Rail Accident Investigation Branch

Rail Accident Report

Buffer stop collision at Chester station
20 November 2013

Report 26/2014
November 2014

This investigation was carried out in accordance with:

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

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Buffer stop collision at Chester station 20 November 2013

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Summary

At 12:12 hrs on Wednesday 20 November 2013 the 10:10 hrs passenger train from London Euston to Chester collided with the buffer stop at the end of the platform as it arrived at Chester station. The impact destroyed the buffer stop and caused the leading vehicle of the train to start to override the platform, demolishing a glass screen and damaging the platform. It was fortunate that there was no-one in this area at the time.

Several passengers fell over as the train stopped, but did not report injuries. One passenger was taken to hospital as a precaution and was released later the same day. The front of the train was damaged by the impact and the leading bogie was derailed.

Platform 1 at Chester station was closed until 04:15 hrs on 22 November for recovery of the train and repair of the buffer stop.

The accident was caused by the train sliding on wet rails that were also contaminated with leaf residue and traces of lubricating oil. The train was not equipped with automatic sanding equipment, which could have applied sand to the rails to improve adhesion. The train was fitted with emergency sanding equipment but the driver did not activate this until the train was too close to the buffers to be able to stop before striking them.

The train involved was a class 221 unit operated by Virgin Trains. The RAIB analysed records of low rail adhesion incidents on Network Rail infrastructure during Autumn 2013 and found several other cases of class 221 trains, and the similar class 220, encountering low adhesion when attempting to stop. In some cases the driver had to use the emergency sanding equipment. The RAIB analysis found that, per attempted stop, class 220 and 221 trains were the most likely type of train to be involved in a low adhesion incident. Almost all other types of train are fitted with automatic sanding equipment, or equivalent.

The RAIB has identified two key learning points and made three recommendations. The operators of class 220 and 221 trains are recommended to fit equipment to their trains to automatically apply sand when wheel slide is detected during heavy braking (Virgin Trains has recently informed the RAIB of its intention to fit such equipment to its fleet of class 221 trains). A recommendation is made to Virgin Trains to amend its operating instructions to drivers and a recommendation is made to RSSB to update the standard which governs the fitment of train sanding equipment.

The first learning point concerns the analysis of data from train data recorders to provide information on the location of low adhesion conditions on the network. The second learning point is that infrastructure managers need to be aware of changes in traffic patterns which necessitate the reassessment of the adequacy of buffer stops in terminal platforms.

Introduction

Preface

1 The purpose of a Rail Accident Investigation Branch (RAIB) investigation is to improve railway safety by preventing future railway accidents or by mitigating their consequences. It is not the purpose of such an investigation to establish blame or liability.

2 Accordingly, it is inappropriate that RAIB reports should be used to assign fault or blame, or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

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

Key definitions

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

5 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

6 At 12:12 hrs on Wednesday 20 November 2013, train reporting number 1D84, the 10:10 hrs passenger train from London Euston to Chester, collided with the buffer stop at the end of platform 1 as it arrived at Chester station (figure 1).

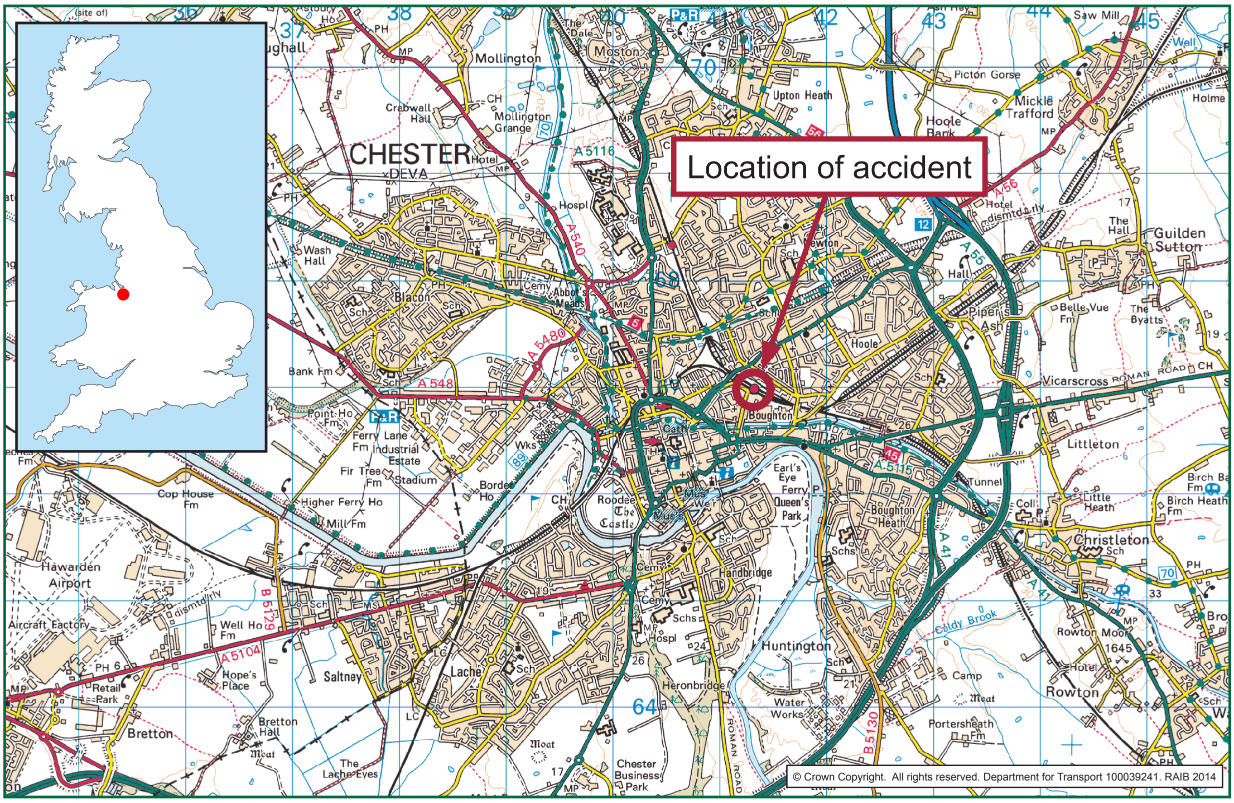

Figure 1: Extract from Ordnance Survey map showing location of accident

7 The impact destroyed the buffer stop and caused the leading vehicle in the train to start to override the platform, demolishing a glass screen and damaging the platform (figure 2). It was fortunate that there was no-one in this area at the time.

8 Several passengers fell over as the train stopped, but did not report injuries. One passenger was taken to hospital as a precaution as he had recently undergone a back operation. He was released later the same day.

9 The front of the train was damaged during the impact and the leading bogie was derailed.

10 Platform 1 at Chester station was closed until 04:15 hrs on 22 November for recovery of the train and repairs to the buffer stop.

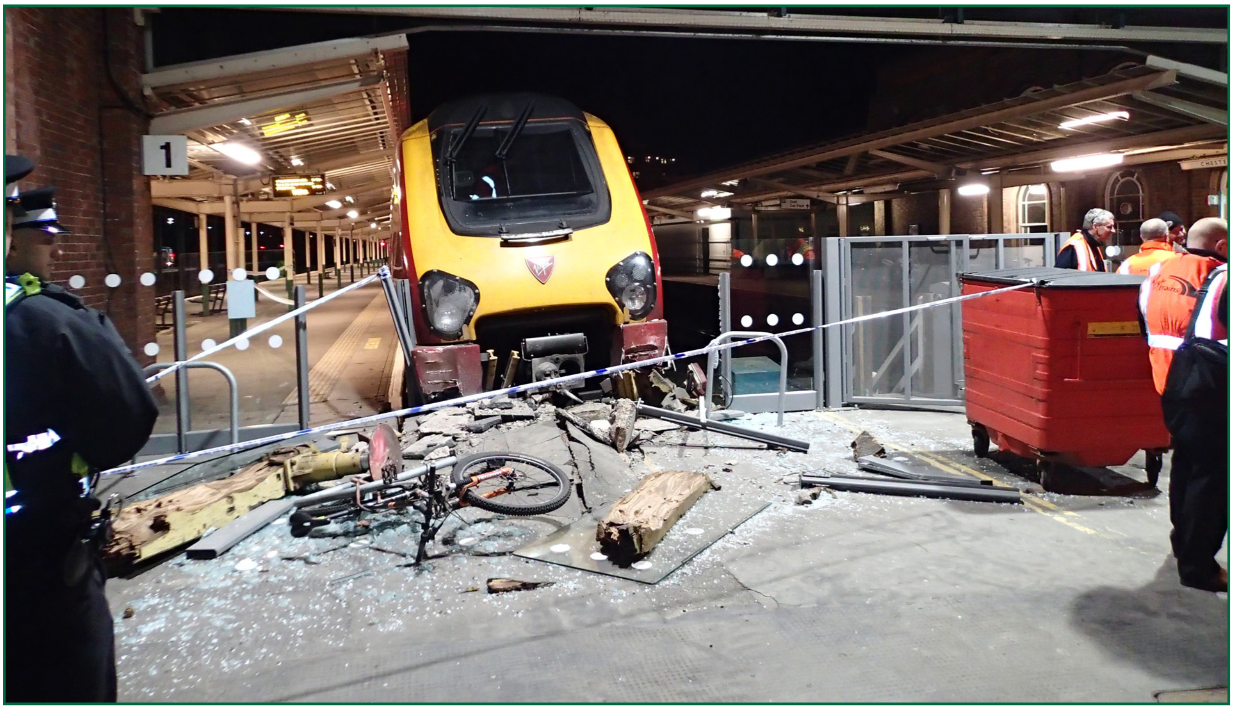

Figure 2: Position of train after the accident

Context

Location

11 The accident occurred in platform 1 at Chester station. This is a *bay platform* that is normally used by trains terminating at Chester after arriving from the Crewe direction. The length of the platform, from the buffer stop to the top of the platform ramp, is 157 metres.

12 The approach to Chester station from the Crewe direction involves passing through a short tunnel beneath the Shropshire Union canal (Christleton tunnel) and the line then curves to the left as it approaches the station. There is a signal before the tunnel (CR27) and another signal on the immediate approach to the station (CR29). A route indicator on signal CR29 shows the driver which platform the train is routed into.

13 Figure 3 is a schematic plan showing the significant features of the approach to the station, including the distance to each feature from the buffer stops in platform 1, as measured by the RAIB after the accident.

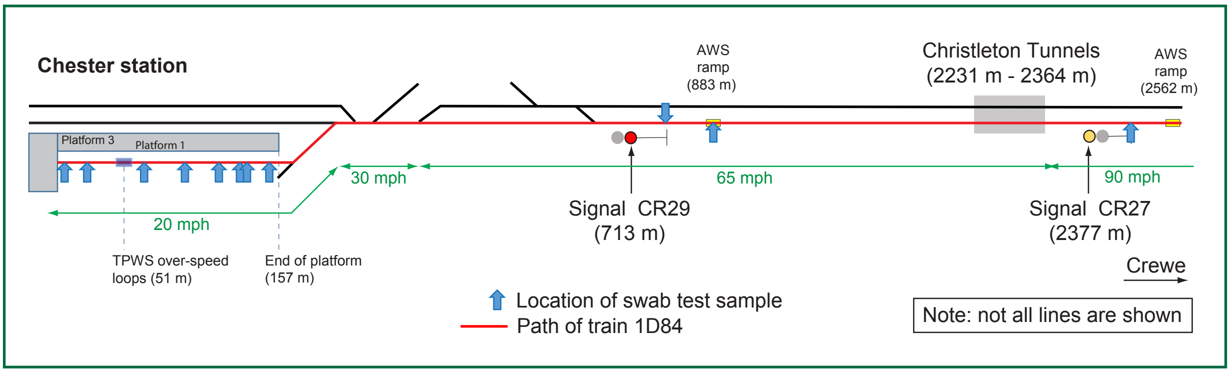

Figure 3: Schematic plan of the approach to Chester from the Crewe direction

Organisations involved

14 The train was operated by Virgin Trains, who also employed the driver.

15 The train was built by Bombardier Transportation in Brugge, Belgium, in 2001 and was fitted with brake control equipment manufactured by Knorr-Bremse.

