management) Regulations[11]. This pack was required to include historic information such as the face wall drawings. Although the drawings were in the Network Rail document management system (paragraph 91), they were not in the PCIP. Network Rail has no record of any relevant searches.

95 The Network Rail remit for the project stated:

> '*Crest drainage is not present; however, issues with surface water run-off are not evident on the slopes. The crest of the Up slow slope lies approximately 5m from the Network Rail boundary fence. The crest area is flat with numerous trees and a walking track to the tunnel portal. Adjacent land falls gently towards the west and Gypsy Lane*.'

96 Without the face wall drawings, Amey, the designer of the protection works, had no information indicating that a major landslip had previously occurred at this location. The designer was also unaware that crest drainage had then been considered necessary when the face wall remedial works were designed. The Amey design options report stated:

> '*The original use of this structure is not known but it is hypothesised that it is likely to have been used during tunnel / cutting construction for access / egress of materials.'*

97 The Amey design options report also stated:

> '*Formal crest drainage was not evident on any of the cutting slopes. However, issues with surface water runoff are not evident on the slope and the land beyond the boundary fence is generally at grade or dipping gently west towards Gypsy Lane. Therefore, it is not anticipated that the installation of crest drainage will have a significant effect on earthwork stability and is not proposed.'*

98 Although the land beyond the boundary fence is generally at grade (ie level) or dips gently west towards Gypsy Lane, it does not do so at the location of the landslip. Here, the cutting intersects the upper end of a small natural valley running approximately east to west, as indicated by contour lines on figure 11. This creates a low point on the cutting crest and a path for surface water to enter the cutting (figure 6). The RAM (geotechnics) team had budgeted for a drainage element at the project commencement, but based on the options report, it accepted a scheme without crest drainage.

99 There is no evidence that the ongoing slope protection project works had an adverse impact on water flows or the stability of the slope. During the rainfall event, some sections of the erosion protection matting (paragraph 82) on the crest of the slope were pushed towards the track by the flow of surface water passing just to the south of the face wall. Although the concrete trough at the top of the face wall had been infilled with boards to prevent a tripping hazard for project site staff, this had no significant effect because the absence of connecting channels meant that this trough was serving no drainage purpose.

---

[11] Construction (Design & Management) Regulations 2007, revised April 2015. Regulation 10 'Client's duty in relation to information'.

Integrated drainage project

100 In 2010, Network Rail's then head of civil engineering commissioned a drainage survey, known as the Integrated Drainage Project (IDP). The ORR's 'Final determination of Network Rail's outputs and funding for 2014-19' (paragraphs 8.102 and 8.103) shows that the IDP was intended to survey earthworks and track drainage where records were incomplete. The IDP did not record any cutting crest drainage at the slow line cutting and the face wall was not recorded as a drainage asset. The scope of the IDP at this location is unclear as Network Rail LNW staff have stated that the survey work, undertaken by Network Rail infrastructure maintenance (Delivery Unit) staff, focused on track drainage and did not identify all off-track drainage. Network Rail staff have also stated that there are areas of the network where basic information on drainage is still lacking (refer to Recommendation 6).

Factors affecting the consequence

Actions of the train crews

101 **The prompt actions of the train crews involved helped to mitigate the consequences of the accident.**

102 The consequences of the accident were mitigated by the actions of the train crews in the following ways:

a. Early use of the GSM-R emergency button by the driver of train 2K04 before his train stopped moving (paragraph 33).

b. Quick response to the emergency stop message by the driver of train 2Y59, by applying his train's brakes in time to significantly reduce the speed of collision. It is likely that this reduced both the extent of injuries and the amount of damage (paragraph 34).

c. Early notification of the accident to the signaller by both drivers (paragraphs 37 and 45).

d. Actions of the guards, including checking and reporting that no passengers were seriously injured, communicating with the drivers, keeping passengers informed, and assisting with detrainment (paragraphs 40 and 47).