16 The infrastructure is owned by Network Rail, who also employed the signallers at Chester signal box and the staff who maintained the track and dealt with reports from drivers of slippery conditions on the track. The area was part of Network Rail's London North West (North) (LNW(N)) route.

17 Platform 1 was also used by train services operated by Arriva Trains Wales.

18 Arriva Trains Wales, Bombardier Transportation, Knorr-Bremse, Network Rail and Virgin Trains freely co-operated with the investigation.

Trains involved

19 The train comprised a 5-car class 221 'Super Voyager' *diesel electric multiple unit* (figure 4), number 221 105, and there were 107 passengers and 7 staff on board.

Figure 4: Class 221 diesel electric multiple unit

20 The previous train to use platform 1 was the Arriva Trains Wales 11:55 hrs departure to Crewe, which consisted of a 2-car class 158 diesel multiple unit, number 158 837.

Rail equipment/systems involved

21 The lines through Chester station are controlled from Chester signal box. The system of signalling employed here is *track circuit block.* The signal box equipment includes a large control panel to display the area controlled by the box.

22 All of the lines used by train 1D84 are equipped with track circuits, which are electrical circuits designed to show the presence or absence of a train on a particular section of track. The status (ie occupied or clear) of these track circuits is displayed on the control panel and also recorded on a data logger at the signal box. The data logger also recorded the operation of other signalling equipment, such as points and signals.

23 The buffer stop in platform 1 was of an old design built from bent rails bolted together (figure 5). It had a timber beam across the top to which were attached hydraulic wagon buffers. The rear part of the buffer stop, behind the timber beam, was concealed beneath the concrete platform surface.

Figure 5: Buffer stop in platform 1 prior to accident and before installation of a glass screen (courtesy of Network Rail)

Staff involved

24 The driver of train 1D84 had worked for Virgin Trains for 14 years, having been trained by that company as a driver. Virgin Trains' records showed that he had not previously been involved in any safety-related incidents. He stated that he had had a good night's sleep before starting duty on 20 November.

25 On the basis of witness and *on train data recorder* (OTDR) evidence, the RAIB does not consider that fatigue was a factor in this accident.

External circumstances

26 The weather conditions on 20 November, as recorded at Hawarden airport (7 km west of Chester station), were rain showers with a minimum temperature of 1 °C, maximum of 8 °C and average of 4 °C. The temperature at the time of the accident was between 6 and 8 °C. The mean wind speed that day was between 25 and 50 km/h with gusting up to 70 km/h at the time of the accident. Total rainfall over the whole 24 hours was 9 mm.

27 Network Rail commissioned daily adhesion forecasts from a weather forecasting company which predicted the likely *rail adhesion* conditions. Each forecast consisted of a prediction of the adhesion conditions expressed as a number between 0 and 10. On this scale values of 0 to 2 are defined as good adhesion, 3 to 5 are moderate, 6 to 8 are poor and 9 and 10 are very poor. For the purposes of this forecast, the UK mainland was divided into 23 geographical areas and an adhesion forecast was provided for each of these areas, based on the expected weather. The route of train 1D84 from Euston to Chester passed through two of these areas which were both rated at 6 for 20 November.

28 Train 1D84 was fitted with forward facing closed circuit television (FFCCTV) equipment and the recording showed that the weather was overcast and dry on the approach to Chester but rain clouds could be seen ahead. Rain started shortly after the train left Christleton tunnel (figure 3) with spots of rain appearing on the windscreen. The rainfall increased, requiring the driver to switch on the wiper to give a single wipe as the train approached signal CR29. The rainfall continued as the train ran into the station, but not so heavily as to require the wiper to be used again.

The investigation

Sources of evidence

29 The following sources of evidence were used:

- witness statements;
- data from the train's OTDRs;
- data from the train's brake control computers;
- closed circuit television (CCTV) recordings taken from within the train, including forward facing and internal passenger saloon cameras;
- data from the OTDRs of other class 221 trains;
- OTDR data from the Arriva Trains Wales unit which ran in and out of platform 1 on the day of the accident;
- data relating to track circuit and signal operation recorded by the data logger in Chester signal box;
- site photographs and measurements;
- weather reports and observations at the site and at Hawarden Airport, 7 km to the west;
- reports of the chemical analysis of samples taken from the rail head;
- Network Rail's records relating to low adhesion management in LNW(N) route;
- data from Network Rail's control centre incident log (CCIL) system for the period 1 September – 31 December 2013;
- Virgin Trains' drivers' manuals and other documents;
- Bombardier Transportation documents relating to design, maintenance and testing of class 220 and 221 trains;
- Knorr-Bremse documents relating to the design and operation of the brake control system fitted to the train; and
- a review of previous RAIB investigations that had relevance to this accident.

Key facts and analysis

Sequence of events

Events preceding the accident

30 The driver of train 1D84 started his shift at 06:10 hrs at Crewe and travelled as a passenger to Euston. The train he travelled on was formed of two class 221 units. After arrival at Euston the driver split the two units and one of them, unit 221 105, became train 1D84, the 10:10 hrs departure for Chester. The driver was scheduled to drive train 1D84 from Euston to Chester, then have a 25 minute meal break, before driving back to Crewe, where his shift finished. He had worked this same work pattern on the day before the accident.

31 Train 1D84 was scheduled to stop at Milton Keynes, Crewe and Chester. The driver reported that the journey was uneventful. He carried out a *running brake test* as the train passed Willesden and reported that the brake worked correctly, although there was a 'slight flicker' from the *wheel slide protection* (WSP) indicator (paragraph 62). This was indicating that the WSP system was detecting intermittent low adhesion conditions. The weather during the journey was clear and dry apart from a heavy shower as the train passed Cheddington (between Euston and Milton Keynes).

32 The driver had no problems in stopping at Milton Keynes and Crewe. However, an earlier train that day, also operated by a class 221 unit, had encountered low adhesion approaching Crewe and its driver had used the one-shot sander (paragraph 70).

33 As the train approached Chester, signal CR27 was showing a single yellow aspect indicating that the driver should be prepared to stop at the next signal (CR29). The driver applied the brake and the speed was reduced from 90 mph (144 km/h) to 40 mph (64 km/h) with no WSP indication. The driver again applied the brake as the train approached the next signal, CR29. This signal is *approach controlled* for trains routed into platform 1, and was consequently held at red as the train approached. During the approach to this signal the driver noticed that the WSP indicator was flickering.

34 The train approached the *automatic warning system* (AWS) *magnet* for signal CR29 at 19 mph just as the signal changed to a single yellow aspect with a route indicator showing 'B1', indicating that the train was routed into platform 1. The driver released the brake and applied power to bring the train speed up to 25 mph (40 km/h). The speed limit approaching the station is 30 mph (48 km/h), but the driver stated that he kept to 25 mph (40 km/h) on this occasion as he had seen from the WSP indicator lamp that there were low adhesion conditions in the area.

Events during the accident

35 As the train approached the station, the driver applied the brake again to reduce the speed for the 20 mph (32 km/h) speed restriction through the points towards platform 1. He applied the brake in the 'L' (low – ie first mark on the scale beside the control handle) position. The WSP indicator immediately became steadily lit. Figure 6 shows the key events recorded by the OTDR plotted on a diagram of the approach to the platform.

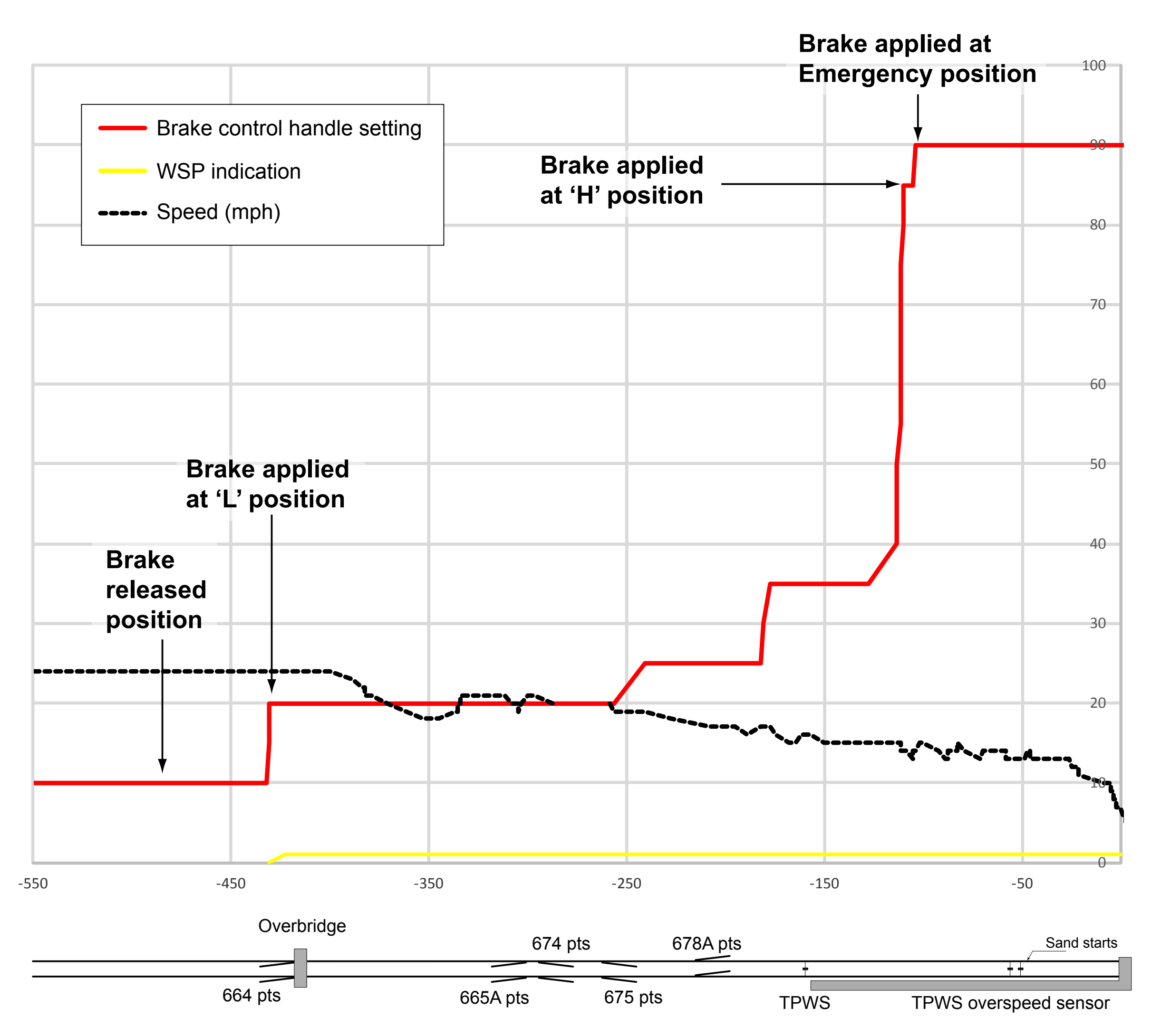

Figure 6: Key events from OTDR recording approaching platform 1 at Chester

36 The *on-train data recorder* (OTDR) showed that the train slowed to 16 mph (26 km/h) as it ran into platform 1. The WSP indicator remained lit throughout this time. The driver increased the brake setting as the train entered the platform.

37 As the train continued along the platform the driver increased the brake setting further, because he judged that the train was not slowing quickly enough. The OTDR shows that the brake control handle was moved to the 'H' (high – ie full service brake) position when the train was 99 metres from the buffer stop. The speed at this time was 14 mph (22 km/h).

38 The WSP indicator remained lit and the train still did not slow down as the driver expected. He pressed the emergency stop 'mushroom' button at about the same time as the train passed over the *train protection and warning system* (TPWS) over-speed sensor 51 metres from the buffer stop. Network Rail's signalling records stated that this was set to trigger a brake demand if a train passed over it at more than 10 mph (16 km/h). The OTDR showed that the train was travelling at 13 mph (21 km/h) at this point, and the TPWS system triggered a brake demand. This had no effect as the driver had already fully applied the brake. In normal adhesion conditions the train would have been able to stop from this speed before reaching the buffer stop.

39 When the driver pressed the emergency stop button, all of the conditions were present for the one-shot sander to automatically activate (paragraph 71). Consequently the leading vehicle started to deposit sand on both rails in front of its rear 2 axles. The RAIB noted that the sand that was deposited was visible on the rail head after the accident and began 47.6 metres from the buffer stop.

40 The sand improved adhesion for the wheels which ran over it and the rate of deceleration of the train increased slightly. However, there was insufficient distance for the train to stop before striking the buffer stop at approximately 5 - 6 mph (8 - 10 km/h).

41 The impact with the buffer stop caused the buffers mounted on it to break away, along with the timber beam on which they were mounted. The timber beam and one of the buffers were thrown onto the platform beyond the buffer stop.

42 The front of the train engaged with the steel rails which formed the uprights of the buffer stop, bending them back and causing the front of the vehicle to override them onto the platform beyond, where it came to rest (figure 2). As the vehicle rode up over the remains of the buffer stop, its front bogie was lifted off of the track (figure 7).

Figure 7: Front of train resting on platform showing derailed bogie

Events following the accident

43 The driver checked that it was safe for passengers to alight from the train then opened the doors.

44 The station staff reported the accident to the Network Rail control office and the emergency services were called.

45 An Arriva Trains Wales manager, who had heard the collision from his office, went to the train and took the driver back to his office for his welfare.

46 Another Virgin Trains driver who was undertaking a *route refresher* day was at the station and shut down the train's engines.

47 As is standard practice, the driver was tested for the presence of drugs and alcohol after the accident; none were found.

48 Network Rail reported the accident to the RAIB at 12:28 hrs and two inspectors were despatched to site to investigate. While they were en-route, the RAIB arranged for Network Rail to take swabs of the rail head and train wheels for subsequent analysis for signs of contamination.

Background information

Wheel/rail adhesion

49 The adhesion between the wheel and rail is normally expressed as a coefficient of friction (symbol μ). The lower the value of μ, the lower the adhesion between wheel and rail. Typical values for μ for dry rail would be at least 0.20. In wet weather, this can fall to 0.10. Under severe low adhesion conditions, the value of μ can fall below 0.03. As trains rely on the coefficient of friction between wheel and rail to stop, the level of adhesion available is critical to the rate at which a train can decelerate. Many trains have four or five fixed braking rates available to the driver, the lowest of which will normally achieve a deceleration rate of 0.3 m/s^2 and the highest a rate of at least 1.2 m/s^2. Although the relationship is not exact, a braking rate of 0.3 m/s^2 can only be achieved if the value of μ is at least 0.03, and a braking rate of 1.2 m/s^2 can only be achieved if the value of μ is at least 0.12.

50 Class 221 trains are fitted with a combined power and brake control handle which gives a continuously variable output, although indicative markings are shown beside the handle, with 5 'steps' between 'L' (low) and 'H' (high). There is also a setting marked 'E' (emergency). The nominal deceleration rate in the 'L' setting is 0.19 m/s^2; this requires a value of μ of at least 0.019.

51 Low adhesion is often associated with contamination of the rail head. RSSB[1] investigated this and published report T354 'The characteristics of railhead leaf contamination' in 2007[2]. However, low adhesion can also be experienced on uncontaminated rail which is slightly wet. This also has been the subject of research and RSSB published a summary of this in report T1042 'Investigation into the effect of moisture on rail adhesion' in July 2014.

[1] A not-for-profit company owned and funded by major stakeholders in the railway industry, and which provides support and facilitation for a wide range of cross-industry activities. The company is registered as 'Rail Safety and Standards Board' but trades as 'RSSB'.

[2] Available from the SPARK website at www.sparkrail.org/Lists/Records/DispForm.aspx?ID=9540.

Adhesion management

52 Low adhesion is managed through a set of measures implemented by Network Rail and the train operating companies. The industry standard, *Railway Group Standard* GE/RT8040 'Low Adhesion between the Wheel and the Rail – Managing the Risk', issue 2, Feb 2009, obliges Network Rail to control the risk of low adhesion by:

- having processes in place to identify locations where low adhesion might occur;
- publishing details of low adhesion sites in the Sectional Appendix (a document providing drivers and other staff with details of the routes over which they drive);
- leading development of site-specific plans to reduce the likelihood of low adhesion occurring;
- leading development of action plans to manage low adhesion at new sites; and
- monitoring performance and reviewing plans to ensure effective action is taken.

53 Network Rail incorporates the requirement of the Group Standard to identify potential low adhesion sites in its standard NR/L2/OCS/096 'Determining High Risk Sites for Low Rail Adhesion'. This standard defines how sites where low adhesion is likely to be a risk should be identified, using either a risk assessment approach or a review of historical records. The high risk sites are then published in the Sectional Appendix so that drivers are aware of them. The process is overseen by the Network Rail Seasons Delivery Specialist (SDS) in each route whose role is to manage Network Rail's response to risks arising from seasonal weather conditions.

54 The high risk sites, along with other sites that the SDS identifies as requiring treatment to improve adhesion, are added to the programme of rail treatment for the coming autumn. Network Rail has several methods of treating low adhesion sites. These include:

- Rail head treatment trains (RHTT);
- Fixed traction gel applicators; and
- Hand treatment by mobile leaf fall teams.

55 RHTTs are maintenance trains which are equipped with high pressure water jetting equipment to clean the rail head of leaf deposits and, in some cases, equipment to deposit an adhesion modification gel[3] to the rail head. The trains operate to a regular schedule that covers a number of low adhesion sites in an area.

56 Fixed traction gel applicators are items of lineside equipment that are arranged to dispense controlled amounts of adhesion modification gel on the rail so that it is picked up by the wheels of passing trains.

[3] Adhesion modification gels are pastes which are applied to the rail head to improve adhesion. They generally consist of sand or metal particles in a gel medium.

57 In some cases it is necessary to provide an immediate response to a report of low adhesion. In such cases Network Rail has leaf fall mobile operations managers (MOMs) and leaf fall teams who provide this response. They can use a variety of tools and techniques to clean the rail and improve adhesion, including manual cleaning of the rail, application of cleaning agents and application of traction gel. The mobile leaf fall teams are normally deployed in response to reports from train drivers of low adhesion conditions, but also proactively visit potential low adhesion sites where problems have arisen in previous years. They also check sites where a planned RHTT run did not occur.

58 Train drivers report low adhesion conditions to the signaller. If the site of the low adhesion is a high risk site that is published in the Sectional Appendix, train drivers are expected to be aware of the potential for low adhesion and to drive accordingly. However, if a driver considers that the conditions are even worse than expected then they must report it to the signaller as ‘exceptionally poor adhesion’. If a driver experiences low adhesion at a location that is not indicated in the Sectional Appendix, and considers the conditions are such that other drivers need to be warned, the driver must report it to the signaller as ‘low rail adhesion’.

59 The approach to Chester station from the Crewe direction was not listed in the Sectional Appendix as a low adhesion site. Network Rail had only received one report during autumn 2013, prior to the accident, of low adhesion here (paragraph 107). Since this was not seen as an area prone to low adhesion, the RHTT was not scheduled to treat this section of line.

Class 221 brake control system

60 Class 221 trains, in common with other modern trains, are equipped with brake control computers. The brake control computer is built into a *brake control unit* (BCU), which also includes other equipment to control the brakes, notably the *analogue control unit* (ACU), which controls the compressed air used to operate the brakes.

61 The BCU takes, as one of its inputs, the brake rate demanded by the driver’s power/brake control handle and determines how the brake effort should be generated. The braking on the class 221 is a mixture of *dynamic braking* and *friction braking* and the BCU controls how these are blended together. The dynamic braking is achieved by the traction control system which indicates to the BCU how much braking effort it has achieved. The BCU then determines the braking effort required from the friction brakes and commands the ACU to generate the compressed air output to the brake cylinders at the appropriate pressure to provide the required level of retardation.

62 The BCU includes a system known as ‘*wheel slide protection’* (WSP). The WSP system has several functions. Firstly it aims to prevent axles locking up, which can damage the wheels. It does this by monitoring the rotational speed of each axle during braking. If the WSP detects that an axle is starting to rotate more slowly than the other axles, a sign that it may be starting to slide or lock up, the WSP releases the brake on that axle to allow the wheels to return to the correct speed. When it determines that the axle is again rotating at the correct speed, it reapplies the brake on that axle.

63 To guard against the possibility of all wheels sliding at the same time, when wheel slide is detected during braking, the WSP periodically partially releases the brake on an axle to allow that axle to return to the speed of the train. This allows the WSP to calculate the true ground speed of the train from the highest of the individual axle speeds.

64 The second function of the WSP is provided to maximise the retardation of the train in the prevailing friction conditions. Research[4] has shown that a degree of sliding contact between wheel and rail is beneficial in that it 'conditions' the wheel and improves the friction between wheel and rail. The WSP on the class 221 was designed to attempt to keep the speed of the wheels 17% below the speed of the vehicle during braking in wheel slide conditions.

65 The dynamic brake can only be applied to powered axles and, since only 2 of the 4 axles on each class 221 vehicle are powered, the dynamic brake can only be applied to 50% of the axles on the train. In low adhesion conditions braking is required on all axles and, if wheel slide is detected, the WSP stops the application of the dynamic brake and attempts to generate all of the brake effort using the friction brakes alone.

66 When the WSP system detects that one or more axles is starting to slide it provides a signal to the driver by switching on a 'WSP' indicator lamp in the cab. This lamp is lit only when the WSP on the leading vehicle detects sliding; however, this is the vehicle most likely to encounter low adhesion conditions as it is the first vehicle in the train and is likely to condition the rail for the following vehicles.

67 The BCU on the leading vehicle also provides the speed output signal to the speedometer and provides an indication of the retardation rate being achieved, which is displayed to the driver on a gauge below the speedometer on the driver's control desk (figure 8).

Train sanders

68 Trains can be fitted with equipment to deposit sand on the rails to improve adhesion. Railway Group Standard GM/RT2461 'Sanding Equipment Fitted to Multiple Units and On-Track Machines*'* was issued in August 2001 and requires sanders to be fitted to all multiple units and on-track machines whose *certificate of conformance for vehicle design* was signed after 3 December 2003. Trains which had entered service before this standard came into force, such as class 221, were not required to be fitted with sanders. However, Virgin Trains and Bombardier decided that the class 220 and 221 trains were to be fitted with sanders during manufacture (for details of the type of sander installed see paragraphs 70 and 71).

[4] BR Research Division Technical Memorandum TM TBC 019 'Reducing braking distance in low adhesion conditions by high creep brake control', J D Tunley, Oct 1988.