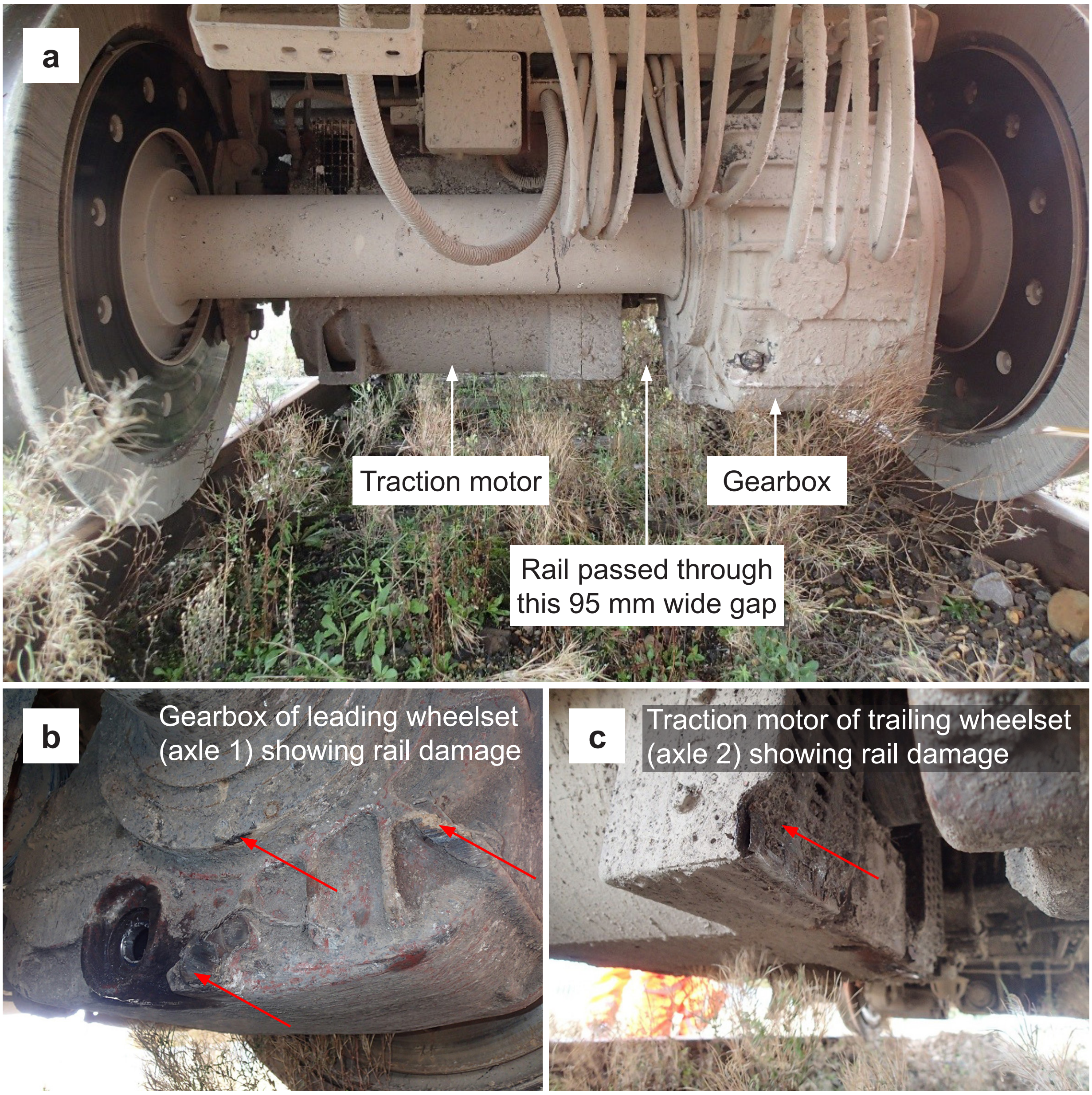
103 In ideal circumstances, an emergency brake application would stop a train of this type more quickly than a full service brake application. However, the on train data recorder (OTDR) from train 2Y59 shows that there was considerable wheel-slide protection (WSP) activity at the time of braking, suggesting that the rails in the tunnel were slippery. For this reason, the RAIB considers it unlikely that train 2Y59 could have stopped without colliding with train 2K04, even if the driver had applied the emergency brake. Module TW1[12] of the railway rule book requires a driver receiving an emergency stop message to bring their train to a stand immediately, but does not specify that the emergency brake should be used. It also requires drivers to avoid stopping the train in a tunnel if possible.

[12] GE/RT8000/TW1 Rule Book Module TW1 issue 9 published September 2013 'Preparation and Moving of Trains', sections 39 and 43.4.

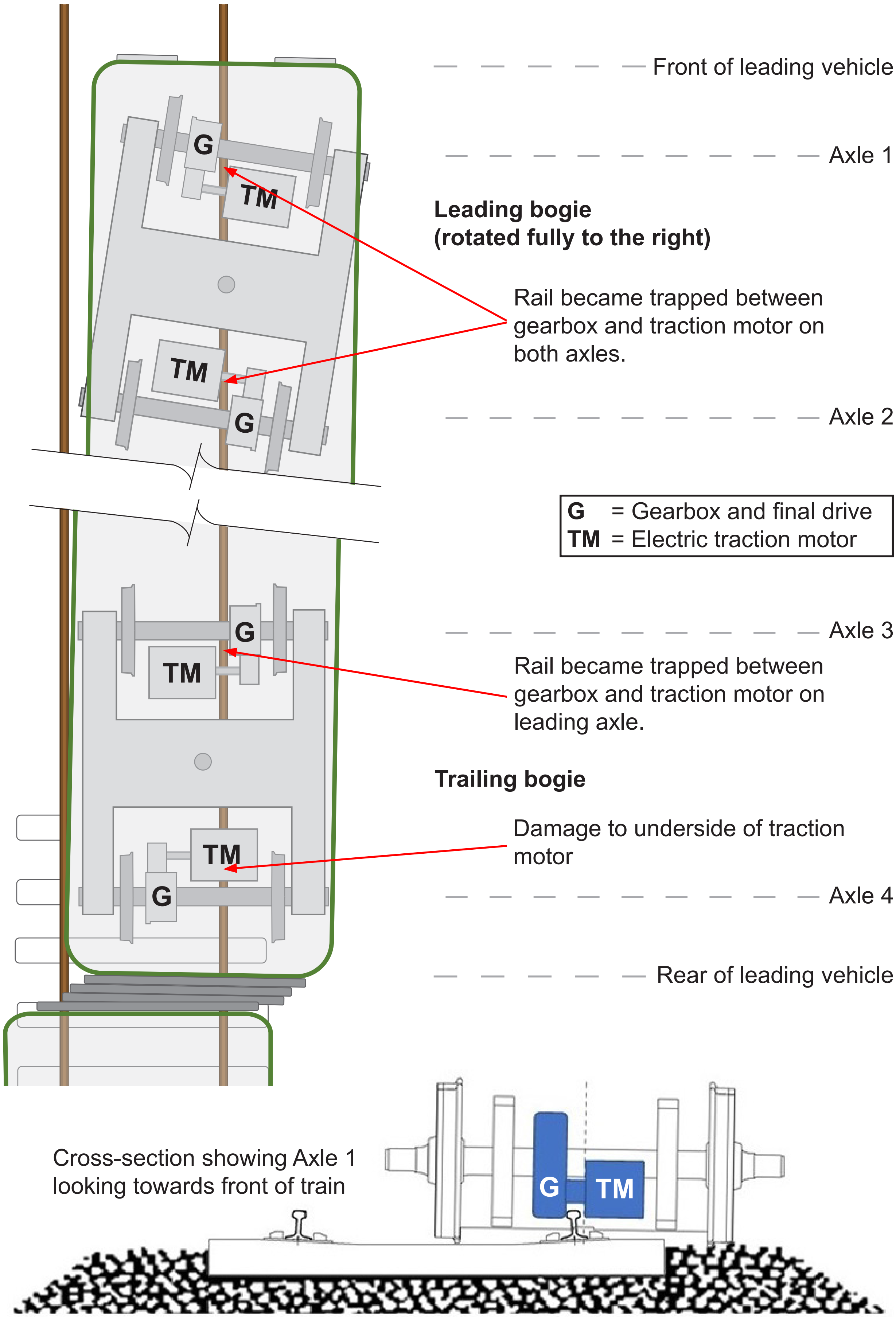
Damage to the trains

104 **Components on both *bogies* on the leading vehicle of train 2K04 engaged with the right-hand (six foot) rail during the derailment. This almost certainly reduced the extent to which the adjacent line was obstructed and the severity of damage and injury due to the collision.**

105 A post-accident examination of the leading vehicle of train 2K04 by the RAIB and Siemens found damage that was consistent with the right-hand (six foot) rail engaging with a gap between a gearbox and a traction motor (figures 14 and figure 15) on three of its four axles. This prevented the vehicle moving a large distance from the track centreline, and it is likely that this reduced the extent to which the derailed train obstructed the adjacent track. As the derailed train slowed, the leading bogie became embedded in the ballast, causing the front of the leading vehicle to drop by about 300 mm and lean slightly towards the opposite track.



Figures 14a, b and c: Images showing examples of damage caused by interaction between traction equipment and rail during derailment beneath the leading bogie of train 2K04



Figures 15a and b: Diagrams showing the leading vehicle of train 2K04 and interaction between traction equipment and right-hand rail during derailment. Figure 15b courtesy of RSSB.

106 The relative position of the cabs of the two trains at the time of collision (figure 16) meant that contact was made by relatively easily deformable bodywork, rather than by stronger and less deformable structural elements. The leading cab of train 2Y59 (figure 17a) was guided so that it ran alongside train 2K04 by the corner pillar of the leading cab of train 2K04 (figure 17b). The rounded corner pillar absorbed some energy in the collision by deformation, a consequence of its shape and the relatively small overlap between the two cabs at the time of the collision. Had the leading vehicle of train 2K04 encroached slightly further towards the down slow line, or contact been made between the *anti-climbers* (buffers) attached to the underframe (chassis) at the front of each unit, the resulting collision would almost certainly have been significantly more serious.