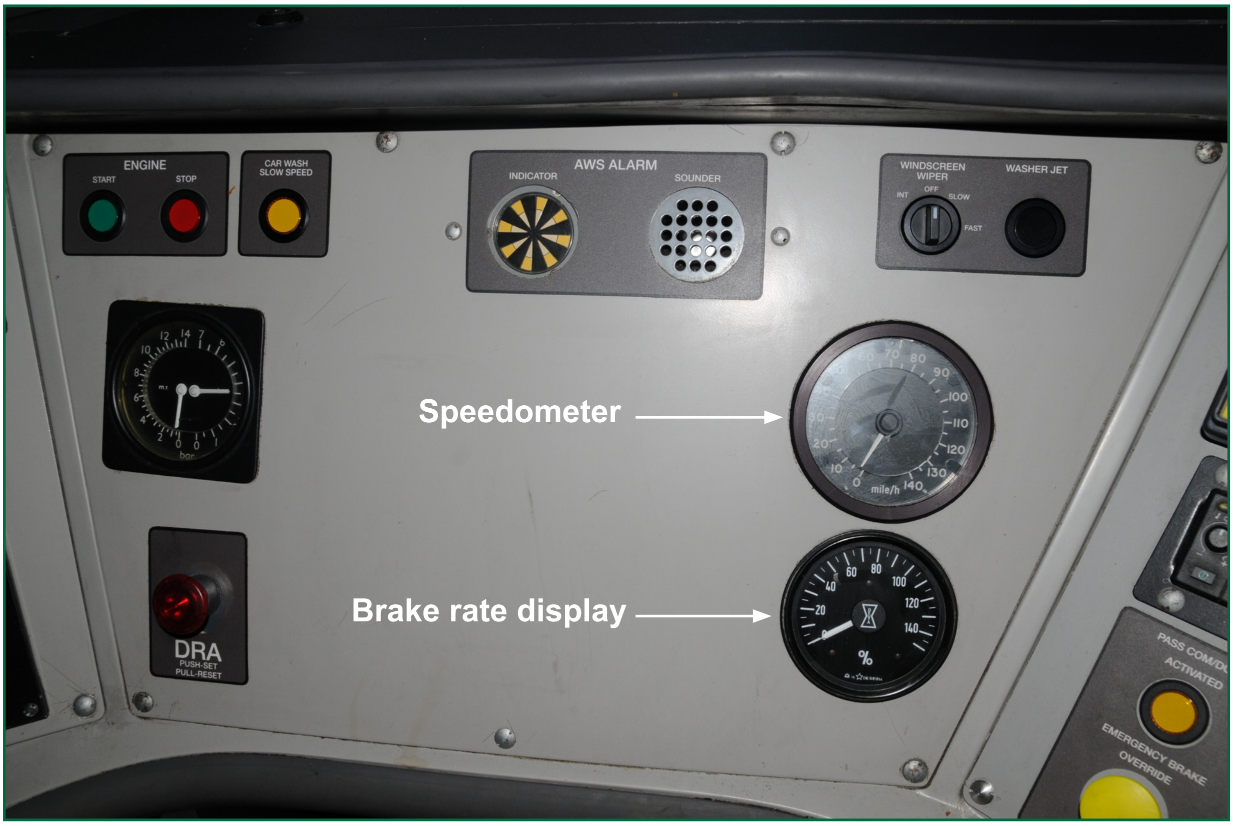

Figure 8: Driver's desk showing speedometer and brake rate display (photo courtesy of BTP)

69 Sanding equipment can be designed to operate automatically, when wheel slide is detected, or manually, controlled by the driver. Clause 6.1 of the Group Standard states:

> *'... as a minimum the sanding equipment shall discharge sand during full service and emergency brake applications when the presence of low adhesion is automatically detected'.*

In practice, this means that sanders which comply with the Group Standard must be automatically operated when low adhesion is detected during full service or emergency braking. The RAIB investigation into low adhesion events during autumn 2005 (report 25(part 3)/2006, paragraph 145) made a recommendation (recommendation 1) that sanding also be used in brake step 2, or its equivalent. At the time of publication of report 25 (part 3)/2006, it was expected that the Group Standard would be reissued shortly and would incorporate the step 2 sanding requirement. However, the Group Standard has not yet been reissued and at the time of publication of this report RSSB stated that it had no plans to do so.

70 Some trains that were built before the Group Standard came into force were fitted with sanders to improve their braking performance in low adhesion conditions. In some cases, the sanders provided were 'one-shot' devices that could be triggered by the driver in emergency conditions. These one-shot sanders were intended only for emergency use and, after being used, arrangements had to be made to control the risk of low adhesion until the sand bottles had been replaced. These arrangements could include running at reduced speed or reversing the train so that the affected cab was not leading.

71 The class 220 and 221 trains were fitted with one-shot sanders during manufacture. They were automatically triggered when all of the following conditions were met:

- driver's emergency stop 'mushroom' button is pressed;
- WSP is detected; and
- train speed is over 8 mph (13 km/h).

72 The reason for the minimum speed requirement was to limit the amount of sand deposited over a given distance so as to avoid potential problems with *track circuits* due to the sand preventing electrical contact between wheel and rail. The Group Standard has a corresponding requirement for the design of sanding systems that the rear two axles of the train do not come to rest on sand laid at a rate of more than 7.5 grammes/metre. As the one-shot sanders do not control the rate of discharge of the sand, the minimum speed requirement is intended to prevent the discharge of sand at low speed to reduce the risk of the rear of the train running onto heavily sanded rail.

73 The need to make special arrangements for the train to continue its journey after using the emergency sander was found to cause operational problems, and the class 220 and 221 trains were subsequently provided with two emergency sand bottles so that, after an activation, the driver could operate a changeover switch and continue the journey.

Identification of the immediate cause[5]

74 **The train was unable to slow down at a sufficient rate to avoid collision with the buffer stop**.

75 The OTDR showed that the driver applied the brake when the train was 430 metres from the buffer stop in platform 1. At this time the speed was 24 mph (38 km/h). The WSP indicator became lit 1 second later. The setting of the power/brake control handle was indicated in the OTDR data as 20%[6]. This would normally produce a deceleration of at least 0.19 m/s^2, but in this case the deceleration was less than 0.1 m/s^2.

76 The train's speed gradually reduced and by the time the train was at a point 253 metres from the buffer stop the OTDR recorded that the speed had reduced to 19 mph (30 km/h). The driver increased the brake setting at this point to 25%. Figure 6 shows the key features of the approach to the platform.

77 As the train approached platform 1, at a point 178 metres from the buffer stop, the driver increased the brake setting to 35%. The OTDR indicated that the speed was around 17 mph (27 km/h) at this point, but the recorded value fluctuates due to the WSP repeatedly re-evaluating the speed as the wheels slid.

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

[6] The position of the driver's brake control handle is recorded on a scale which runs from 10% to 90%, where 10% represents 'brake released' and 90% represents the emergency position.

78 The driver increased the brake setting further when his cab had passed the platform ramp, reaching 40% at 110 metres from the buffer stop. Soon after this, he increased the brake to the maximum setting, reaching 90% (corresponding to the 'emergency' position) when the train was 99 metres from the buffer stop.

79 The OTDR data shows that the two previous class 221 trains into platform 1 that day had approached the platform at similar speeds to the incident train and their drivers had applied the brake at a similar location (one applied the brake earlier than the incident train and one later), but neither of the other trains had used brake settings higher than 35% and were able to stop without incident.

80 Analysis of the track circuit data recorded by the data logger in Chester signal box showed that the train involved in the accident approached the platform slower than most other trains on that day. Comparison between the data logged for the incident train and for the same train the previous day confirmed that the driver approached at a lower speed on 20 November than on the previous day.

81 The fact that the WSP indicator lit up as soon as the brake was applied in the lowest setting indicates that the friction available between the wheels and rails was too low to support even the initial brake application (ie indicating a coefficient of friction less than 0.019).

Identification of causal factors[7]

82 The accident occurred due to a combination of the following causal factors:

- The level of adhesion between wheels and rails was exceptionally low (paragraph 83).
- No action had been taken to improve the coefficient of friction between the wheels and rail by pre-treatment of the rail head (paragraph 102).
- The activation of the train's sander was too late to avoid a collision with the buffer stop (paragraph 112).

It is also considered probable that the following was a causal factor;

- Virgin Trains' defensive driving policy did not apply to the approach to buffer stops (paragraph 126).

Each of these factors is now considered in turn.

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

Level of adhesion between wheels and rails

83 **The effective[8] coefficient of friction between the train's wheels and the rails was exceptionally low. This caused the wheels to slide even at the lowest brake setting.**

84 The RAIB used the data from the train's OTDR to calculate the effective coefficient of friction between the wheels and the rails. However, as the WSP releases the brake on some of the axles occasionally as part of its process for estimating the true ground speed of the train (paragraph 62), the value of friction calculated will be less than the true coefficient of friction between an individual wheel and the rail. Nevertheless, it does allow a comparison to be made with effective coefficients of friction from other trains calculated by the same method.

85 Virgin Trains has a system that remotely downloads the data from the OTDRs of its trains each night[9]. During the autumn period, this data is analysed to locate significant areas where trains have experienced WSP indications. The RAIB obtained copies of this data for some other cases where class 221 trains had encountered low adhesion during the autumn of 2013. This data was analysed, with the track gradient information, to calculate the effective coefficient of friction at the time. The values calculated are shown in table 1, along with values calculated in previous RAIB investigations and typical values.

86 Table 1 shows that the effective coefficient of friction encountered by the incident train in the platform was the lowest found during this analysis, and previous, RAIB investigations. The table also shows that class 221 drivers have generally used the one-shot sanders when the effective coefficient of friction was less than 0.02. This corresponds closely to the minimum value of μ to support the lightest brake application marked on the class 221 power/brake handle (0.019) without wheel slide.

87 The exceptionally low adhesion arose due to a combination of the following:

- the rails were contaminated with traces of leaf residue and, within the platform area, lubricating oil (paragraph 88); and
- the rails were just becoming wet (paragraph 96).

Each of these factors is now considered in turn.

Contamination of the rails

88 **The rails were contaminated with traces of leaf residue and lubricating oil.**

89 Network Rail took swabs of the rail head and train wheels shortly after the accident (paragraph 48). Samples were taken within platform 1 from the rail furthest from the platform face, from the wheels on that side of the train and from the rails on the approach to the station (figure 3). The rail closest to the platform face was not sampled as it was not accessible due to the presence of the train at the time that the sampling was done. These samples were taken before the RAIB arrived at site, but after the heavy rain shower which began just as the train was approaching the station (the station roof does not cover any of the track in platform 1). The samples were analysed by a specialist analysis laboratory and its report was supplied to the RAIB.

[8] The effective coefficient of friction is defined here as that value of μ which would generate a retarding force of sufficient magnitude to produce the same deceleration as was experienced by the train during a particular braking event.

[9] The process is also run early in the day for the first trains over each route.

Event/Conditions	Effective coefficient of friction, μ
Dry rail (RAIB Autumn Adhesion Investigation - report 25(part 3)/2006)	0.20
Minimum friction needed for emergency braking rate used in train design (RAIB Autumn Adhesion investigation report)	0.12
Typical wet rail (RAIB Autumn Adhesion Investigation report)	0.10
221 109 at Chester platform 1, 20 Nov 2013	>0.031+
Minimum friction needed for lowest step brake rate used in train design (RAIB Autumn Adhesion investigation report)	0.03
221 111 at Chester platform 1, 20 Nov 2013	>0.028+
221 112 before Llandegai tnl, Bangor, 21 Nov 2013	0.028
221 105 at signal CR29, Chester, 20 Nov 2013	0.02
Minimum friction needed for lightest brake application on class 221	0.019
221 104 at Uddingston 20 Nov 2013*	0.019
221 143 at Lancaster 21 Nov 2013*	0.018
221 143 at signal CR27, Chester, 14 Nov 2013*	0.017
375 511 at Stonegate 8 Nov 2010 (during brake application in steps 2 & 3) (RAIB report 18/2011)	0.017
221 116 at Holyhead 28 Oct 2013*	0.017
221 112 after Llandegai tnl, Bangor, 21 Nov 2013	0.015
Minimum friction needed to stop in platform 1 at Chester at time of incident	0.014
375 511 at Stonegate 8 Nov 2010 (during braking in emergency position)	0.013
221 109 at Crewe 20 Nov 2013*	0.013
221 112 during final part of platform overrun at Bangor, 21 Nov 2013	0.011
221 105 in platform 1 at Chester 20 Nov 2013*	0.01

* = one-shot sander deployed to stop train (friction values in table are before sanding)

+ = this was the level of friction corresponding to the highest brake setting the driver used; as no slide was indicated, the actual friction value could have been higher than this.

Table 1: Effective coefficients of friction

90 The chemical analysis showed evidence of 'highly degraded leaf/vegetative matter' in the samples taken from the wheels of the last vehicle in the train and in the samples from the *six-foot* rail at signal CR29, the *cess* rail at the AWS magnet for that signal and the cess rail at signal CR27. The cess rail at the AWS magnet for signal CR27 was not sampled by Network Rail but had a black coating, indicative of heavy leaf contamination, when photographed by the RAIB later that evening (figure 9).

Figure 9: Rail contaminated with leaf material at AWS magnet for signal CR27

91 The chemical analysis of the samples from the rail in the platform area also showed traces of 'sand or *sandite'* [10] in the samples. This was also evident on the edges of the rail in some places beneath the train (figure 10). Since the rails within the platform had not been treated for low adhesion, it is likely that this sand was deposited by an earlier train using platform 1. The only trains to use platform 1 that day were the incident train, the two previous Virgin Trains services which were both formed of class 221 units, and the regular hourly Arriva Trains Wales services between Chester and Crewe.

[10] The analysis of the samples did not distinguish between sand and sandite.