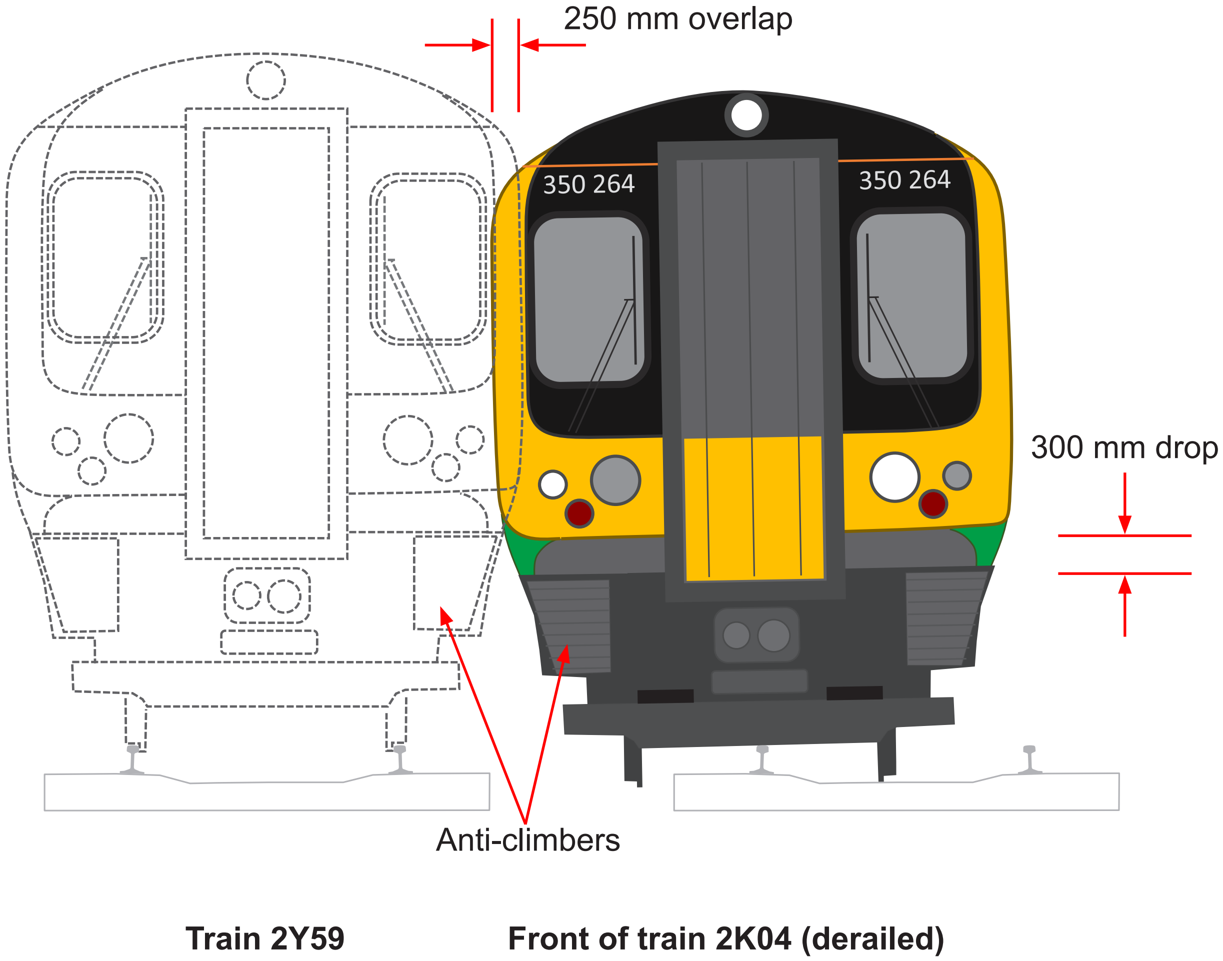


Figure 16: Diagram showing overlap between trains at moment of collision

Figure 17a and b: Front view of train 2Y59 (unit 350233) and train 2K04 (unit 350264) following recovery from the tunnel

107 Although the leading vehicles of both units were seriously damaged, and there was damage to the outer skin of all vehicles of train 2Y59, there was no penetration of the vehicles' inner skins.

108 **The cab-saloon doors on train 2K04 became jammed in the part-open position as a result of the accident. This prevented the driver from leaving the cab other than by climbing down onto the track.**

109 The double-leaf sliding doors became jammed in the part-open position (figure 18). This occurred because small stones and screws collected in the lower guide rail during the accident and became trapped under one of the door leaves. Siemens has confirmed that the doors and frame were undamaged. The RAIB observes that debris collecting in this area may be an unavoidable consequence of a collision, and that similar debris could affect a single leaf door in the same way.

Figure 18: Maximum width that the sliding cab-saloon doors could be opened following the accident

110 **Emergency equipment in both driving cabs was displaced by the collision.**

111 Class 350, and other classes of Desiro unit, have a set of emergency equipment attached to the right-hand side wall of the cab. This includes track-circuit operating clips and a clear plastic case containing detonators and flags (figure 19a). Equipment came loose in the cab of train 2Y59 when the case itself broke (figure 19b), and in the cab of train 2K04 when the case broke off the wall (figure 19c). Fortunately this did not cause injury to either driver, but the risk of injury was illustrated in train 2K04 where the equipment hit the back wall of the cab.

Figure 19a, b and c: Photographs showing the location of cab emergency equipment in an unaffected train, and damage to the leading cabs of trains 2Y59 and 2K04

Observations

112 Network Rail's operational processes did not result in mitigation for the localised extreme rainfall event.

113 Network Rail's weather forecasting contractor provided LNW Route Control with daily forecasts for rainfall, wind and temperature. Warnings were described using colours for guidance, from green status (normal weather), extending through yellow and amber (adverse weather) to red status (extreme weather). When the weather forecast indicated an extreme weather event, the *Extreme Weather Action Teleconference* (EWAT) process was invoked as required by Network Rail standard NR/L2/OCS/021[13].

114 At 02:53 hrs on 15 September, the weather forecaster issued a yellow rainfall warning for London north-west covering Watford and the south end of the LNW Route. This forecast was valid for 24 hours from 06:00 hrs. The forecast was revised at 08:32 hrs to indicate an amber rainfall risk for this area on 15 September.

115 At 02:39 hrs on 16 September, the forecast was updated to an amber rainfall warning for 16 September. Although this should have resulted in the Route Control manager reviewing the situation with an on-call asset engineer, this did not occur. Even if a red rainfall warning had been received, it was unlikely to have resulted in any mitigation being put in place to protect trains passing the accident site. The slow lines cutting had not been considered for inclusion on LNW Route's list of earthworks at risk in adverse weather[14], a consequence of the washout risk not being recognised (the underlying factor given at paragraph 85). Therefore, even if route control staff had imposed speed restrictions, it is unlikely that this site would have been included.

116 The RAIB commissioned the Met Office to provide advice on the actual rainfall and return periods[15] for the intense rainfall which triggered the landslip. The location of the landslip was within the area covered by its weather radar located at Chenies, Hertfordshire less than 8 km from the site. For the four hour period between 02:45 hrs and 06:45 hrs, the weather radar data indicates that 50.7 mm of rain fell. This was equivalent to a storm with a 1 in 42 year return period at Watford for this period.

117 Over the 24 hours until 09:00 hrs on 16 September, the weather radar data indicates that 59.4 mm fell. The radar data has been verified by the Met Office using data from an official rain gauge at Radlett, 6 km east of the cutting. It is also consistent with data obtained by the RAIB from amateur weather stations in the Watford area.

118 This rainfall was a summer convection storm. These can be very intense and difficult to predict accurately. Although control staff had access to real time radar via the Network Rail Weather Service, they did not, and were not required to, make use of this information as part of the EWAT process. This process is best-suited to manage Network Rail's response to slow-moving winter storms with longer warning times.

---

[13] Network Rail standard NR/L2/OCS/021 Issue 6, March 2016: 'Weather – managing the operational risk'.

[14] LNW Route Risk Mitigation Process for Earthworks in Adverse and Extreme Rainfall.

[15] A return period of 42 years means that the likelihood of an event is 1/42 (or 2.4%) in each year.

Emergency response

119 **Road access for the emergency services to the north end of the tunnels was severely restricted, but this was neither identified in Network Rail's Watford tunnel emergency plan nor easily managed by the Fire and Rescue Service.**

120 Network Rail produces emergency plans for its tunnels where there may be particular difficulties in dealing with incidents such as derailment, fire or incident involving injuries to persons. Structures are assessed as being low, medium or high risk. High risk structures, which represent about 10% of the total, have emergency services input into the emergency plan. The plans are required to be reviewed every year, and are owned by the local Route.

121 Network Rail's Watford tunnel emergency plan[16] is based on the tunnels being assessed as 'medium risk'. The plan provides details of vehicular access to a location 1.1 km from the south end of the slow lines tunnel and about 2.5 km from the accident near the north end of the tunnel. The plan also refers to 'suitable foot access at the north end (Gypsy Lane)', about 0.4 km from the north end of the tunnel. The plan was required to be reviewed annually.

122 The emergency plan does not consider the suitability of the road approach to the Gypsy Lane access point. Gypsy Lane is a single track residential road with limited parking and no opportunity for easy turning of road vehicles. These limitations would have a material impact on the emergency services' ability to respond effectively. At an accident scene, vehicle marshalling is the responsibility of the Fire & Rescue Service under the 'Joint Emergency Services Interoperability Programme' (JESIP) principles for joint working by the emergency services. Hertfordshire FRS undertake an annual inspection of emergency access points as required by section 7 of the Fire Services Act, and was aware of the restricted access via Gypsy Lane (figure 20). It does not undertake formal joint access inspections with Network Rail, to address issues such as gate access, foliage management and turning space.

Figure 20: Gypsy Lane, Kings Langley, looking towards the railway access point

[16] Network Rail document ref. WCS/TEP/011, issued April 2016 'Watford tunnel emergency plan'.

123 The senior Hertfordshire FRS officer on the scene reported that Gypsy Lane became completely blocked from responder vehicles and press vehicles. In an incident requiring people to be transported to hospital, the restricted access at this location would almost certainly be a significant problem.

124 The opportunity to manage this issue was impaired by the relatively long period of time taken to summon the fire and rescue service. On 16 September 2016, 34 minutes elapsed between the train driver's first emergency call at 06:56 hrs and the first contact with the Hertfordshire FRS at 07:29 hrs. This occurred because, after being notified at 07:08 hrs, only one member of BTP control room staff was assigned to contact the emergency services until a colleague stepped in to assist (paragraph 51). Only one person was assigned because, in the absence of reported injuries, BTP's response was focused on obtaining information from the scene, and ensuring public safety and welfare at the accident site and at stations where crowd issues could occur.

125 **Communications within the tunnel were restricted.**

126 Communications facilities in the tunnel were very limited. The only communications equipment available in the tunnel was the RIO's hand-held GSM-R phone and Hertfordshire FRS's two-way radios. There was no mobile phone signal or fixed equipment to support the emergency services' radio system (Airwave). Train crews had access to in-cab GSM-R radios, although this failed in the leading cab of train 2K04 when power to the cab was lost (paragraph 58).

Summary of conclusions

Immediate cause

127 Train 2K04 derailed as a result of colliding with a landslip (paragraph 76).

Causal factor

128 There was no crest drainage or sub-surface drainage at this location which meant intense rainfall led to a washout failure on the cutting slope (paragraph 78, **Recommendation 1**).