92 The Arriva Trains Wales services were all formed of the same unit on 20 November 2013, 158 837, which shuttled back and forth between Chester and Crewe throughout the day. The driver of this train did not report any problems stopping in platform 1 and neither did the drivers of the two previous Virgin Trains services. However, the Arriva Trains Wales class 158 units are fitted with automatic sanders which deposit sand if WSP is indicated during step 2 or higher braking. The RAIB obtained a copy of the data from the OTDR on 158 837. This OTDR was not set up to record sander activations or WSP indications but did show that step 2 braking had been used on the train which arrived at 09:44 hrs. It is possible that sand had been deposited by this, or an earlier, train. However, there was not enough sand left on the rails to improve friction for the incident train.

93 The chemical analysis of the samples from the wheels of the train and the rail furthest from the platform face within platform 1 showed that all samples contained traces of a hydrocarbon lubricating oil. However, the RAIB observed that the rail appeared to be generally clean and there were no traces of fresh oil (figure 10).

Figure 10: Rail beneath the train after the accident

94 Samples of oils and greases likely to have caused the rail contamination were taken by Network Rail. These samples were chemically analysed and compared to the lubricating oil found in the rail and wheel samples. The analysis found that the lubricating oil contamination did not match the grease used on the points at the station approach, the grease used on the six-foot rail at signal CR27 or the lubricating oil in unit 221 105. The lubricating oil was likely to have come from vehicles standing in the platform.

95 The lubricating oil contamination was likely to have lowered the friction between wheels and rails in platform 1. The RAIB did not attempt to identify the source of this oil as slight contamination of rails in terminal platforms where trains stand is a predictable occurrence that the trains using the platform should be able to cope with. The previous two Virgin Trains class 221 units to use the platform that day had stopped without any WSP indication and it is likely that the contamination was also present at that time. Therefore it is likely that the low adhesion which affected train 1D84 was due mainly to wet rail phenomenon (also a normal condition), which is discussed below.

Wet rails

96 **The rails were just becoming wet from rain, and this is likely to have created or exacerbated low adhesion conditions.**

97 The train's FFCCTV showed that rain was just starting as the train approached signal CR29. This rain continued as the train ran into platform 1, but was not heavy enough to require the driver to use the wipers continuously (paragraph 28). Rail which is just becoming wet has been recognised by industry as a critical low adhesion condition and was the subject of RSSB research project T1042, 'Investigation into the effects of moisture on rail adhesion'[11].

98 The RSSB T1042 report reviewed previous research and data gathered from actual service experience in the UK and overseas and found that there was evidence for low adhesion being caused by slightly wet rails. The report defined wet rail phenomenon as:

> *'Poor adhesion conditions caused when low levels of moisture are present at the wheel / rail interface. These conditions are associated with dew on the rail head, very light rain, misty conditions and the transition between dry and wet rails at the onset of rain. They are not necessarily associated with the additional presence of other (non-water) rail head contaminants. These conditions are not associated with continuous rain.'*

99 The RSSB report stated that the mechanism causing wet rail phenomenon was not yet fully understood, but that the existing mitigations for low adhesion (rail head cleaning, application of friction modifiers and use of on-train sanders) were also effective in mitigating wet rail phenomenon.

100 However, the results of the chemical analysis of the rail and wheel swabs (paragraph 89) showed that contamination was also present on the rails, and therefore the low adhesion cannot be entirely attributed to wet rail phenomenon.

101 The RAIB investigated a station overrun at Stonegate on 8 November 2010 (report 18/2011) in which a train ran for 3.94 km with the emergency brake applied. The investigation found that there was almost certainly no sand in the hoppers of the train's sanding system. The track had been treated by a RHTT approximately 10 hours earlier, but it was likely that the friction modifier it applied to the rails had dissipated by the time of the incident. Although the circumstances of the Stonegate incident differ from those at Chester, it is likely that wet rail phenomenon was a factor in both.

[11] See http://www.sparkrail.org/Lists/Records/DispForm.aspx?ID=11364.

Management of rail head adhesion

102 The rail head had not been treated to improve adhesion prior to the arrival of train 1D84.

103 Group Standard GE/RT8040, 'Low Adhesion between the Wheel and the Rail – Managing the Risk', issue 2, Feb 2009 clause 2.2 required the infrastructure manager (Network Rail in this case) to 'control the risk of low adhesion between the wheels and the rail to a level that is as low as reasonably practicable'. It also required it to identify sites where low adhesion may occur and publish the details of high risk sites in the Sectional Appendix.

104 Network Rail implements these requirements with its company standard NR/L2/OCS/096 (paragraph 53). The standard sets out the steps to be taken by Network Rail to identify high-risk adhesion sites comprising either a review of historical records or a risk assessment approach. The risk assessment method to be used is outlined on Network Rail standard form NR/L3/TRK/003/TEF3076. It consists of surveying the vegetation and topography of the site in 220 yard (200 metre) sections and using weighting factors to derive a risk score which represents the risk of low adhesion conditions at that site in autumn. If the risk score exceeds 26 the site is entered on the list of low adhesion sites in the Sectional Appendix, after consultation with the train operators. The line between signal CR27 and Chester station was assessed in November 2010, as part of a national tree survey, and the highest risk score was 15, which was below the threshold for inclusion in the Sectional Appendix. The standard is unclear as to when a further risk assessment is required to be undertaken.

105 The method of assessment based on historical data in Network Rail standard NR/L2/OCS/096 defines the criteria for listing a low adhesion site in the Sectional Appendix as having had more than 2 signals passed at danger (SPADs) or more than 4 run-bys[12] in the last 3 years. There had been no SPADs or run-bys reported on the approach to Chester from Crewe in the 3 years before the accident.

106 Clause 2.1.2 of the Group Standard stated that infrastructure managers and railway undertakings should jointly develop site specific action plans, and clause 2.1.3 specified the content of these plans. However, no local action plan had been drawn up for the line between Christleton tunnel and Chester station because the site did not qualify as a low adhesion site on the basis of either historical data or risk score.

107 There was a low adhesion incident on the approach to signal CR27 on 14 November 2013. A Virgin Trains empty class 221 train was approaching Chester early in the morning when the driver found that the train was not slowing as he expected when braking for a 65 mph (104 km/h) speed restriction and the signal. He pressed the emergency stop button to trigger the one shot sanders on the approach to signal CR27 and the train came to a stand before reaching signal CR29. He reported the low adhesion, and the fact that he had deployed the one shot sanders, to the signaller and to Virgin Trains maintenance control. He then switched over to the second set of sand bottles. Network Rail despatched a leaf fall MOM to examine the site and he found evidence of leaf contamination on the rails and arranged for the rails to be cleaned by a RHTT later that day.

[12] A run-by is the situation when a train fails to stop at a station due to low adhesion.

108 The train involved in the 14 November incident also encountered low adhesion at other places on the journey from Crewe to Holyhead. The driver's report of the low adhesion incident approaching Chester was wrongly filed against one of these places and no action was taken by Virgin Trains in respect of the low adhesion on the approach to signal CR27.

109 After the accident, Virgin Trains analysed the OTDR data from all of its trains on the North Wales coast line (between Crewe and Holyhead) and found that there were several sites of low adhesion. It asked Network Rail to add the line to the RHTT programme for the forthcoming autumn.

110 There was also a report of low adhesion at signals CR27 and CR29 made by the driver of an early morning Virgin Trains service from Birmingham to Holyhead on 29 November 2013. The Network Rail leaf fall MOM responded to this report by hand cleaning the rails on the approach to those signals.

111 Following the accident, the SDS arranged for further treatment of the line approaching Chester from Crewe by the RHTT and has added this line to the RHTT programme for the next autumn.

Train-borne equipment

112 The activation of the train's sander was too late to avoid a collision with the buffer stop.

113 The one-shot sanders fitted to class 221 trains do not deploy unless three conditions are met (paragraph 71), one of which is that the driver must press the emergency stop button.

114 Analysis of the OTDR data indicates that, although the driver of train 1D84 on 20 November 2013 put the brake into the 'H' (full service) position when the train was 99 metres from the buffer stop, he did not press the emergency brake mushroom button, which activated the one-shot sander, until the train had travelled another 48 metres. If the train had been fitted with sanders that automatically deposited sand on the rails in accordance with Group Standard GM/RT2461, this would have triggered them to apply sand earlier than this and it is likely that the train would have stopped before reaching the buffer stop[13].

115 However, this standard did not come into force until after the class 221 trains had entered service and did not apply retrospectively.

116 At the time of introduction of the class 221, and the similar class 220, trains the operator of both fleets was Virgin Trains (Virgin West Coast and Virgin CrossCountry). During the design of the trains a decision was made to fit one-shot sanders to both the class 220 and 221 fleets, but neither Virgin Trains nor Bombardier Transportation have been able to provide documents explaining why this option was chosen. Most of the train fleets introduced prior to the Group Standard have subsequently been fitted with automatic sanders.

[13] Testing carried out by Southern Railway following the Stonegate incident (RAIB report 18/2011) and reported in RAIB report 18/2011 found that the value of μ improved by at least 0.03 when sand was applied. The effective friction required for the train to stop within 99 metres was calculated by the RAIB to be 0.023.

117 As it was necessary to take the train out of service or make other arrangements after a one-shot sander has been used (paragraph 70), the current operators of the class 220 and 221 fleets (Virgin Trains and CrossCountry Trains) asked Bombardier Transportation to enhance the sanding system by fitting a second sand bottle. Bombardier Transportation's records show that the Virgin Trains units were modified between December 2008 and March 2009 and the CrossCountry units between February and June 2011.

118 After deploying the one-shot sander, the driver is required to inform the signaller and then contact the maintenance controller before operating a switch to change over to the reserve sand bottles. If the train encounters poor adhesion conditions and emergency sanding is required again before the bottles have been replaced, then further steps must be taken. This situation arose with a class 220 operated by CrossCountry Trains approaching Banbury on 5 December 2013 after it had already used the first set of sand bottles at Stone in Staffordshire earlier in the journey. The unit was swapped for another one at Banbury. The Virgin Trains procedure for dealing with this situation, contained in its working instructions, involves the train proceeding forward at reduced speed to a point at which it can be dealt with (initially 20 mph below linespeed, subject to any further reduction that the driver deems necessary).

Performance of sanding equipment

119 The RAIB carried out an analysis of low adhesion incidents occurring between 1 September and 31 December 2013. The data was obtained from the Network Rail control centre incident log (CCIL) system and included the following types of incident, according to the system's categorisation:

- Poor / Exceptional Rail Head Conditions;
- Signals Passed At Danger (Category A) (Weather Related);
- Station Overrun;
- Station Overrun (Weather Related);
- Leaf fall;
- Freight Adhesion Issues (Leaf Fall); and
- Collision.

120 The data was reviewed to ensure that only incidents involving low adhesion were included in the analysis (some station overruns, for example, were due to the driver forgetting that the train was booked to stop there). The number of incidents occurring each day is plotted in figure 11 and shows that there are several peaks which are likely to correspond to poor weather events. There were 76 low adhesion events on 20 November. This was the fourth highest number on a single day during autumn 2013.