Underlying factors

129 The topography forming a water concentration feature, and the associated risk of a washout failure, was not recognised as a significant risk (paragraph 85, **Recommendation 2**).

130 Network Rail's staff responsible for the management of the earthworks were unaware of a historic slip on the immediately adjacent part of the cutting, and unaware of the face wall drawings showing that it was intended to have a drainage function (paragraph 90, **Learning point 1**).

Factors affecting the severity of the consequences

131 The prompt actions of the train crews involved, particularly the early use of the GSM-R radio, helped to mitigate the consequences of the accident (paragraph 101, **Learning point 2**).

132 Components on both bogies on the leading vehicle of train 2K04 engaged with the right-hand (six foot) rail during the derailment. This almost certainly reduced the extent to which the adjacent line was obstructed and the severity of damage and injury due to the collision (paragraph 104, **Recommendation 3**).

133 The cab-saloon doors on train 2K04 became jammed in the part-open position as a result of the accident. This prevented the driver from leaving the cab other than by climbing down onto the track (paragraph 108, no recommendation made for reasons given in paragraph 109).

134 Emergency equipment in both driving cabs was displaced by the collision (paragraph 110, **Recommendation 4**).

Additional observations

135 Although not linked to the consequences of the accident on 16 September 2016, the RAIB observes that:

a. Network Rail's operational processes did not result in mitigation for the localised extreme rainfall event (paragraph 112, addressed by previous RAIB recommendation - paragraph 136).

b. The process for notifying the local Fire and Rescue and Ambulance services led to delay, and this could have been a significant factor in a more serious accident (paragraph 124, **Recommendation 5**).

c. Road access for the emergency services to the north end of the tunnel was severely restricted, but this was neither identified in Network Rail's Watford tunnel emergency plan, nor easily managed by the fire and rescue service (paragraph 11, **Recommendation 5**).

d. Communications within the tunnel were restricted (paragraph 125, **Learning point 3**).

Previous RAIB recommendations relevant to this investigation

Class investigation into landslips

136 In April 2014, the RAIB published a report (RAIB report 08/2014) 'Class investigation into landslips affecting Network Rail infrastructure between June 2012 and February 2013'. This involved a study of six landslip incidents. The RAIB considers that earlier completion of recommendation 1, particularly provision of real-time rainfall monitoring, could have improved the information available to route control staff concerning the extreme rainfall which was a factor in this accident.

Recommendation 1 reads as follows:

'Network Rail should review and improve its processes for managing earthworks related risk arising from neighbouring land, including associated drainage issues. …The new process should, where reasonably practicable…take advantage of opportunities offered by real-time rainfall monitoring to issue alerts identifying heavy rainfall when this has not been forecast'

137 The ORR reported to RAIB on 31 March 2015 that implementation of this recommendation was on-going. ORR reported that Network Rail is carrying out a national study to identify the locations where third party land could potentially pose a hazard to the safe operation of the railway. Once defined, each location will be reviewed for adequateness of control measures currently employed.

Barrow upon Soar, 1 February 2008

138 In September 2008, the RAIB published a report (RAIB report 18/2008) 'Collision of a train with a demolished footbridge, Barrow upon Soar, 1 February 2008'. The accident involved a train which derailed after colliding with a footbridge which had fallen onto the track.

Recommendation 3 reads as follows:

'RSSB [Rail Safety and Standards Board] should consider the practicability of design elements on the bogie that limit the degree of deviation from the track following derailments and, where appropriate, proposals should be made to the relevant bodies to make changes to appropriate standards.'

139 RSSB informed the ORR that it had reviewed a number of relevant incidents in order to consider the potential impact of such design elements and produced a paper with its findings. The paper recommended that the Rolling Stock Standards Committee should note the work undertaken and consider that the current risk situation is 'as low as reasonably practicable' (ALARP), and request the Infrastructure Standards Committee to consider the scope for provision of suitable protection on the infrastructure at sensitive locations. The Rolling Stock Standards Committee considered this recommendation and the practicability of design elements on the bogie that limit the degree of deviation from the track following derailments and concluded it was inappropriate to recommend changes to appropriate standards as outlined in the recommendation.

140 ORR informed the RAIB that, having reviewed actions taken and the RSSB paper, it agreed that the conclusions RSSB had arrived at were sound. This assessment was based upon both the limited space available in which to mount any additional restraint and the likely strength of any such restraint to actually constrain the level of forces seen during derailment. It did not propose to take any further action.

141 The RAIB notes that guidance from elements of the vehicle bogie probably avoided a head-on collision in Watford tunnel, almost certainly with a worse outcome. For this reason, a similar recommendation is repeated in this report.

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

142 Network Rail has informed the RAIB that in 2017/18, it plans to undertake a full drainage asset survey, including desk study research, and a review of both asset records and Delivery Unit maintenance records. The data will then be validated on site. Effective implementation of this work should identify circumstances, such as the face wall at Watford, in which historic records suggest a need to provide drainage at locations where none is currently maintained '(Recommendation 6).

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

143 Slope protection works have been completed on the north approach to Watford slow lines tunnel. Loose material has been removed and rock-fall netting installed over the failed area.

144 The RAM (drainage) has informed the RAIB that Network Rail is intending to undertake some local reinstatement to the drainage in the vicinity of the landslip to better capture and contain water from the third party. Timescales for this work are currently unknown.

145 LNW control offices have been instructed to hold an emergency EWAT meeting after a forecast for rainfall has been upgraded to amber or red at short notice.

146 LNW geotechnical and drainage RAM teams have started a programme to review cutting slopes and tunnel portals to identify any water concentration features and the adequacy of any associated drainage arrangements.

Recommendations and learning points

Recommendations

147 The following recommendations are made[17]:

1 *The intent of this recommendation is to mitigate the risk of a future slope failure at this historically vulnerable location. Effective implementation of the drainage work described in paragraph 144 is likely to contribute to implementation of this recommendation.*

Network Rail should implement measures to improve surface drainage (eg by provision of a suitable drainage system encompassing the crest), in the vicinity of the 2016 Watford tunnel landslip. It should also investigate whether it is necessary to take steps to manage sub-surface flows which were observed during this accident and could reoccur during a future event (paragraph 128).

2 *The intent of this recommendation is to determine whether other Network Rail locations have an unrecognised washout risk for reasons found at the accident site. Implementation is expected to comprise verification that the current processes identify risk at locations similar to the accident site and a check to find any other sites omitted from washout studies for reasons similar to those at Watford.*

Network Rail should review, and if necessary, improve its process for identification of localised water concentration features which can channel significant amounts of water onto the railway with the consequent risk of slope failure. This review should include:

a. using current Network Rail processes to analyse the washout and earthflow risk for the slow lines cuttings at Watford to determine whether this correctly identifies the landslip site as a high risk location; and

b. verifying that the process has been applied to all relevant track alignments including those such as at Watford where there are closely spaced multiple alignments (paragraph 129).

[17] 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 and Road 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.gov.uk/raib.

3 *The intent of this recommendation is to identify and assess the effectiveness of design features that provide guidance to trains when derailed, so limiting the deviation of trains from the track and reducing the risk of collision with trains approaching on other lines. This could be achieved by the retention or strengthening of features already forming part of the bogie structure, or infrastructure measures such as guard rails. It is also intended that the learning from research in this area is used to derive meaningful design requirements.*

The Rail Delivery Group (RDG), in conjunction with RSSB, should:

a. commission research into the ways in which guidance can be provided to derailed trains. This should include consideration of:
   - how the design of bogies and bogie mounted equipment can assist in limiting the lateral deviation of passenger trains during a derailment;
   - practice in other countries (eg Japan);
   - how specially installed infrastructure features can achieve the same effect at high risk locations;
   - potential design requirements for the retention or enhancement of such features on new trains or infrastructure; and
   - the potential benefits and drawbacks of such measures.

If such features, whether existing or additional, are shown to have a net beneficial effect in reducing risk by limiting lateral deviation, RDG/RSSB should:

b. share this information with the relevant Standards Committees; and

c. record and disseminate the design requirements with a view to their incorporation into future standards.

4 *The intent of this recommendation is to manage the risk caused by displaced emergency equipment located in the driving cabs of the class 350 and other classes of Desiro train, identified as a result of this accident.*

Siemens, in conjunction with the relevant rolling stock owning companies (ROSCOs), should review and improve the physical security and/or location of emergency equipment (eg track circuit clips and detonators) carried in driving cabs. This is to minimise the risk of secondary injury to cab occupants during a collision (paragraph 134).

5 *The intent of this recommendation is to enable a prompt response by fire and rescue and ambulance services following an accident on Network Rail infrastructure. It is envisaged that liaison with the British Transport Police will be required to achieve part (a) and liaison with representatives of the fire and rescue services will be required to achieve part (b).*

Network Rail should improve emergency arrangements for its infrastructure by:

a. reviewing with relevant organisations and, where appropriate, improving its processes in order to minimise the time taken during emergencies to contact organisations providing fire and rescue and ambulance services (paragraph 135b); and

b. considering and, where necessary, implementing liaison with the local fire and rescue service including participation in joint site inspections at access gates which may need to be used by the emergency services where appropriate (paragraph 135c).

6 *The intent of this recommendation is to support the completion of a full survey of drainage assets required to mitigate safety risk on Network Rail infrastructure.*

Network Rail should develop and commit to a time bound plan to complete its planned survey of drainage assets to provide sufficient asset knowledge to adequately manage risk. This should include a desk study of archive records and current records, together with inspections on site (paragraph 142).

Learning points

148 The RAIB has identified the following key learning points[18]:

1 Staff planning new works should ensure that pre-construction record searches are always undertaken. They can reveal essential safety information such as identifying the full range of functions intended to be performed by existing structures (paragraph 94).

2 This investigation shows how the availability of working GSM-R radio equipment, and the prompt use of its railway emergency group call function by train drivers and signallers can provide vital protection for trains during or following an incident if used immediately (paragraph 102a).

[18] 'Learning points' are intended to disseminate safety learning that is not covered by a recommendation. They are included in a report when the RAIB wishes to reinforce the importance of compliance with existing safety arrangements (where the RAIB has not identified management issues that justify a recommendation) and the consequences of failing to do so. They also record good practice and actions already taken by industry bodies that may have a wider application.