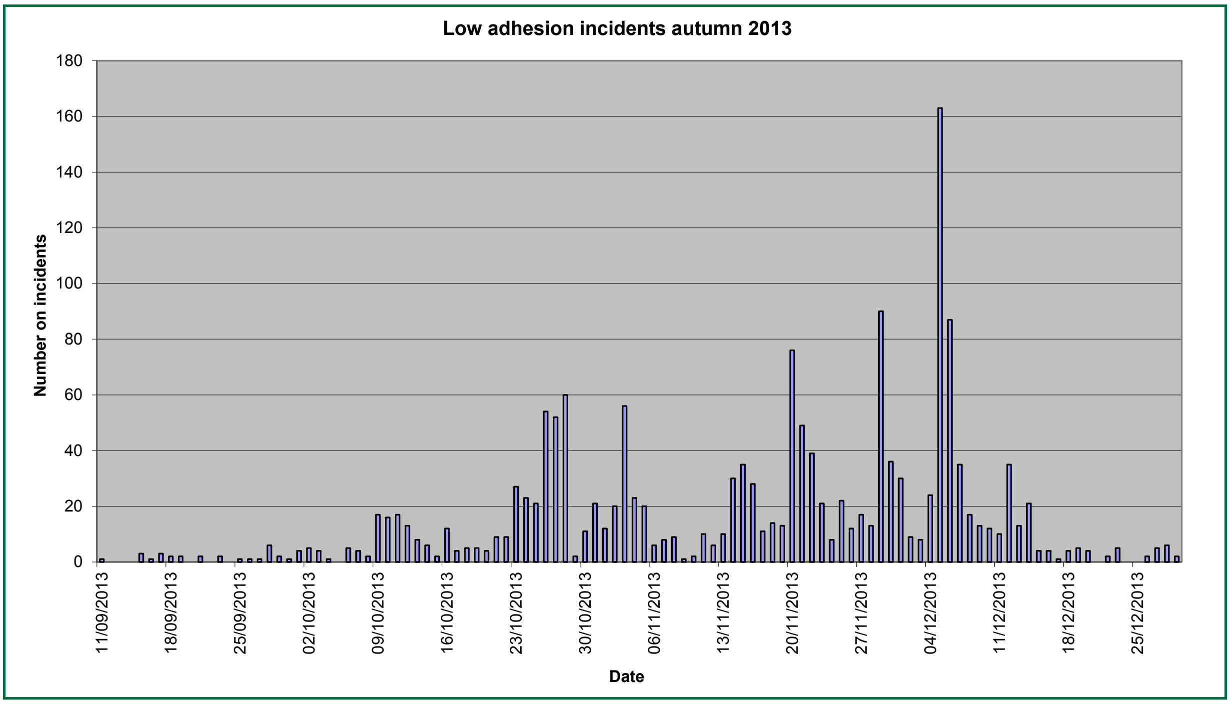

Figure 11: Number of low adhesion incidents recorded in CCIL each day during autumn 2013

121 The events were further analysed to derive the number of braking-related low adhesion events. These were then analysed by train type to determine whether class 220 and 221 trains were typical of modern trains. The analysis grouped trains by their generic types as follows:

- Electric multiple units operating on 25kV ac overhead (AC EMU);
- Electric multiple units operating on 750V dc third rail (DC EMU);
- Merseyrail trains (classes 507 and 508)[14];
- Diesel multiple units (DMUs) (other than class 220 and 221);
- High Speed Trains (HSTs); and
- Voyager type trains (Classes 220 and 221)[15].

122 The number of low adhesion braking events for each generic group was normalised by the total number of units of that type on the network to give the number of low adhesion braking events per unit. The results were further normalised by the typical number of stops per hour that each type of train is scheduled to make (as an indicator of how often a train is exposed to the potential for a low adhesion event during braking). This normalisation was only approximate as the *diagrams* worked by the trains vary within each class. The figures used for this normalisation are given in appendix C. The results of the normalisation of the low adhesion incident data for autumn 2013 are given in figure 12. This indicates that the Voyagers (classes 220 and 221) are significantly more likely to be involved in a low adhesion incident each time they attempt to stop than any other classes of train.

[14] The Merseyrail network has stations which are closely spaced and operates an intensive service with many stops. A relatively high number of low adhesion incidents was reported on this network in autumn 2013, so it was considered separately from the other DC EMU fleets.

[15] Class 222 ('Meridian') trains are also similar to Voyager trains, but were not included with Voyagers as the Meridians are fitted with automatic sanders complying with Group Standard GM/RT2461.

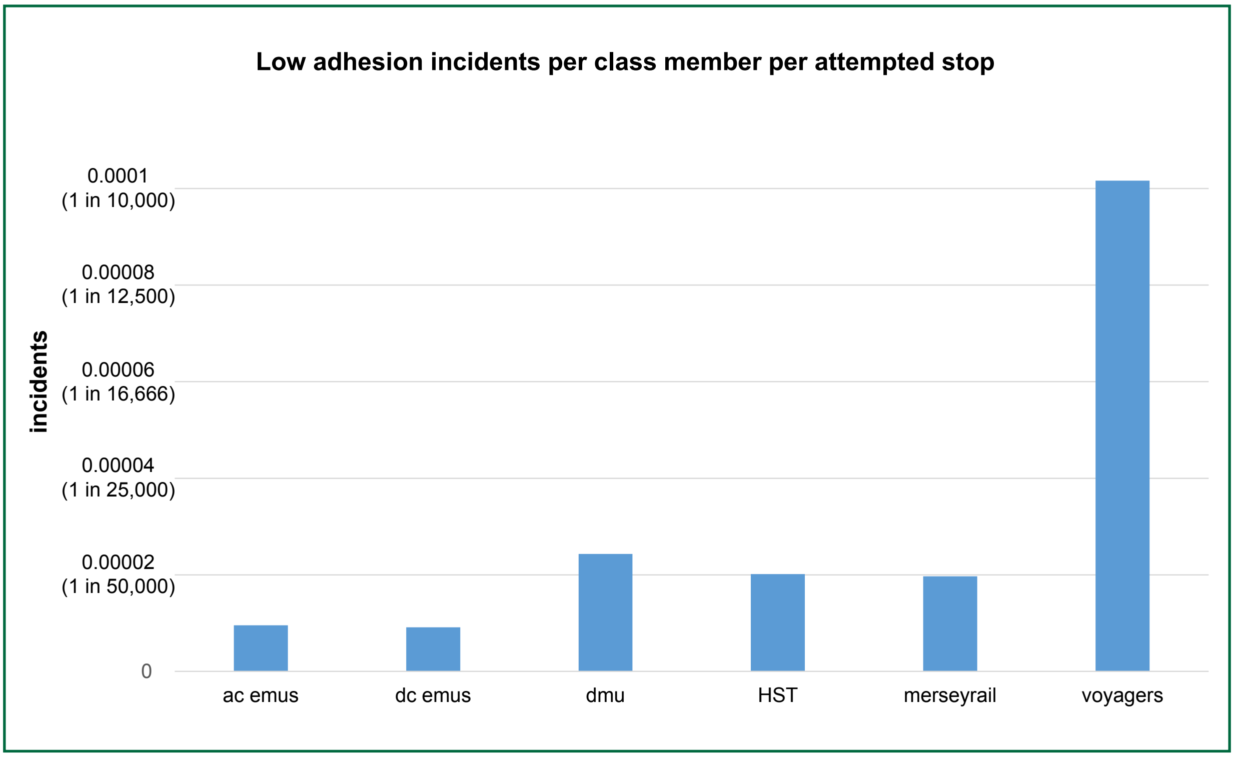

Figure 12: Number of low adhesion incidents by type of train

123 The RAIB asked the rolling stock leasing companies, who own most of the passenger trains running on the UK national network, to supply details of sander fitment within their fleets.

124 The only multiple unit passenger trains operating on the national network (excluding the Isle of Wight) in autumn 2013 without automatic[16] sanders were classes 220, 221, 332 and HST. The class 332 trains were not fitted with sanders when built as they were introduced before the Group Standard was issued. The operator of these trains, Heathrow Express, has made the case, which the Office of Rail Regulation (ORR) has accepted, that fitment was not reasonably practicable on the grounds of disproportionate cost for the risk prevented. The RAIB analysis of autumn 2013 data (paragraph 119) did not find any instances of class 332 trains being involved in low adhesion incidents.

125 HSTs have been in service since 1976 and have never been fitted with sanders, though they were fitted with an early type of WSP system. The train is characterised by having a heavy power car (in effect a locomotive) at each end of unpowered passenger vehicles. In autumn 2013 the rate of low adhesion incidents per attempted stop for these trains was similar to that for trains fitted with sanders.

[16] For the purposes of this analysis, driver operated sanders fitted to trains without WSP systems are included with the automatic sanding category as the sand can be applied at will for as long as required.

Virgin Trains' defensive driving policy

126 **The driver did not adopt the Virgin Trains defensive driving policy for low adhesion conditions because it did not apply to the approach to buffer stops. This was a probable causal factor.**

127 Virgin Trains drivers' manual for class 221 units section 6.1 explains that wet, greasy and contaminated rails will always result in greater stopping distances and it tells drivers how to brake in such situations. In addition, Virgin Trains have a defensive driving policy which contains instructions known as the '10:10:0 Rule'. This states:

'10:10:0 - Low Rail Adhesion

If the train is in a known 'low rail adhesion' area, you must proceed cautiously, travelling at reduced speed through the affected area. If cautionary signals are encountered the brake must be applied earlier and at least Step 3 or 4 (Class 390), or earlier and lighter than normal (other traction). The approach to a stop signal in these conditions must be no greater than 10 mph at a point 200 metres on the approach to the stop signal and stopping no closer than 10 metres from the signal. The above instructions also apply if you encounter low rail adhesion in areas not known for poor adhesion. The brake should be moved to a higher position as required if the train is not slowing sufficiently.'

128 Virgin Trains stated that the '10:10:0 Rule' did not apply to the approach to buffer stops as alternative risk reduction measures were employed here. These measures consist of advising drivers that the TPWS overspeed sensors are to be negotiated at 10 mph and that the speed should be 5 mph one coach length from the final stopping point, 'which will be a point no closer than 5 metres on the approach to the buffer stops, or the Stop Board (where fitted)'.

129 If the '10:10:0 Rule' had been applied to the approach to platform 1 at Chester on this occasion (with the buffer stops being treated as a stop signal), and had the brakes had been applied lightly throughout the train's approach to the buffer stop, the effective coefficient of friction would have needed to be at least 0.006 to enable the train to stop 10 metres from the buffer stop. This is less than the actual minimum value calculated by the RAIB (0.01) from the train's OTDR, and so the train could have stopped. However, this calculation assumes that the brakes remain applied throughout the approach from the 200 metre point. It is possible that, if the adhesion conditions were better outside the platform (as seems likely), the train could have achieved the 10 mph speed by the 200 metre point without the driver being aware of the critical low adhesion in the platform. He might have then released the brakes to coast towards the buffer stop and found that there was insufficient distance to stop when he reapplied them. For this reason, the non-application of the '10:10:0 Rule' is only regarded as a probable factor in this accident.

130 The deceleration rate that the train was achieving as it entered the platform was not significantly different to the rate which the driver expected, as he had applied the brake at a low setting, and he did not perceive that the rail adhesion was so low at that stage. The lack of deceleration became more apparent as he increased the brake setting and did not see a corresponding increase in deceleration rate. He increased the brake setting further then pressed the emergency stop button. The driver had been trained on braking in low adhesion conditions during his initial training.

131 The Virgin Trains defensive driving policy applies to all the types of trains the company operates. Some of these trains have automatic sanders which would deploy sand if WSP was indicated while braking at higher brake rates. This would mitigate the risk of buffer stop collisions for these types of train, as the sand would improve the adhesion conditions.

The operation of the WSP system

132 The brake control computer in the BCU in each of the vehicles in the train was downloaded after the accident and its data analysed by the RAIB.

133 The BCU computer stores information on brake applications for diagnostic purposes. The computer has limited memory capacity and only the first 40 seconds of each brake application where wheel slide was detected are stored. This information is not time stamped and it is necessary to match it to other data, such as the OTDR, to determine which brake application it relates to. The RAIB did this for the braking events at signal CR29 and the stop in platform 1.

134 The BCU data includes records of the rotational speed of each axle, the vehicle speed computed by the BCU (and, in the case of the leading vehicle, displayed to the driver on the speedometer) and any warning messages generated by the BCU. Although only the first 40 seconds of speed data are recorded, all warning messages are logged.

135 The data for the approach to signal CR29 showed that all axles continued to rotate with only small amounts of slide. The WSP system objective of keeping the axles rotating at a speed around 17% less than the ground speed appeared to be met during this braking event and there were no instances of axles locking up and no error messages were logged by the BCUs on any of the vehicles in the train. The 40 second period of the data covered the time when the train speed reduced from 18 m/s (40 mph) to 8.5 m/s (19 mph). The OTDR data showed that the duration of this brake application was 43 seconds and slide was not detected until 5 seconds into the application, so the BCU record is complete for this event for the leading vehicle.