3 Management of the rescue phase of this accident demonstrated the value in providing staff such as RIOs with hand-held GSM-R equipment. This allows communication on sites where there may be limited mobile phone signal and a lack of fixed equipment to support emergency services' radio systems. LNW Route (south) equip their MOMs with a GSM-R handset in each response vehicle (paragraph 135d).

Appendices

Appendix A - Glossary of abbreviations and acronyms

BTP	British Transport Police
EACB	Earthworks Asset Criticality Band
EHC	Earthworks Hazard Category
EWAT	Extreme weather action teleconference
FRS	Fire and rescue service
GSM-R	Global System for Communications – Railways
JESIP	‘Joint Doctrine: The Interoperability Framework’ – emergency services protocol
LIDAR	Light Detection and Ranging (survey)
LNW	Network Rail’s London North Western Route
MOM	Mobile operations manager
OTDR	On-train data recorder
RAM	Route Asset Manager
RDG	Rail Delivery Group
RIO	Rail Incident Officer
RSSB	Rail Safety and Standards Board
RVP	Rendezvous point
VCB	Vacuum circuit breaker
WERM	Washout and earthflow risk mapping
WSP	Wheel-slide protection

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.

Anti-climbers	Grooved buffers attached to the vehicle chassis which are designed to interlock during a collision to prevent vehicle over-riding or telescoping.
Axle counters	A track-mounted device that accurately counts passing axles.*
Bogie	An assembly of two wheelsets in a frame which is pivoted at the end of a long vehicle to enable the vehicle to go round curves.
Catchment area	Area from which rainfall flows towards a river.
Chain	A unit of measurement. One chain equals 22 yards.
Crest drainage	Drainage provided at the top of a cutting slope.
Cutting	An excavation that allows railway lines to pass at an acceptable level and gradient through the surrounding ground. Network Rail categorises its cuttings as soil cuttings, rock cuttings or mixed cuttings. Mixed cuttings are those composed of both soil and rock. For management purposes the soil and rock components are examined and recorded separately.
Detonator	A small disc-shaped explosive device that is fastened to the rail head and exploded by the passage of a railway vehicle.
Down (line)	At Watford, a track on which the normal passage of trains is away from London.
Double yellow	A preliminary caution aspect on a four aspect colour light signal.*
Earthwork	A cutting, embankment, or natural slope segment up to 5 chains (100 m) long lying within the Network Rail boundary that is equal to or greater than 3 m high, or if less than 3 m high whose failure could pose an unacceptable risk to the safe operation or performance of railway infrastructure.
Emergency brake	The position on the brake control that applies the maximum possible braking effort. This is beyond the normal service brake position.
Extreme weather action teleconference (EWAT)	A teleconference involving senior managers drawn from the operations, engineering, communications and commercial functions within a Network Rail route which is activated when extreme weather conditions are forecast.
Full service brake	A full (non-emergency) brake application.
Ground anchors	Steel pins driven into the underlying ground to provide a stable fixing.

GSM-R	A national radio system which provides secure voice mobile communications between trains and signallers, relaying calls via radio base stations built alongside the railway or on suitable vantage points.
Major incident	Defined by the Cabinet Office as: ‘An event or situation with a range of serious consequences which requires special arrangements to be implemented by one or more emergency responder agency.’
Off-track (drainage)	Network Rail drainage assets located away from the line side.
On-track (drainage)	Network Rail drainage assets located at the line side.
Possession	A period during which the operation of normal service trains is suspended on a designated section of line for the purposes of maintenance and/or engineering works.
Reverse curve	A location where a curve to the left or right is followed immediately by a curve in the opposite direction.
Root jacking	The growth of tree roots which results in the prising apart of rocks or the displacement of boulders.
Slow (lines)	At Watford, the lines which are normally used by local passenger services and freight.
Third rail (electrification)	A general term used to cover the type of electrification that involves the supply of DC current to trains by means of a conductor rail laid along one side of the track (the ‘third rail’).
Track-circuit operating clips	A pair of spring clips connected by a wire, used to short out track circuits by connection across the rails in times of emergency.*
Vacuum circuit breaker latching circuit	A train control circuit providing train-wide control of the Vacuum Circuit Breaker opening and closing. When the ‘VCB On’ switch is operated by the driver from the active cab, the VCB latching circuit is energised along with a separate pantograph control circuit which allows the pantographs to be raised or lowered. This circuit is powered by the train battery when operating in battery-normal status.
Washout failure	Water flow eroding surface material from a cutting (or embankment).
Up (line)	At Watford, a track on which the normal passage of trains is towards London.

Appendix C - Investigation details

The RAIB used the following sources of evidence in this investigation:

- information provided by witnesses;
- information taken from the trains' OTDRs;
- closed circuit television (CCTV) recordings;
- site photographs and measurements;
- incident logs provided by the British Transport police and Hertfordshire Fire and Rescue Service;
- weather reports and observations at the site;
- a meteorological report commissioned by the RAIB from the Met Office; and
- a review of previous RAIB investigations that had relevance to this accident.

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

Any enquiries about this publication should be sent to:

RAIB
The Wharf
Stores Road
Derby UK
DE21 4BA

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