136 The brake application for the stop in platform 1 began when the train was travelling at 10.8 m/s (24 mph) and was approximately 430 metres or 58 seconds from the buffer stop. The braking reduced the train speed from 10.8 m/s (24 mph) to 5.8 m/s (13 mph). During this time, none of the axles locked up but there were short periods when all four axles on one of the vehicles went into a deeper slide than the designed 17%. This happened on each of the first four vehicles in the train. The last vehicle did not slide so much, possibly due to improved adhesion due to rail conditioning by the first four vehicles.

137 In summary, the WSP was releasing individual axles occasionally during the slide, to avoid the wheels locking up, as it was designed to. The RAIB analysed the data from the BCU which showed brake valve operation, the speed of each axle and the computed ground speed of the train and found no evidence to suggest that the WSP had malfunctioned. The 40 second limit on data storage (paragraph 133) prevented the full details of the braking event in platform 1 from being recorded and so it is not possible to analyse in detail how the WSP system performed during the final seconds before the impact. However, the RAIB has no evidence to suggest that the WSP system malfunctioned during this time. The WSP system was unable to handle very low adhesion on two previous occasions (paragraph 147), but was able to indicate that WSP was occurring at the time. This meant that, had automatic sanding equipment been fitted, it would have been triggered.

Factors affecting the severity of consequences

Buffer stop design

138 The buffer stop was of an old design (figure 5) which did not comply with the current Group Standard, GC/RT5033 'Terminal Tracks – Requirements for Buffer Stops, Arresting Devices and End Impact Walls'. This requires that new buffer stops are of an energy-absorbing design. For existing buffer stops, the standard requires that all terminal or bay platforms have a current, documented, assessment of the risk arising from a collision with the buffer stop. RSSB document GC/RC5633 'Recommendations for the Risk Assessment of Buffer Stops, Arresting Devices and End Impact Walls' provides a recommended method of meeting this requirement.

139 Network Rail last conducted a risk assessment of the platform 1 buffer stop in September 2002. The assessment was carried out in accordance with the then-current version of the guidance note (GC/GN5633 issue 1) and the result was that the risk score was 0.56 *estimated weighted equivalent fatalities* per 100 years.

140 Guidance note GC/GN5633 contained a note (reference RC20 in issue 1 and RC19 in issue 2) which stated that, since small changes can accumulate over time, the interval between risk reviews should not exceed 10 years. The buffer stop risk assessment for platform 1 at Chester did not comply with this guidance as, at the time of the accident, it had not been reassessed within the previous 10 years. The train service using this platform changed significantly in 2009 when Virgin Trains introduced a higher frequency service. This involved some of its trains terminating at platform 1. Prior to this Virgin Trains services did not use that platform. This change in traffic pattern should also have triggered a reassessment of the risk at the buffer stop.

141 The guidance note gave a table of risk mitigations to be considered, depending on the risk score. For a score between 0.5 and 1, the mitigations to be considered included reducing the permissible speed on approach to 15 mph or less and implementing measures to improve adhesion.

142 Network Rail was unable to provide the RAIB with a record of the outcome of consideration of the mitigations, but the approach speed was limited by the installation of TPWS at approach-controlled signal CR29 and the TPWS over-speed sensor 51 metres from the buffer stop.

Previous occurrences of a similar character

143 Since the RAIB commenced operations in 2005, there have been buffer stop collisions involving passenger trains at Sudbury, Suffolk, on 27 Jan 2006, at West Kirby, Merseyside, on 11 Jan 2007 and at Sheringham, Norfolk, on 10 Oct 2007. However, low adhesion was not a factor in any of these incidents.

144 The collision at Sudbury was the subject of an RAIB investigation (report 26/2006) which made a recommendation to Network Rail regarding the installation of energy absorbing buffer stops (paragraph 158).

145 Previous incidents involving very low adhesion occurred at Esher, Surrey, on 25 Nov 2005, and Lewes, Sussex, on 30 Nov 2005. These incidents were investigated separately by the RAIB (reports 25 (Part 1)/2006 and 25 (Part 2)/2006), and a wider investigation into low adhesion in autumn 2005 was also carried out (report 25 (Part 3)/2006). The recommendations arising from this report are considered in paragraph 154.

146 A low adhesion incident occurred at Stonegate, Sussex, on 8 Nov 2010, in which a passenger train ran for 3.94 km with the emergency brake applied (paragraph 102 and RAIB report 18/2011). The recommendations made in this investigation were all concerned with maintenance of the train and its sanding equipment.

147 There were several other cases of class 220 and 221 units being involved in low adhesion incidents during autumn 2013. According to CCIL records, the one-shot sanders were deployed on 28 occasions between 1 Sep 2013 and 31 Dec 2013. Twelve of these were on class 220 units which are all operated by CrossCountry Trains. Sixteen deployments involved class 221 units; 8 on Virgin Trains units and 8 on CrossCountry Trains units. Bombardier Transportation's records of sand bottle replacement also show a further 27 occasions where sand bottles were replaced on class 220 and 221 trains, because the driver had deployed them, but no corresponding record in CCIL could be located. None of these incidents resulted in a collision. One of the cases of low adhesion involving a class 221 unit occurred on 21 November 2013 as the train was approaching Bangor station on a service from Euston to Holyhead. The driver applied the brake when the train was travelling at 68 mph and the wheels started to slide. The WSP system lost track of the train speed and all wheels on the leading vehicle locked up. After a few seconds the WSP system regained control, though the train overran the station by a short distance. A similar incident occurred on 28 October 2012 as an empty class 221 unit was approaching Andover. This incident resulted in the train having to be taken out of service to deal with wheel tread damage incurred during the slide.

Summary of conclusions

Immediate cause

148 The train was unable to slow down at a sufficient rate to avoid collision with the buffer stop (**paragraph 74**).

Causal factors

149 The causal factors were:

- the level of adhesion between wheels and rails was exceptionally low (**paragraph 83**);
- no action was taken to improve the coefficient of friction between the wheels and rail by pre-treatment of the rails (**paragraph 102**);
  - the site did not qualify as being at risk of low adhesion on the basis of its surroundings
  - the site did not qualify as a low adhesion site on the basis of historical data.
- the activation of the train's sander was too late to avoid a collision with the buffer stop (**paragraph 112, Recommendation 1**).

150 It is probable that the following factor was also causal:

- Virgin Trains' defensive driving policy did not apply to the approach to buffer stops (**paragraph 126, Recommendation 2**).

Factors affecting the severity of consequences

151 A factor that exacerbated the consequences of the event was that the buffer stop was of an old design. A modern energy-absorbing design of buffer stop would have prevented the train from overriding it and mounting the platform (**paragraphs 138 and 158**).

Observation

152 The Group Standard which requires sanders to be fitted to multiple units, GM/RT2461, does not mandate that the sanders operate automatically when wheel slip is detected while braking in step 2, or equivalent (**paragraph 69, Recommendation 3**).

Previous RAIB recommendations relevant to this investigation

153 The following recommendations, which were made by the RAIB as a result of its previous investigations, have relevance to this investigation.

Recommendations that could have affected the factors

154 The RAIB considers that wider implementation of the following recommendations could have addressed one of the factors and either prevented this accident or mitigated the consequences.

Autumn Adhesion Investigation Part 3: Review of adhesion-related incidents Autumn 2005. RAIB report 25(part 3)/2006 published Jan 2007

155 Recommendation 8 read as follows:

RSSB to extend research and testing into how severe low adhesion conditions occur with particular reference to the phenomenon of micro layers of contamination on rail surfaces, invisible to the eye. The research will seek to establish the nature of the contaminant, how it reaches the rail and bonds with it, the circumstances under which the contaminant poses a particular threat to train braking (e.g. the factors that exacerbate its impact), the factors that determine how long it endures, possible methods for identifying its presence and methods for preventing its formation and dispersing it.

RSSB responded to the ORR on 21 August 2007 advising that research project T354 had already looked into the characteristics of railhead contamination during autumnal periods. The work identified pre-treatment measures to reduce the leaves bonding and the effectiveness of removal techniques. The work also generated two RGS guidance note documents setting out methods to simulate and techniques for measuring low adhesion conditions. RSSB indicated at that time that it would initially carry out a literature search and review to summarise existing knowledge. The outcome of the review would be used as a justification to support further research into invisible thin film or other non-seasonal rail head contaminants.

RSSB also indicated that it would complete the work started under research project T354 'the characteristics of railhead leaf contamination' by publishing the reports and associated RGS guidance notes on the measurement and simulation of low adhesion.

The ORR reported to the RAIB on 30 Dec 2010 that it considered that this recommendation had been implemented. However, the RAIB noted, in the 2010 Annual Report Section 2, that it had concerns that the actions taken were insufficient to address the risk identified during the investigation. RSSB has subsequently conducted research project T 1042 (paragraph 51) which also considers this issue. Taken together the RAIB considers that this research meets the intent of this recommendation.

156 Recommendation 9 read as follows:

Train operators to fit automatic sanding equipment to those multiple units of five cars or less that are not currently so equipped, unless they are specifically excluded from doing so by GM/RT2461.

The ORR has informed the RAIB that sanders were fitted to a number of types of passenger trains that were previously unfitted (eg class 390 'Pendolino', class 333 and some class 158 units).

The absence of automatic sanders on class 220 and 221 trains was not mentioned in connection with this recommendation. Virgin Trains was not asked by the ORR to respond to this recommendation as ORR considered that its trains were already fitted with sanders (albeit one-shot sanders in the case of class 220 and 221 trains).

157 The information that the RAIB obtained as part of this investigation (paragraph 123) updated that obtained in 2006 during the autumn adhesion investigation. At that time, some types of train were barred from sander fitment, either due to them having insufficient axles to meet the requirement of GM/RT2461 that there be at least 6 axles behind the point where sand is laid, and/or by them not having a WSP system to trigger the sanding automatically. This particularly affected older trains with only 4 axles in total (classes 142 - 144 and 153). The '6 axles behind the sander' requirement arose from considerations of the likelihood of excess sand causing problems for the track circuits due to all of the axles of the train losing electrical contact with the rail. Since 2006, the industry has devised a sanding system that can be fitted to these types of train, a deviation from the Group Standard has been granted and these fleets have been fitted with sanders. In the case of trains not fitted with a WSP system, the sand is applied when the driver judges that the train is experiencing low adhesion and presses a button. Sand is only deposited while the button is held down.

Collision between train and buffer stops at Sudbury, 26 Jan 2006. RAIB report 26/2006 published Dec 2006

158 Recommendation 2 read as follows:

Network Rail should:

- *carry out a review, including cost benefit analysis, into the practicability of providing energy absorbing buffer stops at terminal platforms;*
- *provide a copy of the review to the safety authority; and*
- *develop a programme to fit energy absorbing buffer stops to terminal platforms where it is reasonably practicable to do so.*

Network Rail reported to the ORR on 1 May 2007 that the following actions would be taken in response to the above recommendation:

- *'Network Rail will undertake a desk-top review to identify the practicability of providing energy absorbing buffer stops at terminal platforms;*
- *If it is decided that the fitment of energy absorbing buffer stops to terminal platforms is reasonably practicable, then such fitment will be on an 'as required' basis (and not as a blanket or retrospective fitment programme)...'*

On 24 May 2007 Network Rail's senior safety risk advisor sent a copy of the review to the ORR and stated that Network Rail would develop a programme to fit energy absorbing buffer stops to terminal platforms if and where it is practicable to do so. On 16 Aug 2008 Network Rail sent the ORR a copy of briefing note which it had issued to its territory engineers on this matter. The ORR confirmed to the RAIB on 4 Jan 2008 that it considered that this recommendation had been closed. The meaning of 'closed' in this context was that the implementer had declared to the ORR that it had taken measures to effect the recommendation and the ORR was either satisfied that the work had been completed or had confidence that it would be completed and intended taking no further action.

The RAIB found no evidence that a risk assessment of the buffer stop in platform 1 at Chester was made in response to this recommendation.

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

159 Immediately after the accident, Virgin Trains issued revised instructions to its drivers regarding the use of the sanders on class 221 trains. The new instruction stated that the driver should use the sanding equipment if they have '... any doubts as to whether sufficient retardation is being achieved on the approach to ANY location (where) the train is required to be brought to a stand'. CrossCountry Trains also issued similar advice to its drivers.

160 Virgin Trains has stated that its fleet of class 221 trains is to be fitted with auto sanders. An order has been issued to Bombardier Transportation for this work and fleet installation is planned for completion by Autumn 2015.

Learning points

161 The RAIB has identified the following key learning points[17] for the railway industry:

1. OTDR data for all trains operated over a route can be analysed to identify areas of line where trains commonly experience sustained WSP activity. This information can be used to provide drivers with a warning of the current areas of risk of low adhesion and inform the infrastructure manager of areas where rail head treatment is required.

   The RAIB notes that some train operating companies, including Virgin Trains, have already implemented systems of this type and this practice would be likely to be beneficial to other operators.

2. Infrastructure managers need to be aware of changes to traffic patterns which make the reassessment of the adequacy of buffer stops in terminal platforms necessary and should carry out such reassessment and upgrade the buffer stops when required.

[17] '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.

Recommendations

162 The following recommendations are made[18]:

1 *The intent of this recommendation is to reduce the risk associated with low adhesion by extending the fitment of automatic sanders.*

Operators of class 220 and 221 units should fit sanders to their trains which comply with Group Standard GM/RT2461 and automatically deposit sand on the rail when wheelslide is detected during heavy braking (equivalent to brake step 2 on step braked trains).The mode of operation of this new equipment should take account of recommendation 1 of RAIB report 25 (Part 3)/2006 (paragraph 114).

2 *The intent of this recommendation is to reduce the risk associated with trains approaching buffer stops in low adhesion conditions by an extension of existing defensive driving policy.*

Virgin Trains should amend its defensive driving policy so that the requirement to reduce speed to 10 mph or less at a distance of 200 metres from the signal when approaching a danger signal in low adhesion conditions is also applied when approaching a buffer stop with a train that is not fitted with automatic sanders (paragraph 129).

This recommendation may also to apply to other train operators.

3 *The intent of this recommendation is that manufacturers of new trains for the UK railway system are made aware of the need for sanders to operate during braking in step 2 (or the equivalent brake handle position for units not fitted with stepped brakes) and above.*

RSSB should propose and promote an amendment to Railway Group Standard GM/RT2461 to extend the requirement that sanders operate automatically when wheel slip is detected in full service and emergency braking, to braking at lower settings (eg step 2 on units with stepped brake controllers) (paragraph 152).

[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.

Appendices

Appendix A - Glossary of abbreviations and acronyms

AWS	Automatic warning system
ACU	Analogue (brake) control unit
BCU	Brake control unit
CCIL	Control centre incident log
DMU	Diesel multiple unit
EMU	Electric multiple unit
FFCCTV	Forward facing closed circuit television
HST	High speed train
MOM	Mobile operations manager
ORR	Office of Rail Regulation
OTDR	On-train data recorder
RHTT	Rail head treatment train
SDS	Seasons delivery specialist
SPAD	Signal passed at danger
TPWS	Train protection and warning system
WSP	Wheel slide protection
μ	Coefficient of friction

Appendix B - Glossary of terms

Analogue control unit	The part of the brake control unit which controls the air pressure to the brake cylinders.
Approach controlled	The system used at some signals whereby the signal is held at red until the train is determined to have reduced its speed to a defined level whereupon the signal is automatically changed to a proceed aspect.
AWS magnet	A part of the automatic warning system (AWS) which is located between the rails and operates a bell or horn in the train cab to alert the driver as to whether the signal is green or not.
Bay platform	A platform adjacent to a track which is not a through line at a station and has a buffer stop at its end.
Brake control unit	A device fitted to each vehicle in the train which takes the brake demand requested by the driver and controls the equipment which provides the corresponding level of retardation.
Certificate of conformance for vehicle design	A document which certifies that the vehicle design meets all the requirements of the applicable standards.
Cess rail	The rails furthest from the centre of a double track railway.
Diagram	The set of timetabled services that a particular train operates.
Diesel electric multiple unit	A type of train powered by diesel engines, with an electric transmission, that can operate in conjunction with other similar trains.
Dynamic braking	A system of braking where the retardation effort is provided by using the traction motors to generate electricity.
Estimated weighted equivalent fatalities	An estimate of the number of injuries and fatalities which might occur over a given period. The number of injuries and the number of fatalities are combined into a single figure representing the number of fatalities.
Friction braking	A system of braking where the retardation effort is provided by frictional contact between brake pads and a moving brake disk.
On-train data recorder	A device fitted to the train which records key operational information, such as speed and position of controls.
Rail adhesion	The friction produced between a rail and a rail wheel. Therefore, loss of adhesion is the absence of this friction and the inability to make any forward progress or resists existing forward movement.
Railway Group Standard	A railway industry standard that must be complied with by the UK railway industry.

Route refresher	A training day where a member of train crew who has not worked over a particular route for some time travels the route to re-familiarise themselves with it.
Running brake test	A brake test made by the driver shortly after starting the journey to confirm that the brakes are working as expected.
Sandite	A mixture of sand, and other, particles in a fluid medium which is used to improve friction on rails.
Six-foot (rail)	The rails nearest the centre of a double track railway.
Track circuit	An electrical circuit through the rails which is used to detect whether a train is present.
Track circuit block	The system of signalling the railway where safe operation of trains is achieved by allowing only one train at a time to occupy a section of track fitted with a track circuit.
Wheel slide protection	A system which adjusts the braking effort on each axle to prevent the wheel sliding on the rail during braking.

Appendix C - Analysis of stopping rates

The following table presents the assumed average number of station stops per hour for generic train types. The average stops per hour for each generic train type was calculated by weighting the stops per hour for each class by a factor calculated as the proportion of that generic group that the class represents.

Generic train type	class	Typical journeys	Average stops/hour, weighted by size of fleet (approx)
AC EMU	321	Northern Rail Leeds – Doncaster (8 stops - 48m)	10.5
		Greater Anglia Liverpool Street – Ipswich (10 stops - 1h 20m)	
		Greater Anglia Liverpool Street – Southend Victoria (11 stops - 1h)	
		Greater Anglia Liverpool Street – Cambridge (8 stops - 1h 10m)	
		Greater Anglia Braintree branch (4 stops - 16m)	
	350	London Midland Euston – Northampton (5 stops - 1h)	
		London Midland Birmingham – Liverpool (9 stops - 1h 41m)	
		London Midland Euston – Crewe (13 stops - 2h 38m)	
	319	First Capital Connect Bedford – Brighton (17 stops - 2h 15m)	
	317	First Capital Connect Kings Cross – Peterborough (14 stops - 1h 31m)	
		Greater Anglia Liverpool St – Stansted Airport (3 stops - 49m)	
		Greater Anglia Liverpool Street – Hertford East (12 stops - 49m)	
		Greater Anglia Liverpool Street – Cambridge (8 stops - 1h 10m)	
	357	C2C Fenchurch St – Shoeburyness (13 stops - 1h 3m)	
		C2C Fenchurch St – Southend Central (16 stops - 1h 15m)	
	313	First Capital Connect Welwyn Garden City – Moorgate (17 stops - 50m)	
		First Capital Connect Hertford North – Moorgate (18 stops - 50m)	
	315	Greater Anglia Liverpool Street – Chingford (8 stops - 27m)	
		Greater Anglia Liverpool Street – Shenfield (13 stops - 43m)	
	390	Virgin West Coast Euston – Manchester (4 stops - 2h 9m)	
		Virgin West Coast Euston – Liverpool (4 stops - 2h 14m)	
		Virgin West Coast Euston – Glasgow (7 stops - 4h 30m)	
		Virgin West Coast Euston – Wolverhampton (6 stops - 1h 54m)	

Generic train type	class	Typical journeys	Average stops/hour, weighted by size of fleet (approx)
DC EMU	377	Southern Victoria – Brighton (3 stops - 52m)	10.6
		Southern Brighton – Ore (18 stops - 1h 26m)	
		Southern Brighton – Southampton (19 stops - 1h 47m)	
		Southern London Bridge – Tonbridge via Redhill (11 stops - 1h 3m)	
		Southern Victoria – East Grinstead (11 stops - 54m)	
		Southern Victoria – Bognor (15 stops - 1h 46m)	
		Southeastern Charing Cross – Gillingham (10 stops - 1h 5m)	
	465	Southeastern Charing Cross – Sevenoaks (12 stops - 50m)	
		Southeastern Victoria – Orpington (12 stops - 39m)	
		Southeastern Charing Cross – Hayes (11 stops - 38m)	
	455	Southwest Trains Waterloo – Chessington South (10 stops - 34m)	
		Southwest Trains Waterloo – Waterloo via Kingston (23 stops - 1h 15m)	
		Southwest Trains Waterloo – Windsor (13 stops - 53m)	
	375	Southern Victoria – Epsom Downs (15 stops - 55m)	
		Southern Victoria – Dorking (7 stops - 49m)	
		Southeastern Charing Cross – Ramsgate (20 stops - 2h 28m)	
		Southeastern Victoria – Dover (19 stops - 2h 5m)	
		Southeastern Victoria – Ashford (16 stops - 1h 32m)	
	450	Southwest Trains Waterloo – Portsmouth (8 stops - 1h 30m)	
		Southwest Trains Waterloo – Basingstoke (10 stops - 1h 16m)	
		Southwest Trains Waterloo – Alton (8 stops - 1h 14m)	

Generic train type	class	Typical journeys	Average stops/hour, weighted by size of fleet (approx)
DMU	158	East Midlands Trains Liverpool – Norwich (15 stops - 5 ½ hrs)	6.7
		East Midlands Trains Matlock – Nottingham (11 stops - 1hr)	
		Northern Rail Leeds – Nottingham (9 stops - 2 hrs)	
		First Great Western Portsmouth – Cardiff (16 stops - 3h 20m)	
		First Scotrail Inverness – Kyle of Lochalsh (16 stops - 2 ½ hrs)	
	170	CrossCountry Nottingham – Cardiff (10 stops - 3h 20m)	
		First Scotrail Glasgow – Edinburgh (4 stops - 45m)	
		First Scotrail Glasgow – Aberdeen (8 stops - 2h 35m)	
		Greater Anglia Norwich – Cambridge (6 stops - 1h 19m)	
	150	First Great Western Bristol TM – Severn Beach (10 stops - 37 m)	
		Arriva Trains Wales Cardiff – Swansea (9 stops - 1h 7m)	
	156	Northern Rail Buxton – Blackpool N (24 stops - 2h 24m)	
		Northern Rail Sheffield – Leeds (11 stops - 1hr 20 mins)	
		Northern Rail Cumbrian Coast (33 stops - 3h 30m)	
		First Scotrail Glasgow – Oban (14 stops - 3h 7m)	
		First Scotrail Glasgow – Edinburgh via Shotts (18 stops - 1h 33m)	
		East Midland Trains Nottingham – Skegness (7 stops - 2h 9m)	
Merseyrail	507 & 508	Chester – Chester via Liverpool (31 stops - 1 ½ hrs)	22
		Southport – Hunts Cross (23 stops - 1hr)	
		New Brighton – New Brighton via Liverpool (18 stops - 50 mins)	
HST		CrossCountry Bristol – Newcastle (13 stops - 5 hrs)	3.2
		First Great Western Paddington – Swansea (9 stops - 2h 58m)	
		First Great Western Paddington – Weston-Super-Mare (10 stops - 2h 22m)	
		First Great Western Paddington – Penzance (19 stops - 5h 30m)	
		East Coast Kings Cross – Inverness (14 stops - 8h 6m)	
		East Coast Kings Cross – Aberdeen (14 stops - 7h 10m)	
		East Midlands Trains Nottingham – London (9 stops - 1h 51m)	
		Grand Central Kings Cross – Sunderland (6 stops - 2h 30m)	

Generic train type	class	Typical journeys	Average stops/hour, weighted by size of fleet (approx)
Voyagers	220 & 221	CrossCountry Glasgow – Penzance (34 stops 11h 54m) CrossCountry Newcastle – Reading (12 stops 5h 3m) CrossCountry Bournemouth – Manchester (18 stops 5h 50m) Bristol – Newcastle (13 stops 5h) Virgin West Coast Euston – Holyhead (12 stops, 3 h 48 m) Virgin West Coast Euston – Birmingham (4 stops 1h 22m) Virgin West Coast Lancaster – Crewe (4 stops 1h 7m)	2.9

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